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REGIONAL RENEWABLE ENERGY (CHINA) (K LO, SECTION EDITOR)

Renewable Energy Development in Hong Kong: Potential, Progress, and Barriers

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Abstract
Purpose of Review Hong Kong is a Special Administration Region of the People's Republic of China and one of the most developed cities in the country. Although Hong Kong has good potential solar, wind, and waste-to-energy, the development of renewable energy in the region has been lagging. Renewable energies remain a negligible player in the city's energy system, contributing to less than 1% of total energy consumption.
Summary This article critically reviews the potential and current development of renewable energy in Hong Kong and identifies key barriers. In concluding, this article outlines some considerations that need to be made to advance renewable energy development in Hong Kong.

Keywords Renewable energy development · Hong Kong · China

Introduction

Located in Southern China, Hong Kong is a very dense and developed city with an administrative area of 2755 km^2, consisting of 1106 km^2 of land and 1649 km^2 of water, a population slightly over 7.3 million as of mid-2016, and one of the world's highest per-capita GDPs (Fig. 1). In 2005, the government of Hong Kong published *A First Sustainable Development Strategy for Hong Kong*, proposing that 1–2% of Hong Kong's electricity demand be met by power generated from renewable sources by 2012 [1]. However, the development of renewable energy in the city has so far lagged behind. According to recent official statistics, renewable energy contributes to only 0.7% of total energy consumption and 0.1% of total electricity consumption in the city [2]. Hong Kong's fuel mix for electricity remains heavily dominated by coal (53%, 2012 data), followed by nuclear electricity imported from mainland China (23%), and natural gas (22%). Not only does this figure fall short of the government's own target, it is also very low compared to China's national target to increase the share of non-fossil fuels of total energy consumption to 15% by 2020 and 20% by 2030 [3]. Addressing the questions of why Hong Kong has failed to develop renewable energies and what the implications of this failure are is at the heart of this article. This article reviews the current and potential state of renewable energy development in Hong Kong, makes sense of the lack of progress through an examination of the key barriers to renewable energy, and outlines the main considerations that need to be made.

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Potential of Renewable Energy Development

Figure 2 summarizes potential renewable energy development in Hong Kong, covering solar, offshore wind, onshore wind, and bioenergy. Turning first to solar, Hong Kong's location in the subtropics means that the city has significant solar energy resources, with an annual average global horizontal radiation of 1.29 MWh/m^2 [4]. Studies have examined the potential for electricity generation through solar photovoltaics (PV) and solar water heating (SWH) in the city. For PV, Peng and Lu [5] estimated that Hong Kong has the potential to install 5.97 GW of rooftop PV, which could produce approximately 6000 GWh of electricity annually. This would meet

