Environmental Protection Department

Agreement No. CE57/2006 (EP) Review of the Air Quality Objectives and Development of a Long Term Air Quality Strategy for Hong Kong - Feasibility Study

Appendix H

Cost Benefit Analysis

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H1 Cost Benefit Analysis

H1.1 Brief Overview of Objectives and Approach

The principal costs to be included in the CBA will be the costs of introducing and implementing the policy, the costs of the policy instruments that the strategy option for pollution control would generate in Hong Kong society, and any other incidental costs on Hong Kong society as a consequence of implementation. The benefits of pollution control have been considered primarily to be cost savings to Hong Kong society. These could be sub-divided into those of a direct nature, principally health related cost savings including the reduced costs of illness and reduced premature mortality, and indirect consisting principally of impacts on the workforce and costs of maintenance and repair to buildings and structures and some lesser items. It has also been acknowledged that there might be certain macro-economic impacts of reducing pollution in addition to the cost and cost saving impacts. Macro-economic benefits might include added attraction of Hong Kong following air pollution reduction for international economic activities to locate or remain here, and the net benefits of additional international tourists and their expenditures.

H1.2 Damage Cost Due to Air Pollution

The approach to the social and economic analysis of the damage that air pollution causes uses two basic concepts: the impact-pathway; and willingness to pay. In brief, sources emit pollution into the environment which results in an impact and hence annoyance or damage to receptors. These impacts on receptors may be assessed in monetary terms by reference to their willingness to pay (WTP) to achieve a reduction of impact by specified amounts, or even elimination. When the impact of the pollution results in costs imposed on society, such as visits to doctors or additional maintenance of buildings, the WTP for a reduction in pollution is taken to be the savings in costs that would otherwise arise.

Thus, the analysis consists of a logical progression from pollution emission, through dispersion and exposure to quantification of impacts and monetary assessment. Impacts and damages for any policy scenario would be calculated according to the following general relationships:

*Impact = pollution * stock * response*

*Economic damage = impact * unit value of impact*

Pollution is expressed in terms of concentrations ($\mu g/m^3$). Stock relates to the quantity of sensitive receptors such as numbers of persons, materials etc. Response refers to the way in which the pollution impacts affects the receptors.

The proposed policy measures will involve reductions in pollution levels for the different components of air pollution. Pollutants cause damage of different natures and to different extents. For example, NO_2, SO_2, suspended particulates (PM_{10} and $PM_{2.5}$) and O_3 have different impacts on respiratory and circulatory diseases.

There are no strictly defined classifications of the types of impacts that arise from pollution. This TN follows the general approach used in the literature. In brief, direct costs are those that involve receptors taking action as a consequence of the pollution, such as the costs of medication, consultations, hospital admissions etc. Indirect costs are those that follow-on from the impact, such as loss of earnings due to the receptors' work absenteeism, costs imposed on family members such as those accompanying a hospitalised patient etc.

H1.2.1 Direct Costs of Illness (COI) and Premature Death

There are several costs arising from an increase in pollution, but the main ones are the cost of illness and increased rate of premature deaths (together referred to as COI).

Two types of COI impacts are recognised. Short-term or acute effects involve the way increased air pollution on a given day or set of days can affect the health of people within the days immediately following the pollution increase. Long-term or chronic impacts take into account changes in life expectancy as a result of prolonged exposure.

H1.2.2 Acute Impacts

There have been a number of important COI studies in Hong Kong that have identified a direct correlation between the daily levels of pollution and the incidence of visits to medical facilities by members of the community in the days immediately following. That is, there is a high correlation between the incidence of pollution and its short-run impact on health. These acute health impacts have been well studied in Hong Kong and the evidence concerning the costs of illness in this case is established and accepted.

A major indirect impact of pollution is due to absenteeism as a result of illness and hospitalisation. The cost involved is the loss of worker's output and lost outputs of any carers. This has been approached in studies as being equal at least to the cost of employing the concerned workers. This output loss equals the wage/salary rate plus any worker overheads and add-ons that the employer incurs.

This study has relied extensively on analyses performed in Hong Kong by Professor CM Wong (2002)[1] and others for the near-term effects of pollution, both in the ambient context and at street level in relation to traffic generated nuisance. Also of considerable interest is the work by Prof Hedley and colleagues at the Hong Kong University, some of which is summarised in graphic form as the Hedley Index at: http://147.8.71.207/pollution/home.php. The Hedley Index gives indicators of the premature deaths as a result of increases in pollution levels which are in line with the evidence used in this study.

H1.2.3 Chronic Impacts

There have not been any studies conducted in Hong Kong on long-term health effects of pollution exposure. However, the work of the Americans and Europeans on the costs of premature deaths caused by long-term air pollution exposure can be applied here with suitable caveats. The studies providing evidence of chronic effects are extensively reviewed and summarised in the UK Government ICGB Report (2007), especially Chapter 2 on Methodology[2], which has been heavily relied on.

Long-term or chronic effects are assessed over prolonged periods after having adjusted for other mortality risk factors. The main impacts will be on respiratory and circulatory diseases, and cancers. There is less evidence of the long-term effects than the short-term. The evidence that has emerged from US studies in recent years indicates that long-term costs of exposure are substantially greater than the short-term acute exposure costs. This presents something of a dilemma for policy makers and the study, since it is evident that the population at large consider the short-term impacts of pollution to be their primary concern. Little attention is given by the community or the political process about whether pollution shortens lives. Understandably, people are unable to as readily relate to the prospect that their lives may be shortened on average by, say, six months in a lifetime of 80 years due to ambient pollution as compared with relating to the immediate and unpleasant impact of a blast of pollution received at the roadside whilst waiting, for example, for a bus.

The evidence from the US which the Europeans have accepted as being valid for application there, suggests that ambient levels of pollution of the kind experienced in US metropolitan regions have a considerable impact on life expectancy. Moreover, US metropolitan regions generally have lower average ambient pollution levels than are experienced in Hong Kong (roughly in the range of 5 to 33 μg/m^3 for $PM_{2.5}$ compared with average levels of about 35 to 40 μg/m^3 for $PM_{2.5}$ in Hong Kong). Indeed, the calculations currently being performed in CBAs in the UK and the EU suggest that these long-term chronic pollution impacts on health and longevity dominate the analyses in terms of the magnitude of health benefits when pollution is reduced. This issue is discussed more fully below in **Section H1.4.2**.

Economists and epidemiologists undertaking the UK cost benefit work into policies to reduce pollution have advised informally that, in their view, the findings for the large number of metropolitan areas and extensive time periods that have been studied for US cities would be applicable to the Hong Kong situation. It has been found that the overall health benefits calculated using this US evidence are not very sensitive to population structure. Accordingly this international evidence is transferable, with suitable caveats and uncertainties expressed, to Hong Kong. Of course, care must be taken in making the assumption that the contribution of various causes of deaths is similar if the mixture of pollutants differs or if the baseline health status of the populations is not similar, or indeed if exposure ranges do not overlap. Given that long-term health impact evidence is not available for Hong Kong and present knowledge is constrained, it is best to proceed using the US/European evidence and approaches to the measurement of health benefits and to ensure that the uncertainties in the analysis are fully recognised in their application to Hong Kong.

This recent evidence uses the “life years saved” approach. In brief the analysts have identified the added life expectancy of the population due to reduction in pollution levels and grossed up these time periods to life-years. Years of potential life gained are a measure of benefits used to evaluate interventions that prevent premature death. Years of life gained are calculated as the difference between the expected duration of life in a particular place with and without the interventions. A valuation of a life-year (VOLY) may be applied to the number of life-years gained for each year into the future based on the predictions generated from the US evidence.

Given the importance of mortality in the CBA calculations an alternative approach to measurement has also been used to provide comparative estimates of the chronic health benefits. This alternative approach uses the value of a statistical life (VSL). In this case the analyst estimates the number of deaths attributable to pollution in a year and multiplies that number by the VSL. The VSL value obviously greatly exceeds VOLY since it represents a capital sum rather than an annual amount. In the literature differences have been observed between the calculated present values of the two values which are commonly applied and investigations are underway both in the US and in Europe to establish the reasons for such differences, given that they have been derived from different sources of evidence.

For the time being the best that can be done is to estimate the costs of premature deaths by the two measures, reflecting the uncertainty of the estimates in the analysis, and making a judgement as to which seems most appropriate to use.

H1.2.4 Indirect Costs

There are several costs imposed on society by air pollution, apart from the health effects.

Loss of output: The COI estimates included in the direct costs also include the output loss of workers who are sick, and their carers. These estimates have been derived from wage rates and other costs associated with employment so although they are considered to be indirect they are already included in the COI direct costs.

Impacts due to reduced visibility, irritants etc: These include the subjective distress caused by the intrusion of the pollution i.e. difficulty with breathing, eye watering etc, not otherwise captured by COI. This cost includes loss of amenity. Some evidence of these effects has been obtained in the study reported by Civic Exchange (2006)[3], based on a telephone interview approach asking respondents to give a WTP to these items. However, sample sizes were too small for reliable results and this effect has not been included.

Buildings and structures: Direct damage to buildings and structures caused by acid rain and other forms of air pollution, referred to as “materials losses”, can be measured by the increased costs of maintenance and repair over normal requirements. There are additional cleaning costs due to deposition of particles and staining. A study by the World Bank (2007a),,[4] found that material losses in southern provinces due to acid rain was valued at about Yuan 6.7 billion of which Guangdong’s share was as much as Yuan 1.6 billion or nearly 25% of the total for southern China in 2003. It seems appropriate, therefore, to consider this item in the Hong Kong context.

Heritage and ecosystems: None of the international literature which has been reviewed has been able to assess the monetary values of impacts of air pollutants on heritage buildings, nor on ecosystems. There is no local evidence that can be used. Accordingly, these effects have not been included into the CBA for Hong Kong.

Agriculture, forestry and fishing: Internationally the direct damage costs of pollution on agriculture (mainly crops) and forestry have been found to be substantial. Studies into acid rain in Hong Kong found a small cost due to damage to crop production of about HK$25 million per annum. This estimate was also supported in general terms by the World Bank study of air pollution impacts in China, referred to above, which found that crop losses in the southern provinces of China were about Yuan 30 billion but very little of it was in Guangdong; only Yuan 0.006 billion in 2003. Due to the absence of any significant agricultural and forestry industries here in Hong Kong, these are unlikely to be factors to be considered in any strategy. Likewise, pollution of sea water resulting from acidic deposition might have an impact on the Hong Kong fishing industry, but the impact was found to be negligible by the acid rain investigations. So, these impacts have not been included in the CBA.

Drinking water: Air pollution deposition into fresh water courses could affect the quality of raw water supplies for Hong Kong both within the territory and for water which is drawn from the Dongjiang River of the PRD. This would affect the cost of treatment to provide potable water and may cause corrosion of equipment for treatment, pumping and pipelines. A recent study found an association of this kind and valued the costs at Euro 45 million (HK$550 million) over the period 1990-2004, which was regarded as being, "…too small to have major consequences for CBA"[5]. No study has been undertaken in Hong Kong of this effect and it is not included in the CBA.

Long-term impacts on the economy: Long-term macro-economic costs need to be considered. Impacts include the adverse effects on the economy from loss of business such as, for example:

- the reluctance of senior executives to locate here
- businesses serving East Asia which prefer to locate or re-locate elsewhere, such as to Singapore, and
- costs to the economy of Hong Kong due to reduced numbers of tourists and visitors.

There is convincing anecdotal evidence of these effects but formal evidence of the actual losses to Hong Kong is problematic. As far as the economic impacts are concerned, evidence is provided in the annual survey of members undertaken by the American Chamber of Commerce (2007)[6]. This survey found substantial evidence of international companies proposing to invest elsewhere due to the poor environmental quality of Hong Kong and difficulties in recruiting professionals to come and work here. Moreover, of the several environmental issues raised in the survey the most significant concern by far was air quality and pollution. Similar findings have been made by the General Chamber of Commerce (2008)[7]. Recruitment consultants based in London advise companies to pay a 10% hardship allowance to encourage expatriates to settle in Hong Kong, partly due to air quality. Thus, although this evidence is compelling it lacks the ability to be transferred into monetary values and the macro-economic impacts have not been included in the CBA.

H1.2.5 The two types of impact: ambient pollution, and concentrations affecting sensitive receptors

The CBA considers impact pathways of air pollution that arise from a general dispersal of pollutants into the atmosphere from different sources and hence which contribute to ambient pollution. Additionally it considers those impacts which are especially concentrated in local areas, which mainly means roadside effects. About 50% of the population lives or works close to a major road.

The CBA uses estimates of pollution concentrations and their associated populations when calculating the health benefits of pollution reduction in the control strategies.

H1.2.6 The Objective Function of the CBA

The same approach to the CBA has been used whether the policy measures to be analysed are:

- regulatory in nature, such as for example a policy of quota restrictions on the numbers of certain types of vehicle, or
- economic, such as would occur with a policy of "polluter pays" through emissions charging, or
- conventional investment-orientated package of measures to which the CBA will be applied or,
- a combination of the policy approaches.

In all these cases it is a necessary step in the procedure to make assumptions about the way organisations and individuals will react to the policy.

The overarching objective is to assess the magnitude of the marginal benefits of taking policy actions to secure the environmental gains and to compare them with the marginal costs imposed on society of the policy measures.

There will be different standards of environmental improvements to be evaluated. Each standard requires identification of the "least cost technical solution", which basically is equivalent to the Best Practicable Measure (BPM) that is required to secure that standard. The costs of the least cost technical solution are then assessed against cost savings that the specified standard of pollution gives rise to.

The CBA considers the costs and benefits of air quality policies which accrue to Hong Kong, which means its residents, businesses and government. Actions taken in Hong Kong will, of course, have some benefits for the rest of the PRD, just as actions taken by the Mainland authorities will also have impacts in Hong Kong. However it is appropriate for the SAR Government to take into account the impacts of its policies and actions on its own community, and this is the focus of the CBA.

H1.3 CBA Methodology

The CBA for the study uses standard methodology. There are many references and practical guidance documents. For example, the UK Government has for many years produced CBA guidance in the Green Book of the HM Treasury[8], which provides the methodology for analysing investments by the public sector and which is widely referred to in Hong Kong. This guidance provides a clear and definitive set of principles and practical applications. The International Financial Institutions of the World Bank, Asian Development Bank and others also provide general guidance for CBA since it is a requirement that investment projects financed by the IFIs are subjected to economic analysis. Of the guidance available from these sources, a useful and very readable guide is by Pedro Belli et al,(2007b). [9]

In outline, the CBA approach is as follows:

- Identify the least cost technical solution(s) (or BPM(s)) for each of the different control strategies to be evaluated.
- Estimate the control strategy costs imposed on society, considering both capital and recurrent costs for the duration of the policy. In practice, where estimates of capital and recurrent costs do not exist but there is evidence of generalised costs (where capital has been incorporated into the recurrent costs using amortisation techniques) the consultants have used the resulting "levelised" costs of both capital and recurrent costs combined. For some of the control strategies (such as nuclear

power where the development of the strategy is out of Hong Kong's hands) the levelised costs are expected to reflect the cost paid by Hong Kong to purchase nuclear power.

- Estimate the policy benefits (i.e. health benefits and other benefits) to society of the reduced pollution levels.
- Calculate a profile of net benefits from the control strategy benefits less costs.
- Incorporate uncertainty of assumptions into the analysis.
- Calculate performance measures for the options.
- Compare and contrast the findings and identify the preferred policy option or packages.

Values are expressed in constant prices, where necessary updated using the GDP deflator. The GDP deflator is used in preference to the CPI because many of the control strategies involve costs of non-consumer goods and services. There is no allowance in the forecasts for general price inflation. Unless there is evidence to identify actual annual values of costs and benefits, values for intervening years between the analysis years are derived by interpolating linearly between the analysis years. For each future year a net benefit figure is derived by subtraction of benefits from costs and, of course, in some years the net benefit figure may be negative.

H1.3.1 The baseline or do-nothing option

The control strategy options for analysis are assessed against the baseline or 'do-nothing' option. The 'do-nothing' option is where no specific action is taken to reduce air pollution other than the implementation of proposals already incorporated into Government policy. Thus, the CBA is a comparison of the incremental costs of policy with the incremental benefits for health etc., which are specifically due to implementation of those policies.

It follows, therefore, that the CBA does not need to consider the costs of policies already committed, since these policies are already incorporated into existing policy proposals and are part of the baseline. For example, baseline policies for the transport sector are described in the Transport Department's Environment Report (2006)[10].

H1.3.2 The CBA model

In order to undertake the CBA of the control strategies a discounted cash flow model has been prepared for each control strategy which analyses the costs and benefits of the strategies and generates performance measures. The basic structure is similar across all the control strategies but variations do exist to reflect the nature of the strategies and the evidence of their costs. Mostly the benefits side of the analysis is analysed in a similar way in all cases with only the magnitudes of the concentrations of pollution and the affected populations varying from one control strategy to another.

The treatment of time is an important element of cost-benefit analysis. All CBAs of the control strategies phase the expected costs and benefits over time which is done year-wise. There is no agreed phasing of policy implementation. So assumptions have been made. These assumptions reflect the practicalities of implementation such as the likely time required to develop the policy, technology differences, investment timetables and so on. But these are broad-based assumptions, not predictions.

The performance measures are then calculated as Present Values (PVs) at the Government's discount rate. The results have been expressed as the ratio of the PV of benefits to PV of costs (B/C). Thus, where this ratio exceeds unity the benefits exceed costs, and *visa versa.*

H1.3.3 The incidence of costs and benefits: who gains and who loses?

The principal purpose of the CBA is to highlight those control strategies which appear to offer Hong Kong best value in terms of their net benefits. However it is of interest to know which sections of the community are most likely to bear the costs of the strategies and, in broad terms, what the incidence of costs is likely to be (for example, whether there would be increases of the price of electricity and by how much, or of the costs of private motoring). This assessment of incidence inevitably is a generalised one and has been treated in this study as a follow-on to the primary task of net benefit estimation. The results on incidence are indicative rather than conclusive of the likely effects and ultimately will be a reflection of future Government policies regarding the use of subsidies.

H1.3.4 Air Quality Improvement

Some strategies may have a large emission reduction potential (such as the energy strategies), but they may be located in less developed areas or their emissions are discharged through stacks such that the population weighted improvement is lower. Similarly, other strategies may have lower emission reduction potential (such as traffic related measures), but their population weighted improvement is higher because of the proximity of receptors (i.e. the public on the street). A population weighted improvement shows the improvement relative to the total population and is used to calculate the benefits in the CBA of each strategy.

H1.4 Principles of Measurement

Unless otherwise stated in a few cases, all estimates of costs and benefits and associated data which have been used in the CBA were taken from external sources, as there are no original research findings. The analysts' task has been to review the evidence and apply judgement as to its use in the CBA.

H1.4.1 Costs of the Control Strategies

Direct costs obviously include the administration of the strategy itself and any costs incurred by Government to bring the strategy into effect (enforcement) and mostly these are relatively small items.

Indirect costs imposed on the community may be substantial. For example switching to nuclear or LNG generated power would have significant impacts. So too would a policy to limit older type vehicles to newer higher Euro standard types, which are more expensive than conventional vehicles and which would affect the purchases of those vehicles.

Some of the costs will be capital in nature such as the additional for hybrid vehicles compared to regular vehicles but many will impact as recurrent costs. For example, a strategy to encourage greater use of public transport in preference to private vehicle use would impose additional time on travellers and these costs have been reflected in the CBA.

Thus the control strategy costs included in the analysis are capital and recurrent cost items and cover both direct and indirect impacts.

H1.4.2 Benefits of the Control Strategies

The principal benefits of the control strategies included in this CBA have been two-fold: a reduction in the cost of illness (COI) both in terms of the short-term or acute impacts and the longer-term chronic impacts; and, a lesser materials benefit arising from reduced maintenance and repair of buildings and structures.

H1.4.2.1 Acute health impacts - concepts

The short-term impacts include the costs associated with attendance at hospitals, GPs and other medical facilities but also include those who die prematurely as a result of the increase in pollution in the periods immediately following. Evidence used to derive these short-term COI benefits have principally been obtained from Department of Community Medicine of the University of Hong Kong (2002)[11], supplemented by the report by Professor Wong Tze Wai et al (2003)[12].

