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GHG emissions from electricity consumption: a case study of Hong Kong from 2002 to 2015 and trends to 2030

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Abstract

Electricity consumption in cities continuously increases. Using a life cycle approach and the fuel mix data from power companies' sustainability reports, this paper analyzes the greenhouse gas (GHG) emissions from electricity consumption in Hong Kong. The analyzed results show that coal contributed on an average of 74.3 percent, liquefied natural gas 25.1 percent, and oil 0.6 percent of the thermal energy to the generation of electricity in Hong Kong between 2002 and 2015. Besides, Hong Kong imported an average of 7.96 billion kWh per year net electricity from a nuclear power plant in Shenzhen. During this period, GHG emissions from annual electricity consumption ranged from 27.0 to 34.1 million tons (MT) and the emission factor ranged from 702 to 792 g CO_2-eq/kWh. Hong Kong's gross domestic product (GDP) increased steadily from USD 176 billion in 2002 to USD 297 billion in 2015. Thus, Hong Kong's electricity productivity increased from 4.62 to 6.75 USD/kWh while GHG emission from electricity consumption per GDP decreased from 0.153 to 0.104 MT CO_2-eq/USD billion during this period. Hong Kong's annual electricity consumption was predicted in short-term periods (from 2016 to 2020) and medium term for the year 2030. Electricity consumption was likely to increase to 44.63 billion kWh by 2030 while GHG emissions from electricity consumption were predicted to increase to 33.92 MT of CO_2-eq. Implications are given at the end of the paper.

Keywords: GHG emissions, electricity consumption, fuel life cycle approach, Hong Kong.

1. Introduction

Approximately 54.5 percent of the world's population i.e., 4.1 billion people, lived in urban areas in 2016 (the United Nations, 2016). While urban areas are made up primarily of cities, 76 of them are large cities with more than 5 million inhabitants, accommodating 0.8 billion of the world's population (the United Nations, 2016). Among these large cities, 14 are in China. Shanghai has a population of 24.5 million, followed by Beijing with a population of 21.2 million. Hong Kong is ranked tenth with a population of 7.3 million. The United Nations (2016) projected that urban areas will house 60 percent of people globally by 2030 and 20 Chinese cities will each have a population larger than 5 million. Since these cities and their economic activities—including household consumption, production, and transportation—are getting recognized as direct causes of climate change (Kennedy et al., 2009, 2010), many of them have started to apply a variety of measures to mitigate the impacts on and the consequences of climate change (de Oliveira et al., 2013; Mi et al., 2016). There is evidence that Chinese cities are now playing a significant role in slowing down the increase in carbon emissions (Meng et al., 2017; Mi et al., 2016; Wang et al., 2012).

In cities, people spend most of their time in indoor environments, e.g., homes, commercial buildings, shopping centers, and schools (Balaban and Oliveira, 2016). Naturally, they need electricity for lighting, ventilation, air-conditioning, heating, entertaining, and powering a wide range of electronic and computing devices. Specifically, Andrae and Edler (2015) explored the global electricity usage of communication technology between 2010 and 2030. Their worst-case scenario analysis shows that communication technology would use as much as 51% of global electricity and would contribute to 23% of the global GHG emissions in 2030. Nevertheless, Andrae and Edler (2015) suggests that the worst-case scenario is unlikely to happened because of the improvement in electricity efficiency of wireless and fixed access networks and data centers and the continued growth of renewable energies. As for economic activities such as service creation, product manufacture and transportation, electricity is either the sole source of power or is an increasingly important form of energy source. Consequently, the consumption of electricity in cities has become one of the fundamental causes of climate change (Kennedy et al., 2009, 2010, 2014; Olazabal and Pascual, 2015). For instance, Hong Kong is one of the major cities in Asia and a member of C40 Cities Climate Leadership Group (C40), whose electricity consumption is a major cause of greenhouse gases (GHG) emissions in the respective regions. Specifically, Hong Kong's electricity consumption is 42 billion kWh (including about 8 billion kWh net imported from the Daya Bay Power Plant in Shenzhen) each year and its annual GHG emissions are about 31 million tons of CO_2-eq (To et al., 2012). Such electricity consumption means a total energy consumption of about 1200 PJ each year, which comes from fossil fuels including coal, liquefied natural gas, and oil. Around 37 percent of this primary energy consumption is associated with the electricity generated by the three coal-fired and natural gas-fired power plants in Hong Kong.

To et al. (2012) reviewed the historical electricity consumption data for the period of 1970-2010. They reported that Hong Kong's total annual electricity consumption increased from 4.5 billion kWh in 1970 to 41.9 billion kWh in 2010 and its growth pattern followed a logistic curve with the highest growth rate appearing during the period 1980-2000. To et al. (2012) then presented a 4-parameter logistic function that models Hong Kong's total electricity consumption. They also determined that emission factor due to the electricity consumed in Hong Kong was 722 g CO2-eq/kWh using an attributional life cycle approach (ISO, 2006; Soimakallio et al., 2011). Treyer and Bauer (2016a,b) studied GHG emissions from electricity production and consumption in 71 geographies covering 50 countries. Treyer and Bauer (2016a) reported that emission from electricity production ranged from 814 to 1445 g CO_2/kWh using coal, and ranged from 398 to 823 g CO_2/kWh using natural gas for the reference year 2008.

Treyer and Bauer (2016b) highlighted that the imported electricity shall be considered because it affects the fuel mix and market mix of the studied geographical region.

The annual growth rate of electricity consumption has been around 1.3 percent on average since 2000. As a way of engaging stakeholders and enhancing environmental awareness, Hong Kong's power companies have published sustainability reports providing detailed accounts of fuels consumed since 2002. Hence, the first objective of the paper is to determine the fuel mix of electricity production, and total GHG emissions based on data from these sustainability reports. The second objective of the paper is to forecast the GHG emissions from the city over the short- and medium-terms. Short-term projections cover a five-year time span from 2016 to 2020 while a medium-term projection is set to 2030 – a milestone year in the Sydney Declaration (HKEB, 2015) and the Paris Agree of the United Nations Framework Convention on Climate Change (Wang et al., 2017). This paper is one of the first studies in the literature to examine the impact of fuel mix as well as GDP on the total GHG emissions from electricity consumption in the context of a major city of Asia. Specifically, the findings of the paper contribute to policy makers, power companies, and other stakeholders by offering insights on the trend of GHG emissions from electricity consumption and demonstrating that the GDP growth of a developed city may reduce electrical energy intensity in terms of CO_2-eq/USD but not the total GHG emissions from electricity consumption. The paper will also highlight certain overall lessons of special interest to other cities operating in the globalized environment.