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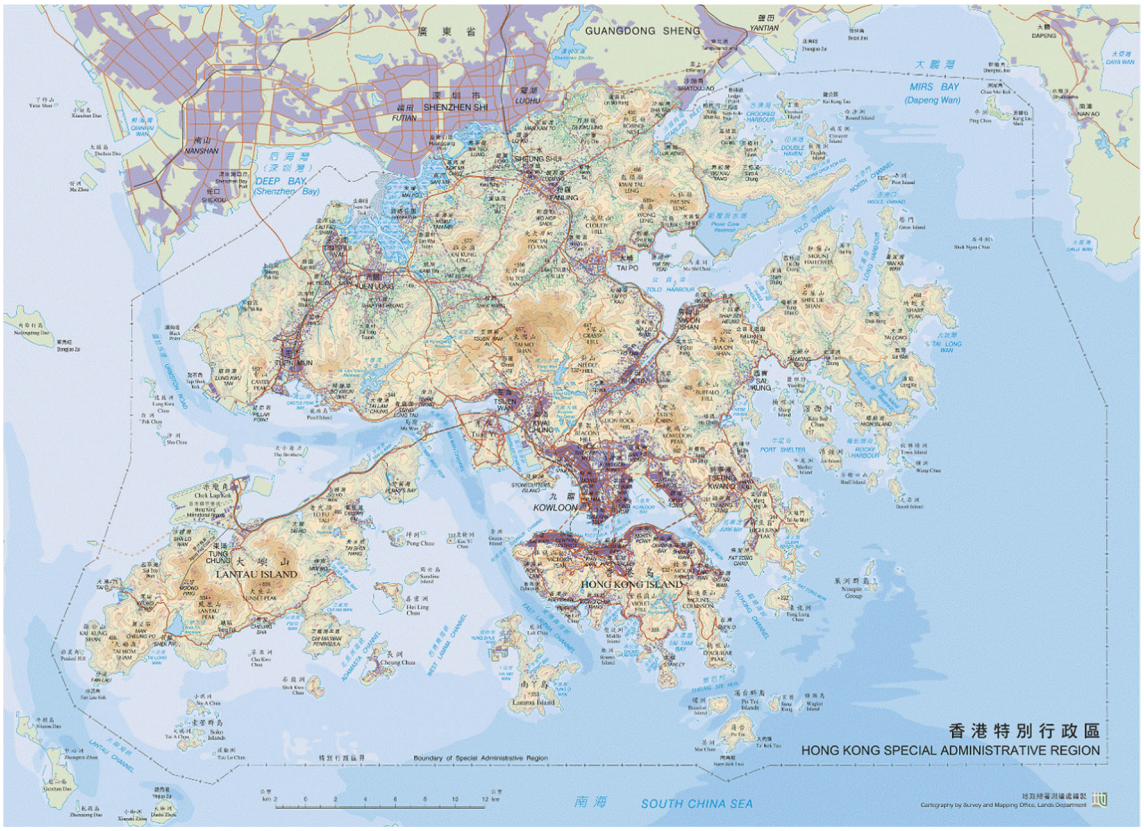

Fig. 1 Hong Kong Special Administrative Region

approximately 14% of Hong Kong's electricity demand (calculated based on the 43,912 GWh of electricity consumed in 2015). In a more recent study, Wong et al. [6] estimated more conservatively that Hong Kong has a rooftop PV potential of 2660 GWh/year, or about 6% of Hong Kong's electricity demand. A consultation study by the government estimated that Hong Kong has a total PV potential of 5944 GWh/year, which includes rooftops, roads, railways, airports, and open space [4]. Turning to SWH, hot water production accounts for about 4% of the total energy use in Hong Kong, with town gas (produced from naphtha and natural gas), electricity, and liquefied petroleum gas (LPG) as the main energy sources [7]. Several studies have found that it is technically feasible and economically attractive to utilize SWH in buildings in Hong Kong, but there are no quantitative studies on its overall potential [8, 9].

