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The growth pattern and fuel life cycle analysis of the electricity consumption of Hong Kong

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Abstract
As the consumption of electricity increases, air pollutants from power generation increase. In metropolitan such as Hong Kong and other Asian cities, the surge of electricity consumption has been phenomenal over the past decades. This paper presents a historical review about electricity consumption, population, and change in economic structure in Hong Kong. It is hypothesized that the growth of electricity consumption and change in gross domestic product can be modeled by 4-parameter logistic functions. The accuracy of the functions was assessed by Pearson's correlation coefficient, mean absolute percent error, and root mean squared percent error. The paper also applies the life cycle approach to determine carbon dioxide, methane, nitrous oxide, sulfur dioxide, and nitrogen oxide emissions for the electricity consumption of Hong Kong. Monte Carlo simulations were applied to determine the confidence intervals of pollutant emissions. The implications of importing more nuclear power are discussed.

1. Introduction

In built environments such as Hong Kong and other Asian cities, electricity consumption has increased rapidly since the 1970s. The growth of electricity consumption is partly attributed to population growth, economic growth, change in life style, and the expansion of the services sector. According to the Hong Kong Census and Statistics Department, Hong Kong's electricity consumption increased from 4451 million kWh in 1970 to 41,862 million kWh in 2010 (Censtatd, 2011a). Hong Kong's population increased from 4.00 millions in 1970 to 7.10 millions in 2010 (Censtatd, 2011b), total gross domestic product (GDP) from US$ 22.6 billion in 1970 to US$ 223.9 billion in 2010 (both figures chained to 2009), and contribution of the services sector to the total GDP from 62 percent in 1970 to over 92 percent in 2010. Nowadays, Hong Kong's per capita electricity consumption and electricity productivity are 5898 kWh/year and US$ 5.35 per kWh/year — one of the highest electricity productivity in the world, respectively. Nevertheless, the surge of electricity consumption also leads to rapid increase in pollutant emissions. The discharge of greenhouse gases including carbon dioxide, methane and nitrous oxide, and other gaseous pollutants such as sulfur dioxide, and nitrogen oxides will not only contribute to the global climate change (IPCC, 2007), but also causes adverse effects on human health (Kampa and Castanas, 2008; Markandya et al., 2009; Wong et al., 2002). Combining with a high level of particulate matters, aerosols, and other organic matters discharged from various sources, the number of haze days in many Asian cities has increased rapidly in the past ten years, especially in winter months between October and March (Lam and Lau, 2005). The number of severe respiratory and cardiovascular diseases was also found to be strongly associated with the concentrations of sulfur dioxide and nitrogen oxides in Hong Kong (Wong et al., 2002). For these reasons, this paper explores the growth patterns of electricity consumption, population, and GDP in Hong Kong. We also apply the life cycle approach (To et al., 2011) to determine the environmental impact of the electricity consumption of Hong Kong.

2. Literature review

2.1. Electricity consumption, population, and economic growth

The relationships between electricity consumption, population, and economic growth have been the focus of intense research over the past fifty years. Foss (1963) showed that electricity consumption was strongly associated with the utilization of capital
equipment, in turn affected economic growth in an industrial country such as the United States. Heathfield (1972) followed Foss’s idea to measure capital usage using electricity consumption data in the United Kingdom. Costello (1993) performed a cross-country, cross-industry comparison of productivity growth and suggested that electricity consumption, as a measure of capital usage, was strongly associated with productivity/economic growth. Ehrlich and Holdren (1971) published their article “Impact of Population Growth” in Science. They reported that there was 760 percent increase in electricity consumption from 1940 to 1969 and suggested that this increase was partly contributed to increase in population and electrification of the society. Brown and Roomey (2003) and Lai et al. (2008) found that population growth partly contributed to the growth of electricity consumption in California and Macao, respectively. In Hong Kong, Lam (1998), Lam et al. (2008), and Yan (1998) investigated the effect of climate on residential and commercial electricity consumption. They showed that electricity consumption increased rapidly during the summer months and concluded that air conditioning consumed more than 50 percent of the total amount of electricity consumption in the residential and commercial sectors. Other researchers approached the associations between electricity consumption, GDP, and/or population using econometric modeling (Chontanawa et al., 2008; Kraft and Kraft, 1978; Lai et al., 2011; Lee, 2005; Meherara, 2007; Sharma, 2010; Soytas and Sari, 2003; Yoo, 2006). Many of them reported that the long-run and short-run causal relationships from electricity consumption to GDP exist in most developing countries and cities (Chontanawa et al., 2008; Lai et al., 2011; Soytas and Sari, 2003). However, there were mixed causal relationships in many other countries (Sharma, 2010). In fact, none of the extant literature has examined the fuel life cycle impact of electricity consumption on the environment in Hong Kong.

