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Analysis of Hong Kong's Wind Energy: Power Potential, Development Constraints, and Experiences from Other Countries for Local Wind Energy Promotion Strategies

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Abstract: The wind energy utilization in Hong Kong is limited, although its potential has proven to be significant. The lack of effective policy for wind energy development is the main constraint. In this paper, the wind power potential in Hong Kong is analyzed, and the wind power potential assessment is conducted based on one-year field measured wind data using Light Detection & Ranging (LiDAR) technology in a proposed offshore wind farm. Results show that the offshore wind power potential in Hong Kong was 14,449 GWh which occupied 32.20% of electricity consumption in 2017. In addition, the electricity market and power structure in Hong Kong are also reviewed with the existing policies related to renewable energy development. Conclusions can be made that the renewable energy target in Hong Kong is out of date and until now there have been no specific effective policies on wind energy. In order to urge Hong Kong, catch up with other countries/regions on wind energy development, the histories and evolution of wind energy policies in other countries, especially in Denmark, are reviewed and discussed. Suggestions are provided in the aspects of economics, public attitude, and political factors which can stimulate wind power development in Hong Kong.

Keywords: Wind energy policy in Hong Kong; wind power potential; wind energy development; promotion strategies; public attitudes; political factors

1. Introduction

Renewable energy policy is a country's strategy on renewable energy production, distribution, and consumption, in which legislation, incentives, target and taxation are included [1–5]. Feed-in tariff (FIT) and Renewable Portfolio Standard (RPS) are two typical incentive types in renewable energy policy all over the world [6–8]. Figure 1 shows the number of countries with types of renewable energy policies [9]. Note that not all policy types in use are shown in this Figure. Countries are considered to have policies when at least one national or state/provincial-level policy is in place. It can be seen that until 2018, more than 130 countries have power regulatory incentives/mandates which can stimulate the development of renewable energies.

As costs fall, it was recorded that renewable energy markets continue to diversify geographically all over the world [10–14]. Europe remains an important market, as well as an innovation center, and also, activities continue to shift towards other regions with China again leading the world in new RE power capacity installations in 2018 [15–20].

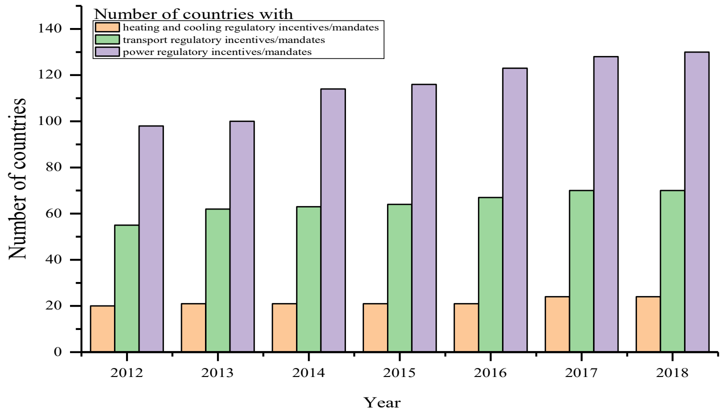

Figure 1. Number of countries with types of renewable energy policies (From [9]).

Meanwhile, various countries have different RE electricity generation targets [21–24]. RE target is a defining feature of the global energy landscape. At the end of 2016, more than 176 countries around the world with at least one kind of RE target, which was about four-fold of 43 countries in 2005. 50% is Denmark's target during the year 2020–2021 while in fact, most of this RE power comes from wind energy. Besides Denmark, wind energy market all over the world was brisk with a total of installation capacity of 39.125 GW by the end of 2017 [25].