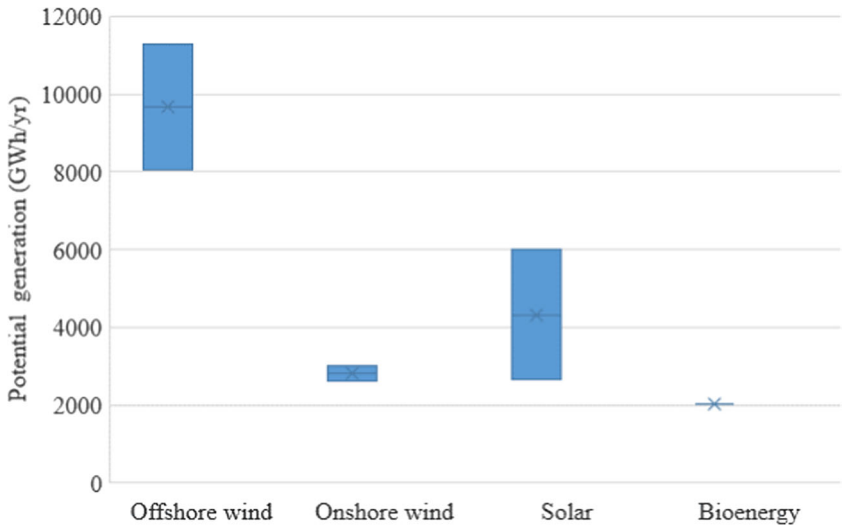

Fig. 2 Hong Kong's renewable energy potential

Several studies have examined wind energy potential in Hong Kong. Lu et al. [10] conducted a case study at Waglan Island, a small, uninhabited island southeast of Hong Kong Island. The authors concluded that the island has good wind potential with an average wind speed ranging from 5.82 m/s in April to 8.32 m/s in October. Their simulation found that, with a hub height of 37 m, a wind turbine with 10 kW nameplate capacity can operate for 6820 h (i.e., 78% of the time) of a year, generating 32,400 kWh of electricity, which equates to a capacity factor of 39%. Looking at the wind energy potential of Hong Kong as a whole, it is estimated that there is 393 km^2 of land in Hong Kong with suitable wind resources, mostly in the mountainous areas [4]. It is technically feasible to install 1000 wind turbines at a density of 2.5 turbines per square kilometer, which could produce about 2630 GWh of electricity annually, meeting approximately 6% of Hong Kong's electricity demand. It is also feasible to install wind turbines on rooftops of buildings, and it is estimated that up to 3000 GWh/year of electricity could be produced this way [11].

Furthermore, offshore wind has significant potential in Hong Kong, as approximately 60% of the total area of the region is sea, and sea has better wind resources than land. Li [12] estimated that it is technically feasible to install up to 7688 wind turbines in Hong Kong's waters to produce up to 25,000 GWh of electricity annually, which could meet 57% of Hong Kong's electricity demand. This figure is obviously unattainable in practice, as the placement of wind turbines is limited by shipping routes, fishing, and conservation and recreational areas. A more realistic estimation that takes these constraints into account gives a potential of 11,281 GWh/year [13]. The Electrical and Mechanical Services Department [4] estimated that the suitable sea area for wind development after excluding marine parks and shipping channels is 744 km^2, with an estimated energy potential of 8058 GWh/year.

Turning to bioenergy, Hong Kong has limited farmland so the potential for energy crop plantation is minimal. However, the city produces a large quantity of municipal solid waste daily, which is landfilled. There is, therefore, a significant opportunity to use this waste for electricity generation. It is estimated that each ton of MSW can produce approximately 550 kWh of electricity [4]. In 2015, 3.71 million t of MSW was disposed in landfills, which have the potential to generate up to 2041 GWh of electricity annually, meeting 4.6% of the city's demand.

Several studies have also examined the potential of developing zero-carbon buildings and communities in Hong Kong using renewable energy. Fong and Lee [14] conducted a study to show that achieving net-zero-energy building is technically feasible in Hong Kong's typical 3-storey rural townhouses using renewable technologies, including wind turbines and PV. Ma et al. [11] showed that an entire island community can be made fossil-fuel free by using wind, solar, and pumped-hydro storage systems.

Current State of Renewable Energy Development

Figure 3 outlines Hong Kong's renewable energy deployment by type. The most established form is bioenergy (waste-to-energy), which contributes to 98% of renewable energy in the city and mainly comprises of two types. First, Hong Kong's three active landfills capture biogas to generate electricity for onsite uses, leachate treatment, and for export to produce town gas [15]. Together, the quantity of biogas captured and utilized is 12,581 m^3/h. Several closed landfills are also equipped with gas collection and utilization facilities. Second, Hong Kong has three biodiesel production facilities that produce renewable fuel from waste cooking oil [16]. However, most locally produced biodiesel is exported to Europe due to a small local market. Furthermore, an incineration plant equipped with two 14 MW steam turbine generators was opened in 2016, where 1200 t of sludge from Hong Kong's 11 wastewater treatment plants are treated and recovered daily to generate electricity [17].

Hong Kong has limited PV installed (~1.5% of total renewable energy deployment). The leading case of utility-scale PV application is the Lamma Solar Power System, which was first commissioned in 2010 with a capacity of 550 kW and was expanded to 1 MW in 2013 [18]. The solar power system comprises 8662 panels installed on the rooftop and open space at Lamma Power Station, and produces around 1100 MWh of electricity annually. Another example is the Town Island Renewable Energy Supply Project. Town Island is a remote island off the coast of Sai Kung that previously had no access to electricity, with the inhabitants relying on diesel generation units. To improve electricity access, in 2012, the CLP Group completed Hong Kong's first micro grid renewable energy system with 180 kW of PV, allowing the island to now completely rely on renewable energy [19]. Other cases of PV applications are typically that of distributed rooftop PV, such as the 350 kW system installed on the rooftop of the headquarters of the Electrical and Mechanical Services