2.2. Life cycle approach

According to the US EPA (2006), life cycle analysis is a technique for identifying significant environmental aspects of a product, process and/or service and evaluating the associated impacts on the environment. It consists of four major stages; (i) defining the goals and scopes of the study, (ii) compiling an inventory of energy and material inputs and pollutant emissions; (iii) assessing the impacts associated with the identified inputs and emissions on natural resources, ecosystem and human health; and (iv) interpreting the analyzed results that help management/policy-makers in a decision-making process. A comprehensive life cycle analysis is normally a “forward” approach in which an analyst uses a multi-layer procedure to identify and determine direct and indirect use of resources and pollutant emissions along raw materials extraction and processing, components production, production of a product/service, and consumption and disposal of a product/service. However, as the number of layers increases, uncertainties increase (Ney and Schnoor, 2002). Recently, To et al. (2011) propose the life cycle approach to analyze greenhouse gases emissions due to the electricity consumption of Macao. By realizing that Macao, as most other cities, does not have primary energy sources, To et al. (2011) traced backward to locate the sources of primary energy and determined the direct emissions due to the fossil fuel extraction, processing, transportation, and combustion. They demonstrated that greenhouse gases emissions could be underestimated by (i) neglecting the emissions from the extraction, transportation, and refining of fuels, and (ii) not taking the imported electricity into consideration. Extending To et al.’s (2011) approach, this study focused on emissions of greenhouse gases and other pollutants due to the electricity consumption of Hong Kong. We determined the direct emission of air pollutants from the extraction, processing, transportation, refining, storage, and combustion of fuels.

3. Data sources

Data of electricity consumption, population, the total GDP for the period of 1970–2010 were gathered from the Hong Kong Census and Statistics Department (Censtatsd, 2011a, 2011b). Fuel data were also gathered from the Department (Censtatsd, 2011a), and the environmental or sustainability reports of power companies in Hong Kong and Shenzhen.

4. Results and discussions

4.1. Growth patterns of electricity consumption, population, and GDP

Hong Kong is a services center in Asia and an international finance center that had the largest total funds raised through new initial public offerings in 2010. It, as a former British colony, used to be a major manufacturing center for light industrial goods in the 1960s and 1970s because of its low labor cost. Hong Kong transformed to a commercial and trading center in the 1980s when manufacturers started moving their labor-intensive operations to mainland China. Over the past two decades, Hong Kong has transformed itself as an international finance center, emphasizing its strong link between East and West and a gateway to mainland China. In the past couple of years, Hong Kong has benefited significantly

![Fig. 1. Hong Kong’s electricity consumption from 1970 to 2010.](image-url)
from the Individual Visit Scheme and its Close Economic Partnership
Arrangement with mainland China. Under the Individual Visit
Scheme, 0.27 billion residents in 49 Mainland cities are allowed to
visit Hong Kong in their individual capacity. In 2010, Hong Kong
attracted over 36 million visitors and most of them were short stay
visitors from mainland China. Electricity consumption grew by an
order of magnitude between 1970 and 2010. More specifi-
cally, the
commercial electricity consumption increased by 19 times between
1970 and 2010.