Hong Kong, by contrast, has been stagnant in this. The limitation of relevant incentives and policies in Hong Kong makes the local renewable energies contribute to an insignificant energy share [26]. According to the annual Hong Kong Energy End-use Data, which include the RE data from the year 2010, the weighting of RE in energy end-use was 0.6%. "The End-use Data 2018" indicated that the total RE was 1913 TJ with a weighting of 0.655% [27] and the RE weighting in electricity consumption is only 0.1% (shown in Figure 2), which was with an unincreased percentage compared with that of 2010, and was far behind the target of 1–2% energy share (HK RE Net, 2017). Among this 0.6%–0.7%, the weighting of wind energy was less than 1%.

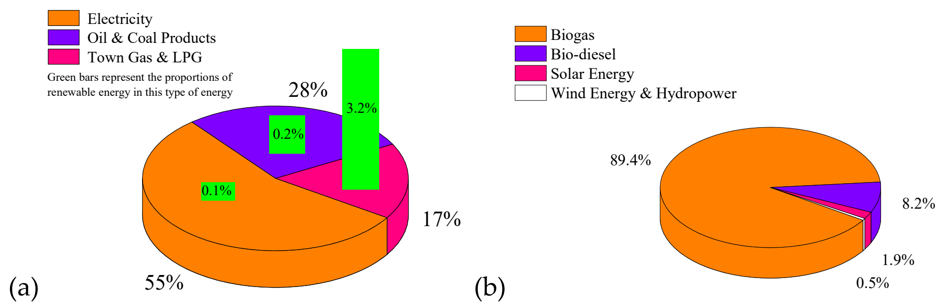

Figure 2. Hong Kong Energy End-use Data: (**a**) The weighting of RE (renewable energy) in respective fuel type in 2016 and (**b**) Types of RE capacities in Hong Kong.

How about the wind energy potential in Hong Kong? A comprehensive wind power potential analysis with the cost of energy (analysis) is indispensable for policy-making in the decision-making process for wind energy development strategies. To investigate the wind power potential of a specific region or district, the chronological and probabilistic method are the commonly used in wind data analysis [28,29]. Studies emerge every year about different locations all over the world. Genç, M.S.'s team has forced the topic of wind energy power potential combined with other systems, as well as the energy cost analysis in Turkey, and some outstanding contributions have been made [30]. For example, the wind energy power potential and wind characteristics in Kayseri are evaluated [31], and the economic analysis for separate wind energy conversion systems are conducted for different locations in Turkey [32,33]. Besides, the combined wind energy systems such as the water pumping system [34,35] and wind-electrolyzer fuel cell system [36], with their cost analysis, are provided, which give comprehensive ideas and methods for the wind energy system analysis. Bilgili, M. and Besir Sahin have also studied wind energy potential in Turkey using Weibull and Rayleigh probability density functions, as well as WAsP (Wind Atlas Analysis and Application Program) which quantified the energy potential in different regions of Turkey [37,38]. Wind energy potential in Taiwan, Egypt, and India are also evaluated and analyzed [39–41]. For Hong Kong, the wind energy potential is investigated by different researchers with some economic analysis which will be stated in the following sections. It is believed to be significant that Hong Kong has great wind power potential in our previous studies [42–44]. However, the exploitation and utilization of wind energy are far behind. How to make Hong Kong catch up with the global push on wind energy development, is of great significance for energy independence and security, especially for Hong Kong with its high population density.

It was found that wind energy development is highly correlated with local electricity market situations, which means that developing wind power is a response to high electricity demand [45,46]. Meanwhile, considering energy security in countries which depend highly upon foreign oil, the volatility of oil price can also affect wind capacity development [47,48]. Developing wind energy can liberate a country or region from high dependence upon electricity importation [49,50].

Meanwhile, from the aspect of environment, the average temperatures of Hong Kong in selected years are shown in Figure 3. The report from the Observatory showed that, in 2015, the hottest June and July were recorded 130 years since records began in 1885. The average temperature of these two months was at least 1 degree Celsius higher than the long-term average one with many hot days and nights. It means that people need to beat the heat by turning on their air conditioning, which will inevitably use more electricity and cost more money, initiating a vicious cycle. The electricity generated in Hong Kong relies heavily on imported fossil fuels, especially coal. Meanwhile, the more energy we use, the more greenhouse gases we produce, which will accelerate global warming. The development of wind energy can help Hong Kong to halt this and prompt it to get rid of energy importation with the improvement of energy security [51,52].