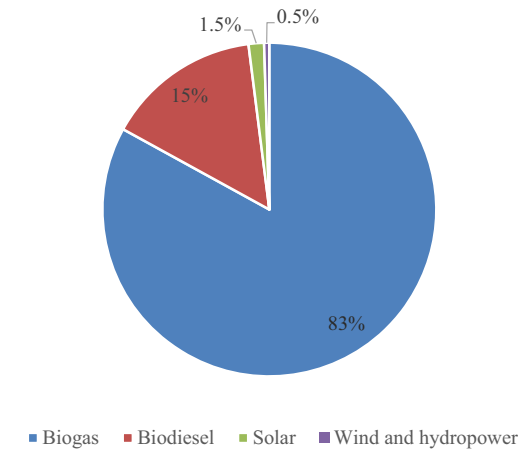

Fig. 3 Renewable energy deployment by type

Department (EMSD) and the 198 kW system installed in Science Park.

Wind energy development is also very limited in Hong Kong (<0.5% of total renewable energy deployment). In 2006, HK Electric commissioned the Lamma Wind Power Station consisting of a single 800 kW turbine [20]. The wind turbine produces approximately 920 MWh of electricity annually. The pilot project remains, up until today, the only utility-scale wind power plant in Hong Kong. There are also a number of distributed wind energy systems, such as a 16 kW system installed on Town Island, a 12 kW system at Ma Wan Theme Park, and a 2.5 kW system at the EMSD Headquarters.

Recently, Hong Kong has been developing hydropower on a very small scale. In 2013, the Water Supplies Department installed the Tuen Mun Hydropower Plant with a capacity of 500 kW [21]. The innovative project utilizes the difference in elevation between the Tai Lam Chung Reservoir where water is stored and the Tuen Mun Water Treatment Works where the water is treated. The hydraulic power plant was completed in 2015 and has been generating approximately 3000 MWh of electricity annually, meeting 10% of the total energy consumption of the water treatment plant.

Overall, renewable energy developments in Hong Kong mainly comprise of pilot projects initiated by the government and power companies. These pilot projects have confirmed Hong Kong's potential to develop renewable energy, especially in the areas of solar, wind, and bioenergy. However, the experiences generated from these projects have failed to translate into other projects, nor have they created momentum for further renewable energy development. The next section looks at some of the key reasons for the current impasse.

Barriers to Renewable Energy Development

There are several challenges currently hindering the development of renewable energy in Hong Kong. Physical limitations, particularly the lack of space, constitute the most obvious barrier. Hong Kong is a city with very high density and few flat areas. Most renewable energies, however, are dispersed and therefore require lots of land to generate a meaningful amount of electricity. Even smaller scale distributed generation systems are limited by space factors. Rooftops on Hong Kong's buildings are utilized for various activities such as gardens, playgrounds, sport facilities, and storage for equipment, and, therefore, renewable energy systems on rooftops need to compete with these alternative uses.

The lack of policy support is another key barrier. The "One Country Two System" guarantees Hong Kong a high level of political, economic, and legal independence. Therefore, unlike other regions of China, Hong Kong is not bounded to energy and carbon laws and policies set up by the central government [22, 23], nor has the central government assigned Hong Kong energy/carbon targets like other regions [24]. This unique political context has contributed to the government's inactivity in promoting renewable energy [25]. No renewable energy targets have been released since the 1–2% target. In the recently released *Hong Kong's Climate Action Plan 2030+*, the government suggested it is feasible to achieve a 3–4% target by 2030, but fell short of making this an official target. Besides the lack of credible targets, the only supportive renewable energy policy is the provision of financial incentives to power companies to develop renewable energy by allowing them to earn an additional 1% return on renewable energy investments. There is no policy that supports distributed renewable energy. This has created a policy void as international experience shows that successful deployment of renewable energy depends on policy support measures such as feed-in tariffs, net-metering, renewable energy portfolios, direct subsidies, and low-interest loans [26–28]. Moreover, Hong Kong has no policy in place to internalize the externalities of carbon emissions, such as carbon taxes or emissions trading. This greatly disadvantages renewable energies when competing with fossil fuels. In contrast, mainland China has only has established generous feed-in tariffs for solar and wind, but is also moving towards a national carbon market [22, 23, 29]. The result of the lack of policy support is that investments in renewable energy systems in Hong Kong typically incur a payback period that is much longer than the typical lifespan of renewable energy equipment [14, 30].