Fig. 1 shows Hong Kong’s electricity consumption from 1970 to 2010.
The growth of electricity consumption resembled a typical
logistic curve. To et al. (2011) and Cho et al. (2007) demonstrated
that the logistic growth model had explanatory power in modeling
electricity consumption and predictive power for energy demands
in short-term. Hence, a 4-parameter logistic function was applied to
the data set. The resulting formula is:

$$\text{Electricity consumption}_{\text{year}} = 2000 + \frac{42800}{1 + \exp(0.138 \times (1990 - \text{year})} \text{ million kWh}$$

(1)

The value of $R^2$ of Eq. (1) was 0.999. $R^2$ is the coefficient
of determination, a measure of the proportion of the variation in one
variable that is explained by the variation in another variable. The
predicted values of Hong Kong’s electricity consumption are also
shown in Fig. 1. The accuracy of this 4-parameter logistic function
was also assessed by using scale invariant measures – mean abso-
lute percent error (MAPE) and root mean squared percent error
(RMSPE). The calculated MAPE and RMSPE were 1.59 percent and
2.09 percent respectively, representing a highly accurate prediction
(Witt and Witt, 1992).

Fig. 2 presents Hong Kong’s population from 1970 to 2010. It
shows that population increased quite linearly between 1970 and
2010 and $R^2$, MAPE and RMSPE between the fitted linear curve and
the actual data were 0.979, 2.37 percent and 2.18 percent, respec-
tively. By plotting electricity consumption as a function of pop-
ulation, Fig. 3 shows the nonlinear relationship between them. As
in the other cities (Brown and Koomey, 2003; Lai et al., 2008), the
increase in Hong Kong’s total electricity consumption was partly
due to population growth, but more importantly due to changes in
economic structure over the past forty years. Details of these
changes were described earlier.

Fig. 4 shows Hong Kong’s total GDP from 1970 to 2010. Again,
a 4-parameter logistic growth function could be employed to
represent the economic growth of Hong Kong.

The function of economic growth is given as:

$$\text{Total GDP}_{\text{year}} = 10000 + \frac{190000}{1 + \exp(0.138 \times (1999 - \text{year})} \text{ million US$}$$

(2)

The value of $R^2$ of Eq (2) was 0.965. However, if only the data set
before 1997 were considered, the $R^2$ value was 0.997. The change in
$R^2$ value between the data sets 1970–2010 and 1970–1997 can be
understood because Hong Kong has gone through two critical
changes in the past fourteen years. The first one was the Asian
financial turmoil in 1997 in which Hong Kong’s economic was
slowed down drastically. The second one was the Severe Acute
Respiratory Syndrome (SARS) outbreak in 2003. And fortunately,
Hong Kong has benefited greatly from the Individual Visit Scheme
and Close Economic Partnership Arrangement with mainland China
since then. The predicted values of Hong Kong’s total GDP are also shown in Fig. 4. It should be noted that a discontinuous 4-parameter logistic function could be employed to model Hong Kong’s GDP closely; one (as given in Eq. (2)) for the period 1970–1997, and another one for the period 1998–2010. The general form of the logistic function is:
\[
\text{Total GDP}_t = \text{GDP}_\text{initial} + \frac{\Delta \text{GDP}}{1 + \exp\left(\tau \times (t_{\text{mid}} - t)\right)} \text{ million US}
\]
(3)
where GDP_{initial} is the base level of GDP, \(\Delta \text{GDP}\) the eventual increase in GDP, \(\tau\) time constant, and \(t_{\text{mid}}\) the year of the highest growth rate. These values were 10,000, 190,000, 0.138, and 1990 for \(t = 1970, 1971, ..., 1997, 1998, 1999, ..., 2010\), respectively. The \(R^2\), MAPE, RMSPE of the discontinuous 4-parameter logistic function were 0.997, 3.19 percent, and 4.56 percent for the former period and 0.977, 1.07 percent, and 2.31 percent for the later period respectively. Again, the function produced highly accurate predictions as shown in Fig. 4.