2. Method and data

2.1. Determination of GHG emissions

Emissions from electricity consumption are usually determined using the fuel life cycle approach (e.g., To et al., 2011, 2012). This approach takes not only emissions from the burning of fuels in power plants into consideration, but more holistically accounts for emissions from processes such as the extraction of fuels, transport of fuels, refinery processes and storage modes, regardless of where these processes are taking place (Brynoff et al., 2014; To et al., 2011, 2012). The magnitudes of the emission factors of the fuels involved in the current analyses are summarized in Table 1. Table 2 shows the emission factors of different fossil fuels burnt in power plants.

"Insert Table 1 here"

"Insert Table 2 here"

2.2.Forecasting of GHG emissions

Using the fuel life cycle approach, To et al. (2012) developed a 4-parameter logistic function that had effectively predicted Hong Kong's total annual electricity consumption during the period 1980–2000. The logistic function is given in Eq. (1) as below.

$$Elec(t) = 2000 + \frac{42800}{1 + \exp(0.138 \times (1990 - t))} \text{ million kWh} \qquad (1)$$

where $Elec(t)$ is the amount of total electricity consumption at year t.

This study uses Eq. (1) to predict Hong Kong's total annual electricity consumption values for the period 2016–2020 and 2030. The year 2030 is an important year to Hong Kong because when the Hong Kong Government signed the Sydney Declaration in 2007, it promised to reduce its energy intensity at least 25 percent using 2005 as the base year (HKEB, 2015). Next, using the mean percentage values of net imported electricity and net thermal efficiency of local electricity production, the total thermal energy associated with electricity production is predicted. Finally, GHG emissions are determined for three scenarios: (i) the upper bound, i.e., the worst case based on fuel mix ratio values in which the percentage of thermal energy from coal was the highest during the period 2002–2015, (ii) the most likely values, i.e., the mean fuel mix ratio during the period 2002–2015, and (iii) the lower bound, i.e., the best case based on the fuel mix ratio in which the percentage of thermal energy from LNG was the highest during the period 2002–2015.

2.3.Data sources

Fuel data were obtained from the sustainability reports of the two power companies in Hong Kong (CLP, 2016; HK Electric Investments, 2016). Data on Hong Kong's total electricity consumption, population, and gross domestic product (GDP) for the period 2002–2015 were gathered from the Hong Kong Census and Statistics Department (Censtatd, 2016a). Hong Kong's total electricity consumption and GDP for the period of 1970-2002 were obtained from the Hong Kong Census and Statistics Department (Censtatd, 2016b, 2016c).

3. Results and analysis

3.1.Electricity consumption

Table 3 reports on the consumption of fuels in Hong Kong's plant powers and the net imported electricity from the Daya Bay Nuclear Power Plant in Shenzhen for the period of 2002–2015 (CLP, 2016; HK Electric Investments, 2016). For instance, in 2015, the bulk of the electricity was produced by burning coal (69.5 percent), supplemented by burning LNG (29.8 percent) and fuel oil (0.7 percent). Based on the information given in Table 3, the fuel mix figures for electricity production were determined for the period 2002-2015 (see Fig. 1). The figure indicates that coal had contributed 66.4 to 81.1 percent (mean = 74.3 percent; SD = 4.06 percent) of total thermal energy to the generation of electricity in Hong Kong while liquefied natural gas contributed 18.3 to 33.2 percent (mean = 25.1 percent; SD = 4.10 percent) of the thermal energy. Fuel oil (see HFO and LFO figures in Table 3) contributed 0.3 to 2.3 percent (mean = 0.6 percent; SD = 0.50 percent) of total thermal energy. Fig. 1 also reveals that liquefied natural gas had contributed relatively high levels of thermal energy (i.e. about 30 percent or more) in Years 2002, 2010, and 2015.

“Insert Table 3 here”

“Insert Fig. 1 here”

Fig. 2(a) shows Hong Kong’s electricity consumption during the period 2002–2015 (CLP, 2016; HK Electric Investments, 2016). It reveals that Hong Kong’s annual electricity consumption had increased from 38 billion kWh in 2002 to 43.9 billion kWh in 2015. It also indicates that the net imported electricity had increased from 8 billion kWh in 2002 to 10.6 billion kWh in 2015. Yet, the percentages of the gross imported electricity over the total consumption were quite steady; they remained in the range 23.4–27.0 percent with a mean of 25.5 percent over this period. The mean percentage values of net imported electricity (25.5 percent) would be used for forecasting future GHG emissions in the next section (Section 3.2) of this paper.

Fig. 2(b) shows that household electricity consumption had increased from 9.3 billion kWh (24.4 percent) in 2002 to 11.8 billion kWh (26.8 percent) in 2015 and commercial electricity consumption from 22.1 billion kWh (58 percent) in 2002 to 26.3 billion kWh (59.8 percent) in 2015, while industrial electricity consumption dropped from 4.5 billion kWh (11.8 percent) in 2002 to 3.2 billion kWh (i.e. 7.2 percent) in 2015. Electricity consumption by Hong Kong’s government increased slightly from 2.2 billion kWh (5.9 percent) in 2002 to 2.7 billion kWh (6.2 percent) in 2015 (HKEB, 2015; HKLCQ, 2008).

"Insert Fig. 2 here"

The net thermal efficiency of Hong Kong's electricity production was determined using the total thermal energy from different fuels (shown in Table 3) and the electricity produced locally (shown in Fig. 2(a)). It was found that the net thermal efficiency ranged from 30.8 to 33.3 (mean = 31.8; SD = 0.86) percent during the period 2002–2015. The mean of the net thermal efficiency (i.e. 31.8) would be integral information in the forecasting of future GHG emissions presented in the next section (i.e. Section 3.2) of this paper.