The basic approach used in these studies is to correlate the increase in medical events such as visits to hospitals, GPs etc., with changes in the level of air pollution, whether ambient or localised in nature. The researchers estimate the costs associated with those events from secondary source data so that there is the possibility of linking changes in pollution levels, through impacts to costs of illness. The estimates of costs associated with visits to hospitals, GPs, medication etc., are relatively straightforward to estimate. Moreover, there is a marked distributed-lagged effect such that after a specified number of days the effect of the pollution change has worked its way through the system. These estimates of costs of illness are therefore fairly precise.

More difficult to estimate are the indirect costs of illness associated with loss of earnings (economic output), not only of the affected persons but any friends or relatives acting as carers. There are particular difficulties, of course, in measuring the costs of lost time at school for children and for members of the community who do not normally work in the formal economic system but who undertake activities as housewives and voluntary workers. The researchers into COI have grappled with these issues and the results are regarded as reliable.

More difficult still is the estimation of mortality consequences of increases in pollution. There is a correlation between pollution changes and the rate of deaths from diseases which are affected by pollution and care has been taken to isolate the pollution related impacts on the death rates of the community. Converting these death rates to monetary values requires the application of the concept of a value of life, or more precisely, value of a statistical life (VSL). This is a commonly encountered concept in policy analysis since many sectors of the Government's activities involve safeguarding life in one form or another. North American and European countries have generated considerable research findings and have adopted values for the VSL which are widely regarded as reasonable and these have been applied to the Hong Kong situation.

Thus, the acute impacts of pollution changes have been assessed in the Hong Kong studies and internationally and cover medical costs, indirect costs of lost outputs and the loss of life using the VSL concept.

H1.4.2.2 Chronic health impacts - concepts

New evidence has been generated internationally into the long term chronic health effects of air pollution. Two approaches have been used to derive monetary valuations. The first of these uses the concept of the value of a statistical life or VSL as mentioned under the previous acute health effects heading. Latterly analysts have been using a different but related concept of the Value of a Statistical Life Year or VOLY. Neither method has been applied previously in Hong Kong for chronic effects. In this study the VSL approach has been used only as a cross-check on the values derived using the VOLY approach. If US and European evidence is used, both methods give broadly similar results for this study, though the VSL approach tends to return higher benefits consistent with literature that it overestimates benefits.

The VSL approach identifies attributable deaths from chronic air pollution exposure, which are equal to {the annual air pollution related death rate * population size * relative risk per $\mu g/m^3$ of $PM_{2.5}$ * change in $PM_{2.5}$}.

The valuation is equal to {the attributable deaths from chronic exposure * the VSL}. The WHO suggests a figure of Euro 1.5 million is the appropriate VSL [13]. It should be noted, however, that values adopted by different countries may vary and US valuations are higher. For example, the USEPA in their Year 2000 study of tightening heavy duty standards used a value of US$6 Million per statistical life in 1999 prices.

The long-term or chronic health effects have been estimated for the UK and also for Europe from US data. There is a consensus view that there is sufficient evidence of a long-term effect of exposure to particles on mortality which can be quantified although there is uncertainty in terms of overall size. A large number of studies report such an association between long-term exposure to PM (in particular) and mortality. The US data is the best available but US findings have been confirmed, at least in broad terms, in Europe.

The VOLY approach used here is based on the IGCB (2007)[14]. This report assumes that the age distribution and background mortality rates can be taken to be similar across regions since the findings are not sensitive to these factors. In the UK the relevant national or regional populations have been used to estimate these chronic effects based on population data by adjusting the life tables for England and Wales to reflect the other parts of the UK such as Scotland, and the UK as a whole. It is possible to use the same approach in applications to Hong Kong by making the same assumptions but bearing in mind, of course, that there is a large measure of uncertainty surrounding the central values which has been incorporated into this analysis.

Epidemiological models take into account the structure of populations over an extended time period of 100 years or more and include any feedback into population structure resulting from changes in death rates and fertility. The details of these modelling exercises are complex.

Reliance has to be placed on evidence from the US and Europe since time profiles of Hong Kong's population structure do not exist for the chronic health effects of air pollution. The Europeans and WHO recommend using a hazard coefficient of 6% per 10µg/m^3 for $PM_{2.5}$ (95% CI 2% to 11% per 10µg/m^3 $PM_{2.5}$) which has been derived from the most extensive US study undertaken by Pope et al, 2002[15]. The UK analysis has been transferred to the Hong Kong context and adapted to take into account population numbers and levels of pollution concentration reduction achieved by the control strategies. A recent study by the California Air Resources Board suggests an even higher mortality hazard risk factor of 10% per 10µg/m3 $PM_{2.5}$[16].

The underlying methodology is to obtain information on base-line time profiles of mortality rates and to predict future mortality using current rates and life tables and assumptions about demography in the absence of any changes in air pollution, other than those already incorporated into the baseline. The analysis then creates an alternative scenario by adjusting mortality rates according to the impacts of the control strategy but leaving other assumptions unchanged. Two calculations are then performed. First, the difference in life-years between the baseline and the control strategy for each future year is calculated to obtain life-years saved. Second, the life-years saved are multiplied by the value of a life-year and discounted to the present to obtain a PV of the life years saved.

It has been found in various studies that relationships between pollutant concentrations and impacts on mortality rates are approximately linear. That is, as pollutions concentrations rise or fall, so the chronic health impact changes in a linear fashion. It is reasonable to make this assumption for Hong Kong.

For the control strategy the appropriate population is multiplied by the standard factor of life-years per hazard rate reduction for the control strategy and the appropriate coefficient of reduction in concentration of $PM_{2.5}$. This result is then multiplied by the assumed value of a life-year. For the latter, as is the case for the VSL, the adopted values vary from country to country. In the UK it has been assumed to be GBP 29,000 in recent studies (HK$435,000), rising with the approximate rate of real GDP increase (assumed in the UK to average 2% pa). It should be noted that the value of GBP 29,000 per life year is low by comparison to values used in the US, which range from US$100,000 to US$170,000.

The principal source used for the Hong Kong estimates of chronic effects is the ICGB report[17]. This report provides an extensive review of the evidence relating to chronic effects and in particular considers whether the more recent US evidence can be applied to the UK and, if so, with what confidence intervals. Similar reviews have been undertaken by the EU in the CAFÉ programme (the same consultants were used for both the UK and EU reviews).

The methodology used here for Hong Kong is based on the IGCP report. For example

- The ICGB report Chapter 2, **Table 2.8** reports on the number of life years which are gained for a 1% reduction in the hazard rate (equal to 6,741,659 life years for the UK)
- These life years are then multiplied by the assumed hazard rate of 0.6% per μg/m^3 $PM_{2.5}$, and similarly for the lower and upper bounds of 0.2% and 1.1% per μg/m^3 consistent with the 95% confidence intervals.
- These life years are spread over 100 years for the UK analysis so the life years saved per year are adjusted accordingly
- The Hong Kong population[18] is roughly 12% of that of the UK so the life years saved for Hong Kong would be 12% of those of the UK
- The life years saved per annum are then multiplied by the VOLY to obtain a monetary value. In the UK the VSLY is equivalent to HKD 435,000 rising at 2% per annum to reflect increasing real incomes.

The VOLY approach has several advantages over the application of a VSL approach for chronic effects. These stem from the fact that the VOLY approach applies to a total population which changes only with births and deaths, whereas the VSL approach applies to a fixed population. However it is worth comparing the VOLY with the VSL approach since the latter has been used both in Europe and the US until the more recent VOLY approach was developed following the generation of recent long-term research findings.

The resulting PV of life-years lost is extremely large even within the limits of uncertainty surrounding these figures.

H1.4.2.3 Materials benefits

A study undertaken in Hong Kong by the University of Science and Technology (2001)[19], submitted for the provision of service to the Environmental Protection Department, found that material damage was about HK$400-500m (in 1999 prices), or about 10% of the estimated health costs caused by pollution at that time. This means, of course, 10% of the estimated acute health costs. This 10% finding is consistent with international evidence. Accordingly, this assumption has been used in the material benefits estimates for this CBA.

H1.4.3 Sources of Evidence

The study has endeavoured to relate the control strategies and their costs and benefits to Hong Kong conditions. Evidence from Hong Kong of the costs and benefits strategies has been used as far as practicable. However, there are instances where evidence is not available for Hong Kong but for which there is solid international research or investigation which can be transferred to Hong Kong. In the latter cases the evidence from overseas has been reviewed by Hong Kong experts as far as possible to ensure that it has validity. Of course, in these cases, the uncertainty increases with the assumptions which are used. The next section deals with uncertainty but in general the international evidence is subjected to wider margins of confidence than is the case for evidence from Hong Kong.

Discussion of the individual control strategy options includes the sources of evidence. For the transport sector options, the transport implications have generally been analysed using the Arup transport and traffic model which is used for general strategic planning purposes. This model provides information on the traffic implications of changes to the transport system and has a high degree of reliability and acceptability.

For the energy sector options, discussions have been held with the energy generators from which assumptions have been made about the costs of the control strategy options.

For some of the other strategies, there is more uncertainty about some of the costs and benefits. For example, the control strategies affecting operations at the airport and in the port have not been thoroughly reviewed locally and reliance has been placed on studies undertaken elsewhere at international airports and ports.

In all cases, the sources of elements of costs and benefits have been spelled out in the relevant sections of the CBA.

H1.4.4 Treatment of Uncertainty

The CBA is subject to considerable uncertainties of the assumptions. These uncertainties are extensive enough to require them to be confronted systematically. The uncertainties occur for the dosage impacts of air pollution on society and the measures of the benefit (i.e. cost savings noting for chronic effects the risk factor of 6% per 10 ug/m3 $PM_{2.5}$, and 95% CI 2% to 11% per 10μg/m^3 $PM_{2.5}$) associated with reduced air pollution impacts. They are also apparent and significant in the costs of the policy measures as well, such as the costs of traffic restraint measures, future international prices of LNG fuel, and implementation. Given the pervasive and extensive nature of uncertainties in this analysis it is necessary in this CBA to take into account and confront uncertainties in the formal steps of the analysis.

This requirement to treat uncertainty as part of the analysis is in marked contrast to the traditional project CBA approach which considers uncertainty of assumptions only after the principal analysis has been completed. Typically the traditional analyst will consider the impact on the results of changes to selected assumptions, such as a 10% increase in costs, 20% reduction in benefits etc. Some sophisticated techniques have been developed to make these traditional sensitivity tests more rigorous. One such approach is switching values where the value of a variable is identified that change the value at which the strategy performance measure changes from positive to negative. The analyst is then able to identify those variables which most critically determine the outcome of the analysis.

In this analysis, however, these traditional approaches to the treatment of uncertainty seem inappropriate since a large number of assumptions have critical impacts on the outcomes of the analyses. In order to confront the uncertainties associated with these assumptions and to embed them into the analysis itself, a Monte Carlo technique has been used to analyse the uncertainties. The technique works as follows. For each main assumption and each category of uncertainty there will be an assumed distribution of values around the central assumption; for example, a normal distribution. The range of deviations of the distributions around the central assumption is greater for those assumptions for lower levels of confidence, and narrower for those for higher level of confidence. The Monte Carlo technique involves a simulation of the analysis a large number of times (such as 5,000 iterations) selecting points on the distribution for each assumption at random for each of the simulation runs such that the overall results of the analysis expressed in terms of the performance measures of the control strategy options are also expressed as a distribution around a central finding.

In this way, the analyst automatically derives the best estimate of the net benefit of the control strategy *and* the range of its uncertainty. The limits of the range of uncertainty used in the CBA for the strategy performance measure are at the 95% percentile. That is, on the basis of the assumptions used, we are 95% certain that the true value lies between the limits stated.

In a few cases the extent of the uncertainty surrounding an input assumption is known as it has been derived from the literature. Where this uncertainty is not known for a key assumption in the analysis, the professional judgements of the consultants' team members have been used. Generally the benefits assumptions are more uncertain than the cost assumptions, especially as the dominant benefits for most of the strategies are chronic health benefits for which there is considerable uncertainty as to the estimates from the literature. This approach gives an indication of the degree of uncertainty surrounding the findings of the analysis, as well as the best estimate of the findings.

H1.4.5 Treatment of Unquantifiables

Not everything can be measured in the CBA. Every effort is made to attempt to measure the costs and benefits in monetary units because of the information value of having monetary estimates. In using the Monte Carlo technique for uncertainties it is possible to include much of the uncertainty over measurement into the analysis. Wherever possible, it is better to have dollar values than no values at all and to incorporate the uncertainty into the study findings.

Nevertheless in a few cases some items are not quantified but are identified and listed as such, and a description is given of their effects. Probably the most important ones of these are the macro-economic effects.

H1.4.6 Approach when Air Quality Improvements are Incidental Benefits of the Control Strategies

Some of the control strategies attack air pollution directly by changing the source of pollution. For example, strategies include the use of low sulphur fuels for transport and energy production and these have a direct impact on the level and nature of emissions. In these cases, the CBA is able to relate costs of the policy directly to the benefits of reduced emissions on health, materials etc.

However, there are some control strategies where the improvements in air quality are incidental to the achievement of other policy objectives. One such case, for example, is road congestion charging for traffic. The purpose of congestion charging is to reduce congestion, to free up traffic and reduce travel times and costs. In so doing, however, there will be reduced emissions as a result of the freer flow of traffic.

In the Feasibility Study of Congestion Charging undertaken (2001) there was virtually no mention of air pollution as a benefit of the policy[20]. The benefits were seen almost entirely as traffic benefits. Moreover, the feasibility study found great complexity in analysing the benefits and in determining whether there would be overall advantage to Hong Kong through having a congestion charging scheme. No decision was taken following the earlier study. Following the successful experience of schemes overseas, a new feasibility study of this policy is launched by the Government.

It is not possible for this and in some other cases (principally affecting the transport sector through modifications to traffic management arrangements) for this study to analyse the full costs and benefits of the strategy since this would require months or years of endeavour and considerable resources, way beyond those available. Where air quality benefits are incidental to the achievement of the policy benefits for control strategies, as in the congestion charging case, this analysis is limited to the estimation of the air pollution improvement arising from the policy and which should be incorporated into CBAs undertaken elsewhere for those options.

Because the CBA is focused on the impacts within the territory, one of the benefits that have not been included is carbon emissions. Probably this has the greatest effect for the energy control strategies which substitute low carbon fuels for coal.

H1.4.7 Presentation of the Results

The principal measures of performance of strategies in this CBA are the ratios of present values of benefits and costs. The B/C ratio is given by the PV of benefits divided by the PV of costs. For control strategies for which this ratio exceeds unity, the net benefit is positive, and for B/C ratios which are less than unity the net benefits are negative.

H1.4.8 Structure of the CBA Model

Although the basic CBA model differs in detail from one control strategy to another there is a structure which is common. This structure comprises a set of excel worksheets. There are worksheets for the presentation of data and data analysis of the main elements of benefits and costs. These lead to estimations of costs and benefits in monetary terms at constant prices, and the summary results are brought forward to a “cashflow” worksheet which places the costs and benefits into a year-wise time profile. Discounting procedures are used to generate PVs of costs and benefits. Summary worksheets showing basic assumptions and results are also provided.

H1.4.9 Common assumptions

The costs and benefits are measured in 2008 constant prices, unless otherwise stated. Historical prices have been escalated to 2008 levels using the GDP deflator. This index is used in preference to the CPI as the prices to be escalated are far wider than consumer goods (although it was found in tests that the actual choice of index makes no material differences).

The discount rate used in this analysis is 4% as used by the Financial Services and the Treasury Bureau. This is the measure of social time preference advised by the Government and is roughly equal to the Government's long-term borrowing costs.

Health benefits have been escalated at 2% pa to reflect an effect of rising real incomes on the valuation of health benefits.

In order to undertake the discounted cash flow calculations assumptions have had to be made by the consultants about the timing and phasing of the individual control strategy costs and benefits. These assumptions have been made as realistic as possible, but they are assumptions, not policy. The principal assumptions made by the consultants are as follows:

- Implementation begins at the earliest practical date from 2009 onwards
- Allowance is made for phasing of changes in sectors, such as the phased retiring of older vehicles (rather than a one-year abolition)
- Allowing for the time taken to make the developments of policy itself, or in some cases the introduction of new technology such as hydrogen fuel cells, or sometimes of commercial factors such as power units, some strategies are referred to as follows:
  - Phase I control measures – to be implemented by 2015
  - Phase II control measures – to be implemented by 2020
  - Phase III control measures – to be implemented by 2030.

All costs and benefits have been calculated to 2058 (a 50 years time horizon). They may not end then, of course, but this is a practical cut-off that reflects in discounted cash flow terms the fact that the influence of events after that date on the findings of the analysis is negligible. Moreover, the base case or "do-nothing" option against which the strategies are assessed becomes increasingly difficult to define.

H1.5 Outline of the Control Strategies

H1.5.1 Introduction

Before considering the assessment of their costs and benefits in the sections which follow, this section provides a brief introduction to the several control strategies. They fall into four main groups which:

- reduce the pollution emissions at source by capping arrangements;
- focus on the incidental reductions of emissions from vehicles and other parts of the transport sector by encouraging transport management schemes which alter the patterns of consumption of transport services, and which have other sectoral objectives;
- involve infrastructure development and planning controls which influence behaviour to reduce transport and energy consumption; and,
- focus on the incidental reductions of emissions from the energy sector by changing the pattern of consumption of energy to more efficient management schemes.

H1.5.2 Emission Capping Control Strategies

The largest pollution sources in Hong Kong are the energy and transport sectors. Accordingly, the first group of control strategies looks at the implications of capping emissions from these two sectors and comprise the majority of the proposed measures.

The energy options focus on capping the sources of pollution from the three main power stations. Electricity demand forecasts indicate annual growth rates of about 2%. Thus the industry is relatively stable and changes to production would be made in this context.

The main approach to pollution reduction at source is to change the fuel. No new coal-fired generation units have been allowed since 1997 because of the high emissions from coal relative to other fuels. To improve air quality, both companies have installed and will continue to install emission reduction facilities focusing on 2010 as the first target date and Government has requested them to accelerate these projects. Recent amendments to the APO are relevant for this strategy. There are various incentives incorporated in the agreements with the companies to invest in facilities to reduce emissions.

Helpful for the analysis of energy options was the Stage II Consultation by EDLB (2005)[21].

LNG is already in the base case but further and more urgent application of LNG as a fuel would reduce pollutants. For this fuel there would be both capital and recurrent expenditure requirements at the generators to speed up the process of power generation from this source. Renewable energy supply obviously represents another approach although it is strictly limited in the scale of application which is possible in Hong Kong. The power companies are reviewing the feasible options for wind power production.

Nuclear represents a third fuel option but since there are no opportunities for locating nuclear facilities in Hong Kong this would require investment in China from which Hong Kong would purchase a supply allocation.

The transport sector is the other main producer of emissions and private vehicles represent one of the main sources. A control strategy has been included to reduce private vehicle numbers through a policy of permit quotas. Another approach is to retire those vehicles which are causing heavy pollution.

Changing the fuel system is another approach and strategies encouraging vehicles with hybrid engines and hydrogen fuel cells represent other approaches. These strategies attack the pollution emissions problem directly as would a strategy to speed up the introduction of Euro V standards. These could be brought in line with the European launch such that all new vehicles must meet this standard at an earlier date than otherwise would be the case.

Apart from road vehicles, pollutants could be reduced from marine sources by introducing low emission fuels such as low sulphur diesel and selective catalytic reduction from marine engines. Studies elsewhere suggest that electrification of onshore support equipment would also lead to improvements in the emissions from the marine sector.

Likewise at the airport, aviation could contribute by further electrification of ground support equipment. Hong Kong could only introduce emission standards for aircraft through international agreements governing fuel use. Although changing aviation emission standards is one of the study control strategies, this has not been subjected to cost benefit analysis due to the practicability of implementation and very high level of uncertainties involved.