In fact, the total electricity consumption was significantly correlated to the total GDP (\(R^2 = 0.962, p < 0.001\)). The plot of Hong Kong’s total electricity consumption vs. total GDP is shown in Fig. 5.

Fig. 5 indicates that there was piece-wise linear relationship between electricity consumption and GDP. In the first period, i.e. 1970–2002, electricity consumption increased by about 2.5 million kWh when the total GDP increased by US$ 10 million. During the recent period, i.e. 2003–2010, electricity consumption increased by about 0.5 million kWh when the total GDP increased by US$ 10 million. It is because the finance and service sector that has expanded rapidly since 2003 does not consume electricity as much as the manufacturing or logistics industry per unit of GDP gain. Hence, the preferential treatment from mainland China greatly boosts the energy effectiveness of Hong Kong.

As Hong Kong’s population was 7.10 million in 2010, per capita electricity consumption was 5898 kWh. Hong Kong’s electricity productivity was US$ 5.35 GDP per kWh. Moreover, Hong Kong’s electricity consumption is going to increase by more than 300 million kWh each year in the near future. How much more gaseous pollutants will be generated?

4.2. Fuel life cycle analysis

Table 1 shows the fuel consumed to generate electricity in Hong Kong for the period of 2002–2010 (no data were available from Hong Kong Electric before 2002). In 2010, the majority of electricity generated was made by burning coal (66.4 percent), supplemented by burning natural gas (33.2 percent) and oil (0.4 percent).

Fig. 6 shows the fuel life cycle for the electricity consumption of Hong Kong. This figure indicates the operating greenhouse gases and other air pollutants emitted along the paths of fuel life cycle. Specifically, Hong Kong’s power companies imported fuels from Indonesia (for 90 percent coal), Australia (for natural gas via Shenzhen LNG terminal for Hong Kong Electric (HKE) only and for 4.3 percent coal), China (for natural gas from Hainan province for CLP only and 3.8 percent coal), and the Middle East (for heavy fuel oil and light gas oil via oil refineries in Singapore) in 2010. Fig. 7 shows the transportation routes of those fuels.

4.2.1. Emissions of gaseous pollutants for the “Mine/well-to-electricity” process

The fossil fuel extraction (or production), transportation, refining and combustion generate carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), nitrogen oxides (NOx), and sulfur dioxide (SO2). Their amounts are dependent on the extraction method, production method, transport mode, refinery process, storage mode, the combustion efficiency, and flue gases treatment. To et al. (2011) suggest that each fuel can be analyzed individually and an emission table can be compiled (see Table 2). Table 2 shows that the emission factors of different fuels are very different. For example, the...
Intergovernmental Panel on Climate Change (IPCC, 2010) indicates that emission factors of coal, liquefied natural gas, heavy fuel oil, and light gas oil are 94600 kg CO₂/TJ, 64200 kg CO₂/TJ, 77400 kg CO₂/TJ, and 74100 kg CO₂/TJ while Sovacool (2008) found that the mining, processing and transportation of nuclear fuels would emit 0.58–118 g (mean: 25.09 g) CO₂-equivalent/kWh while the operation of a nuclear plant would produce 0.1–40 g (mean: 11.58 g) CO₂-equivalent/kWh.