3.2.Electricity consumption and GDP

Electricity productivity refers to the effectiveness of the electricity consumption in creating GDP for the economy. Fig.3 shows Hong Kong's GDP and electricity productivity for the period 2002-2015. As Hong Kong's GDP growth rate (shown in Fig. 3(a)) was higher than the growth of Hong Kong's electricity consumption (shown in Fig. 2) during this period, electricity productivity increased from 4.62 USD/kWh in 2002 to 6.75 USD/kWh in 2015. This is one of the highest values in the world (c.f. the U.S. overall electricity productivity at 3.76 USD/kWh and the U.S. leading ten states at 6.10 USD/kWh in 2005; Mims et al., 2009).

"Insert Fig. 3 here"

Fig. 4 shows Hong Kong's electricity consumption versus Hong Kong's annual GDP using longer term data for the period 1970–2015. It shows that Hong Kong's electricity consumption increased linearly with Hong Kong's GDP at a rate of about 0.22 kWh/USD (see the regression formulas in Fig. 4) during the period 1970–2002. After 2002, Hong Kong's electricity consumption increased at a rate of about 0.05 kWh/USD, i.e., the consumption of 0.05 kWh electricity for each US dollar of GDP. The improvement in the efficiency of the electricity consumption with respect to GDP was because of the rapid growth in the service sector (e.g., finance, retail, and hospitality sectors). In particular, the implementation of the Mainland-Hong Kong Closer Economic Partnership Arrangement and Individual Visit Scheme has brought enormous economic benefits to Hong Kong's finance and tourism sectors since 2003. Since 2000, Hong Kong's finance sector has grown at a compound annual growth rate (CAGR) of 2.1 percent (Zhang, 2016) while total tourism expenditure increased from USD 9.9 billion in 2002 to USD 46 billion in 2014 (HKTB, 2016) i.e. at a CAGR of 13.7 percent. These low energy intensive sectors (Mi et al., 2015) have improved Hong Kong's electricity productivity very significantly.

"Insert Fig. 4 here"

3.3.The use of alternative or renewable energies

The CLP Power sustainability report (CLP, 2016) indicates that, on average, 5 million kWh electricity was produced each year by using landfill gas over the past decade, i.e., about 0.014 percent of the total electricity was generated. The sustainability report of another power company in Hong Kong, HK Electric, indicates that 1.94 million kWh electricity, i.e., about 0.018 percent of its annual electricity, was produced each year by thin film photovoltaic power systems and a wind farm at Lamma Island (HK Electric Investments, 2016). Hence, Hong Kong's two power companies and their stakeholders (e.g., the Hong Kong Government) should find ways to increase the share of alternative or renewable energies in the production of electricity as well as the adoption of latest technologies (e.g., smart grid) that can further improve the plants' future environmental performance and have potential for having more distributed electricity generations from different alternative/renewable energy sources.

3.4. Pollutant emissions caused by electricity consumption

3.4.1. GHG emissions

Table 4 shows the GHG emissions from Hong Kong's electricity consumption to be 30.8 MT of CO_2-eq. that included 0.43 MT of CO_2-eq due to the import of nuclear power in 2015. Table 4 also indicates that the majority (74.5 percent) of GHG emissions were produced by the burning of coal in Hong Kong's power plants, whereas 21.6 percent of GHG emissions were produced by the burning of LNG in the plants. The extraction, processing, and transport of fuels contributed 1.8 percent of the total GHG emissions, whereas the figure pertaining to nuclear power consumption from Shenzhen was only 1.4 percent.

"Insert Table 4 here"

By using the computation method presented in Table 4, the annual GHG emissions from electricity consumption, the figures for the period 2002–2015 were determined (see Fig. 5). The annual GHG emissions ranged between 27.0 and 34.1 (mean = 31.3; SD = 1.8) MT of CO_2-eq during this period. Fig. 5 also shows that the annual GHG emissions were relatively low in the years 2002, 2010, and 2015 during which a higher percentage of the electricity was generated by using LNG (see Fig. 1).

"Insert Fig. 5 here"

3.5.Sensitivity analysis of GHG emissions using Monte Carlo simulations

As mentioned earlier, the use of the fuel life cycle approach in the determination of GHG emissions involves examining various processes such as the extraction, processing, and transport of fuels, and the accuracy of this approach is also affected by a wide range of factors such as the geographical locations of the mines, mining methods, processing techniques, and modes of transport. Besides, IPCC(2010) recommends that the 95 percent confidence intervals of CO_2 emissions from coal, LNG, LGO, and HFO are [87,300,101,000], [58,300, 70,400], [72,600, 74,800], and [75,500, 78,800] kg/TJ, respectively. The 95 percent confidence intervals of CH_4 and N_2O emissions for coal are [0.3, 3] and [0.5, 5] kg/TJ, respectively while the 95 percent confidence intervals of CH_4 and N_2O for LNG, LFO, and HFO are [1, 10] and [0.2, 2] kg/TJ, respectively. The values of CO_2, CH_4 and N_2O emissions for coal, LNG, LFO, and HFO follow lognormal distributions (IPCC, 2006). The Monte Carlo simulations were performed 1000 times, using lognormal distributions for pollutant emissions arising from fuel combustion and uniform distributions for the others. The results showed that GHG emission factor due to Hong Kong's electricity consumption was 700.3 g CO_2-eq/kWh with the 95 percent confidence interval being [663.4, 745.3] g CO_2-eq/kWh in 2015.

3.6.Forecasting of GHG emissions in the short term

To forecast the GHG emissions over the short term (i.e., 2016–2020), it was necessary to forecast the total annual electricity consumption of the same period. We used Eq. (1), i.e., a 4-parameter logistic function (To et al., 2012), to "predict" the annual electricity consumption for the period 2002–2020 (see Fig. 6). By evaluating the actual and the predicted annual electricity consumption figures for the period 2002–2016, we found that the percentage error ranged from -1.41 to 1.33 percent during this period. The mean percentage error was -0.33 percent while the root mean square percentage error was 0.88 percent. These results indicate the prediction accuracy. The prediction suggested that, by 2020, the total annual electricity consumption would be 44.13 billion kWh.