H1.5.3 Transport Management Control Strategies

By encouraging mode switching it is possible to reduce the amount of emissions especially from private vehicles and Government has several policies associated with this end. In all cases the objectives of transport management schemes are to improve the efficiency of the transport sector, such as reducing congestion, and any pollution reduction is incidental to the primary objective. The study has considered the CBA of a strategy of Low Emission Zones, and other forms of improved transport management could also reduce emissions.

These include pedestrianisation schemes, electronic road pricing and congestion charging, reducing car parking provision to restrain car usage and rationalisation of the bus routes to reduce bus numbers on the roads.

Since transport management schemes have much wider benefits than air pollution reduction and for which the implications of the strategies are complex and far reaching, the control strategies governing transport management have not been subjected to full CBA here. Reference is made to the evaluations of those policies where they already exist or are proposed, and only an assessment of the air pollution benefits has been undertaken in this assessment. The strategies for which this is the case include road pricing and congestion charging which would reduce vehicle congestion, and reduced parking provision which would suppress the number of trips made by private vehicles and involve mode switching.

H1.5.4 Infrastructure Development and Planning Control Strategies

Taking a more strategic view, the Government is encouraging expansion of rail networks to encourage people to travel by these modes. They have lower pollution impacts than use of private vehicles. This effort could be speeded up or widened in scope.

A third area where infrastructure provision could lead to a mode switch having beneficial pollution effects is for the cycling network where cycle routes and cycle reception facilities to public transport hubs are being provided and which could be expanded in scope.

There are smaller but still significant emissions from the industrial sector particularly the construction industry. These may be reduced by changing the nature of the off-road vehicles and equipment to lower emission standards or different kinds of power units.

Introduced in 2007, the Government has regulations governing VOC emissions. These regulations are in line with international practice. However it is possible that these regulations could be strengthened and hence there is a control strategy for this issue.

H1.5.5 Energy Efficient Management Control Strategies

Government has several policies for greater energy management. These could be speeded up or extended to achieve improvements in the efficiency of power consumption.

The control strategies include improved efficiency of buildings, labelling of electrical appliances, use of LED for street lighting and other public display purposes, extension of the district cooling policy and modifications to buildings to reduce emissions through tree and other planting on roofs.

H1.6 Basic Approach to the CBAs of the Control Strategies

Full or partial CBAs have been undertaken for those of the control strategies where data are available, which have been grouped together under the four broad headings used in this section of the report. For each control strategy the approach to measurement of costs and benefits is briefly described in the following four sections and the main assumptions used in the analysis are presented. The results are than summarised in the presentation of the results of the analyses in Section **H1.11**.

On the benefits side of the CBAs, the approach to measurement is essentially the same for each control strategy and only the magnitude of the pollution concentrations and populations affected may differ from strategy to strategy. Population benefiting in Hong Kong is assumed to be the total population of 6,963,100 unless otherwise stated. The CBA analyses the pollution concentrations and populations to deliver a monetary benefits measure for health benefits including reduced premature mortality, and for materials damage to buildings and structures.

Benefits have been expressed initially as savings in pollution tonnages covering SO_2, NO_X, and PM_{10}. These have been converted to concentrations expressed as $\mu g/m^3$.

The control strategies range across several sectors and policy interventions so the approach for each one is different on the cost side. A statement of the principal assumptions used on the costs side of the analysis has been provided for each strategy. A small allowance on the cost side for Government policy development and administration has been included. Generally the sums are HK$8.65 Million for development and variable amounts for administration where this is appropriate.

In the discussion of the CBAs for each control strategy the format for the presentation is that the principal assumptions are set out followed by the results.

H1.6.1 Uncertainty assumptions

Two basic tests have been undertaken reflecting the uncertainties associated with the analysis. The first is a Monte Carlo analysis which is the main part of the uncertainty analysis and has been undertaken wherever the full CBA has been possible. Where benefits only have been calculated (as is the case, for example, with the electronic road pricing strategy) the test used has focussed exclusively on the uncertainties associated with chronic health benefits.

The assumptions used for these two tests were as follows for the Monte Carlo analysis performed:

- on total benefits assuming a distribution about a central estimate which reflects the published uncertainties of the chronic health estimates of pollution reduction and hence which varies very little from control strategy to control strategy (i.e. 0.2% to 1.1% per ug/m³ $PM_{2.5}$);
- on total costs assuming distribution about a central estimate which reflects, in the main, the consultants' judgement as to the reliability of the estimates for each of the control strategies and hence which varies from control strategy to control strategy.

Health benefits analysis performed when benefits only have been calculated are based on the chronic health benefits estimated margins of error around a central value of risk of 0.6% / $\mu g/m^3$ $PM_{2.5}$ of between 0.2% and 1.1% $\mu g/m^3$ chronic health risk.

H1.7 CBA of Emission Capping Control Strategies

H1.7.1 Increasing the Ratio of Natural Gas in Local Electricity Generation

H1.7.1.1 Background

Hong Kong has an existing policy that no new coal fired units will be approved as existing coal units are naturally retired. These units would be replaced with natural gas. The control strategy has three scenarios which instead of allowing coal units to be retired naturally, that is at the end of their life, they are retired early to provide a local energy supply in phases:

- Phase I control measure - 50% natural gas with additional emission abatement measures;
- Phase II control measure - 75% natural gas with additional emission abatement measures; and
- Phase III control measure - 100% natural gas.

By 2015, in the base case natural gas will supply 38% of local energy demand and coal fired units will supply 62% of local demand and these coal fired units that contribute 12% of supply will be retired naturally by 2020. Therefore the near term control strategy measure proportionately allocates costs for early retirement of the coal units by 5 years and replaces their supply contribution with natural gas to meet the 50% supply requirement. Benefits are also allocated over this same period of 5 years because after 2020, these benefits would have occurred naturally as the coal fired units are retired naturally and replaced by natural gas.

In 2020 and assuming the 50% natural gas strategy for the near term is implemented, coal fired units supply 42% of local demand and natural gas supplies 58% of local demand up to the 75% level under Phase II control measure. In the base case by 2023 these coal fired units would have been retired naturally and the 75% natural gas scenario met. So in the medium term strategy the costs and benefits are allocated to reflect their early retirement by 3 years.

Finally, in the base case by 2030 coal fired units supply 6% of demand and by 2033 they are all retired naturally. In the long term strategy the 100% of local generation is supplied by natural gas by 2030 and so costs and benefits are allocated to reflect their early retirement by 3 years.

Natural gas is an expensive fuel and uncertainty exists about the reliability of supply given the competition for it internationally, and its future price which has risen considerably in recent years. Levelised costs are in the order of $US70/MWh and a large component of this value reflects the cost for natural gas itself. Discussions with Hong Kong energy experts suggesting the price could be higher at up to US$90/MWh and this has been included in this study's sensitivity analysis.

In order to increase the natural gas ratio, long term natural gas supply is required to be secured. According to the Memorandum of Understanding signed between the HKSAR Government and the National Energy Administration on 28 August 2008, it guarantees a long-term and stable supply of nuclear electricity, and the supply of natural gas from three different sources — namely, offshore gas, piped gas, and liquefied natural gas (LNG) to be supplied through an LNG terminal to be built, as a joint venture, on a neighbouring Mainland site.

If the proportion supplied by natural gas was to rise significantly above 50% and approach 100% as proposed in the long term scenario, then Hong Kong would be reliant on a single energy supply source for its power needs which has implications for supply security. Hong Kong could be seriously disadvantaged should that single source of supply be unavailable. A single source of supply policy would require standby facilities in case of interruptions for which there would be additional cost implications, which have not been included here.

Finally, there are additional considerations which go beyond economic perspectives. Nuclear with its lower levelised cost will always be an attractive fuel alternative to LNG, yet there are social implications regarding its use and the expectations of the community. Similarly, reduction in the emission of air pollutants is only one of the benefits of fuel switching. The other major benefit is reduction in carbon emissions leading to global warming benefits. These carbon emission benefits are not included in the CBA, which is limited to costs and benefits which accrue to Hong Kong.

H1.7.1.2 Assumptions

The basic assumptions used in the CBA for this control strategy are provided in **Table H1.1** below for each of the 50%, 75% and 100% scenarios.

Table H1.1: Assumptions – Increasing the ratio of natural gas in local electricity generation

50% natural gas for local generation
Existing coal fired units will be retired early and replaced with gas units to achieve 50% natural gas local generation in 2015
LNG modeled at a cost of USD 70 per MWh with sensitivity undertaken at USD 90 per MWh [a]
Coal cost USD50 per MWh [b]
Policy is no new coal fired units in Hong Kong[c]
No additional gas fired generation is required after 2020 to meet the 50% LNG strategy [d]
Cost and benefit allocated until coal fired units retired and 50% natural gas utilized
Local electricity consumption in 2008 is 40,930 GWh.
Annual electricity consumption growth 2% (based on feedback from power companies)
Nuclear intake is assumed to be at current level
75% natural gas for local generation
Existing coal fired units will be retired early and replaced with gas units to achieve 75% natural gas local generation

50% natural gas for local generation
Natural gas modeled at USD 70 per MWh with sensitivity undertaken at USD 90 per MWh [a]
Coal cost USD50 per MWh [b]
Policy is no new coal fired units in Hong Kong and at least 50% LNG already in place to deliver the emission reduction potential of 50% LNG strategy[c]
Cost and benefit allocated until coal fired units retired and 75% LNG local generation utilized
No additional gas-fired generation is required after 2023 to meet the 75% LNG local generation strategy[d]
Local electricity consumption in 2008 is 40,930 GWh. Annual electricity consumption growth 2%
Nuclear intake is assumed to be at current level
100% natural gas for local generation
Existing coal fired units at that time will be retired early and replaced with gas units to achieve 100% natural gas local generation
Natural gas modeled at USD 70 per MWh with sensitivity undertaken at USD90 per MWh [a]
Coal cost USD50 per MWh [b]
Policy is no new coal fired units in Hong Kong[c]
At least 75% LNG strategy already in place to deliver the emission reduction potential of 75% LNG strategy. Cost and benefit allocated until coal fired units retired and 100% LNG utilized
Local electricity consumption in 2008 is 40,930 GWh. Annual electricity consumption growth 2%
Does not include cost of maintaining supply side security (e.g. backup coal or nuclear).
Nuclear intake is assumed to be at current level

Note [a]: Various sources including private discussion with Hong Kong energy experts
[b]: IEA and OECD-NEA (2005) - Projected Costs of Generating Electricity
[c]: EPD data
[d]: Fuel mix and electricity projection from EPD

H1.7.1.3 Air Quality Improvement

Air quality improvements for each of the three control strategies are provided below in **Table H1.2** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³).

Table H1.2: Air quality improvements – Natural gas

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures (Near Term)	13,402	25,225	523	0	0.337	0.5756	0.2765	0
Increasing the ratio of natural gas in local electricity generation to 75% with additional abatement measures (Additional to Phase I measure) (Medium Term)	5,163	5,761	178	0	0.13	0.1334	0.105	0
Increasing the ratio of natural gas in local electricity generation to 100% (Additional to Phase II measure) (Long Term)	6,553	7,430	270	0	0.1641	0.1646	0.1358	0

H1.7.1.4 Results of the CBA

The results for each scenario are presented below in **Table H1.3**.

Table H1.3: CBA Results – Natural gas at US$70 per MWh levelised cost

Control Strategy (US$70/MWh)	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures (Near Term)	2,032	1,803	0.9
Increasing the ratio of natural gas in local electricity generation to 75% with additional abatement measures (Additional to Phase I measure) (Medium Term)	1,702	383	0.2
Increasing the ratio of natural gas in local electricity generation to 100% (Additional to Phase II measure) (Long Term)	348	255	0.7

Using a levelised cost of US$ 70 per MWh, the results suggest that under the assumptions used, the early retirements of coal fired units are not advantageous proposals with the costs outweighing the benefits.

The results using higher assumptions for the future costs of natural gas fuel at US$ 90 per MWh are, of course, substantially less advantageous with substantial negative estimates for NPVs in all cases which are shown below in **Table H1.4**.

Table H1.4: CBA Results – Natural gas at US$90 per MWh levelised cost

Control Strategy 90 US$/MWh	Cost ($HKM)	Benefit ($HKM)	B/C Ratio
Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures (Near Term)	4,908	1,803	0.4
Increasing the ratio of natural gas in local electricity generation to 75% with additional abatement measures (Additional to Phase I measure) (Medium Term)	4,057	383	0.1
Increasing the ratio of natural gas in local electricity generation to 100% (Additional to Phase II measure) (Long Term)	821	255	0.3

H1.7.2 Increasing the Ratio of Renewable Energy (2% wind energy)

H1.7.2.1 Background

One of the prerequisites of the use of renewable energy will always require a comprehensive and stable electricity grid system. The practical potential is limited by a number of factors, including cost, variability, intermittency and siting. The Hong Kong Government has pledged to have 1% to 2% of the generation coming from renewable energy by 2012 and is very likely coming from IWMF - Integrated Waste Management Facilities. A Technical Guidelines on Grid Connection of Small-scale Renewable Energy Power Systems was released by the EMSD 22 to provide information on the safety, equipment protection, reliability, and power quality aspects of small-scale renewable energy systems. In Year 2005, the EMSD put into service the largest photovoltaic (PV) installation in Hong Kong (350kW) and a 1kW small wind turbine on the roof of the EMSD Headquarters building.

In this strategy, a further 2% penetration of renewable energy is assumed. Rough estimation indicates that about 220 sets of 2.5 MW wind turbines will be required with the capacity factor around 15%. Local trial data is essential to study the feasibility. The availability of land for the large number of turbines would be a major hurdle for developing wind power in Hong Kong. Off shore wind farm will be one possible option. However, it will introduce other environmental impacts during construction. Another option is to obtain renewable energy from the Mainland. This will require further negotiation between the Mainland government and Hong Kong power generation companies.

Costs for this control strategy have been allocated by comparing the costs for 2% of wind generated energy supply compared to an equivalent supply of coal until all coal fired plants are retired naturally, after which the comparison is with LNG for the remainder of the assessment period. Benefits have been allocated in the same manner by comparing additional health improvements that would occur using wind rather the coal and LNG.

The World Bank (2007b) study provided generalised international levelised cost data for several renewable options for which the wind option was the cheapest in terms of average levelised costs. The study concluded that for 100,000 kW rated output the costs would be of the order of US$0.0563 per kWh in 2004 prices.

Discussions with Hong Kong energy experts indicate that capital costs in Hong Kong would be significantly higher due to land availability and the higher engineering cost for offshore locations.

The same observations concerning global warming benefits apply to renewable as to LNG, namely that reduction in the emission of air pollutants is only one of the benefits of fuel switching. The other major benefit is reduction in carbon emissions leading to global warming benefits. These carbon emission benefits are not included in the CBA, which is limited to costs and benefits which accrue to Hong Kong.

H1.7.2.2 Assumptions

The basic assumptions used in the CBA for this control strategy are shown in **Table H1.5** below.

Table H1.5: Assumptions – Increasing the ratio of renewable energy (2% Wind Energy)

Renewable (2% penetration for local generation)
Renewable Price (Wind) USD175/MWh [a]
LNG modeled at USD 70 per MWh
Energy experts suggest cost could be higher and up to USD 90 per MWh. Sensitivity undertaken at USD 90 per MWh [a]
Coal cost USD50 per MWh [b]
Only marginal cost (difference between renewable and coal allocated as cost of strategy - 2% renewable compared to 2% coal until 2032 when all units are retired, afterwards compared to 2% cost of LNG)
Local electricity consumption is 40,930 GWh. Annual electricity consumption growth 2%

Note [a] : Various Sources including private discussion with Energy expert
[b] : IEA and OECD-NEA (2005) - Projected Costs of Generating Electricity

H1.7.2.3 Air Quality Improvement

Air quality improvements for the control strategy are presented in **Table H1.6** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.6: Air improvements – Increasing the ratio of renewable energy (2% Wind Energy)

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (µg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Increasing the ratio of Renewable Energy (2% Wind Energy)	502	852	25	8	0.0126	0.0195	0.0107	0

H1.7.2.4 Results of the CBA

The results for this control strategy are shown below in **Table H1.7**. The use of wind is a costly strategy as reflected by its high levelised cost. As with the LNG strategies, there are also carbon and greenhouse gas benefits which have not been included in the analysis.

Table H1.7: CBA Results – Increasing the ratio of renewable energy (2% Wind Energy)

Control Strategy	Cost (HK$M)	Benefit ($HKM)	B/C Ratio
Increasing the ratio of Renewable Energy (2% Wind Energy)	13,069	206	0.02

H1.7.3 50% nuclear power and 50% natural gas for electricity generation

H1.7.3.1 Background

This control strategy proposes comparing a total supply strategy of 50% LNG and 50% Nuclear (Alternative Case) with 85% LNG and 15% nuclear supply (Base Case).

Daya Bay nuclear plant now supplies 70% electricity to Hong Kong (https://www.clpgroup.com/HK/Bus/Fac/Gen/GDNuclear/Pages/GenerationGuangdongNuclearPowerStation.aspx). This contract will expire in 2014. According to the Memorandum of Understanding signed between the HKSAR Government and the National Energy Administration on 28 August 2008, it guarantees a long-term and stable supply of nuclear electricity, and the supply of natural gas from three different sources — namely, offshore gas, piped gas, and liquefied natural gas (LNG) to be supplied through an LNG terminal to be built, as a joint venture, on a neighbouring Mainland site.

Currently this source is capable of providing up to about 20% or so of the territory's total energy requirements. Further extensions of nuclear would be out of Hong Kong's control simply because there are no opportunities within Hong Kong for siting facilities.

Supply from other nuclear plants (e.g. proposed Shaoguan nuclear plant) would be required to increase nuclear power ratio in Hong Kong. It is anticipated that 2 x 1000MW nuclear plants are required in order to fulfil the need.

The costs and benefits for this strategy have been allocated as a straight comparison between the Base and Alternative Cases over the assessment period.

This strategy would have carbon emissions and greenhouse gas implications, as is the case with other low carbon fuels. Additionally, there are social and community expectations regarding the use of nuclear regarding safely, disposal of spent fuel etc., which are not reflected in the analysis. There are supply security issues also associated with minimising reliance on only one supply source which is out of Hong Kong's control.

H1.7.3.2 Assumptions

The basic assumptions used in the CBA of this control strategy are listed below in **Table H1.8**.

Table H1.8: Assumptions - Increasing Nuclear Supply

Increase Nuclear Supply
Increasing Nuclear (50% Natural gas and 50% nuclear on total generation basis)
Two cases: 1) Base Case - 75% Natural Gas local generation with natural growth; and 2) Alternative Case - 50% Natural Gas and 50% nuclear
Base case replaces naturally retired coal fired units with Natural gas until 100% LNG local generation achieved. On total generation basis this equates to 85% Natural gas and 15% Nuclear.
Nuclear cost modelled at USD68 per MWh and Natural gas USD70 per MWh with sensitivity at USD90 per MWh[a] Coal cost USD50 per MWh [b] Cost of supply for both options compared over assessment period together with relative air

Increase Nuclear Supply
improvements for each Least cost option most favourable

Note [a]: Various Sources including private discussion with Energy expert
[b]: IEA and OECD-NEA (2005) - Projected Costs of Generating Electricity

H1.7.3.3 Air Quality Improvements

Air quality improvements for this control strategy are presented in **Table H1.9** below showing the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.9: Air quality improvements - Increasing Nuclear Supply

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m³)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
50% nuclear power and 50% natural gas (Alternative case compared to Base Case of 75% natural gas)	6,554	8,422	381	210	-	-	-	-
Base Case of 75%natural gas	-	-	-	-	0.164	0.165	0.136	0
Alternative Case 50% Nuclear 50% Natural Gas	-	-	-	-	0.164	0.189	0.143	0

H1.7.3.4 Results of the CBA

The results for this control strategy at US$ 70 per MWh are shown below in **Table H1.10**. The results suggest that under the assumptions used, the Alternative Case of supplying 50% Nuclear and 50% Natural Gas provides a cost saving of HK$2,894M and additional benefit of HK$91M compared to the Base Case. This is simply due to the lower levelised cost for nuclear compared to Natural Gas.