According to the Intergovernmental Panel on Climate Change (IPCC, 2007), CO₂, CH₄, and N₂O are greenhouse gases that have a profound effect on global warming. The global warming potentials (GWP) of CH₄ and N₂O relative to CO₂ are 25 and 298, respectively.
Based on the information provided in Table 2 and the GWPs of CO₂, CH₄, and N₂O, pollutant emissions due to the electricity consumption of Hong Kong in 2010 were determined (see Table 3). Table 3 shows that 29.09 million tonnes of CO₂, 576 tonnes of CH₄, and 413 tonnes of N₂O were generated in Hong Kong’s power plants in 2010. By converting CH₄ and N₂O to CO₂-equivalent using GWP, greenhouse gas emissions amounted to 29.23 million tonnes of CO₂-equivalent in Hong Kong power plants. Table 4 shows that 17,770 tonnes of SO₂ and 27,010 tonnes of NOₓ were generated in Hong Kong’s power plants in the same year. In addition, there were 210 kilotonnes of CO₂, 4,679 tonnes of SO₂, and 5,936 tonnes of NOₓ for fuel transport, and 384 kilotonnes of CO₂-equivalent, 108 tonnes of SO₂, and 109 tonnes of NOₓ for the extraction and processing of fuels. Hence, the fuel life cycle for Hong Kong’s power plants produced 29.82 million tonnes CO₂-equivalent greenhouse gases, 22,557 tonnes of SO₂, and 33,055 tonnes of NOₓ. As the plants generated 38,292 million kWh in 2010, emission factors due to the electricity generated locally was 778.8 g CO₂-equivalent/kWh, emission factors due to the electricity consumption of Hong Kong would be 722.1 g CO₂-equivalent/kWh, 0.539 g SO₂/kWh, and 0.790 g NOₓ/kWh.

### 4.2.2. Sensitivity analysis of emissions using Monte Carlo simulations

As shown in Section 4.2.1, the amounts of greenhouse gases, SO₂, and NOₓ generated due to the extraction, production, and processing of a fuel depend on the geographical location of the mine, mining method, and processing techniques. Besides, the IPCC (2010) suggests that the 95 percent confidence intervals of CO₂ emission for coal, LNG, heavy oil, and light gas oil are [87,300, 101,000], [58,300, 70,400], [75,500, 78,800], and [72,600, 74,800] kg per TJ respectively. The 95 percent confidence intervals of CH₄ and N₂O emissions for coal are [0.3, 3] and [0.5, 5] kg per TJ respectively while the 95 percent confidence intervals of CH₄ and N₂O for LNG, heavy oil, or light gas oil are [1, 10] and [0.2, 2] kg per TJ respectively. The values of CO₂, CH₄, and N₂O emissions for coal have lognormal distributions [27].

In order to assess the impact on the overall emissions, Monte Carlo simulations were performed 1000 times, using lognormal distributions for pollutant emissions due to fuel combustion and uniform distributions for the others. The results showed that emission factors due to the electricity generated locally was 776 g CO₂-equivalent/kWh with the 95 percent confidence interval of [735, 820], 0.589 g SO₂/kWh with the 95 percent confidence interval of [0.587, 0.591], 0.863 g NOₓ/kWh with the 95 percent confidence interval of [0.861, 0.866].

On the other hand, by taking the net imported electricity, emission factors due to the electricity consumption of Hong Kong would be 720 g CO₂-equivalent/kWh with the 95 percent confidence...
Table 2
Emission factors of coal, liquefied natural gas, and oil products.