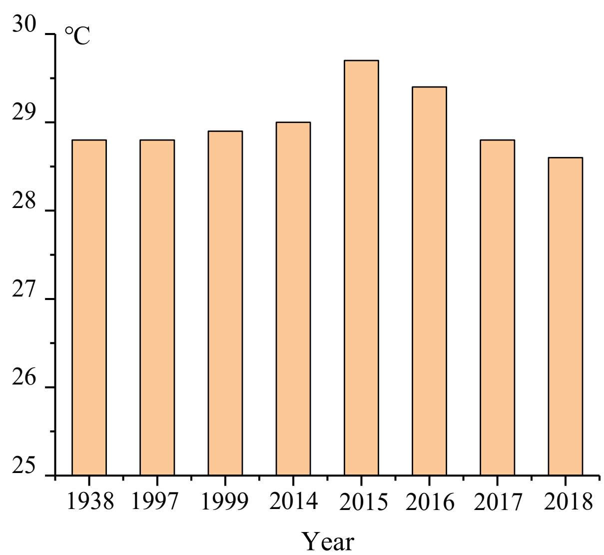

Figure 3. The average temperature of Hong Kong in June in selected years (°C) [53].

In this paper, both the electricity market and the wind energy developing condition in Hong Kong will be analyzed with the renewable energy policies in Hong Kong related to wind energy. Hong Kong's offshore wind power potential will be investigated by employing one-year wind data measured from the proposed offshore wind farm near Lamma Island. Based on the wind energy policy reviews from other countries, especially Denmark, suggestions will be provided on driving the growth of wind energy in Hong Kong from the aspects of economics, public attitude, and political factors.

2. Wind Power in Hong Kong

2.1. Wind Power Potential of Hong Kong in the Literature

In general, wind resources in Hong Kong are divided into two categories, including wind energy on land and offshore wind resources.

2.1.1. Wind Resources on Land

The wind resources on land include the wind farms in rural locations and individual wind turbines in high-rise buildings.

1. Wind farm in rural locations

Studies on wind power density in terms of energy per unit area (W/m^2) in Hong Kong land area at a height of 65 m above ground level generated by WAsP show that high wind resources generally occur on top of mountains or hills [54] and based on these, considering the wind farm in rural areas are installed in a linear arrangement on mountain ridges, the estimated resource potential from this arrangement in Hong Kong is 2630 GWh/yr (26.3 × 10^8 kWh/yr), given the total area of the relatively high wind resource in Hong Kong is about 393 km^2. Lu et al. has also conducted some research on the wind power in Hong Kong's island which analyzed wind data in five typical locations in Hong Kong [55,56]. Results in these studies showed that there is great wind power potential on land in Hong Kong.

2. Individual turbines in high-rise buildings

It is well known that high-rise buildings have the effect of enhancement on wind conditions. Small wind turbines may theoretically be installed on the rooftops of existing high-rise buildings. Lu et al. [57,58] investigated the wind aerodynamics and wind flows over the buildings based on local meteorological data and local high-rise building characteristics. It was concluded that wind power utilization in high-rise buildings in Hong Kong is feasible theoretically. In the EMSD report [54] feasibility was determined under the following three assumptions: (1) Approximately 30,000 buildings in Hong Kong, with the height equal or greater than 65 m; (2) No constraints to installation of wind turbines on buildings; and (3) Installation of one turbine per building on average. The resulting theoretical wind resource for urban high-rise buildings in Hong Kong is therefore between 2 and 3 TWh/yr (20–30 × 10^8 kWh/yr).