Table H1.10: CBA Results – Nuclear (Natural Gas US$70 per MWh)

Control Strategy (LNG US$70/MWh)	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
50% nuclear power and 50% natural gas (Alternative case compared to Base Case of 75% natural gas)	-2,894 [a]	91	NA
Base Case of 75% natural gas	341,375	1,562	NA
Alternative Case 50% Nuclear 50% Natural Gas	338,481	1,654	NA

Note [a]: Reported as saving – Alternative Case (50% LNG 50% Nuclear) is HK$2,894 M cheaper than the Base Case. Based on Natural Gas fuel price of US$70/MWh

At a levelised cost of US$90 per MWh, the Alternative Case provides an even greater total cost saving of HK$ 36,743 M (**Table H1.11**).

Table H1.11: CBA Results – Nuclear (Natural Gas US$90 per MWh)

Control Strategy (LNG US$90 /MWh)	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
50% nuclear power and 50% natural gas (Alternative case compared to Base Case of 75% natural gas)	36,652	91	NA
Base Case of 75% natural gas	424,187	1,562	NA
Alternative Case 50% Nuclear 50% Natural Gas	387,535	1,654	NA

H1.7.4 Vehicle Permit Quota System

H1.7.4.1 Background

This long term control strategy assumes that there would be 50% fewer private cars registered in Hong Kong and that it would be implemented by a process of import quota and registration restrictions.

In Singapore, the Land Transport Authority (LTA) controls the number of vehicles on roads using the Vehicle Quota System. The system requires owners of vehicles (except for buses and emergency vehicles) to have a certificate of entitlement. Under this system, the authority determines the number of new vehicles allowed for registration while the market determines the price of owning a vehicle. In this system, vehicle owners must bid for a Certificate of Entitlement (COE) before the vehicle can be registered. Only a fixed number of COEs are made available every month. Prospective owners must bid to obtain a COE. Successful bidders then pay the quota premium for their vehicle. In determining the number of cars allowed for registration, LTA takes into account the prevailing traffic conditions and the number of vehicles taken off the roads permanently. The quota allocated to each vehicle category is in proportion to that category's share of the total vehicle population. Making cars more expensive may impact heavily upon people living in rural areas.

The basic finding of the traffic modelling is that the quota would reduce the numbers of trips and hence reduce emissions. The model estimated the avoided costs of operation and maintenance that not making these trips would generate. Although there are cost savings from the suppressed trips there are also lost trip-making benefits to be taken into account. It is logical to assume that the benefit people derive from driving a vehicle is greater than the cost they incur as a result of making that trip. Conventional transport and traffic economic analysis suggests that the net benefit loss of these suppressed trips might be given approximately by the "half cost difference rule"[23]. In brief, with a transport systems-wide cost saving due to the suppressed trips of "X" the net benefit loss is given by "X / 2". The CBA has made this assumption in assessing the impact of this scenario.

There are a number of practicalities to be overcome before implementation of this control strategy including community acceptance of a strategy which limits their rights to own a vehicle. It is anticipated that the introduction of vehicle permit quota system in HK may receive strong public objection both from the driver and public because this system will artificially limit the right of car ownership regardless of the affordability issue. In addition, the effectiveness of this system in Hong Kong is in question as this system is likely affecting the private car owners who are mostly weekend drivers and currently amount to only 20% in car ownership.

H1.7.4.2 Assumptions

The basic assumptions used in the CBA of this control strategy are presented in **Table H1.12**.

Table H1.12: Assumptions – 50% Vehicle Permit Quota

50% Vehicle Permit Quota
Vehicle Permit Quotas (50% reduction on PC)
Reduce private cars by 50%
Not making vehicle trips provides savings in terms of vehicle operating costs. Estimate is that 50% reduction in PC provides a HK$3,120M annual saving in vehicle operating costs [a]
Cost to vehicle owners is that they can no longer drive car
People value the benefit of driving their car more than the cost of doing so which coarsely is 50% greater than the cost of doing so. Therefore cost of not being able to drive their car is HK$1,560M
Policy development HK$8.65M annual for 2 years[b]

Note [a]: Vehicle operating costs and travel time savings estimated according to In-house data
[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.4.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.13** showing the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.13: Air quality improvements –Vehicle Permit Quota System

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Vehicle Permit Quota System	28	93	3	119	0.0005	0.1651	0.02	0

H1.7.4.4 Results of the CBA

The results for this control strategy are shown below in **Table H1.14** which suggests that under the assumptions used, the cost of the strategy outweighs the benefits.

Table H1.14: CBA Results –Vehicle Permit Quota System

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Vehicle Permit Quota System	691	251	0.4

H1.7.5 Early Retirement of Aged / Heavily Polluting Vehicles (Pre-Euro, Euro I and Euro II commercial vehicles and franchised buses)

H1.7.5.1 Background

This control strategy assumes that all pre-Euro, Euro-I and Euro-II diesel commercial vehicles and franchised buses would be retired in the near term. This was similar to a proposal put to LegCo's Panel on Environmental Affairs in 2006 for per-Euro and Euro-I vehicles. The proposal pointed out that these pre-Euro and Euro-I commercial vehicles account for a disproportionately large share of emissions from the diesel commercial vehicle fleet although some of them still have comparatively long life remaining.

The proposal suggested that a one-off grant be given to compensate owners for their losses and in order to make the scheme attractive. The Transport Department assessed the financial implications of this grant arrangement by considering each category of diesel commercial vehicles. The numbers of vehicles that were pre-Euro and Euro-I were assessed and incentive figures to reflect the loss to owners were calculated. The loss in 2002 prices was estimated to be HK$3,176 million for 74,367 vehicles. This grant estimate of the compensating amount to owners was also an approximate estimate of the economic loss of the scheme.

The compensating amount for this control strategy has been updated to reflect the expected future vehicle profile, by which time there will be a significant reduction in the numbers of these vehicles through natural retirement. Costs have been allocated by calculating the remaining age of the vehicle and valuing the remaining life using straight line depreciation.

H1.7.5.2 Assumptions

The basic assumptions used in the CBA of this control strategy are shown in **Table H1.15**

Table H1.15: Assumptions – Early retirement of aged / heavily polluting vehicles

Early retirement of polluting vehicles
Early retirement of all Pre-Euro, Euro I, and II commercial diesel vehicles (incl light/medium/heavy goods vehicles, private/public light buses, and non-franchised buses) and franchised buses and replaced by Euro V
Natural retirement age is determined based on 5 percentile on the age profile
No of Pre Euro vehicles replaced: 0 (LGV: 0; HGV (with non-franchised buses): 0)
No. of Euro I vehicles replaced: 2,062 (LGV: 1,099; HGV(with non-franchised buses): 736; franchised bus: 227 [a])

Early retirement of polluting vehicles
No. of Euro II vehicles replaced: 27,068 (LGV:13,802; HGV(with non-franchised buses): 10,643; franchised bus: 2,623 [a]
Replacement cost allocated as average remaining value of vehicle using straight line depreciation and additional 20% cost for new Euro V compliant vehicle. Cost HK$4,687M allocated 2012 to 2014
New LGV cost HK$ 215,572 and new HGV cost HK$600,000 [b]
Policy development HK$8.65M annual for 2 years[c]

Note: [a]: Vehicle Population: Projected based on TD 2007 vehicle population
[b]: Toyota Price 2008
[c]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.5.3 Air Quality Improvements

Air quality improvements for this control strategy are presented in **Table H1.16** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.16: Air improvements Early retirement of aged / heavily polluting vehicles

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Early Retirement of aged / heavily Polluting Vehicles (Pre-Euro I and Euro II commercial vehicles and franchised buses)	0	3,102	300	184	0	3.3711	0.95	0

H1.7.5.4 Results of the CBA

The results suggest that under the assumptions used, the strategy is attractive and retiring aged vehicles results in significant benefits that outweigh the costs of doing so (**Table H1.17**).

Table H1.17: CBA Results – Early retirement of aged / heavily polluting vehicles

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Early Retirement of aged / heavily Polluting Vehicles (Pre-Euro I and Euro II commercial vehicles and franchised buses)	3,882	24,344	6.3

H1.7.6 Earlier Replacement of Euro III Commercial Diesel Vehicles with models meeting latest Euro standards

H1.7.6.1 Background

This control strategy assumes 50% of Euro III commercial diesel vehicles or below other than franchised buses would be required to be Euro V compliant in near term. It would bring Hong Kong closer and more in line with the European launch year. Currently no date has been determined for Hong Kong other than for heavier goods vehicles for which October 2009 has been identified.

The approach to measuring the costs has been to estimate the additional value of the replacement Euro V vehicles together with the remaining value of the old vehicles. The expected LGV profile in 2015 has been estimated by projecting the 2007 TD vehicle population. Costs have been allocated between 2012 and 2014.

H1.7.6.2 Assumptions

The basic assumptions used in the CBA of this control strategy are presented in **Table H1.18**.

Table H1.18: Assumptions – Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards

Earlier uptake Euro V
Earlier uptake of 50% Euro III commercial diesel vehicles by Euro V
Natural retirement age is determined based on 5 percentile of the age profile [a]
Number of commercial diesel vehicle in Euro III to be replaced : 16,921 (LGV: 10,166; HGV (with non-franchised bus):6,755)[a]
Replacement cost allocated as average remaining value of vehicle using straight line depreciation and additional 20% cost for new Euro V compliant vehicle. Cost HK$3,211 Million between 2012 and 2014.
New LGV cost HK$ 215,572 and new HGV cost HK$600,000. [b]
Policy development HK$8.65M annual for 2 years[c]

Note: [a]: Vehicle Population: Projected based on TD 2007 vehicle population
[b]: Toyota Price 2008
[c]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.6.3 Air Quality Improvements

Air quality improvements for each of the control strategy are presented in **Table H1.19** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.19: Air improvements – Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (µg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards	0	743	75	24	0	0.807	0.24	0

H1.7.6.4 Results of the CBA

The results suggest that under the assumptions used, the earlier uptake of Euro V vehicles is advantageous in cost-benefit terms with the benefits outweighing the costs of the strategy (**Table H1.20**).

Table H1.20: CBA Results – Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards

Control Strategy	**Cost (HK$M)**	**Benefit (HK$M)**	**B/C Ratio**
Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards	2,668	6,134	2.3

H1.7.7 Wider Use of Hybrid / Electric Vehicles or Other Environment-friendly vehicles with similar performance

H1.7.7.1 Background

A hybrid vehicle is a vehicle that adopts two or more distinct power sources to propel the vehicle. Common power sources include: on-board rechargeable energy storage system (RESS) and a fueled power source (e.g. internal combustion engine). Some hybrid vehicles do produce less emission than conventional petrol or diesel vehicles.

Although widely discussed and having receiving considerable publicity, the introduction of hybrid vehicles into Hong Kong has been slow. The official Monthly Traffic and Transport

Digest for February 2008 indicate that only 21 private cars were registered in the category of vehicles which includes hybrids.

With regard to hybrid buses, there is no hybrid bus in Hong Kong now. However, in London, double deck hybrid buses are in operation. Their Transport Department is hoping to add 40 double-decker hybrid buses to the fleet this year and then gradually increase that number. They aim for every bus purchased for London (up to 500 per year) to be a hybrid bus by the time of the 2012 Olympics. http://news.bbc.co.uk/1/hi/england/london/6458601.stm

The failure of hybrid buses in Toronto was due to the short working life [around 1.5 years] of the lead acid batteries used. Hybrid buses in Ottawa, however, have adopted newer lithium ion batteries with a working life of more than five years, requiring only little maintenance, lightweight and very efficient.

The popularity of hybrid vehicles depends on technology availability and their cost relative to conventional vehicles. The government may consider providing additional financial incentives to encourage wider use of hybrid vehicles. Nevertheless, the improvement in fuel efficiency in hybrid vehicles is a strong incentive for car owners given the prevailing high gas fuel cost.

This control strategy comprises three variants implemented in the near, medium and long term:

- Near term - 20% of private cars and 10% of buses would be hybrid (or other environmentally friendly vehicles with similar performance such as Euro V or above diesel-engine buses);
- Medium term – 30% of private cars and 15% of buses would be hybrid (or other environmentally friendly vehicles with similar performance such as Euro V or above diesel-engine buses); and
- Long term - 50% of private cars and 50% of buses would be hybrid (or other environmentally friendly vehicles with similar performance such as Euro V or above diesel-engine buses).

The mechanism by which this is to be achieved has not been determined. To some extent, private owners have an incentive to purchase hybrid vehicles given the prevailing fuel cost but it seems clear from the Transport Department statistics that this incentive is insufficient for significant take-up. Something further would be required to achieve the target.

The costs have been allocated by estimating the additional cost for the hybrid vehicles, based on the future estimates of number of vehicles. There is uncertainty in the additional costs and operational cost savings that would be incurred, particularly for the heavier vehicles. Honda prices indicate that the 2008 Civic hybrid is about 20% more expensive than the conventionally fuelled vehicle. An additional 66% cost difference has been allowed between regular and hybrid heavy vehicles and buses.

Hybrid vehicles do provide operational cost savings due to their lower fuel consumption. This has been conservatively estimated at 2% of the additional capital costs, which is likely to be at the lower end of the potential savings.

H1.7.7.2 Assumptions

The basic assumptions used in the CBA of this control strategy are as follows **Table H1.21**.

Table H1.21: Assumptions – Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance

Wider use of hybrids (Near Term 20% PC and 10% Bus)
Vehicles population size is based on 2007 data and is projected (with current vehicle policy incorporated) to determine the portion of Euro types vehicles
20% of Euro III private cars and franchised Euro III buses amounting to 10% bus-fleet change to hybrid vehicles

PC 88,815 and 589 buses
Assumes replacement natural and not compulsory and only additional cost between hybrid and regular allocated
Price difference between PC hybrid and conventional PC 20% [a]
Price difference between hybrid light and heavy bus and conventional light and heavy bus 66% [b]
Conventional PC HK$216,995, LGV HK$220,000, Light Bus/HGV HK$600,000, Heavy bus HK$3.6M
Total additional cost HK$5,226M
Operational cost savings to motorists 2% of total capital cost
Policy development HK$8.65M annual for 2 years d]
Admin and enforcement cost HK$4.31M[1] annual for 3 years while changeover occurs (estimated labour cost)
Wider use of hybrids (Medium Term 30% PC and 15% franchised bus, LGV, HGV (non-franchised buses))
Vehicles population size is based on 2007 data and is projected (with current vehicle policy incorporated) to determine the portion of Euro types vehicles
30% of private cars and 15% franchised buses, LGV and HGV (including non-franchised buses) change to hybrid vehicles by 2020
Type of vehicles to change to hybrid — Total LGV 11,074 HGV 6,711 Non-Franchised Buses 1,257 Franchised Buses 884 PC 150,729
Assumes replacement natural, therefore only additional cost of Hybrid compared to conventional vehicle allocated
Price difference between PC 20% [a]
Price difference between hybrid and conventional LGV, HGV, Light bus and heavy bus 66% [b]
Conventional PC HK$216,995, LGV HK$220,000, Light Bus/HGV HK$600,000, Heavy bus HK$3.6M[b,c]
Total additional cost HK$13,316M
Operational cost savings to motorists 2% of total capital cost (HK$113M/yr)
Policy development HK$8.65M annual for 3 years d]
Admin and enforcement cost HK$4.31M annual for 2 years (estimated labour cost)
Wider use of hybrids (Long Term 50% PC and 50% franchised bus, LGV, HGV (non-franchised))
Vehicles population size is based on 2007 data and is projected to Year 205 (with current vehicle policy incorporated) to determine the portion of Euro types vehicles
50% of private cars and 50% buses, LGV and HGV (non-franchised buses) change to hybrid vehicles
Types of vehicles to change to Hybrid — Total vehicle LGV 19,400 HGV 11,758 Non-Franchised Buses 2,202 Franchised Buses 1,473 PC 160,789
Assumes replacement natural, therefore only additional cost of Hybrid compared to conventional vehicle allocated
Price difference between PC 20% [c]
Price difference between hybrid and conventional LGV, HGV, Light bus and heavy bus 66% [b]
Conventional PC HK$216,995, LGV HK$220,000, Light Bus/HGV HK$600,000, Heavy bus HK$3.6M [b,c]

[1] Enforcement costs are calculated based on labour costs

Total additional cost HK$18,641M
Operational cost savings to motorists 2% of total capital cost
Policy development HK$8.65M annual for 2 years[d]
Admin and enforcement cost HK$4.31M annual for 2 years (estimated labor cost)

Note [a]: Arup In house data
[b]: EPD data
[c]:www.honda.co.uk/car/; www.automobiles.honda.com/civic-sedan/; www.automobiles.honda.com/civic-hybrid
[d]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.7.3 Air Quality Improvements

Air quality improvements for each of the three control strategies are presented in **Table H1.22** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.22: Air quality improvements – Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance (20% private cars and 10% franchised buses) (Near Term)	15	216	7	173	0.0003	0.2377	0.02	0
Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance [30% private cars, 15% buses (including franchised buses), 15% light goods vehicles (LGVs) plus 15% heavy goods vehicles (HGVs)] (Additional to Phase I measure) (Medium Term)	40	849	79	174	0.0007	1.246	0.52	0
Wider use of hybrid / electric vehicles or other environment- friendly vehicles with similar performance (50% private cars, 50% buses (including franchised buses), 50% HGVs plus 50% LGVs) (Additional to Phase II measure) (Long Term)	63	789	42	232	0.0011	1.3922	0.38	0

H1.7.7.4 Results of the CBA

The results suggest that under the assumptions used, the medium term strategy is advantageous due to the higher benefits. This is because the medium term strategy includes more heavily polluting vehicles which increases the benefits. The near and long term strategies incur costs that outweigh the benefits under the assumptions used (**Table H1.23**). There is uncertainty in the cost estimates used for the three strategies, particularly the operational cost savings and additional capital costs for heavy goods vehicles and buses and further more detailed investigation is recommended. Potentially all strategies may be advantageous in cost-benefit terms.

Table H1.23: CBA Results – Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance (20% private cars and 10% franchised buses) (Near Term)	4,326	2,417	0.56
Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance [30% private cars, 15% buses (including franchised buses), 15% light goods vehicles (LGVs) plus 15% heavy goods vehicles (HGVs)] (Additional to Phase I measure) (Medium Term)	9,026	14,447	1.6
Wider use of hybrid / electric vehicles or other environment- friendly vehicles with similar performance (50% private cars, 50% buses (including franchised buses), 50% HGVs plus 50% LGVs) (Additional to Phase II measure) (Long Term)	8,530	7,751	0.91

Note: The strategies have been calculated as being additional to each other, thus the medium term strategy assumes the near term strategy is in place, and the long term strategy assumes both the near and medium term strategies are in place

H1.7.8 Use of Hydrogen Fuel Cell Vehicles or Equivalent Alternatives (40% penetration)

H1.7.8.1 Background

The hydrogen technology is still under development and yet to be commercially viable because the associated cost and durability are the major challenges to fuel cell commercialization. In addition, the size, weight, thermal and water management of the fuel cell are other barriers to the commercialization of fuel cell technology. In transportation applications, extensive infrastructure is required to produce, distribute, store and dispense the hydrogen fuel. However, the California Air Resources Board (CARB) has predicted that mass production will be likely in 2014.

In order to distribute hydrogen to cars, the current gasoline fueling system would need to be replaced, or at least significantly supplemented with hydrogen fuel stations. Safety is a major issue for developing hydrogen infrastructure in Hong Kong and it is anticipated that there will be strong objection from the public.

This control strategy proposes the implementation of hydrogen fuel cells vehicles into Hong Kong in long term. Hydrogen cells are a developing technology and are not yet widespread commercially available. Costs are uncertain as cells in Hong Kong would depend heavily on their rate of uptake internationally. There would also be a need for investment into the supporting infrastructure to make this technology as convenient and accessible as conventional fuels.

Accordingly, it would be misleading to try to attempt to estimate these costs presently. As technology becomes more commercial available, cost will decrease and this needs to be monitored over time and subsequent analysis undertaken. Currently only the potential benefits have been estimated.

H1.7.8.2 Assumptions

The basic assumptions used in the CBA of this control strategy are listed in **Table H1.24**.