| Fuel Type | Processes | Description | Emission Factors | Reference |
|-----------|-----------|-------------|------------------|-----------|
| Coal      | Extraction | Surface mining and coal processing in Indonesia. | i. Mining: 0.3−2.0 m\(^3\) CH\(_4\)/tonne | IPCC (2010) |
|           | Transport  | From PT Indonesia Bulk Terminal at Pulau Laut to Hong Kong by Post-Panamax type bulk carriers. | ii. Processing: 0−0.2 m\(^3\) CH\(_4\)/tonne | Psaraftis and Kontovas (2009) |
|           | Combusion  | Burnt in Hong Kong’s power plants with desulfurization and selective catalytic reduction systems. | i. 94,600 kg CO\(_2\)/TJ | IPCC (2010); Hong Kong’s power companies and Census and Statistics Dept. |
| Liquefied Natural Gas (LNG) | Extraction in Australia | Vventing of CO\(_2\), flaring and processing of natural gas (NG) to LNG at North West Shelf Gas in Australia. | i. 70 kg CO\(_2\)/tonne | Australian Greenhouse Office (1998) |
|           | Transport from Australia | From North West Shelf in Australia to Guangdong LNG Terminal at Shenzhen by LNG carriers (for HK Electric) Distance: 5140 km | i. 13.6−19.5 kg CO\(_2\)/bbl of crude oil; 1 barrel of oil = 138.8 kg | US DOE (2009); Al-Hamad and Khan (2008) |
|           | Extraction and transmission in Hainan, China | Provision of LNG from the Yacheng Gas Field to Hong Kong’s CLP Power using subsea pipeline. | i. 2000 m\(^3\) CH\(_4\)/km/yr | IPCC (2010) |
|           | Combustion | Burnt in Hong Kong’s power plants. | i. 64,200 kg CO\(_2\)/TJ | IPCC (2010); HK Electric’s sustainability reports. |
| Oil       | Extraction in the Middle East | Flaring, venting and processing of oil in the Middle East. | i. 11.6−19.5 kg CO\(_2\)/tonne | US DOE (2009); Al-Hamad and Khan (2008) |
|           | Transport | Crude oil is transported to Singapore for refining. Heavy fuel oil (HFO) and light gas oil (LGO) are transported from Singapore to Hong Kong by Aframax oil tankers. Distances- Middle East → Singapore: 6870 km; Singapore → Hong Kong: 2710 km | i. 5.63 g CO\(_2\)/tonne | Psaraftis and Kontovas (2009) |
|           | Refining | Crude oil is processed in refineries in Singapore. | i. 17 kg CO\(_2\)/tonne of HFO | Babusiaux and Pierru (2007); EC (2003) |
|           | Combustion | Burnt in Hong Kong’s power plants. | i. 77,400 kg CO\(_2\)/TJ | IPCC (2010); Hong Kong’s power companies and Census and Statistics Dept. |
| Nuclear   | Mining, processing, and transport | Nuclear fuel is processed in France and transported to Shenzhen's Daya Bay Nuclear Power Station. | i. 0.58−118 g (mean: 25.09 g) CO\(_2\)/kWh | Sovacool (2008) |

Table 3
Greenhouse gases emissions due to the electricity consumption of Hong Kong in 2010.

| Fuel Type | Used in | KT | CO\(_2\) (tonne) | CH\(_4\) (tonne) | N\(_2\)O (tonne) | Transport CO\(_2\) (tonne) | Extraction and Processing CO\(_2\)/CO\(_2\)-equiv (tonne) | CH\(_4\) (tonne) |
|-----------|---------|----|----------------|-----------------|----------------|----------------------------|-----------------------------------------------|----------------|
| Hong Kong | Coal    | HKE & CLP | 8669 | 21,651,347 | 228.9 | 343.3 | 169,921 | 7770 |
|           | Heavy fuel oil | HKE | 6 | 18,762 | 0.7 | 0.1 | 324 | 802 |
|           | Light gas oil | HKE & CLP | 25 | 78,472 | 3.2 | 6 | 1328 | 3537 |
|           | Natural gas (China) | CLP | 1526 | 5,329,049 | 249.0 | 1.5 | 1560 | 1099 |
|           | Natural gas (Australia) | HKE | 576 | 2,012,798 | 94.1 | 18.8 | 37,688 | 40,342 | 415 |
|           | Overall CO\(_2\) | 29,227,812 | 127,911 | 277,140 | 277,140 |
| Shenzhen | Nuclear | Nuclear a | 127,911 | 277,140 | 277,140 |

a HKE and CLP stand for “Hong Kong Electric” and “CLP Power”, respectively.

b Sovacool (2008) indicates that nuclear power emits 25.09 g CO\(_2\)-equivalent kWh due to the mining, processing, and transportation of nuclear fuel and 11.58 g CO\(_2\)-equivalent kWh due to the operation of a nuclear power plant including cooling and fuel cycles, backup generators, and during outages and shutdowns.
interval of [678, 770], 0.539 g SO₂/kWh with the 95 percent confidence interval of [0.537, 0.541], and 0.790 g NOₓ/kWh with the 95 percent confidence interval of [788, 792].