By using the predicted electricity consumption, the mean percentage value of net imported electricity (25.5 percent), the mean net thermal efficiency of local electricity production (31.8 percent), and the mean fuel mix ratio (coal – 74.3 percent, LNG – 25.1 percent, oil – 0.6 percent), we computed the annual GHG emissions from electricity consumption for the period 2016–2020 (see Fig. 6). We found that GHG emissions from electricity consumption would increase steadily from 33.1 MT of CO_2-eq in 2016 to 33.5 MT of CO_2-eq by 2020. If the fuel mix ratio is changed to (coal – 88.1 percent: LNG – 18.3 percent: oil – 0.6 percent), GHG emissions from electricity consumption would increase to 34.3 MT of CO2-eq in 2020, i.e. the worst-case scenario. If the fuel mix ratio is changed to (coal – 66.4 percent: LNG – 33.2 percent: oil – 0.4 percent), GHG emissions from electricity consumption would only amount to 32.6 MT of CO_2-eq in 2020, i.e., the best-case scenario.

"Insert Fig. 6 here"

3.7.Reduction of energy intensity in the medium term

Hong Kong is a member of Asian Pacific Economic Cooperation (APEC). It had signed the Sydney Declaration in 2007. Under this declaration, Hong Kong, like other member economies, agrees to reduce its energy intensity by at least 25 percent by 2030, using 2005 as the base year (HKEB, 2015). In 2005, Hong Kong's total electricity consumption was 40.05 billion kWh, and it produced 31.23 MT of CO_2-eq. Hong Kong's GDP was USD 211.71 billion in that year. The electrical energy intensity, i.e., GHG emission from electricity consumption divided by GDP, was 0.148 MT of CO_2-eq/USD billion. In 2015, Hong Kong's total electricity consumption was 43.91 billion kWh and it produced 30.84 MT of CO_2-eq. Hong Kong's GDP was USD 296.57 billion in that year. Hence, the electricity energy intensity was reduced to 0.104 MT of CO_2-eq/USD billion. This represented a 29.7 percent reduction using 2005 as the base year.

Using Eq. (1), we could predict that Hong Kong's total electricity consumption would be 44.13 billion kWh by 2020 and 44.63 billion kWh by 2030. The total GHG emissions from electricity consumption would be 33.49 MT of CO_2-eq using the mean fuel mix ratio, 34.26 MT of CO_2-eq in the worst case scenario, and 32.60 MT of CO_2-eq in the best case scenario, respectively in 2020 while the total GHG emissions from electricity consumption would be 33.92 MT of CO_2-eq using the mean fuel mix ratio, 34.63 MT of CO_2-eq in the worst case scenario, and 33.02 MT of CO_2-eq in the best case scenario, respectively in 2030. In 2016, the Hong Kong Government had predicted that Hong Kong's GDP would grow by 1-2 percent in that year. This was because the global economic growth was slow (Hong Kong Government, 2016) and Hong Kong was a very mature economy. Assuming that Hong Kong can maintain a 1.5 percent growth in GDP per year between 2016 and 2030, Hong Kong's GDP will increase to USD 319.49 billion by 2020 and USD 370.78 billion by 2030. Hong Kong's GDP may increase to USD 399.14 billion by 2030 in the best-case scenario if Hong Kong can attain 2 percent growth in GDP per year between 2016 and 2030. At worst, Hong Kong's GDP may increase to USD 344.31 billion by 2030 when Hong Kong has only 1 percent growth in GDP per year. Hong Kong's electrical energy intensity is likely to be 0.105 MT of CO_2-eq/USD billion in 2029 and 0.0915 MT of CO_2-eq/USD billion in 2030 using the GHG emissions based on the mean fuel mix ratio and mean economic growth at 1.5 percent per year. This is equivalent to a 38.2 percent reduction by 2030 using 2005 as the base year. At worst, Hong Kong's electrical energy intensity would be 0.101 MT of CO_2-eq/USD billion, i.e., 31.8 percent reduction by 2030 using 2005 as the base year. At best, Hong Kong's electrical energy intensity would be 0.0817 MT of CO_2-eq/USD billion, i.e. 44.8 percent reduction by 2030 using 2005 as the base year. Nevertheless, the total GHG emissions from electricity consumption would increase by at least 1.5 MT to over 32.60 MT of CO_2-eq a year for the year 2030.

4. Conclusion

Cities are crucial to human development and are important for climate change mitigation. This paper has analyzed the fuel mix of and the GHG emissions from electricity consumption in Hong Kong using a fuel life cycle approach. The analyzed results have shown that coal had contributed on average 74.3 percent, liquefied natural gas 25.1 percent, and oil 0.6 percent of the thermal energy, to the generation of electricity in Hong Kong during the period 2002–2015. Alternative and renewable sources contributed less than 0.02 percent to the generation of electricity. During the same period, the annual GHG emissions ranged between 27.0 MT and 34.1 MT of CO_2-eq with an average of 31.3 MT of CO_2-eq. The emission factor ranged between 702 and 792 g CO_2-eq/kWh with an average of 759 g CO_2-eq/kWh. In 2015, Hong Kong's power companies used more LNG to produce electricity. Thus, the GHG emission factor was 702 g CO_2-eq/kWh.

4.1.Implications

To summarize, the findings from this case study offer several generalizable insights regarding electricity consumption and GHG emissions. First, economic growth has a strong association with electricity consumption, which in turn is strongly associated with GHG emissions. Thus, cities with rapid economic growth currently or potentially must pay strategic attention and resources to alleviate the resultant GHG emissions. Second, one effective means in reducing GHG emissions resulting from electricity consumption is to increase the use of LNG in the generation of electricity. From this viewpoint, governments' environmental policies would be crucial in that they offer incentives that affect power companies' relevant decisions (Zhao et al., 2016). Third, even in developed cities such as Hong Kong, the use of alternative or renewable energies is still limited. Since there could be varying reasons, governments and power companies may work together to investigate the actual reasons and come up with appropriate solutions. Finally, cities' active participation in international forums and treaties concerning the environment or climate change is likely to be influential in their relevant environmental policies. In particular, by signing certain treaties (such as the Sydney Declaration in the case of Hong Kong), governments can pledge to achieve some specific environmental goals by proactively dealing with various environmental issues, e.g., reducing household electricity consumption or incentivizing power companies to use environment-friendly fuel mix in the electricity generation.