2.1.2. Offshore Wind Resources

A rough assessment of the total area of relatively high wind resource (larger than 200 W/m^2) in Hong Kong offshore (about 744 km^2) was also conducted in the EMSD report. The estimated wind power potential in this report is 8058 GWh/yr [54]. Figure 4 shows the potential sites after considering all constraints in offshore wind farm development, which is colored in green. In our previous study, wind characteristics from the Hong Kong observatory were analyzed in the four selected offshore locations in different areas [42]. The 5 MW wind turbines are selected to be installed in the wind farm after the micro-siting by a multiple population genetic algorithm. Economic analysis considering different factors, i.e., the capital cost of wind turbines, fixed charge rate, as well as maintenance charge, labor force, etc., are conducted. The cost of energy ranges from 1.87 HKD/kWh to 11.88 HKD/kWh with the payback periods ranges from 14.44 year to 75.89 year. Higher costs of energy and longer payback periods show that the water area near Sha Chau is not suitable for wind energy development and thus, results show that the potential offshore wind farm area in and beyond (2 km away from its boundary) Hong Kong is 357.78 km^2 and the annual wind power potential is 112.81 × 10^8 kWh, which is 25.06% of the annual electricity consumption of Hong Kong in 2011.

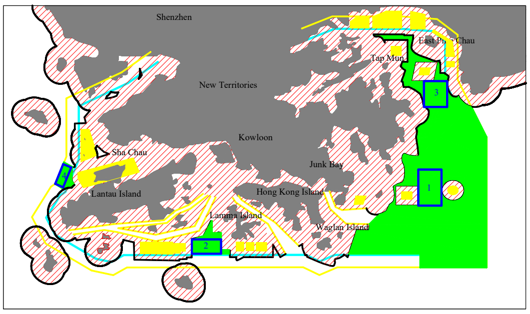

Figure 4. Wind resources in Hong Kong Territorial Waters.

Li also conducted a study on the offshore wind power potential, in which two types of turbine layout spacing (10D × 10D, 10D × 5D) are selected in a hypothetical offshore wind farm in the southeastern water area [59]. The results are concluded in Table 1 with some typical studies on Hong Kong's wind power potential.

Table 1. Wind power potential in Hong Kong in literatures.

	Category	Total Area	Total Annual Potential	
EMSD's Report [54]	Wind power in rural locations Turbines in high-rise buildings Offshore wind	393 km^2 30,000 buildings in HK > 65 m -	126.8–136.8 × 10^8 (kWh)	30.22% of 2011's electricity consumption
	Turbine Spacing	**Total Area**	**Total Annual Potential**	
Li's Study [59]	10D × 10D	-	14 TWh	40% of 1998's electricity consumption
	5D × 10D	-	25 TWh	72% of 1998's electricity consumption
Gao's Study [42]	Scatter	-	112.81 × 10^8 (kWh)	25% of 2011's electricity consumption

Note that the studies on offshore wind power potential in previous studies are based on the wind data measured by Hong Kong Observatory on land near the water area [60], such as the Automatic Weather Station in Waglan Island. The limitations of wind data measured by Hong Kong Observatory cannot represent the wind condition on the wind farm site. Thus, site-measured wind data has great advantages in evaluating wind power potential offshore. The field measurement of wind data will be introduced and analyzed in Section 2.2.

2.2. Offshore Wind Power Potential Analysis Based on Field Measurement Using LIDAR

The Hongkong Electric Co., Ltd. (HK Electric) proposed building an offshore wind farm which would be located at a 600-hectare site about 3.5 km southwest of Lamma Island with the wind monitoring station at the selected wind farm [61]. A wind monitoring station had been set up within the proposed wind farm to pursue a meteorological and oceanographic data collection campaign in March 2012. Light Detection & Ranging (LiDAR) technology was adopted for wind monitoring.