4.2.3. Effect of fuel mix on emissions of air pollutants

The fuel life cycle approach was then applied to determine emissions of air pollutants from 2002 to 2009, the period in which the amount of fuels consumed and the total electricity generated locally were known (see Table 1). Fig. 8 shows that greenhouse gases emission ranged from 774.6 to 832.6 g CO₂-equivalent/kWh between 2002 and 2010. It also shows that SO₂ emission peaked at 2.493 g/kWh in 2003 and then dropped to 0.589 g/kWh in 2010 while NOₓ emission peaked at 1.708 g/kWh in 2003 and then dropped to 0.863 g/kWh in 2010. Fig. 9 shows the energy mix in Hong Kong’s power industry during the period 2002 to 2010. By performing a covariance analysis between the coal consumed in percentage and air pollutants discharged, it was found that greenhouse gases emission was strongly and positively associated with the coal consumed in percentage ($R^2 = 0.913$, $p < 0.001$). Results of the covariance analysis also indicated that NOₓ emission was strongly and significantly associated with the coal consumed ($R^2 = 0.646$, $p < 0.01$) and SO₂ emission was moderately associated with the coal consumed ($R^2 = 0.406$, $p = 0.07$). Nevertheless, it should be noted that SO₂ emission was affected by changing fuel mix, sources of fuels, and improvement works in power plants. The footnote of Fig. 8 listed out CLP and HKE implementing a number of strategies as well as improvement works from 2002 to 2010 so that SO₂ varied more considerably then other air pollutants.

In sum, emissions of air pollutants decreased when the percentage of coal in the fuel mix decreased, i.e. the percentage of liquefied natural gas increased.

| Table 4 |

SO₂ and NOₓ emissions due to the electricity consumption of Hong Kong in 2010.

| Fuel Type | Used in | KT | Com- bustion | Transport | Extraction and Processing |
|-----------|---------|----|-------------|-----------|---------------------------|
|           |         |    | SO₂ (tonne)| NOₓ (tonne)| SO₂ (tonne) | NOₓ (tonne) |
| Hong Kong | Coal | HKE & CLP | 8669 | 3814.5 | 4854.9 | - | - |
|           | Heavy fuel oil | HKE | 6 | 6.9 | 8.6 | 21.2 | 21.3 |
|           | Light gas oil | HKE & CLP | 25 | 28.3 | 35.4 | 86.8 | 87.4 |
|           | Natural gas (China) | CLP | 1526 | - | - | - | - |
|           | Natural gas (Australia) | HKE | 576 | 829.6 | 1037.0 | - | - |
| Overall emissions | - | 17,770 | 27,010 | 4679.3 | 5935.9 | 108.0 | 108.7 |
| Shenzhen | Nuclear | - | - | - | - | - | - |
| Overall emissions | - | - | - | - | - | - | - |

Notes: 1. In 2002, the energy mix of Hong Kong’s power industry (local) was 68.9 : 30.5 : 0.6 (coal : LNG : oil)

The ratios of energy mix were 51.6 : 47.7 : 0.7 for CLP and 99.5 : 0 : 0.5 for HKE (coal : LNG : oil)

2. CLP changed the energy mix, i.e. its primary energy from LNG decreasing from 47.7 % to 27.7 %.

3. CLP started burning ultra low sulfur coal.

4. HKE changed its energy mix with 4.7% of primary energy from LNG. CLP optimized boiler performance.

5. HKE increased the use of LNG, i.e. its primary energy from LNG increasing to 13.6%.

6. CLP changed the energy mix, i.e. its primary energy from LNG increasing to 33.4 % in 2008 (from 22.6% in 2007).

7. HKE increased the use of LNG, i.e. its primary energy from LNG increasing to 27.9 %. CLP implemented emission control projects.