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Fig. 1. Fuel mix of electricity production in the period 2002–2015.

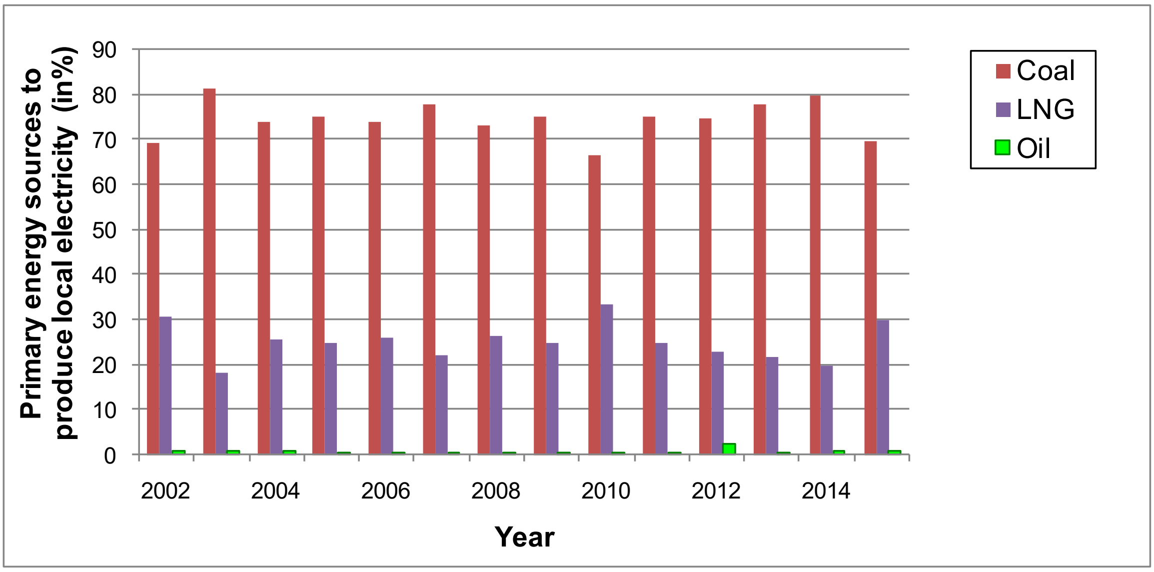
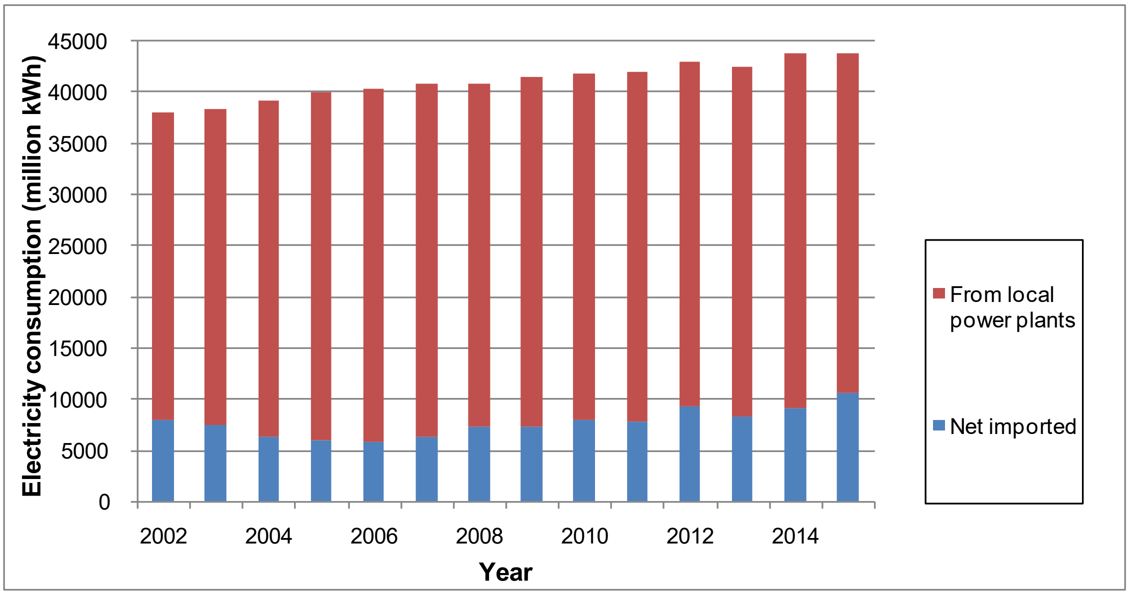
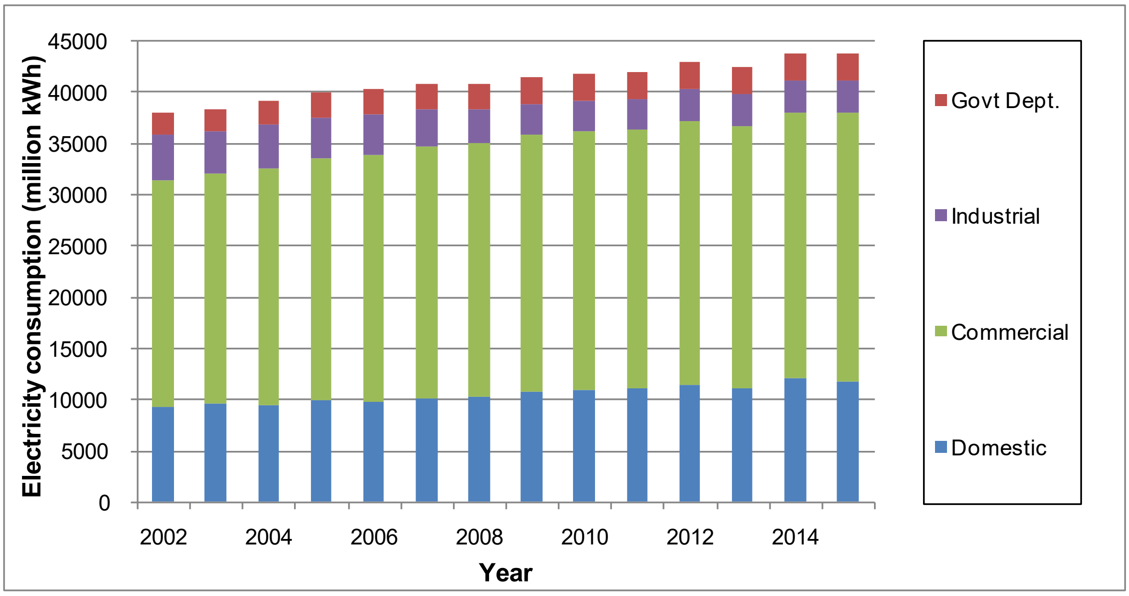