The wind monitoring campaign aimed to collect additional data for optimizing the offshore wind farm design. The measurement range of wind speed of LiDAR is 0–50 m/s with the instantaneous wind speed. In this paper, the one-year wind data from March 2012 to February 2013 were used for the wind farm optimization analysis. Diagram of the one-year wind speed at the turbine hub height of 82 m is shown in Figure 5. Note that the wind data was calculated using the wind shear formula. The long term annual average wind speed measured at the Southwest Lamma offshore is 7.03 m/s.

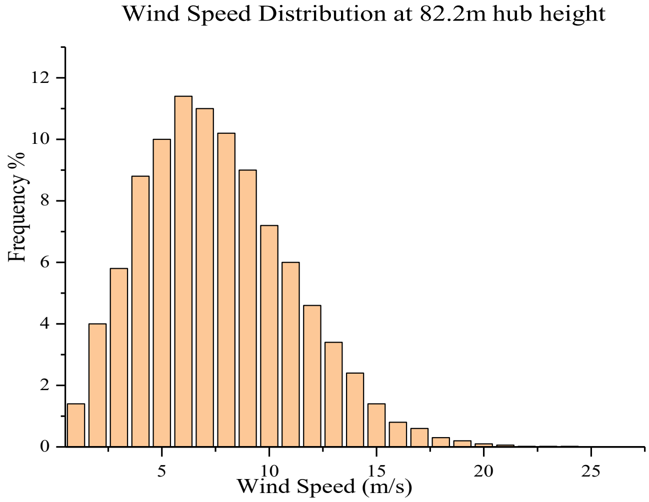

Figure 5. Wind distribution and speed probability.

Results in our previous study which conducted the Hong Kong offshore wind power assessment [42] show that Lamma Island has an intermediate wind condition compared with those three locations. Meanwhile, considering the geographical of Hong Kong, Lamma Island in the Southern water which, facing the South China Sea, can represent the wind conditions to some extent. Thus, in this paper, combining the field measured wind data, the hypothetical offshore wind farm in Figure 4 marked No. 2 was selected to conduct the assessment as it was at the same locations with the Hong Kong Electric's wind farm. The Multi-Population Genetic Algorithm program developed by the author in previous studies [42,62] was used to search the optimal layout pattern of this selected wind farm with the assessment of Hong Kong offshore wind power potential. Details are shown in Table 2. With the optimal number of 25 turbines (5MW) installed in the wind farm, the annual power generation is 5.78×10^8 kWh, and the cost of energy (COE) is 1.55 HKD/kWh. Compared with that conducted using the wind data provided by the Hong Kong observatory [42], the COE has decreased from 1.87 HKD/kWh to 1.55 HKD/kWh, which indicate significance of the field measured wind data. According to this, the total annual offshore wind power potential in Hong Kong is 14,449 GWh, which occupies 32.02% of the electricity consumption of Hong Kong in 2017 [27].

Table 2. Optimization results of the selected wind farm and Hong Kong offshore wind power potential assessment.

Area (km^2)	Number of WTs	Total Power ($\times 10^8$ kWh)	COE (HKD/kWh)	Potential Offshore Area (km^2)	Total (GWh)	% of Electricity Consumption in 2017
16.86	25	5.78	1.55	421.48	14449	32.02

It can be seen that there is a significant wind energy resource potential which, if captured and exploited, would undoubtedly create a material contribution for the reduction of the environmental impact caused by conventional energy supplies.

2.3. Current Situation of Wind Energy in Hong Kong

There are no indigenous energy resources in Hong Kong, and all energy sources are imported from overseas. Currently, two investor-owned companies, the China Light & Power Hong Kong Limited (CLP) and the Hongkong Electric Company Limited (HK Electric) supply electricity for Hong Kong with their networks covering different areas. Coals are the main fuels which make up about half of total fuel consumption [63]. The application of wind energy in Hong Kong is at the early stage of demonstration phase.