Moreover, complex planning requirements and slow approval processes are inhibiting renewable energy development in Hong Kong [31]. For example, building regulations do not allow installers to suspend the solar panels or solar collectors above the roof to preserve valuable rooftop space for other uses. Furthermore, because renewable energy systems are not considered essential or a public service, the area they occupy cannot be included as a concession in the calculation of total allowable gross floor area (GFA). In another example, the sludge treatment facility project mentioned previously has encountered difficulties due to regulations from the land departments, the immigration department, and the fire services department. These cases exemplify the lack of coordination among various government apparatus in the context of renewable energy development and highlight the need to update existing regulations to create a more favorable regulatory environment for renewable energy development.

Conclusion

This article has critically reviewed renewable energy development in Hong Kong. Despite the significant potential for renewable energy development in the city, at present, Hong Kong utilizes a negligible amount of renewable energy. Other than a handful of pilot/demonstration projects initiated

by the government and power companies, Hong Kong has little to show. This lack of progress is mainly due to the lack of supportive policies towards distributed generation, the presence of regulatory barriers, and physical limitations associated with limited open space and roof space.

Given the global consensus on climate change mitigation and China's pledge to reduce carbon emissions, it seems that Hong Kong must do more to contribute to climate mitigation. *Hong Kong's Climate Action Plan 2030+* features an ambitious target to reduce Hong Kong's carbon intensity by 65–70% by 2030 compared with the 2005 level, which translates to an absolute reduction of 26–36%. What is the role of renewable energy in achieving this target? Answering this question involves addressing two related discussions. First, given the severe physical limitations in terms of land resources, should Hong Kong develop renewable energy locally or should Hong Kong establish cross-boundary cooperation mechanisms with neighboring provinces such as Guangdong, which not only have more land but also better renewable energy resources? Developing and importing renewable energy from outside Hong Kong overcomes this physical barrier, but brings its own set of challenges, including increased institutional complexity, dependency on mainland China, lower reliability, limited local employment opportunities, and the displacement effect, where importing renewable energy would lower Hong Kong's emissions at the expense of mainland China. Some of these issues, however, can be addressed by forming joint-ventures with mainland power companies so as to retain control, ownership, and certainty over the investment. Obviously, the two options are not mutually exclusive, but could be pursued simultaneously. In fact, if Hong Kong is to achieve full carbon neutrality, looking at renewable energy from a both a local and a regional perspective seems necessary.

The second discussion concerns promoting renewable energy development. This is partially a technical question: what type of renewable energy is best for Hong Kong? Options for local generation are limited to wind, solar, and waste-to-energy, but there is more technological flexibility when developing renewable energy outside Hong Kong. Answering this question is relatively straightforward and requires a comparative analysis of different technologies from the perspectives of resource availability, levelized costs of electricity, and environmental and social impacts. The discussion also involves dealing with questions of governance; that is, how can society work together to achieve renewable energy development? One pressing task is to identify the supportive policy instrument best suited for Hong Kong. Will market-based instruments such as feed-in tariffs, net-metering, and renewable portfolio standards with tradable certificates work in Hong Kong? Should the government impose carbon taxes or emissions trading on power companies? What about more authoritarian approaches such as mandatory renewable energy installation? At the same time, we should not forget that governance is not limited to government but also includes the private sector and civil society, as well as communities and individuals. How to encourage or facilitate these non-state actors to contribute to the development of renewable energy is therefore another important aspect of the governance question. For instance, does community based renewable energy have a role to play in Hong Kong? If so, how can communities be mobilized to pursue renewable energy goals? Addressing these important questions will advance the debate on renewable energy in Hong Kong, and, therefore, deserve more research attention than they have thus far received.

Compliance with Ethical Standards

Conflict of Interest The author declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by the author.

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