Fig. 2. Hong Kong's electricity consumption during the period 2002–2015.

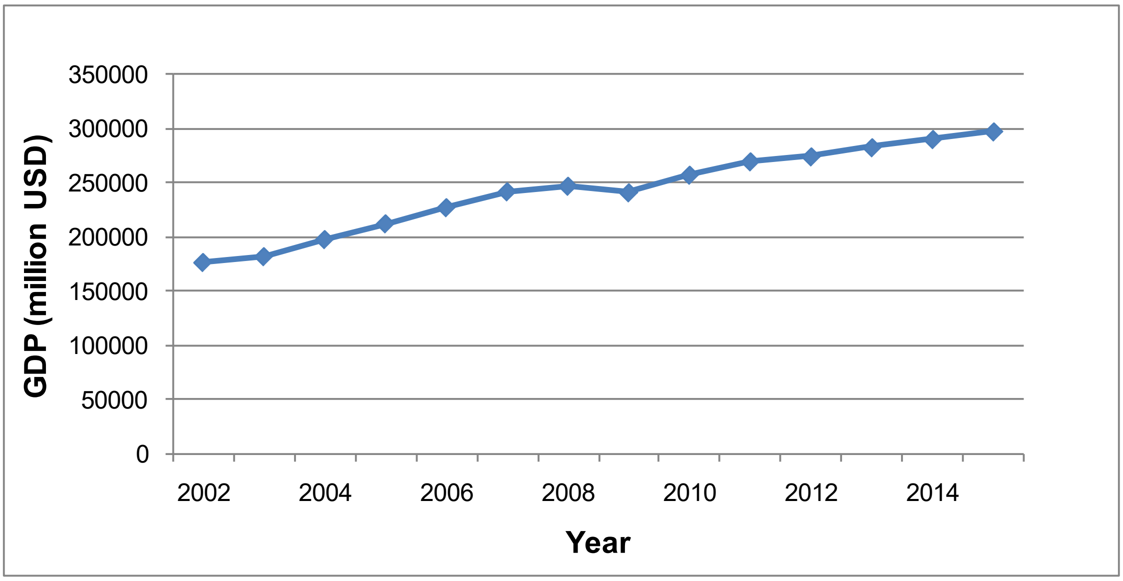


(a) Electricity consumption by sources

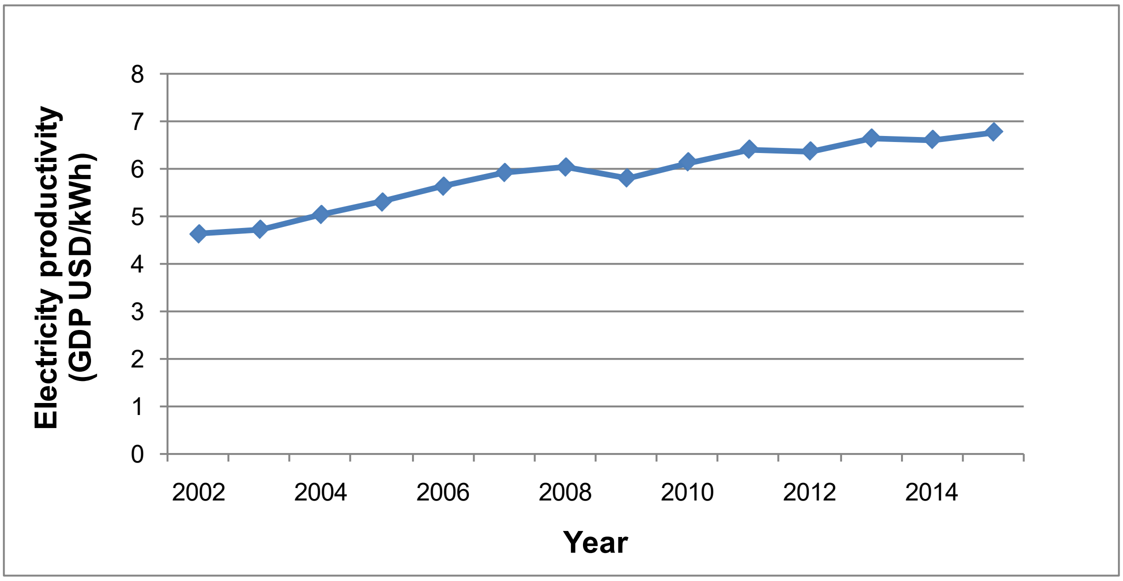


(b) Electricity consumption by sectors

Fig. 3. Hong Kong's GDP and electricity productivity for the period 2002–2015.



(a) GDP in million USD



(b) Electricity productivity in USD/kWh

Fig. 4. Hong Kong's electricity consumption vs. GDP for the period 1970–2015.