2.3.1. Wind Energy Application in Hong Kong

Although there is great wind power potential in Hong Kong, the wind power utilization is barely satisfactory. As it is mentioned above, the weighting of wind energy provided by Hong Kong energy end-use data in 2016 was less than 1% of the total RE, while the weight of RE in Hong Kong was 0.56% in 2013 [27]. There are some small wind turbine projects supported by both government and non-government and proposed yet ultimately aborted offshore wind farms as well.

1. Small wind turbine projects

Most small wind turbine projects in Hong Kong are rooftop turbines, or stand-alone power supply systems, probably in conjunction with PV panels. Some typical projects are listed in Table 3. Note that the list given in Table 3 is not meant to be exhaustive. No new projected has been installed after the year 2011.

Table 3. Examples of small wind turbine projects in Hong Kong [64].

Examples of Small Wind Turbine Projects by the Government				
Year	**Venue**	**Installed Capacity**		
2011	Shatin Sewage Treatment Works	21 nos. of lamp pole mounted wind and solar PV hybrid system (each 0.41 kW wind turbine and 0.16 kW solar PV)		
2010	Shau Kei Wan Government Secondary School	100W micro wind turbine system		
2007	EMSD Headquarters	1.5 kW vertical wind turbine		
Examples of Non-government Small Wind Turbine Projects in Hong Kong				
Year	**Organization**	**Venue**	**Installation Type**	**Capacity**
2010	Tung Chung Catholic School	Roof top of building	Turbines providing electricity for weather station	
2008	HK Electric	Marsh Road Station	Grid-connected horizontal-axis turbine	2 × 2.5 kW
2007	Ho Koon Nature Education 400 W Astronomical Centre	Building roof & campus	Wind turbines and solar PV modules	2 × 250 W
2006	Sun Hung Kai Properties	Ma Wan Theme Park	Grid-connected wind power system	2 × 6 kW

2. Large wind turbine projects

The first commercial-scale wind turbine in Hong Kong was installed by HK Electric. It is a Nordex N50/800 kW machine with a rotor diameter of 50 m and hub height of 46m. The rated power of the turbine is 800 kW and on average provides slightly over 100 kW of power, with a capacity factor of 13%. It is installed at Tai Ling on Lamma Island and was inaugurated in February 2006. It can offset 800 tonnes of CO_2 emission every year on average [64,65].

3. Offshore wind farm projects

Two offshore wind farms were proposed by HK Electric and CLP at southwest Lamma waters (SLW) and Southeastern Waters (SEW), respectively [66,67].

The total capacity of the offshore wind farm at SEW was 100 MW, with 28–35 turbines rated 2.5–3.6 MW installed. If it is operated, its 100 MW capacity can generate about 170 million kWh per year, which can offset 62,000 tonnes of coal and 150,000 tonnes of carbon dioxide emissions. The EIA report of the SLW Offshore Wind Farm was approved in May 2010. HK Electric is carrying out wind monitoring work using LiDAR technology at the site to collect wind resources data [61]. The offshore wind farm is scheduled for completion by 2015; however, it was postponed due to capital-intensive consideration and critical voices from the public.

The above reactions happened for the SEW offshore wind farm as well, which is a double of the SWL Offshore Wind Farm's. The proposed SEW has a capacity of 200 MW, with an area of 16 km^2. More than 67 wind turbines of 3 MW or 40 turbines with 5 MW were suggested to be installed. It was reported that about 1% of total Hong Kong electricity needs in 2008 can be produced by this wind farm [66]. However, critical voices come from different parties on the environmental effects and longterm payback period. The public's attitude towards wind energy in Hong Kong is negative. According to the government consultation document on the future of Hong Kong electricity, having an offshore wind farm to power 1–2% of the city will result in a 3–5% increase in the electricity tariff [68]. However, the high cost of offshore wind energy can be offset and decreased with maturation of the technologies.