Table H1.24: Assumptions – Use of hydrogen fuel cell vehicles or equivalent alternatives

Use of Hydrogen Fuel Cells
Hydrogen fuel cells – Benefits only (40% penetration rate)
Strategy commences in long term
Costs not calculated because technology not wide spread commercially available. As technology becomes more commercial available, cost will decrease

H1.7.8.3 Air Quality Improvements

Air quality improvements for this control strategy are presented in **Table H1.25** showing the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.25: Air quality improvements – Use of hydrogen fuel cell vehicles or equivalent alternatives

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Use of Hydrogen Fuel Cell vehicles or equivalent alternatives (40% penetration)	140	2,778	94	1,453	0.0024	4.8049	0.8621	0

H1.7.8.4 Results of the CBA

The benefits calculated under this control strategy are provided in **Table H1.26**.

Table H1.26: CBA Results – Use of hydrogen fuel cell vehicles or equivalent alternatives

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Use of Hydrogen Fuel Cell vehicles or equivalent alternatives (40% penetration)	See Note	10,420	NA

Note: Strategy is not yet mature. There are no reliable local cost data and accordingly, only benefits have been calculated.

H1.7.9 Ultra Low Sulphur Diesel for Vessels

H1.7.9.1 Background

The Merchant Shipping (Prevention of Air Pollution) Regulation (Cap 413M) imposes restrictions on ship emissions of harmful substances such as ozone-depleting substances, VOC, NO_X and SO_2. It also seeks to control the quality of fuel oil used on board vessels and regulates shipboard incineration. Moreover, survey and certification will be required for ships of 400 gross tonnage or above. This Regulation is applicable to all Hong Kong registered ships, foreign ships within Hong Kong waters, as well as “local vessels” as defined in the Merchant Shipping (Local Vessels) Ordinance, Cap. 548, including locally licensed vessels, Hong Kong registered river trade vessels and PRC coastal/river trade vessels trading to Hong Kong. Marine Department is responsible for enforcement of the regulation. International Maritime Organisation (IMO) has recently approved some amendments to MARPOL Annex VI. The amendments will be effected progressively from 2012.

International agreements govern MARPOL Annex IV requirements which came into effect in June 2008. One consequence is that vessels in Hong Kong’s waters must use fuel oil with sulphur content below 4.5%. Under MARPOL Annex VI, countries can propose their waters to be designated as a 'Sulphur Emission Control Area' (SECA), in which ships will be required to burn low-sulphur fuel (not exceeding 1.5% sulphur).

Recently, the concept of Micro-Emission Control Area (MECA) has been proposed by shipping organisations to restrict fuel sulphur content to 0.1% at a distance of no more than 24 nautical miles from the baseline. The stretch of Hong Kong waters is too small for becoming MECA. Cooperation with Guangdong is required for establishment of MECA in the region. In fact, further implementation of ULSD standard to other vessels in HK water will require International collaboration. The long term plan of IMO would be followed.

This control strategy comprises two staged scenarios:

- Near term - local vessels switch from regular fuel to ULSD; and
- Medium term – all ocean going vessels and local vessels switch from regular fuel to ULSD.

Costs have been allocated as the additional cost for ULSD compared to regular fuel over the assessment period. A capital cost allocation has been made for construction and installation of bunker facility, but operational costs for the facility has not been included. The actual costs for the construction and operation of the bunker are uncertain and greater investigation is recommended to confirm these costs.

This control strategy would have cost implications for the fuel itself and the bunker storage facilities. Any extension to shipping more generally would require international collaboration especially for ocean-going cruisers that are governed by international standards.

H1.7.9.2 Assumptions

The basic assumptions used in the CBA of both scenarios under this control strategy are shown in **Table H1.27**.

Table H1.27: Assumptions – Ultra Low Sulphur Diesel for Vessels

ULSD diesel for local vessels
Local vessels will be required to use ultra low sulphur diesel (ULSD)
Average fuel price difference between ULSD and regular fuel HK$188.75/kL. (Averaged over October 2006 – September 2007)[a]
Fuel consumption 2006 was 43,234 kL(local)[b]
Annual 0% increase applied in fuel consumption for local vessels since Yr 2006 [b]
Policy development HK$8.65M annual for 2 years[c]
Admin and enforcement cost HK$1.7M annual (estimated labour cost) HK$350M allocated for bunker facilities
ULSD diesel for ocean going vessels
Ocean going vessels will be required to use ultra low sulphur diesel (ULSD) in medium term
Average fuel price difference between ULSD and regular fuel HK$188.75/kL. (Averaged over October 2006 – September 2007)[a]
Fuel consumption 2006 was 43,234 kL(local)[b]
Annual 2% increase applied in fuel consumption for ocean-going vessels
Policy development HK$8.65M annual for 2 years[c]
Admin and enforcement cost HK$1.7M annual
HK$350M allocated for bunker facilities

Note [a]: Legislative Council Panel on Environmental Affairs Mandating the Use of Ultra Low Sulphur Diesel in Industrial and Commercial Processes 17 December 2007

[b]: According to Port of Hong Kong Statistical Tables 2006 – 2008 by MD, there is no increasing trend for the number of Hong Kong licensed vessels. Hence, 0% increasing trend in fuel consumption for local vessels is assumed for conservative purpose.

[c]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.9.3 Air Quality Improvements

Air quality improvements for both control strategies are presented in **Table H1.28** and shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.28: Air quality improvements – Ultra Low Sulphur Diesel for Vessels

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m³)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Ultra low sulphur diesel (ULSD) for local vessels	675	0	18	0	0.336	0	0.254	0
Ultra low sulphur diesel for ocean-going vessels and local vessels (Additional to Phase I measure)	2,392	1,145	15	0	1.081	0.4314	0.772	0

H1.7.9.4 Results of the CBA

The results suggest that under the assumptions used, both strategies are advantageous in cost benefit terms with benefits that outweigh the costs by wide margins (**Table H1.29**).

Table H1.29: CBA Results - Ultra Low Sulphur Diesel for Vessels

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Ultra low sulphur diesel (ULSD) for local vessels	378	6331	16.7
Ultra low sulphur diesel for ocean-going vessels and local vessels (Additional to Phase I measure)	4,563	15,087 [a]	3.3

Note [a]: In this study, it is assumed that there is no switching in fuel for ocean going vessels outside the control zone. In practice, vessels are able to switch fuel types.

H1.7.10 Selective Catalytic Reduction for Vessels

H1.7.10.1 Background

SCR of NO_X using ammonia or urea has been used for many years in stationary and marine diesel applications, and also for gas turbine NO_X control. The catalysts employed for SCR units are typically vanadium pentoxide embedded in titanium dioxide, and additionally are often dosed with tungsten trioxide and molybdenum trioxide to optimize the catalytic properties. The biggest issue with SCR is to tune the SCR system to the engine operating cycle. This requires running the engine through a simulation of the operating cycle of the machine which will be fitted. Another common problem with all SCR systems is the release of unreacted ammonia referred to as ammonia slip. Slip can occur when catalyst temperatures are not in the optimal range for the reaction or when too much ammonia is injected into the process.

The CARB has proposed cleaner engine (new or retrofits) for reducing vessel emission, expected to be implemented in 2010. By 2014, ships visiting California's ports would have either new engines or a mix of retrofit technology that would achieve an overall reduction of NO_X and PM of 30%.

A local ferry operator has tried the use catalytic convertor before but found that it was only usable in a few vessels. Since there has not been much experience in implementing the catalytic reduction on local ferries, it cannot be certain about the real impact on ferry operation and total cost implications. The technical feasibility and cost implications will need to be further reviewed in future.

Nevertheless, in order to have a significant effect on air quality, it is necessary to extend the strategy to all shipping areas around Hong Kong. International collaboration is thus required to control the installation of the device. The long term planning of IMO would be followed.

This control strategy requires all new local vessels to install Selective Catalytic Reduction (SCR) technology to reduce exhaust emissions. The control strategy comprises two scenarios:

- Near term – SCR for local vessels and
- Medium term – SCR for to ocean going vessels and local vessels.

Costs have been allocated by estimating the number of local vessels that would require SCR installation, together with the cost for installation itself.

H1.7.10.2 Assumptions

The basic assumptions used in the CBA of this control strategy are provided below in **Table H1.30**.

Table H1.30: Assumptions – SCR for vessels

SCR for local vessels
SCR fitted to local vessels in near term
Assume existing vessels adopted SCR is 146 (derived from Port Statistics 2006, MD)
Each SCR cost HK$2M (local vessels) to HK$9M (ocean going) [a]
Policy development HK$8.65M annual for 2 years[b]
SCR for ocean going vessel
SCR fitted to ocean going vessels in medium term
Each SCR cost HK$2M (local vessels) to HK$9M (ocean going) [a]
~ 350 ocean going vessels registered in Hong Kong (derived from Port Statistics 2006, MD)
Policy development HK$8.65M annual for 2 years[b]

Note [a]: EPD data
[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.10.3 Air Quality Improvements

Air quality improvements for each both of the control strategies are presented in **Table H1.31** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.31: Air quality improvements – SCR for Vessels

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Selective catalytic reduction (SCR) for local vessels	0	304	0	0	0	0.1295	0	0
Selective catalytic reduction for ocean-going vessels and local vessels (Additional to Phase I measure)	0	7,153	0	0	0	2.623	0	0

H1.7.10.4 Results of the CBA

The results for both control measures are shown below in **Table H1.32**. Under the assumptions used, neither of the control measures has a B/C ratio greater than unity.

Table H1.32: CBA Results – SCR for Vessels

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Selective catalytic reduction (SCR) for local vessels	249	74	0.3
Selective catalytic reduction for ocean-going	1,333 [a]	1,173	0.9

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
vessels and local vessels (Additional to Phase I measure)			

Note [a]: Regional collaboration is required for the installation of SCR to ocean going vessels. Total costs for all international and Hong Kong based vessels estimated at $HK28 Billion. The presented cost reflects only Hong Kong registered vessels (~350 number)

H1.7.11 Electrification of On-shore Power Supply

H1.7.11.1 Background

The on-shore power commissioned in 2004 for the Port of Los Angeles was the first of its kind in the world. According to the Green Port Annual Report 2005, the Port of Long Beach also initiated a master plan for upgrading its electrical infrastructure to accommodate shore-power throughout the Port. Also, Nippon Yusen Kabushiki Kaisha has built the world's first container vessel designed according to POLA's shore-side power specifications and plans to retrofit or build 39 container ships with shore-side electrification technology by 2010.

The CARB proposes on shore support power supply for reducing auxiliary engine emissions, to be implemented in 2010, aiming at reducing emission by 80% in 2020. Ocean-going vessels always adopt different power standards. In order to accommodate the on-shore electricity supply, the vessels power standards will have to be changed. It is difficult to enforce this measure to all ocean-going vessels without international agreement.

In HK, there is a proposal for development of on shore support power supply in cruise terminal at Kai Tak. The lease conditions have also made provision for such requirement. However, the lease conditions do not restrict the vessels to use the on-shore power supply.

It is assumed under this control strategy the electrification of onshore support equipment. The infrastructure cost for grid-based shoreside power at the Port of Los Angeles was US$200million, which consisted of 16 berths. There are 24 berths at HK container terminals. At a cost per berth of US$12.5 million the cost for the HK container terminals would be HK$2.3 Billion. This cost has been assumed to be allocated over three years from 2012-2014.

Cost estimates for this strategy has relied on background literature and it is recommended that greater investigations be undertaken with the Port to confirm the assumptions that were used and the resulting cost estimates.

H1.7.11.2 Assumptions

The basic assumptions used in the CBA of this control strategy are shown in **Table H1.33**.

Table H1.33: Assumptions – Electrification of On-shore Power Supply

Onshore electrification for marine sector
Fully utilization of shoreside power for ocean going vessels by 2020
Infrastructure cost for grid-based shoreside power at Port of LA is US$200M, (Green Harbours: Hong Kong & Shenzhen, civic exchange, 2006) which consists of 16 berths.
24 berths at HK container terminal
Cost per berth is US$12.5M
Cost for HK container terminal HK$2.3Billion
Policy development HK$8.65M annual for 2 years [a]

Note [a]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.11.3 Air Quality Improvements

Air quality improvements for each of the three control strategies are presented in **Table H1.34** below showing the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.34: Air quality improvements – Electrification of On-shore Power Supply

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Electrification of On-shore Power Supply	377	2,361	297	404	0.1761	0.8937	0.314	0

H1.7.11.4 Results of the CBA

The results for this control strategy are shown below in **Table H1.35** and suggest that under the assumptions used, the strategy is advantageous in cost-benefit terms with benefits outweighing the costs. Further investigation is recommended to confirm the cost estimates used.

Table H1.35: CBA Results – Electrification of Onshore support Equipment

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Electrification of On-shore Power Supply	1,579	6,243	4.0

H1.7.12 Electrification of Aviation Ground Support Equipment and Tightening Aviation Emission Standards

H1.7.12.1 Background

Ground support equipment (GSE) at the airport includes the mobile diesel-fueled compression ignition equipment to service and support aircraft operations. It comprises a diverse range of vehicles and equipment to service aircraft after landing and before takeoff. Major services include cargo loading and unloading, passenger loading and unloading, potable water storage, lavatory waste tank drainage, aircraft refuelling, engine and fuselage examination and maintenance, and food and beverage catering. The CARB encourages the use of electric GSE and proposes a progressive tightening fleet emission target to be met for the GSE, starting from 2009. There are different requirements for small, medium and large fleets.

The application of electric GSE requires early phasing out of existing equipment. In order to accommodate the GSE electricity supply, the electricity infrastructure inside the airport will have to be modified.

This control strategy involves the reduction of the airport's use of non-electrified vehicles and equipment in near term. Cost estimates are very preliminary and reliant on data produced in the US for a military airport, rather than a commercial one. Greater site specific investigation is required regarding the anticipated costs for GSE equipment and the required supporting infrastructure at Hong Kong international airport.

For the tightening of aviation emission standards, most air pollution due to aviation is produced during landing and take-off (including climb-out, final approach and taxiing modes). In 2006, the NO_X and PM_{10} emissions due to civil aviation contributed about 5% and 0.4% of total emission respectively. The emissions from aircraft are constrained by international standards. International collaboration is required to tighten the standard. Moreover, trade off between emissions (e.g. CO and NO_X) shall be considered.

According to Statement from the ICAO to the Twenty-Sixth Session of the UNFCCC Subsidiary Body for Scientific and Technological Advice, 2007, aircraft produced today are required to meet engine certification standards adopted by ICAO. The first standards for NO_X were adopted in 1981 and made more stringent in 1993, 1999 and 2004. Based on the reviewing work of the organization's committee on Aviation Environmental Protection held in its seventh meeting (CAEP/7), the medium and long term technology goals for NO_X were developed. Relative to mid term goals (2016), the group estimated a 45% reduction from the current standards. As for the long term goal (2026), it estimated that a reduction of some 60% would be attainable.

This control strategy involves the tightening of aviation emission standards in medium term. The cost will be borne by aircraft industries worldwide.

H1.7.12.2 Assumptions

The basic assumptions used in the CBA of this control strategy are provided in **Table H1.36**.

Table H1.36: Assumptions – Electrification of Ground Support Equipment and Tightening of Aviation Emission Standards

GSE electrification
Electrification of GSE Equipment
Cost per unit HK$2.4M [a]
700 GSE units at Hong Kong airport to be electified
Cost for electrical distribution HK$50M
Policy development HK$8.65M annual for 2 years[b]
Tightening of aviation emission standard
Cost will be borne by the aircraft worldwide

Note [a]: Navy Environmental Leadership Program, Navy Air station (NAS) North Island, 23 January 2002

[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.12.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.37** showing the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.37: Air improvements – Electrification of Ground Support Equipment and Tightening Aviation Emission Standards

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (μg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Electrification of aviation Ground Support Equipment	85	759	21	67	0	0.011	0	0
Tightening aviation emission standards [a]	0	3,587	0	0	0	0.043	0	0

Note [a]: Emission reduction is based on Statement from the ICAO to the 26 Session of the UNFCCC, Subsidiary Body for Scientific and Technological Advice (SBSTA), 2007

H1.7.12.4 Results of the CBA

The results suggest that under the assumptions used, this control strategy has very low B/C ratios. The expected benefits are very small relative to the costs for implementation (**Table H1.38**). It is anticipated that even with greater certainty in cost estimates, the strategy will still not be advantageous in cost-benefit terms simply because of the low population weighted benefits that are provided.

Table H1.38: CBA Results – Electrification of Ground Support Equipment and Tightening Aviation Emission Standards

Control Strategy	**Cost ($M)**	**Benefit ($M)**	**B/C Ratio**
Electrification of aviation Ground Support Equipment	1,449	3.8	0.003[1]
Tightening Aviation Emission Standards	Note [2]	12	NA

Note [1]: Due to the remoteness of the airport from the populated urban centres, only a relatively small resident population can benefit from the improved air quality. The B/C ratio would, therefore, be low. However, the emission reduction would help improve the regional air quality and a higher B/C ratio will be resulted if it is considered in a regional context.
[2]: Cost will be borne by the aircraft industry worldwide

H1.7.13 Emissions Control for Off-Road Vehicles / Equipment

H1.7.13.1 Background

Off-road vehicles and equipment, which consist of diesel engines, are found mostly in construction industry in HK. Some familiar examples of off-road vehicles include tractors, excavators, dozers, scrapers, portable generators, irrigation pumps, welders, compressors, scrubbers, and sweepers. The technology of controlling emissions from off-road vehicles and equipment is mature. Many new diesel engines are able to comply with the latest USEPA and CARB emission requirements. According to the "Non-road diesel emission reduction study" prepared by Gensis Engineering Inc & Levelton Engineering Ltd, 2004, compact EGR (Exhausted Gas Recirculation) / DPF (Diesel Particulates Filter) packages are one of the possible options for off-road equipment emission control. However, with long life span of the off road vehicles and equipment, it may require years to phase out the old engines. Subsidisation or regulation would be required to implement the strategy.

This control strategy requires plant and equipment at construction sites to be installed with emission reducing equipment to comply with new emission standards. It has been assumed that all new pieces of construction equipment would be compliant with the new standards and would not need installation of further special equipment. Costs include the purchase of new emission reducing equipment together with the expected number of off road vehicles and have been allocated.

H1.7.13.2 Assumptions

The basic assumptions used in the CBA of this control strategy are listed in **Table H1.39**.

Table H1.39: Assumptions – Emission Control for Off Road Vehicle / Equipment

Emission control for off road vehicles and equipment
Installation of ULSD + EGR / DPF to all construction equipment to control emissions from construction vehicles in near term
Cost per construction equipment HK$51,000[24]
No of construction sites in Hong Kong = 1007 (Projected from 2007 data 946 [a])
Average number of construction equipment per site = 30
Total cost HK$1 Billion
Policy development HK$8.65M annual for 2 years[b]
Admin and enforcement cost HK$1.1M annual (estimated labour cost)

Note [a]: Hong Kong Census 2007
[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.13.3 Air Quality Improvements

Air quality improvements for this control strategy are shown in **Table H1.40** detailing the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.40: Air quality improvements – Emission Control for Off Road Vehicle / Equipment

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (μg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Emission Control for Off Road Vehicles / Equipment	4	950	239	326	0.002	0.2402	0.0815	0

H1.7.13.4 Results of the CBA

The results are presented below in **Table H1.41** and suggest that under the assumptions used, the strategy is advantageous in cost-benefit terms with benefits outweighing costs by a significant margin.

Table H1.41: CBA Results –Emission Control for Off road Vehicle/ Equipment

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Emission Control for Off Road Vehicles / Equipment	845	2,123	2.5

H1.7.14 Strengthening Volatile Organic Compounds Control

H1.7.14.1 Background

The current VOC regulation controls the VOC emissions of certain products. The new VOC regulation imposes maximum limits on the VOC content of architectural paints/coatings, printing inks and six selected consumer products - air fresheners, hairsprays, multi-purpose lubricants, floor wax strippers, insecticides and insect repellents. The scope of control of VOC limits stipulated in the VOC Regulation is a result of intense negotiations with the trades and much scrutiny by LegCo. In any case, the VOC limits are in line with that adopted in California over many years, which are the most stringent standards in the world.