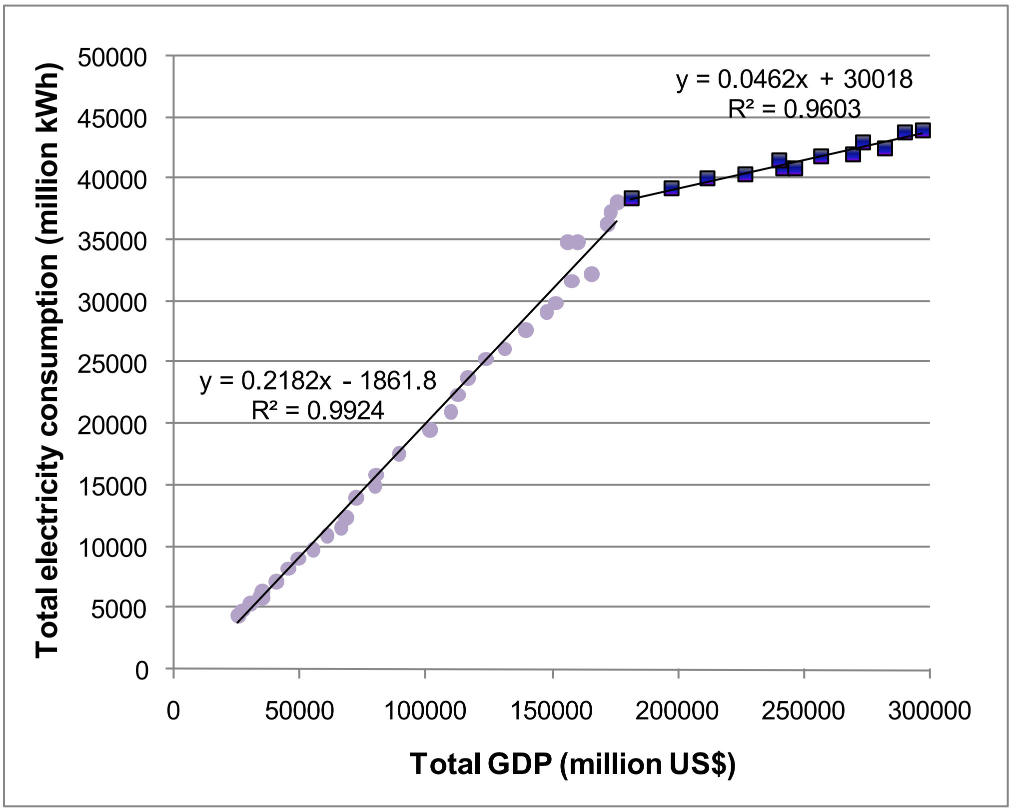


Fig. 5. GHG emissions from electricity consumption during the period 2002–2015.

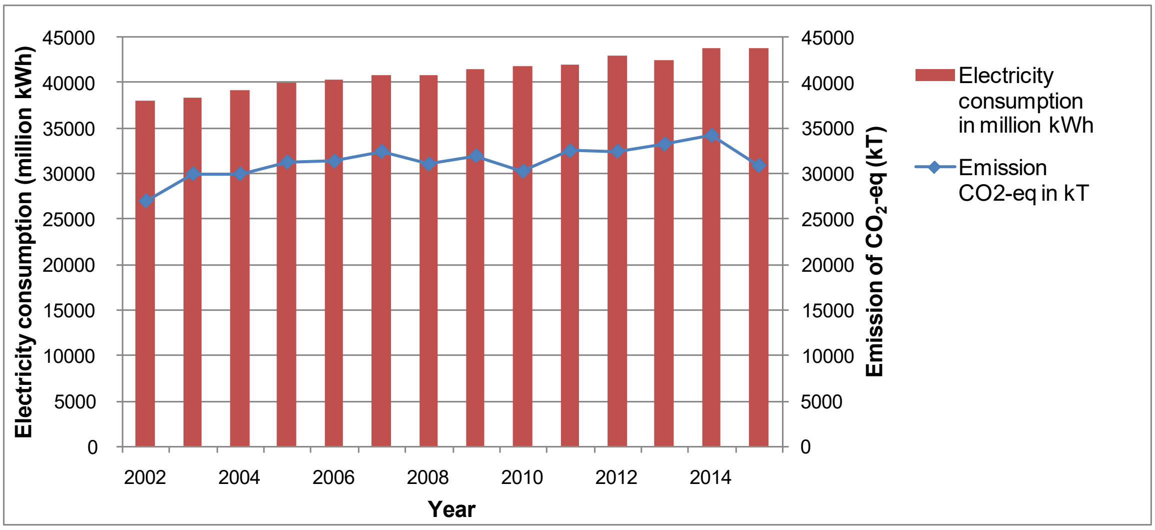


Fig. 6. GHG emission forecasts for the period 2016–2020.

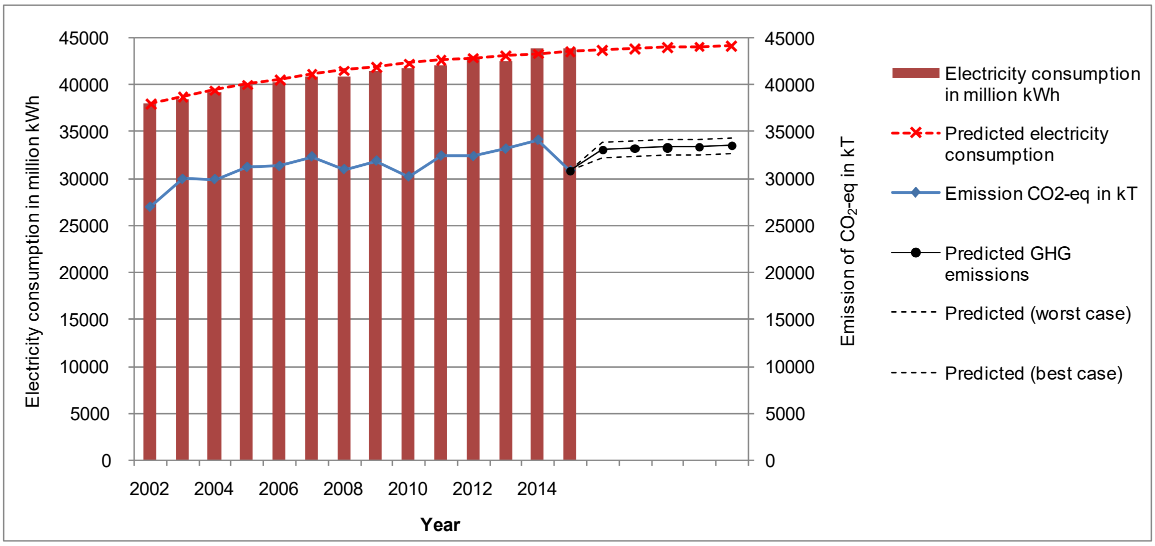


Table 1
Emission factors of coal, natural gas, oil and nuclear power – an attributional life cycle approach.

