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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 is steadily increasing. Using a life cycle approach and fuel mix data from power companies' sustainability reports, this paper analyzes greenhouse gas (GHG) emissions from electricity consumption in Hong Kong. The results show that coal contributed on an average 74.3 percent, liquefied natural gas 25.1 percent, and oil 0.6 percent of the thermal energy consumed for generating 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 between 27.0 and 34.1 million tons (MT) and the emission factor ranged between 702 and 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 by 2015. As a result, 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. Hong Kong's annual electricity consumption was predicted over the short-term period (2016–2020) and medium term (up to year 2030). Electricity consumption is likely to increase to 44.63 billion kWh by 2030 while GHG emissions from electricity consumption would increase to 33.92 MT of CO_2-eq. The implications are discussed at the end of the paper.

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 presently 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 such 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 now being 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 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 de Oliveira, 2016). Naturally, they need electricity for lighting, ventilation, air-conditioning, heating, entertainment, and powering a wide range of electronic and computing devices. Andrae and Edler (2015) examined 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 up to 23% of the global GHG emissions in 2030. Nevertheless, Andrae and Edler (2015) suggest that the worst-case scenario is unlikely to materialize because of the improvement in electricity efficiency of wireless and fixed access networks and datacenters and continued growth in renewable energy generation. As for economic activities such as service creation, product manufacture and transportation, electricity is either the sole source of power or an increasingly important form of energy source. Consequently, the consumption of electricity in cities has become

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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 gas (GHG) emissions in the respective regions. Presently, 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 Hong Kong's three coal-fired and natural gas-fired power plants.

To et al. (2012) reviewed the historical electricity consumption data for the period 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. They then used a 4-parameter logistic function to model Hong Kong's total electricity consumption. They also determined that the 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. They reported that emissions from electricity production ranged between 814 and 1445 g CO_2/kWh using coal, and between 398 and 823 g CO_2/kWh using natural gas for the reference year 2008. They also pointed out that consideration of imported electricity need to be included because of its effect on the prevailing fuel and market mixes in the geographical region.

The annual growth rate of electricity consumption in Hong Kong 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. 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 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 the medium-term projection is set to 2030—a milestone year in the Sydney Declaration (HKEB, 2015) and the Paris Agreement of the United Nations Framework Convention on Climate Change (Wang et al., 2017). This paper is one of the first, examining 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. Prior relevant studies tend to examine such issues concerning a specific industry (e.g., Andrae and Edler, 2015) or from a global perspective (e.g., Treyer and Bauer, 2016a,b). The findings of the paper should be useful to policy makers, power companies, and other stakeholders; they offer insights on how GHG emissions from electricity consumption are likely to change in the near future and demonstrate 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 also highlights several 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 burning 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 (Brynolf 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 associated with different fossil fuels burnt in power plants.

2.2. Forecasting of GHG emissions

Using the fuel life cycle approach, To et al. (2012) developed a 4-parameter logistic function capable of predicting Hong Kong's total annual electricity consumption over the period 1980–2000. The logistic function is as follows:

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

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. Year 2030 is of particular importance 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, the total thermal energy associated with electricity production is predicted using the mean percentage values of net imported electricity and net thermal efficiency of local electricity production. Finally, GHG emissions are determined for three scenarios: (i) the upper bound, i.e., the worst case scenario 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 ratios over the period 2002–2015, and (iii) the lower bound, i.e., the best case scenario 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 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). Figures of 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 2002–2015 (CLP, 2016; HK Electric Investments, 2016). Note that, in 2015, the bulk of the electricity was produced by burning coal (69.5percent), 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