In California, three measures have been developed by CARB to address this issue.

Measure CONS-1: The CARB committed to develop a measure, to be implemented by 2006, that would achieve a VOC emission reduction from consumer products of at least 2.3 tpd in the South Coast Air Basin, and 5.3 tpd statewide, in 2010.

To fulfill this commitment, in June 2004, the Board approved amendments to the Consumer Products Regulation to satisfy Measure CONS-1. These amendments established VOC limits for 15 product categories that will achieve an estimated emission reduction of 6.0 tpd in California, including 2.8 in the South Coast, by December 31, 2006.

Measure CONS-2: The CARB committed to develop a measure, to be implemented by 2008 and 2010, that would achieve VOC emission reductions from consumer products of 8.5 - 15 tpd in the South Coast Air Basin in 2010. Statewide, this measure would achieve 20 - 35 tpd in emission reductions in 2010.

Further Reductions from Consumer Products: In addition, it is expected that further emission reductions will be needed from all source categories, including consumer products, to meet the long-term emission reduction targets included in the South Coast SIP. More reductions will also be needed to satisfy the new 8-hour ozone standard. As such there is an ongoing commitment to pursue additional technologically and commercially feasible reductions in consumer product emissions.

This control strategy involves strengthening control over VOC emissions. There are two scenarios under this control strategy:

- Near term - strengthening VOC control for non-architectural paints, solvents, sealant and adhesives; and
- Medium term – further strengthening VOC control

VOC regulations are already in place and Government is reviewing the scope of control under them. The control strategy would involve strengthening these further. Costs are based on estimates from the US and allocated for the near and medium term strategy.

H1.7.14.2 Assumptions

The basic assumptions used in the CBA of this control strategy are as follows **Table H1.42**.

Table H1.42: Assumptions – Strengthening VOC Control

VOC control for non-architectural paints, solvents, sealant and adhesives, and further strengthening VOC control.
Strengthen VOC control for non-architectural paints, solvents, sealant and adhesives in near term, and further strengthening VOC control in medium term
Cost HK$8 per kg of emission reduced [a]
Total cost is ~HK$5.6M
Policy development HK$8.65M per year over 2 years[b]

Note [a]: Californian Environmental Protection Agency http://www.arb.ca.gov/consprod/geninfo/cpsmog.htm

[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.7.14.3 Air Quality Improvements

Air quality improvements for both scenarios under this control strategy are listed in **Table H1.43** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.43: Air quality improvements – Strengthening VOC Control

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (µg/m³)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**O_3**
Strengthening Volatile Organic Compounds Control	0	0	0	700	0	0	0	0.295
Further Strengthening Volatile Organic Compounds Control	0	0	0	4,870	0	0	0	1.93

H1.7.14.4 Results of the CBA

The results suggest that under the assumptions used, both strategies are advantageous in cost-benefit terms with benefits outweighing the costs by a significant margin (**Table H1.44**).

Table H1.44: CBA Results – Strengthening VOC Control

Control Strategy	**Cost (HK$M)**	**Benefit (HK$M)**	**B/C Ratio**
Strengthening Volatile Organic Compounds Control	18	124	6.9
Further Strengthening Volatile Organic Compounds Control	37	634	17.2

H1.8 CBAs of the Transport Management Control Strategies

H1.8.1 Low Emission Zones

H1.8.1.1 Background

A low emission control zone (LEZ) aims to reduce road transport emissions over a defined geographic area, by restricting certain vehicle types, ages or technologies from entering the zone. The feasibility of LEZ in HK will be subject to further investigation and will require more detailed consideration of the costs to transport operators and road users and change in traffic behaviour to surrounding areas.

The basic intention behind this control strategy is to exclude vehicles which are Euro III or below standards from selected areas of the territory – Central, Causeway Bay and Mong Kok. There is still considerable uncertainty regarding implementation. For example would enforcement utilise an expensive camera system? What would be the fee levied on non compliant vehicles? This would have implications for the costs incurred by vehicle owners as they decided whether to change their vehicle to a newer more compliant one, upgrade it through installation of equipment to reduce emissions, or simply stopped driving into these areas altogether and utilised public transport instead.

The LEZ of London came into effect on February Yr 2008. The LEZ is intended to improve the quality of air in London and to reduce the concentrations of harmful pollutants, by accelerating the introduction of cleaner vehicles and reducing the numbers of older, more individually polluting vehicles within the LEZ. There is a planned phase introduction of an increasingly stricter regime up to 2012. All heavy good vehicles (HGVs), buses and coaches would have to meet a tighter emission standard of Euro IV for PM in 2012. Non-compliant vehicles could still drive within the LEZ, but their owners would have to pay a charge (up to £200 per day) to do so. The zone deviates to allow diversionary routes and facilities to turn around without entering the zone. Study shows that the LEZ would deliver reduced emissions of both NO_X and PM_{10}, particularly after 2012 following the implementation of Euro IV standard. The results would be greatest along main roads, and in the background areas within London.

The setting of low emission zone should be started in smaller areas as it would be easier to implement the scheme. It is anticipated that this measure will be more effective in pollution hot spots. However, cost-effectiveness declines with smaller zones and with less polluted vehicles. Emission charges will be introduced for non-complying vehicles. Hence, non-compliant vehicles will be diverted to other districts. Inside the LEZ, affected vehicles and shop operators may object to the proposal.

The demarcation of the LEZ in Mongkok, Central and Causeway Bay by streets are outlined as follows:

Mong Kok	Central	Causeway Bay
Boundary Street	Garden Road	Marsh Road
Yim Po Fong Street	Connaught Road Central	Victoria Park Road (in Western)
Soy Street	Lower Albert Road	Gloucester Road
Tong Mi Road	Hollywood Road	Leighton Road
Pitt Street	Queen's Road West	Morrison Hill Road
Ferry Street	Charter Road	
	Ko Shing Street	

The costs estimated for this strategy assume a camera system for enforcement. It also assumes that those vehicle owners travelling regularly into LEZ areas would continue to do so and either upgrade or replace their vehicle, rather than utilising some other form of transport means, while less frequent visitors would consider alternative means, or payment of a charge.

H1.8.1.2 Assumptions

The basic assumptions used in the CBA of this control strategy are shown below in **Table H1.45**.

Table H1.45: Assumptions – Low Emission Zones

Transport management: LEZ – Central, Mongkok and Causeway Bay
LEZ in central, Mongkok and Causeway Bay, applicable to all vehicles Euro III or less
Vehicles affected takes into account all proposed transportation strategies
LEZ charging regime not included and would need to be worked out, but it is assumed that the charge would be high enough to cause a shift in vehicle owner behavior. That is, over time, it would be cheaper for people who regularly entered the LEZ to change transportation mode, upgrade or replace their vehicle rather than continually paying the charge.
Cost will be subject to the design and technology adopted for the LEZ
Population affected in Central 293,830 = 30,455 resident + one third of 790,125 visitors (only

Transport management: LEZ – Central, Mongkok and Causeway Bay
exposed for 8 hours per day)
Population affected in Mongkok 110,427 = 83,998 resident + one third of 79,286 visitors (only exposed for 8 hours per day)
Population affected in Causeway Bay = 57,094 = 32,941 resident + one third of 72,459 (only exposed for 8 hours per day)
Area of LEZ in Central : 810,000m^2
Area of LEZ in Mongkok : 1,324,634m^2
Area of LEZ in Causeway Bay: 369,886m^2
AVI camera system cost HK$ 205 Million, Operational cost HK$12.4 Million per year [a]
91,340 Diesel Vehicles Euro III or less in 2015 (Note: this is 50% of the total and allows for the effects of other strategies such as early retirement of aged and polluting vehicles).
Total number of vehicle trips predicted in 2011 in Central and Western is 147,983.
Total number of daily vehicle trips in Central 103,588
Total number of daily vehicles trips in Mongkok is 239,038
Total number of daily vehicles trips in Causeway Bay is 358,597
Percentage of vehicle trips from total is roughly 18% in central and 30% in Mongkok [c]
These 18%, 16% and 30% (Central, Causeway Bay and Mongkok respectively) are assumed to be entering Central, Causeway Bay and Mongkok regularly (based on vehicle trips) and would be most affected by the LEZ. The remainder (82% in central, 84% in Causeway Bay and 70% Mongkok) would travel to the LEZ less frequently and hence pay the charge
Of those that enter regularly (18%, 16% and 30%), two thirds upgrade by installing emission reducing equipment (as their vehicles are relatively new and it is cheaper to do so) and the remainder one third replace their vehicles (more expensive, but they have an older vehicle that is closer to the age of replacement.
People who replace bring forward their decision to buy a new car because of policy – therefore average bring forward cost assumed 45% of cost of new car
Upgrade cost HK$7,142 per vehicle [b]
Average vehicle replacement costs HK$216,995 (PC), HK$220,000 (LGV), HK$240,000 – HK$600,000 (HGV/Light bus), HK$2.4M - HK$3M (heavy bus/truck). [d]
Total upgrade and replacement costs Central HK$955M
Total upgrade and replacement costs Mongkok HK$1,592M
Total upgrade and replacement costs Causeway Bay HK$849M
Vehicle upgrade and replacement occurs over 2 year period – 2015 to 2016
Policy development HK$8.65M annual for 2 years [e]
Admin and enforcement cost HK$4.31M annual (estimated labor cost)

Note [a]: Cost Budget AVI system, Arup In house data
[b]: Toyota Price 2008, CAFÉ (2005), Scenario Analysis, Report no 5.
[c]: CTS model, Arup Traffic Engineers
[d]: Toyota Car Price 2008 and Traffic Department
[e]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.8.1.3 Air Quality Improvements

Air quality improvements under each of the LEZ control strategies are presented in **Table H1.46** showing the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.46a: Air improvements – Low Emission Zones

Control Strategy	Emission Reduction Potential (Tonnes)[a]				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
LEZ in Central	NA	NA	NA	NA	NA	NA	NA	NA

Control Strategy	Emission Reduction Potential (Tonnes)[a]				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
LEZ in Mongkok	NA	NA	NA	NA	NA	NA	NA	NA
LEZ in Causeway Bay	NA	NA	NA	NA	NA	NA	NA	NA

Note [a]: Low Emission Zones are the transport management strategies. They will divert traffic to other districts. Hence, the overall emission reduction is zero. The benefit shown in the table is the net benefit.

H1.8.1.4 Results of the CBA

The results for this control strategy are shown below in **Table H1.47**. They suggest that under the assumptions used, the LEZ in Central would be advantageous in cost-benefit terms while a LEZ in Mongkok and Causeway Bay is not. The reason for the lower result is that, while more vehicles regularly enter the area resulting in higher costs, the number of sensitive receptors (i.e. the population affected) is less, hence the benefits are lower. The LEZ for all areas combined is therefore marginal with estimated costs slightly higher then the benefits. The results are underpinned by uncertainty in the cost estimates which reflects the potential implementation method and the response by vehicle owners. In addition, the presence of a LEZ may cause vehicle owners to change behaviour and utilise other routes rather then pass through the LEZ, resulting in increased emission in surrounding areas. All of these points would require more detailed investigation.

Table H1.47: CBA Results - Low Emission Zones

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
LEZ All [a]	3,696 [b]	2,586	0.7
LEZ in Central	1,100	1,899	1.7
LEZ in Mongkok	1,575	318	0.2
LEZ in Causeway Bay	1,021	369	0.4

Note [a]: LEZ All is the combination of Central, Mongkok and Causeway Bay LEZ's
[b]: Subject to the monitoring strategy, the present study adopts the cost of CCTV. The number of vehicles moving into the area LEZ requires further investigation as it influences cost. Current assumptions may overestimate the number of vehicles regularly entering the LEZ. Reducing cost will increase the benefit cost ratio.

H1.8.2 Car Free Zone / Pedestrianisation Schemes

H1.8.2.1 Background

In a car-free zone or pedestrisation scheme, use of automobiles is prohibited. Transport Department is following an environmentally friendly approach in managing traffic and transport matters and is committed to putting more emphasis on the interests of pedestrians. Since 2000, Transport Department has been implementing pedestrianisation schemes in several areas, including Causeway Bay, Central, Wan Chai, Mong Kok, Tsim Sha Tsui, Jordan, Sham Shui Po, Stanley and Shek Wu Hui.

The setting of car-free zone or pedestrianisation scheme should be started in smaller areas as it would be easier to implement the scheme. It is anticipated that this measure will be more effective in pollution hot spots. However, cost-effectiveness declines with smaller zones. Vehicles will also be diverted to other districts. Inside the car free zone, affected vehicles and shop operators may object to the proposal.

Government has a policy of closing areas to traffic in order to create significant environmental improvements for pedestrians and shoppers. This control strategy would extend this policy. The air quality improvement benefits are part of the strategy but are subordinate to the other environmental improvements that pedestrians and others enjoy. It is possible that the additional distances travelled by vehicles to detour the pedestrian areas might actually lead to greater vehicular emissions overall, although this would only be known by study of individual schemes. The feasibility of car free zone in HK will be subject to further investigation and will require more detailed consideration of the costs to transport operators and road users and change in traffic behaviour to surrounding areas.

The control strategy comprises three different areas in Mong Kok, Central and Causeway Bay to be implemented by 2015.

H1.8.2.2 Assumptions

The basic assumptions used in the CBA of this control strategy are provided in **Table H1.48**.

Table H1.48: Assumptions – Car Free Zone / pedestrianisation scheme

Car free zone/ pedestrianisation for Central, Mong Kok and Causeway Bay
Assume that the present time restrictions in pedestrian streets in Mongkok, Causeway Bay and Central are extended to all time
Assume vehicle restrictions for all type in traffic calming streets in Mongkok, Causeway Bay and Central
Affected population ~22,085 (Mong Kok), 11,419 (Causeway Bay), 58,766 (Central)
No costs to implement system – just ban cars using the area
Policy development HK$8.65M annual for 2 years[a]
No adm and enforcement cost as it involves the banning of vehicles into the zone.

Note [a]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.8.2.3 Air Quality Improvements

Air quality improvements under each scenario of the control strategy are presented in **Table H1.49** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.49: Air quality improvements – Car Free Zone / pedestrianisation scheme

Control Strategy	Emission Reduction Potential (Tonnes)[a]				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Car Free Zone / pedestrianisation scheme (Causeway Bay)	NA	NA	NA	NA	NA	NA	NA	NA
Car Free Zone / pedestrianisation scheme (Central)	NA	NA	NA	NA	NA	NA	NA	NA
Car Free Zone / pedestrianisation scheme (Mongkok)	NA	NA	NA	NA	NA	NA	NA	NA

Note [a]: The Car free zones are transport management strategies. They will divert traffic to other districts. Hence, the overall emission reduction is zero. The benefit shown in the table is the net benefit.

H1.8.2.4 Results of the CBA

The results for this strategy are shown below in **Table H1.50**. All strategies are advantageous in cost-benefit terms as the costs for implementation are very small, both absolutely and relative to the expected local benefits.

Table H1.50: CBA Results – Car Fee Zone / pedestrianisation scheme

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Car Free Zone/ pedestrianisation scheme All [a]	42	400	10

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Car Free Zone/ pedestrianisation scheme (Causeway Bay)	14	61	4.4
Car Free Zone / pedestrianisation scheme (Central)	14	303	21.8
Car Free Zone / pedestrianisation scheme (Mongkok)	14	36	2.6

Note [a]: Car Free Zone / pedestrianisation scheme (All) is a combination of the three Car Free Zones in Central, Mongkok and Causeway Bay.

H1.8.3 Electronic Road Pricing (ERP) / Congestion Charging Scheme for Hong Kong Island North

H1.8.3.1 Background

Electronic Road Pricing (ERP) allocates road space more efficiently. Those prepared to pay can use the roadways. Under normal condition, other vehicles will remain using non-toll roadways. As ERP can reduce traffic volume, it will in turn improve the air quality inside the charging areas.

There are schemes being operated in the United States of America and Singapore which have proven that the concept is workable. At present, Electronic Road Pricing (ERP) is being considered in the Netherlands, United Kingdom and Japan.

In UK, the Feasibility Study of National Road Pricing Report was published in 2004. The scheme is currently under review and no decision has been made on national road pricing. The UK government, however, is working with local authorities to develop local schemes to tackle local congestion. Congestion charging was introduced into central London. Motorists entering congestion charging zone between a prescribed period of hours are required to pay a fee. Interim air monitoring data in 2006 suggested that there is no observed improvement on ambient air quality, although traffic entering the charging zone decreased by 20%.

The main purpose of the ERP scheme is to reduce traffic congestion, and the benefit to air quality is a side effect. The ERP scheme is more viable if vehicle growth is more than 3%. In order to receive public support, the income generated can be used to encourage greener vehicles and transport choices. Nevertheless, traffic may be diverted to other districts, which may cause traffic congestion in other areas.

Government has considered for some time the introduction of a possible road pricing scheme and a preliminary feasibility study was undertaken in 2001. The main focus of the feasibility study at that time was to tackle traffic congestion. It was estimated that about 40% of car trips in the morning peak could be diverted to public transport and 10% might change their time of travel. The remaining 50% would pay the road user charges but would benefit from higher travel speeds and lower congestion. Various estimates were made of the net benefits of such a scheme including journey time savings and lower vehicle operating costs. The scheme itself would be costly both for initial capital costs and annual running costs.

The estimated net economic benefit resulting from journey time savings and lower vehicle operating costs in 2001 was about HK$2 Billion/year. The estimated cost of the scheme was HK$1Billion including the cost of in-vehicle units for existing vehicles, and with an additional annual recurrent cost of HK$200Million. There would be substantial savings in travel times and vehicle operating costs but the offsetting costs of the scheme would be in the same broad order of magnitude.

No decision was taken following the preliminary feasibility study to introduce such a scheme in Hong Kong. Since then there have been several cities elsewhere in the world where schemes have either been introduced or extended with significant positive effects including Singapore, Stockholm and Oslo.

There has been continuous evaluation of the London congestion charging scheme[25] (see Transport for London, Central London Congestion Charging, Impacts Monitoring, Fifth Annual Report, July 2007). This has found that there was no clear evidence of a congestion charging effect on PM_{10} concentrations although it is possible that the true effect has been obscured by other factors. In particular, year-on-year improvements to the emissions performance of the UK vehicle fleet are now the dominant factor reducing emissions in London and this confirms the important role of non-charging factors in determining overall air quality.

It is not possible for the current study to undertake a full CBA of this control strategy but preliminary estimates have been made of the air pollution reduction benefits of such a scheme which should be considered by the consultants undertaking the new assessment.

H1.8.3.2 Assumptions

The basic assumptions used in the CBA of this control strategy are shown in **Table H1.51**.

Table H1.51: Assumptions – Electronic Road Pricing / Congestion charging scheme for Hong Kong Island North

Transport management: ERP / Congestion charging
ERP charges vehicles for usage of the road at times when its capacity falls well near of demand. It manages demand and by varying charges to reflect the degree of congestion, smoothes out peak flow.
Improvement of air quality is an additional effect
Area of application: Central to Causeway Bay
Benefits only calculated as primary purpose is to reduce traffic rather than air improvement.
The estimated cost for the proposed ERP scheme is $1 billion (including the cost of in-vehicle units for existing vehicles) with an annual recurrent cost of $200 million

H1.8.3.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.52** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.52: Air quality improvements – Electronic Road Pricing / Congestion charging scheme for Hong Kong Island North

Control Strategy	Emission Reduction Potential (Tonnes)[a]				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Electron Road Pricing / Congestion charging scheme for Hong Kong Island North	NA	NA	NA	NA	NA	NA	NA	NA

Note [a]: The Electronic road pricing / congestion charging schemes are the transport management strategies. They will divert traffic to other districts. Hence, the overall emission reduction is zero. The benefits of the emission reduction are likely to be specific to the zone. The estimated cost for the proposed ERP scheme is of the order of $1 billion (including the cost of in-vehicle units for existing vehicles) with an annual recurrent cost of the order of $200 million[26]

H1.8.3.4 Results of the CBA

The benefits calculated for this strategy are shown below in **Table H1.53**.