Fuel	Process	Description	Emission Factor			Reference
			CO_2 or CO_2-eq	CH_4	N_2O	
Coal	Extraction	Surface mining and coal processing in Indonesia		0-2.2 m^3 CH_4/T		IPCC (2010)
	Transport	From Indonesia to Hong Kong by Post-Panamax type bulk carriers. Distance - 4000 km	4.92 g CO_2/T-km			Psaraftis and Kontovas (2009)
	Combustion	Hong Kong's power plants. Net calorific value: 26.4 GJ/T.	94,600 kg CO_2/TJ	1 kg CH_4/TJ	1.5 kg N_2O/TJ	IPCC (2010); Hong Kong's power companies
Liquefied natural gas	Extraction	Venting, flaring and processing in Australia	70 kg CO_2/T	0.68-0.76 kg CH_4/T		Australian Greenhouse Office (1998)
	Transport	From Australia to Shenzhen terminal, then to Hong Kong. Distance - 5140 km	12.72 g CO_2/T-km			Psaraftis and Kontovas (2009)
	Extraction & transmission	Supply of LNG from the Yacheng Gas Field to Hong Kong's CLP Power using subsea pipeline. Distance – 780 km		2000 m^3 CH_4/km/yr		IPCC (2010)
	Combustion	Hong Kong's power plants Net calorific value: 54.4 GJ/T.	64,200 kg CO_2/TJ	3 kg CH_4/TJ	0.6 kg N_2O/TJ	IPCC (2010)
Oil	Extraction	Venting, flaring and processing of oil in the Middle East	13.6-19.5 kg CO_2eq/ bbl of crude oil; 1 barrel of oil = 138.8 kg			US DOE (2009); Al-Hamad and Khan (2008)
	Transport	From the Middle East to Singapore, then to Hong Kong. Total distance - 9580 km	5.63 g CO_2/T-km			Psaraftis and Kontovas (2009)
	Refining	Crude oil is processed in Singapore	17 kg CO_2/T of HFO 27 kg CO_2/T of LFO			IPCC (2010)
	Combustion	Hong Kong's power plants Net calorific value: - 40.4 GJ/T of heavy fuel oil (HFO) - 43.0 GJ/T of light fuel oil (LFO).	77,400 kg CO_2/TJ of HFO; 74,100 kg CO_2/TJ of LFO	3 kg CH_4/TJ	0.6 kg N_2O/TJ	IPCC (2010)
Nuclear	Mining, processing, and operation	Pressurized water reactors are operated in Shenzhen while nuclear fuel is processed in France.	0.68-158 g CO_2eq/kWh (mean: 36.67 g)			Sovacool (2008)

Table 2

Emission factors of burning different fossil fuels in power plants.

Fuel	Emission Factor (kg/TJ)			Emission Factor
	CO_2	CH_4	N_2O	(kg CO_2-eq/TJ)
Coal	94,600	1	1.5	95,072
Liquefied natural gas	64,200	3	0.6	64,454
Heavy fuel oil	77,400	3	0.6	77,654
Light fuel oil	74,100	3	0.6	74,354

Note: The global warming potentials of CH_4 and N_2O relative to CO_2 are 25 and 298, respectively (IPCC, 2010).

Table 3
Fuel consumption in Hong Kong's power plants and net imported electricity from China for the period 2002-2015.

Year	Hong Kong						China
	CLP Power [a]			Hong Kong Electric [a]			Net imported
	Coal (TJ)	LNG (TJ)	LFO (TJ)	Coal (TJ)	LNG (TJ)	HFO & LFO (TJ)	electricity (TJ)
2002	100645	92915	1358	109190	0	586	28825
2003	153450	59367	1671	110035	0	460	26601
2004	133403	85777	2024	111989	0	417	22431
2005	144938	85733	1202	114233	0	417	21223
2006	148830	85462	1116	107923	5331	457	21142
2007	179599	63552	863	96254	15178	377	22706
2008	153565	77487	1048	98921	14144	457	26094
2009	169753	70393	895	94591	17190	1011	26036
2010	148229	83007	844	80644	31352	457	28446
2011	188407	57665	1044	80655	31392	457	28001
2012	182651	50420	7900	84632	32022	457	33543
2013	205198	47545	1491	78031	32022	457	29949
2014	215367	42465	1785	81308	31337	457	32624
2015	161988	71406	2160	79348	32045	457	37999

[a] Hong Kong's power companies – CLP Power and Hong Kong Electric provided information about fuels consumed in TJ in their sustainability reports and facility performance statistics(CLP, 2016; HK Electric Investments, 2016).

Table 4
GHG emissions from electricity consumption in 2015.

	Fuel	Used in [a]	Mass (kT) [b]	Combustion CO_2-eq (kT)	Transport CO_2-eq (kT)	Extraction and Processing CO_2-eq (kT)
Hong Kong	Coal	CLP & HKE	9142	22944	179	205
	LNG (China)	CLP	1313	4602	1.6	92
	LNG (Australia)	HKE	589	2065	39	41
	LFO	CLP & HKE	55	177	3	8
	HFO	HKE	6	19	0.3	0.8
			Total [c]:	29807 [i]	222.9 [ii]	346.8 [iii]
Shenzhen	Nuclear			431 kT CO_2-eq for 37999 TJ		

[a] CLP and HKE stand for "CLP Power" and "Hong Kong Electric", respectively.
[b] The masses of fossil fuels were converted from TJ to kT based on the calorific values of 26.4 GJ/T for coal, 54.4 GJ/T for LNG, 43 GJ/T for LFO, and 40.4 GJ/T for HFO, respectively (based on IPCC Guidelines and HK government and power companies' energy statistics).
[c] The total GHG emissions (i+ii+iii) due to the consumption of fossil fuels in Hong Kong was 30.38 MT CO_2-eq.