Fig. 8. Emission factors due to the electricity generated locally.
5. Conclusion and implications

The consumption of electricity has increased rapidly worldwide in the past decades. In Hong Kong, electricity consumption increased by 9.4 times from 4451 million kWh in 1970 to 41,862 million kWh in 2010. Hong Kong’s electricity productivity was US$5.35 GDP per kWh in 2010. Unfortunately, high electricity productivity comes at an environmental cost. By analyzing the data of electricity consumption, population, and GDP in Hong Kong spanning over the past forty years, it was found that the growth of electricity consumption resembled a logistic growth curve closely, population increased quite linearly, and increase in GDP could be modeled accurately using a discontinuous logistic function. The pair-wise comparisons indicated that the growth of electricity consumption was partly contributed by the increase of population, and the growth of electricity consumption and change in GDP were strongly associated. In fact, the later pair was characterized very accurately by a piece-wise linear relationship with a turning point in 2003 — the year Hong Kong’s economic to be badly hit by the SARS epidemic but fortunately then fully supported by the Central Government for its preferential policy on the development of the finance and tourism sectors.

Using a holistic view of fuel life cycle analysis, we found that the emission factors due to the electricity generated in Hong Kong was 778.8 g CO₂-equivalent/kWh, 0.589 g SO₂/kWh, and 0.863 g NOₓ/kWh in 2010. However, Hong Kong imported electricity from a nuclear power plant in Shenzhen with relatively low CO₂-equivalent emission at 36.67 g CO₂-equivalent/kWh. By taking account of the imported electricity and the associated greenhouse gases emissions, emission factors due to the electricity consumed in Hong Kong would be 722.1 g CO₂-equivalent/kWh, 0.539 g SO₂/kWh, and 0.790 g NOₓ/kWh. We also found that the extraction, production, transportation, and processing of fossil fuels contributed to 1.65, 5.65, and 5.72 percent of the overall greenhouse gases emissions for coal, heavy oil and light gas oil, and 3.48 and 4.19 percent of the overall greenhouse gases emissions for LNG from China and Australia, respectively. By using the logistic growth model of Hong Kong’s electricity consumption, it is expected that there is a net increase of 1624 million kWh from 2010 to 2015, representing an increase of 3.87 percent. Assuming that there is no change in the imported electricity from the nuclear power plant in Shenzhen, Hong Kong’s power companies need to generate an additional 4.86 percent of electricity locally, resulting in a probable increase of 1.42 million tonnes of CO₂-equivalent.

Some Hong Kong’s people advocate importing more electricity from nuclear power plants in Shenzhen. Nevertheless, this strategy will not solve the problem because the electricity demand in Shenzhen has also surged rapidly in the past two decades. Besides, the true cost of nuclear power shall not be underestimated, from both environmental and economic perspectives. Sovacool (2008) concluded that the emissions for nuclear energy over the lifetime of a power plant should range from 14 to 288 g CO₂-equivalent/kWh. Specifically, he indicated that the construction, treatment of nuclear waste, and decommissioning of a nuclear power also contributed quite significantly to greenhouse gases emissions indirectly. In terms of the economic cost, the Daya Bay Nuclear Power Plant — the one supplying over 10,000 million kWh electricity to Hong Kong every year — cost US$ 4 billion in construction in 1994. The pressurized water reactors have a life-span of 40 years. At the end of their life, it is expected that US$ 1.3 billion needs to be spent for the plant’s decommissioning. By taking all construction, operating and decommissioning expenditures into consideration, the levelized cost of electricity from nuclear power is about US$ 0.05 per kWh (Grubler, 2010). However, in light of the disaster in Fukushima nuclear power stations, a nuclear accident may eventually cost US$ 30 billion for containment, not counting the potential loss of human lives and destruction of ecosystems in the affected region.

Based on the fuel life cycle analysis, it is proposed that Hong Kong should change fuel composition to increase the percentage of liquefied natural gas in the total fuel mix. It is because liquefied natural gas is more efficient as a fuel than coal and produces less greenhouse gases, SO₂ and NOₓ per kWh generated as shown in Table 3.4. In addition, Hong Kong can consider (i) using more renewable energy such as wind and solar energy because wind turbines and solar power systems do not emit air pollutants during operations, and (ii) planting trees to reduce building energy use (Akbari, 2002). In so doing, the amount of air pollutants discharged from power generation can be reduced.

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