Table H1.53: CBA Results – Electronic Road Pricing / Congestion charging scheme for Hong Kong Island North

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Electronic Road Pricing / Congestion charging scheme for Hong Kong Island North	Note [a]	577	NA

Note [a] : See note of Table H1.52

H1.8.4 Reduce Parking Provision (25%) to Restrain Car Usage for Central

H1.8.4.1 Background

Parking control is traffic demand side management to control private car trips. Reducing the number of parking spaces may help to discourage drivers from entering the Central business areas. However, the needs for disabled people should also be considered. It is feasible to convert existing public car parks to other uses. This requires consensus from the public as it may affect local economic activities. Opposition may come from shopping malls, as the number of customer may be reduced with the reduction of car parks. The strategy requires more detailed investigations regarding the impacts on operators and users. The government may also consider reviewing the parking space provision standards under the Hong Kong Planning Standards and Guidelines.

This medium term control strategy assumes a 25% reduction in parking spaces territory-wide to deter the use of private vehicles. Transport modelling found that there would be a reduction of vehicle trips of around 300,000 pa or about 1% of the total.

Costs have been allocated by estimating the private parking space that would need to be purchased in order to implement the strategy. It should be noted that the release of space from carparking would enable alternative uses but there is no way of knowing what these would be, nor their benefits and costs of their provision. Accordingly, this approach adopted was to measure only the direct costs and benefits of the policy. Hence, approximately HK$1.1 billion was allocated for purchase of parking space. These costs have been allocated between 2018 and 2019 and compared with the expected benefits.

H1.8.4.2 Assumptions

The basic assumptions used in the CBA of this control strategy are as follows **Table H1.54**.

Table H1.54: Assumptions – Reduce Parking Provision (25%) to restrain car usage for Central

Transport management: Reduced parking provision
Reduce parking space by 25% which is a demonstration case and considered feasible in the Central business district
Parking dimension 2.5m x 5m = 12.5 m^2
Total parking space 5,400,850 m^2 [a]
Parking Space in Central 7% of total [a]
Cost per square meter = HK$7,425 (average of basement and multi story) [a]
Privately owned car parking space = 50%
Cost HK$1,123M
Policy development HK$8.65M annual for 2 years[c]

Note [a]: Arup In house data
[b]: Rider Levett Bucknall (2007) [27]
[c]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.8.4.3 Air Quality Improvements

Air improvements for each of the control strategies are presented in **Table H1.55** below and which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.55: Air improvements – Reduce Parking Provision (25%) to restrain car usage for Central

Control Strategy	**Emission Reduction Potential (Tonnes)[a]**				**Population Weighted Improvement (µg/m³)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Reduced Parking Provision (25%) to restrain car usage for	NA	NA	NA	NA	NA	NA	NA	NA

Central								

Note [a]: The reduction of car park is a transport management strategy. They will divert traffic to other districts. Hence, the overall emission reduction is zero. The benefits of the emission reduction are likely to be specific to the zone.

H1.8.4.4 Results of the CBA

The results for this strategy are presented in **Table H1.56** and suggest that the B/C ratios are very small under the adopted assumptions. The benefits that result are very small relative to the costs for implementation. Costs have been calculated based on the purchase prices of private car parking spaces.

Table H1.56: CBA Results – Reduce Parking Provision (25%) to restrain car usage for Central

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Reduced Parking Provision (25%) to restrain car usage for Central	757	18	0.02

H1.8.5 Bus Route Rationalization

H1.8.5.1 Background

Rationalization of bus routes will optimise the bus trips and hence reduce the number of buses travelling on roads.

The government and franchised bus companies have been taking progressive steps to rationalise bus routes. However, objection has been received from local communities and passengers. According to TD information, from 1999 to 2007, a total of 109 franchised buses have been withdrawn (5,889 in 2007 vs. 5,998 in 1999) from the road, and some 5,700 bus trips per day and 4,800 bus stoppings per peak hour at the relevant busy corridors were reduced.

To ensure more efficient use of bus resources and to provide more choice of routes, bus interchange schemes have been promoted and since 2006 a total of 27 have been introduced. This control strategy would extend the concept and comprise a set of procedures to reduce the amount of franchised bus movements in commercial centres by dropping off long distance passengers at interchange points on the outskirts of the centres and improving the efficiency of transportation within the centres. There is an assumption of about 10% reduction in bus trips as a result of the rationalization programme which was studied in the HKIN Traffic Study.

Discussions with bus experts also suggest that there is sufficient excess capacity in the system that a 10% reduction in bus trips would be feasible outside of peak hours without impacts to either bus operators or passengers, as many buses are underutilised at this time. Buses are run because of legislative requirements and the loss in revenue would be at least equalled by the savings in vehicle operating costs. Therefore it has been assumed that the 10% reduction would be undertaken outside of peak travel times and without additional cost to bus operators.

The strategy requires more detailed investigations regarding the impacts on operators and users.

H1.8.5.2 Assumptions

The basic assumptions used in the CBA of this control strategy are as follows **Table H1.57**.

Table H1.57: Assumptions – Bus Route Rationalisation

Transport management: Bus route rationalisation – Benefit only
Reduce bus trips by 10%
Assumes that bus trips are reduced in non peak times where additional capacity in the system exists. Buses run with excess capacity because they are regulated to do so to provide a level of service.

Transport management: Bus route rationalisation – Benefit only
By implementing in non peak times, loss in revenue at least equalled by saving in operational and maintenance costs – therefore no cost allocated apart from policy and development costs [a]
Policy and development costs HK$8.65M per year over two years[b]

Note [a]: Arup In house data
[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.8.5.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.58** below which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.58: Air quality improvements – Bus Route Rationalisation

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Bus Route Rationalisation	4	156	7	9	0	0.172	0.02	0

H1.8.5.4 Results of the CBA

The results of this strategy suggest that the B/C ratio greatly exceeds unity under the assumptions used due to the low costs for implementation relative to the benefits as shown in **Table H1.59**.

Table H1.59: CBA Results – Bus route Rationalisation

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Bus Route Rationalisation	14	548	39

H1.9 Infrastructure, Development and Planning Control Strategies

H1.9.1 Expand Rail Network

H1.9.1.1 Background

Railways are the most environmentally friendly form of mass transport. Vehicles using road networks will contribute to air pollution, in particular NO_X and PM_{10}. Extensive rail network (as an alternative mode of transport) will form a cleaner public transport mode. In the policy address Yr 2007 - 2008, Government has committed on the development of rail system as the backbone of transportation infrastructure in Hong Kong. As a result, it is expected that the public will make full use of the rail network, thereby significantly reducing pollutant emissions associated with vehicles.

In Year 2007, Hong Kong has 1977km road and 210km railway (i.e. about 10% of road length). The Government are constructing or planning nine strategic highway projects. For railway network, it will be increased to about 220 km in length by Yr 2009.

According to the Chief Executives' Policy Address, some of the rail infrastructure (Express Rail Line, part of SCL, East Kowloon Line, West Island Link, South Island Link, Kowloon Southern Link) will be in place by Yr 2015. The capital cost for railway construction is considerable. The consideration of the feasibility of rail is also subject to other dominant factors, including economics, travelling time and policy.

Given the main benefit of this control strategy is reducing road congestion and private vehicle use only pollution benefits have been calculated.

H1.9.1.2 Assumptions

Only benefits have been estimated and the basic assumptions used in this control strategy are shown below in **Table H1.60**.

Table H1.60: Assumptions – Expand Rail Network

Expand rail network
The major benefits of railway are to facilitate co-ordination with other public transport services at key interchanges nodes, maximising efficiency of service to passengers in terms of time and cost.
Air quality improvements is an additional benefit
The railway strategy includes Express Rail Line, Sha Tin to Central Link (the Tai Wai to Hung Hom section), West Island Line, South Island Line (East), Kowloon Southern Link, and Kwun Tong Line Extension. The railway strategy will have additional ride-on effect on improvement of air quality. Hence, the strategy is purely benefit. For reference, Capital Cost: HK$56 Billion[28] .

H1.9.1.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.61** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.61: Air quality improvements – Expand Rail Network

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (μg/m³)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Expand Rail Network	17	501	46	207	0.0003	0.550	0.15	0

H1.9.1.4 Results of the CBA

The expected benefits calculated under this strategy are shown in **Table H1.62**.

Table H1.62: CBA Results – Expand Rail Network

Control Strategy	**Cost (HK$M)**	**Benefit (HK$M)**	**B/C Ratio**
Expand Rail Network	Note	3,850	NA

Note [a]: The railway strategy includes Express Rail Line, Sha Tin to Central Link (the Tai Wai to Hung Hom section), West Island Line, South Island Line (East), Kowloon Southern Link, and Kwun Tong Line Extension. Hence, the strategy is purely benefit. For reference, Capital Cost: HK$56 Billion. (Second Railway Development Study ES, 2000)

H1.9.2 Rail for Transport of Cross-Boundary Goods

H1.9.2.1 Background

Government has for many years considered reducing the quantity of cross boundary freight movements going to/from the port by truck by developing a rail connection into the Kwai Chung container port area from the Mainland.

PRL, connection from Lo Wu to Kwai Chung, has been considered by the Highways Department. It allows direct cross-boundary freight service through Lo Wu to the Kwai Chung ports. The number of heavy vehicle trips will be reduced with the PRL.

There would be wide-ranging implications of such a policy if implemented and emissions are an incidental effect. The main benefit of this strategy is to attract containerised goods from the deeper hinterland and it may reduce road congestion to a certain extent. Accordingly, only pollution benefits have been calculated.

H1.9.2.2 Assumptions

Only benefits have been estimated and the basic assumptions used in the benefits estimation of this control strategy are shown in **Table H1.63**.

Table H1.63: Assumptions – Rail for Transport of Cross Boundary Goods

Rail for Transport of Cross-Boundary Goods
The major benefits of railway is to reduce the quantity of cross boundary freight movements going to/from the port by truck
Air quality improvement is an additional benefit
Capital Cost: HK$5-9 Billion. (Second Railway Development Study ES, 2000)

H1.9.2.3 Air Quality Improvements

Air quality improvements for this control strategy are provided in **Table H1.64** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the benefit analysis.

Table H1.64: Air improvements – Rail for Transport of Cross Boundary Goods

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Rail for Transport of Cross Boundary Goods	1	11	1	9	0	0.0195	0.01	0

H1.9.2.4 Results of the CBA

The estimated benefits for this strategy are shown below in **Table H1.65**.

Table H1.65: CBA Results – Rail for Transport of Cross Boundary Goods

Control Strategy	Cost ($M)	Benefit ($M)	B/C Ratio
Rail for Transport of Cross Boundary Goods	Note[a]	115	NA

Note [a]: The railway strategy will have additional effect on improvement of air quality.

H1.9.3 Cycling Network to Major Public Transport Hubs

H1.9.3.1 Background

Experience in many different cities of the world suggests that there would be a marked shift to cycling and away from PCs for relatively near distance trips if cycling facilities were made more generally available, especially for parking of cycles at railway stations and transport interchanges. A recent British study estimated that a pro-environment pro-bike transport policy could convert 20% or more of short-distance non-pedestrian trips to bicycles displacing between 5% and 24% of total car trips. This would have an effect on vehicle-related emissions.

The strategy is proposed for new town development areas instead of dense urban area. According to the LegCo paper on Cycle Track Network in the New Territories (CB(1)1602/07-08(07)) in May 2008, a total length of ~82km (From Tuen Mun – Ma On Shan section, and Tsuen Wan – Tuen Mun section) will be proposed for the New Territories. The cycle track network is planned for completion in phases from 2013 onwards.

The expansion of cycling network acquires the development of infrastructure, such as parking lots, lighting and bike lockers etc. There are, however, constraints for implementing such scheme in urban districts, e.g. road safety requirements. Major changes in transportation and urban planning are required. The scheme is more feasible for sub-urban area and incorporated into new town development.

The near term control strategy requires the construction of new bicycle tracks. Costs have been estimated for the construction of approximately 50km of track around new town developments throughout Hong Kong.

H1.9.3.2 Assumptions

The basic assumptions used in the benefits estimation of this control strategy are as follows **Table H1.66**.

Table H1.66: Assumptions – Cycling Network to Major Public Transport Hubs

Cycling network
Cycling network to major public transport hubs
One cycling network 10 km long, 4 m wide
5 cycling networks total
Cost per m^2 $HK5,000 [a]
Total cost for 5 networks – HK$ 1 Billion

Cycling network
Policy development HK$8.65M annual for 2 years[b]
Daily passenger trips reduced – 0.15% territory-wide [c]

Note [a]: Arup in house data

[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

[c]: The figure was derived by referencing to the "Cycling Study (Contract No TD100/2002) - Final Report 2004" commissioned by TD in Yr 2001 which estimated that the existing cycling track of around 170km would contributing to daily passenger trips of about 2% (in new town) or 0.5% (territory wide). On the conservative side, it is assumed that the reduction in passenger trips is applied to bus trips only.

H1.9.3.3 Air Quality Improvements

Air quality improvements for the control strategy are shown in **Table H1.67** which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.67: Air quality improvements – Cycling Network to Major Public Transport Hubs

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Cycling Network to major public transport hubs	0.1	2.3	0.1	0.1	0.000	0.0026	0.000	0

H1.9.3.4 Results of the CBA

The results for this strategy are provided below in **Table H1.68**. The strategy is not advantageous in cost-benefit terms under the assumptions used, as the capital costs are well in excess of the air quality improvements. However this strategy would provide other benefits not included in the analysis, including transportation, recreational, tourism, healthier lifestyles and social benefits. Consideration of these benefits, some of which are not quantifiable would justify the strategy, consistent with international findings.

Table H1.68: CBA Results – Cycling Network to Major Public Transport Hubs

Control Strategy	Cost ($M)	Benefit ($M)	B/C Ratio
Cycling Network to major public transport hubs	836	8	0.01

Note: Strategy provides other benefits other than just air improvements and no BC Ratio is calculated.

H1.10 Energy Efficient Management Control Strategies

H1.10.1 Mandatory Implementation of Building Energy Codes

H1.10.1.1 Background

Electricity generation is a significant source of air pollution in HK, contributing to 91%, 49% and 48% of emissions of SO_2, NO_X and PM_{10} respectively in 2005. Improvement of energy efficiency would also help improving local air quality. In this study, it is assumed that 1% saving in electricity will have 1% reduction in pollutants.

The Government has issued a consultation paper on A Proposal on the Mandatory Implementation of the Building Energy Codes, EMSD (2008)[29]. It is estimated that the implementation of the proposals which affect new commercial buildings such as offices, hotels, shopping complexes as well as communal areas of new residential and industrial buildings, will lead to a saving of 2.8 billion KWh in the first decade of implementation. Further energy savings would result from improving energy efficiency of existing buildings through retrofit works and energy saving measures recommended by energy audits as proposed in the mandatory scheme.

When adopting the mandatory building energy performance code, the following practical issues shall be considered:

- Whether existing buildings to be covered
- Variation in the functional use of the premises concerned
- Affected parties' ability to comply with the requirement
- Freedom of choice and enforcement issues
- Issue of fairness

The control strategy is planned for implementation in near term and the reported energy savings over 10 years are 2,800 GWh at an average cost of production and transmission of HK$1.27M/GWh. Energy savings every ten years therefore are about HK$3.5 Billion, which are reported to offset the additional capital costs every 6-7 years.

H1.10.1.2 Assumptions

The basic assumptions used in the estimation of this control strategy are sown below in **Table H1.69**.

Table H1.69: Assumptions – Mandatory Implementation of Building Energy Codes

Mandatory building code
Mandatory Implementation of Building Energy Codes
Energy savings per 10 years 2,800 GWh
Average $M/GWh 1.27 [a]
Energy saving every ten years HK$3.5 Billion, allocated in 2030 and 2040 [b]
Assumes that increased capital cost offset by energy efficiency every 6-7 years [b]
Conservatively, energy savings assumed every ten years to cancel out additional capital cost. No energy saving benefit allocated in 2020.
Policy development HK$8.65M annual for 2 years[c]
Admin and enforcement cost HK$5M annual (estimated labour cost) until 2058
Note – benefits in this strategy driven by energy saving, hence the low population weighted average exposure yet high benefit cost ratio

Note [a]: Lighting Division Highways Dept, May 2008
[b]: EMSD (2008)
[c]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.10.1.3 Air Quality Improvements

Air quality improvements under the control strategy are presented in **Table H1.70** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.70: Air quality improvements – Mandatory Implementation of Building Energy Codes

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (μg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Mandatory Implementation of Building Energy Codes	151	256	8	3	0.0001	0.0059	0.013	0

H1.10.1.4 Results of the CBA

The results for this strategy indicate the B/C ratio greatly exceeds unity under the assumptions used. The majority of benefits are due to the energy savings that occur, rather then health based benefits. The results are shown below in **Table H1.71**.

Table H1.71: CBA Results – Mandatory Implementation of Building Energy Codes

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Mandatory Implementation of Building Energy Codes	95	2,634	28

H1.10.2 Energy Efficiency Standards for Domestic Electrical Appliances

H1.10.2.1 Background

This control measure will be implemented in near term. The Energy Efficiency (Labelling of Products) Ordinance for implementing the first phase of the mandatory energy efficiency labelling scheme was gazetted in May 2008 with an 18-month transitional period. The scheme affects the prescribed products of room air conditioners, refrigerating appliances and compact fluorescent lamps and reported energy savings of 150 GWh per year could be achieved.

The typical electrical appliance composition per family has been obtained from a 2007 Arup technical note on control trend technology for this study, supplemented by data in Annex A of the LegCo Environmental Affairs Proposed Mandatory Energy Efficiency Labelling Scheme, 13th June 2006[30].

The useful role of mandatory compliance of minimum energy efficiency requirements in promoting energy efficiency and conservation in buildings is well established internationally. Some overseas countries, including Australia, Singapore, the United Kingdom and the United States have implemented minimum energy efficiency requirements for buildings. The Mainland China has also put in place minimum energy efficiency requirements for buildings.

No cost other than an administration cost (which covers application cost by industry) has been assumed.

H1.10.2.2 Assumptions

The basic assumptions used in the benefits estimation of this control strategy are as follows **Table H1.72**.

Table H1.72: Assumptions – Energy efficiency standards for domestic electrical appliances

Energy efficiency standards for domestic electrical appliances
Labelling of energy efficiency on electrical appliances (specifically refrigerators, room air conditioners, and compact fluorescent lamps)[a]
No cost other than admin cost (which covers application cost by industry)
Policy development HK$8.65 Million annual for 2 years
Admin and enforcement cost HK$4.31 million annual (estimated labour cost)
Benefits in this strategy driven by energy saving, hence the low population weighted average exposure yet high benefit cost ratio

Note [a]:
Room air conditioner", subject to clause 7.1.3 of the Code -
(a) means an encased assembly or encased assemblies that are designed to be used together where:
- (i) the assembly or assemblies is or are designed primarily to provide free delivery of conditioned air to an enclosed space, room or zone ("conditioned space"); and
- (ii) the assembly or assemblies has or have a prime source of refrigeration for cooling or heating; and

(b) includes single package type and split type room air conditioners that:
- (i) use mains electricity as the primary power source;
- (ii) operate by using the vapour compression cycle;
- (iii) are non-ducted;
- (iv) are air-cooled;
- (v) are of either cooling only type or reverse cycle type; and
- (vi) have a rated cooling capacity not exceeding 7.5 kilowatts.

"Refrigerating appliance", subject to clause 8.1.3 of the Code-

(a) means a factory-assembled insulated cabinet with one or more compartments and of suitable volume and equipment for household use, cooled by internal natural convection or a frost-free system where the cooling is obtained by one or more energy-consuming means;
(b) includes a refrigerator, frozen food storage cabinet, food freezer, and their combinations; and
(c) includes refrigerating appliances that:
    (i) use mains electricity as the primary power source;
    (ii) operate by using the vapour compression cycle; and
    (iii) have a rated total storage volume not exceeding 500 litres.

"Compact fluorescent lamp", subject to clause 9.1.3 of the Code-
(a) means a type of fluorescent lamp which has a single lamp cap; and
(b) includes integrated type compact fluorescent lamps that:
    (i) use mains electricity as the primary power source;
    (ii) have a rated lamp wattage up to 60 watts; and
    (iii) have a screw or bayonet cap.

H1.10.2.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.73** which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.73: Air quality improvements – Energy efficiency standards for domestic electrical appliances

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (μg/m³)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Energy efficiency standards for domestic electrical appliances	84	142	4	1	0.0019	0.0029	0.0016	0

H1.10.2.4 Results of the CBA

The results suggest the strategy is advantageous under the assumptions adopted with the estimated benefits exceeding the costs of implementation. The majority of benefits are due to energy savings while health based benefits are relatively modest **Table H1.74**.

Table H1.74: CBA Results - Energy efficiency standards for domestic electrical appliances

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Energy efficiency standards for domestic electrical appliances	84	2,277	27

H1.10.3 Light Emitting Dioxide (LED) or equivalent alternatives for Traffic Signal / Street Lighting

H1.10.3.1 Background

This near term control strategy assumes the use of LED for street lighting. There are several advantages from using LEDs. They produce more light per watt than incandescent bulbs and have a relatively long useful life, typically more than 30 times longer than incandescent light-bulbs. However they are currently more expensive on an initial capital cost basis and there are some operational disadvantages. However, the consumption of power by progressive introduction of LEDs in the public arena such as streetlights would result in reduced energy consumption.

The numbers of street lighting for retrofitting and replacement are made reference to "Energy Efficient Management for Street Lightings", prepared by the Lighting Division of Highway Department in Yr 2008. It is thus assumed that there would be retrofitting of 15,000 street lights and replacement of 6,000 lanterns by LED as an initial guess for this strategy.

The energy saving would be $HK5 Million per year. The LED life is about 10 years, following initial replacement over 3 years, then every 10 years thereafter.

H1.10.3.2 Assumptions

The basic assumptions used in the benefits estimation of this control strategy is provided below **Table H1.75**.

Table H1.75: Assumptions – LED or equivalent alternatives for Traffic Signal / Street Lighting

LED for street lighting
LED for street lighting
15,000 street lights, 6,000 lanterns (21,000 total) [31]
HK$800/unit, total cost GHK$16.8 Million
Energy saving $HK5 Million per year [a]
Led life 10 years, initial replacement over 3 years 2009 to 2011, then every 10 years thereafter
Policy development HK$8.65M annual for 2 years[b]
Admin and enforcement cost HK$5M annual (estimated labour cost)
Note – benefits in this strategy driven by energy saving, hence the nil population weighted average exposure improvement yet high benefit cost ratio

Note: [a]: Energy efficient management for street lighting, Lighting Division, Highways Dept, May 2008
[b]: Based on 12 juniors full time 12 months a year, 6 seniors 6 months a year and one manager one month per year, plus overheads

H1.10.3.3 Air Quality Improvements

Air quality improvements for the control strategy are listed below in **Table H1.76** below which shows the emission reduction potential (tonnes) and the population weighted improvement (µg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.76: Air quality improvements – LED or equivalent alternatives for Traffic Signal / Street Lighting

Control Strategy	Emission Reduction Potential (Tonnes)				Population Weighted Improvement (µg/m^3)			
	SO_2	NO_X	PM_{10}	VOC	SO_2	NO_X	PM_{10}	VOC
Light-emitting diode or equivalent alternatives for traffic signal / street lighting	3	5	0.1	0	0	0	0	0

H1.10.3.4 Results of the CBA

The results for this control strategy are presented in **Table H1.77** which suggests that it is advantageous in cost-benefit terms under the adopted assumptions. The majority of benefits are from energy savings rather than health based benefits.

Table H1.77: CBA Results – LED or equivalent alternatives for Traffic Signal and Street Lighting

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
Light-emitting diode or equivalent alternatives for traffic signal / street lighting	47	105	2.2

H1.10.4 District Cooling System

H1.10.4.1 Background

District cooling system has higher energy efficiency as compared to individual cooling tower. Hence, the use of district cooling system will reduce the electricity usage and eventually lead to a reduction in emissions.

According to Policy Address 2008 – 2009, to further promote energy efficiency and conservation, and to reduce carbon dioxide emissions substantially, the government plan to implement a district cooling system at the Kai Tak Development to supply chilled water to buildings in the new development area for centralised air-conditioning. Apart from the benefits of saving energy, District Cooling Scheme can eliminate the need of chiller plant rooms in individual buildings. This scheme can also provide the following intangible benefits:

- Better city building design by allowing more flexible and innovative building design (no need for space and external louver provision for chillers or cooling towers)
- More efficient and effective utilization of building floor space
- More environmental friendly, as there are less noise pollution, global warming and ozone layer depletion

This control strategy comprises the scenarios of near term implementation in South East Kowloon and for the medium term of a District Cooling System Territory wide covering 35% of the existing area and 90% of new areas.

The advantages of district cooling are greater for new development areas than for existing areas where retrofitting difficulties would add considerably to the expense. A feasibility study for such a scheme was undertaken for Kai Tak and the SEKD. In the case of the Kai Tak development, the main applications of the cooling system would be for non-domestic buildings although advantages would accrue if the service is extended to domestic premises. The district cooling design would produce significant savings in energy and can reduce overall energy consumption by between 19 and 35% compared with standalone air conditioning systems operating on cooling towers and air-cooled chillers.

The feasibility study for the South East Kowloon DCS found that it would take about 25 years to achieve a positive return on the investment assuming the maximum demand uptake by customers. There are a number of uncertainties surrounding the costs estimates including land costs for the district cooling system operator, pipe network fees, pipe distribution system requirements for private customers, project delay and the demand for the system (customer uptake), all of which have financial implications.

A district wide cooling system report found that the handling of the pipeline wayleave charge is critical to the financial viability of the scheme. If the charge is required, only a small number of DCS are likely to be commercially viable.

No formal allowance was made in the earlier assessment for the reduction in pollutants arising from the reduced power consumption and emissions from generation. The costs have been allocated as per those estimated in this previous investigation, and the expected air benefits have been included.

H1.10.4.2 Assumptions

The basic assumptions used in this control strategy are listed below in **Table H1.78**.

Table H1.78: Assumptions – District Cooling System

District cooling system for SEK	
District cooling system in Kai Tak Development implemented in 2013	
Undiscounted costs[32]	
Capital Costs	HK$M
Site 1N5(Construction cost of plants, chillers and pumps)	356
Site 5B(Construction cost of plants, chillers and pumps)	190
Seawater pumphouse	274
Chilled water distribution network	222
Customer substations	92
Land cost for DCS chiller plants + pumphouse	19

District cooling system for SEK	
	1153
Operating costs (for 30 years)	
Pipe network license fee	624
Non energy operation and maintenance cost	258
Energy cost (electricity)	2079
Total over 30 years	2961
Cost per year	98.7
Assumes no project delay and maximum customer uptake.	
Note – revenue streams are the main benefits (ramp up from HK$28M per yr in 2013 to HK$313M per year in 2026 onwards), hence the low population weighted average exposure improvement yet high benefit cost ratio	
District cooling system for whole territory	
District cooling for whole territory will be implemented in Yr 2020	
Total External and internal Capital Cost (Pump stations, thermal storage, chiller): HK$19,290 Billion [a]	
Total recurrent cost (water, electricity, non energy): HK$2.1 Billion [b]	
Annual Benefits (non health) HK$1.2Billion [a]	
Note: Land costs not included, and only a small number of DCS reported as financially feasible, hence the reason that non health benefits (revenues) less than recurrent costs	

Note: [a] EMSD 2003 [33]
[b] Arup (2003) Implementation Study for a District Cooling Scheme at South East Kowloon Development, December

H1.10.4.3 Air Quality Improvements

Air quality improvements for the control strategy are presented in **Table H1.79** below and which shows the emission reduction potential (tonnes) and the population weighted improvement (μg/m³). The population weighted improvement has been used in the CBA analysis.

Table H1.79: Air quality improvements – District Cooling System

Control Strategy	**Emission Reduction Potential (Tonnes)**				**Population Weighted Improvement (μg/m^3)**			
	SO_2	**NO_X**	**PM_{10}**	**VOC**	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
District Cooling System for Kai Tak Development	6	16	0.5	0.2	0.00023	0.0004	0.0002	0
District Cooling System (35% in existing areas and 90% in new development areas)	120	197	5.5	1.9	0.003	0.005	0.003	0

H1.10.4.4 Results of the CBA

The results for both control strategies are shown below in **Table H1.80**. As previously mentioned, there is considerable uncertainty in the costs estimates that underpin the analysis. The South East Kowloon District cooling system has assumed maximum demand uptake by customers and no delays which could be overly optimistic. Similarly, the Territory wide District Cooling System, has included the pipe wayleave charge is levied hence the low reported NPV. Further investigation is required to confirm the cost estimates and provide more robust results.

Table H1.80: CBA Results – District Cooling System

Control Strategy	Cost (HK$M)	Benefit (HK$M)	B/C Ratio
District Cooling System for Kai Tak Development	2,788	4,047	1.5
District Cooling System (35% in existing areas and 90% in new development areas)	19,347	11,578	0.6

H1.10.5 Tree Planting / Roof-Top Greening

H1.10.5.1 Background

A green roof is a roof of a building that is partially or completely covered with vegetation and soil, or a growing medium, planted over a waterproofing membrane. The green roof can bring a number of benefits including reducing heat gain from roof and mitigating urban heat island. The replacement of the natural land cover with anthropogenic surfaces alters the thermal, moisture, and visual properties of an urban climate in both direct and indirect ways. Direct benefits, which are generally related to individual buildings, include primarily cover from the solar radiation and protection from the wind; however, trees can also provide scrubbing of air pollutants, shielding from noise pollution, and stabilization of soil against erosion. Indirectly, vegetation cools buildings by reducing the temperature of the air surrounding them via evapotranspiration, a process by which a plant releases water vapor into the air.

Green roofs are becoming popular in the United States and Canada. One of the largest extensive green roofs is found at Ford Motor Company's River Rouge Plant, Dearborn, Michigan, USA. The 42,000 m² assembly plant roof has been covered with sedum and other plants. Michigan has a temperate climate with well-defined seasons. Dearborn has a normal daily mean temperature of 10°C, ranging from –4°C in January to 23°C in July.

Practical consideration for green roof will include the following:

- Energy saving will be less significant in multi-story buildings because of the low ratio of roof area to the total exposed building facade.
- Green roof demand more stringent structural requirements. Some existing buildings cannot be retrofitted with a green roof because of the weight load of the soil and vegetation.
- The maintenance costs of green roof will also be higher.

A study undertaken in Toronto (Banting et al 2005) by the Department of Architectural Science at Ryerson University[34], identified many environmental benefits from a roof-top scheme. Those most quantifiable based on currently available research data were benefits from storm water flow reduction, improved air quality, reduced direct energy use and reduced heat island effects. For Toronto the estimated pollution saving arising from the proposed scheme was CAD$2.5 million pa or about 7% of the total cost savings from the scheme.

Green roof technology is an emerging technology and there is still considerable work to be done to make it a practicable and operational option. The costs estimates have relied on a single study and are nor based on local data for Hong Kong. Hence more detailed investigation is required.

H1.10.5.2 Assumptions

The basic assumptions used in the benefits estimation of this control strategy are as follows **Table H1.81**.

Table H1.81: Assumptions – Tree Planting / Rood-top Greening

Tree planting / roof top greening
No local emission and cost data available

Tree planting / roof top greening		
Costs – HK$561 per sq meter[a]		
Urban area 137.4 km^2		
Benefits[a]		
	Initial	Annual
Stormwater	118,000,000	
Air		2,500,000
Combined sewer overflow	46,600,000	750,000
Building energy	68,700,000	21,560,000
Urban heat island	79,800,000	12,320,000
	313,100,000	37,130,000
HK$	2,129,080,000	252,484,000

Note [a]: Banting et al (2005)

H1.10.5.3 Air Quality Improvements

There is no local data available for the emission reduction.

H1.10.5.4 Results of the CBA

The results for this control strategy are shown below **Table H1.83** and based on the assumptions adopted, the B/C ratio is well below unity.

Table H1.83: CBA Results – Tree Planting / Rood-top Greening

Control strategy	Cost ($M)	Benefit ($M)	B/C Ratio
Tree Planting / Roof Top Greening	6,357	1,603	0.3

H1.11 Summary of CBA Findings

H1.11.1 Findings from the CBA

The CBA section presents the central estimates of the results which lie within a range produced through a comprehensive sensitivity analysis. A summary of the CBA findings is presented below in **Table H1.84**. This table shows the best estimates derived in the analysis of costs and benefits and the strategy performance measures of the cost-benefit ratio.

In some cases, however, only the benefits of have been estimated. These strategies that could not be assessed in CBA terms were cases where the principal objectives of the strategies are substantial, complex to unravel and are not directly related to reductions in air pollution. A full CBA was beyond the scope of this study for these strategies. In these cases, the analysis has been limited to an estimate of the air pollution benefits that are likely to be generated by the strategy, if implemented. The concerned responsible authorities can take these estimates into account when arriving at decisions about whether to proceed with those particular strategies.

Table H1.84: CBA Summary of Findings

Control Strategy		Cost (HK$M)	Benefit (HK$M)	B/C Ratio
1	Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures	2032[g]	1803	0.9[g]
2	Early retirement of aged / heavily polluting vehicles (pre-Euro, Euro I and Euro II commercial diesel vehicles and franchised buses)	3,882	24,344	6.3
3	Earlier replacement of Euro III commercial diesel vehicles with models meeting latest	2,668	6,134	2.3

Control Strategy		Cost (HK$M)	Benefit (HK$M)	B/C Ratio
	Euro standards			
4	Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance (20% private cars and 10% franchised buses)	4,326	2,417	0.56
5	Ultra low sulphur diesel (ULSD) for local vessels	378	6331	16.7
6	Selective catalytic reduction (SCR) for local vessels	249	74	0.3
7	Electrification of aviation ground support equipment	1,449	3.8	0.003[h]
8	Emission control for off-road vehicles / equipment	845	2,123	2.5
9	Strengthening Volatile Organic Compounds control	18	124	6.9
10	Low emission zones	3,696	2,586	0.7
a	Low emission zone (banning pre-Euro, Euro I , Euro II and Euro III commercial vehicles) for Central	1,100	1,899	1.7
b	Low emission zone (banning pre-Euro, Euro I , Euro II and Euro III commercial vehicles) for Mongkok	1,575	318	0.2
c	Low emission zone (banning pre-Euro, Euro I , Euro II and Euro III commercial vehicles) for Causeway Bay	1,021	369	0.4
11	Car-free zone / pedestrianisation scheme	42	400	10
a	Car-free zone / pedestrianisation scheme for Causeway Bay	14	61	4.4
b	Car-free zone / pedestrianisation scheme for Central	14	303	21.8
c	Car-free zone / pedestrianisation scheme for Mongkok	14	36	2.6
12	Bus Route Rationalisation	14	548	39
13	Expand rail network	Note [a]	3,850	Note [a]
14	Cycling network to major public transport hubs	836	8	0.01
15	Mandatory implementation of Building Energy Codes	95	2,634	28
16	Energy efficiency standards for domestic electrical appliances	84	2,277	27
17	Light-emitting diode or equivalent alternatives for traffic signal /street lighting	47	105	2.2
18	Tree planting / roof-top greening	6,357	1,603	0.3
19	District cooling system for Kai Tak Development	2,788	4,047	1.5
20	Increasing the ratio of natural gas in local electricity generation to 75% with additional abatement measures (Additional to Phase I measure)	1,702	383	0.2
21	Increasing the ratio of renewable energy (2% wind energy)	13,069	206	0.02
22	Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance [30% private cars, 15% buses (including franchised buses), 15% light goods vehicles (LGVs) plus 15% heavy goods	9,026	14,447	1.6

Control Strategy		Cost (HK$M)	Benefit (HK$M)	B/C Ratio
	vehicles (HGVs)] (Additional to Phase I measure)			
23	Ultra low sulphur diesel for ocean-going vessels and local vessels (Additional to Phase I measure)	4,563	15,087	3.3
24	Selective catalytic reduction for ocean-going vessels and local vessels (Additional to Phase I measure)	1,333	1,173	0.9
25	Electrification of on-shore power supply	1,579	6,243	4.0
26	Tightening aviation emission standards	Note [b]	12	Note [b]
27	Further Strengthening Volatile Organic Compounds control	37	634	17.2
28	Electronic road pricing (ERP) / congestion charging scheme for Hong Kong Island North	Note [c]	577	Note [c]
29	Reduce parking provision (25%) to restrain car usage for Central	757	18	0.02
30	District cooling system (35% in existing areas and 90% in other new development areas)	19,347	11,578	0.6
31	Increasing the ratio of natural gas in local electricity generation to 100% (Additional to Phase II measure)	348	255	0.7
32	50% nuclear power and 50% natural gas (Alternative Case compared to Base Case of 75% natural gas)	-2894	91	-
a	Base Case of 75% natural gas	341,375	1,562	NA
b	Alternative Case 50% Nuclear 50% natural gas	338,481	1,654	NA
33	Wider use of hybrid / electric vehicles or other environment- friendly vehicles with similar performance (50% private cars, 50% buses (including franchised buses), 50% HGVs plus 50% LGVs) (Additional to Phase II measure)	8,530	7,751	0.91
34	Vehicle permit quota system (to reduce around 50% private cars and 50% motorcycles)	691	251	0.4
35	Use of Hydrogen Fuel Cell vehicles or equivalent alternatives (40% penetration)	Note [e]	10,420	Note [e]
36	Rail for transport of cross-boundary goods	Note [f]	115.0	Note [f]

Notes:

[a] The railway strategy includes Express Rail Line, Sha Tin to Central Link (the Tai Wai to Hung Hom section), West Island Line, South Island Line (East), Kowloon Southern Link, and Kwun Tong Line Extension. Only air quality improvement benefits are estimated. For reference, Capital Cost of these Lines would be about HK$56 Billion

[b] Costs for this strategy will be borne by the aircraft industry (and hence consumers) worldwide and only air quality benefits to Hong Kong have been calculated

[c] The ERP strategy will have incidental improvements to air quality but only these benefits have been calculated. The estimated cost for the proposed ERP scheme is about $1 billion (including the cost of in-vehicle units for existing vehicles) with an annual recurrent cost of about $200 million

[d] Reported as saving – Alternative Case (50% LNG 50% Nuclear) is HK$2,803 M cheaper than the Base Case. Based on Natural Gas fuel price of US$70/MWh

[e] This strategy has not yet matured, and there are no local cost data. Hence only the likely air quality improvement benefits have been calculated

[f] This railway strategy will have additional improvements to air quality but only the air quality improvement benefits have been calculated here. The capital cost would be about HK$5-9 Billion.

[g] The figure includes estimated costs due to increasing the ratio of natural gas in local electricity generation to 50%. It does not cover the costs of the additional emission abatement measures, such as enhancing the SCR systems of the existing coal-fired units, the technical feasibility and financial viability of which would be subject to further examination

[h] Due to the remoteness of the airport from the populated urban centres, only a relatively small resident population can benefit from the improved air quality. The B/C ratio would, therefore, be low. However, the emission reduction would help improve the regional air quality and a higher B/C ratio will be resulted if it is considered in a regional context.

H1.11.2 Health Benefits

The calculated benefits include chronic benefits that dominate the results, with the remainder comprising acute benefits and reduced material damage, while for a number of energy efficient strategies, the benefits also includes reduced energy consumption (demand). The estimated number of life years saved per year from reduced risk of chronic illness assuming implementation of all control strategies are presented in **Table H1.85**.

Table H1.85: Estimated Life Years Saved per Year

Term	0.6% ug/m³ $PM_{2.5}$	0.2% ug/m³ $PM_{2.5}$	1.1% ug/m³ $PM_{2.5}$
Short Term	7,348	2,450	13,470
Medium Term	5,928	1,976	10,868
Long Term	5,734	1,911	10,511

Note: 0.6% ug/m³ $PM_{2.5}$ used in the central analysis.

It should be noted that while the improvement appears small when averaged across the total population, the benefits are in fact large for the small percentage of the population who would have otherwise developed a chronic illness through exposure. In these cases, the saved life years would be substantial.

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