2.3.2. Wind Energy Policy in Hong Kong

In Hong Kong, the lack of government support and incentives remains the key limiting factor for the promoting of wind energy. Although sustainability was the theme of the Hong Kong Government's environmental review paper from 1996 [63,69], extremely little had been mentioned and done for promoting renewable energy.

In the "First Sustainable Development Strategy for Hong Kong" published in 2005 [70], a target of 1–2% of HK's electricity supply met by RE by 2012 was set. However, compared with targets in other countries/regions shown in Figure 2, this target is far from being satisfied.

The "Scheme of Control Agreements (SCA) 2009–2018" was an agreement signed by the government and the two local power companies, in which an environmental incentive was proposed and it encouraged power companies to develop renewable energy. 11% of the average renewables net fixed assets was permitted to return. The SCA was theoretically effective because both the government and power companies can benefit and the government can realize its RE target while the power companies can get a higher permitted rate of return. Under the effect of SCA, both the offshore wind farm at SLW and SEW were proposed. However, it turned out that the SCA is not effective enough because of low average net fixed assets compared with the higher investment long time payback period.

Unfortunately, in the "Public Consultation on Future Fuel Mix for Electricity for Hong Kong" in 2014 [71], there was no clear target for Renewable Energy while in "A Clean Air Plan for Hong Kong" in 2013 [72], only the goal of achieving the new Air Quality Objectives (AQOs) by 2020 was mentioned.

It has been criticized that Hong Kong completely lacks legislation, strategies, and incentives for the integration of renewable energy. In general, except policy from the government, when developing RE in a specific region, four other factors should also be considered: technical personnel, geographical conditions, public attitude, and social capitals. For Hong Kong, the five aspects' conditions, which affect the RE development is shown in Figure 6. Hong Kong has abundant geographical conditions for wind energy development with enough technical personnel and social capitals; however, social consciousness is not very high. There is no pressure from the public to the government for developing RE technologies and also, both the government and power company react less positively to the long-time payback, high risk, and low return RE project. It is essential to learn from other countries/regions to raise passions of the social and power company, as well as to help the government to propose effective policies for RE development, especially for wind energy.

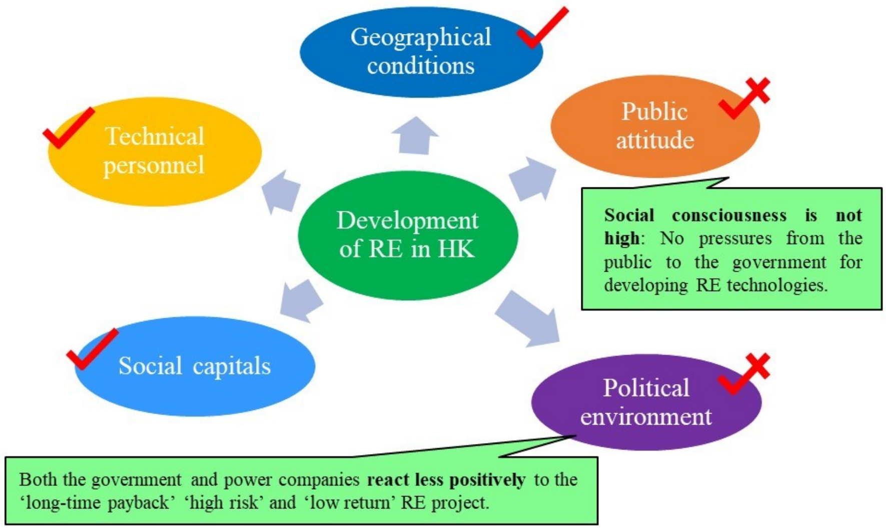

Figure 6. Factor analysis of development conditions for RE in HK.

3. Lessons for Effective Wind Energy Policy from Denmark

3.1. Typical Concepts in Wind Energy Policy

Policy for promoting renewable energy is designed to reduce reliance on fossil fuels and ensure security of power supply, reduce environmental impacts such as greenhouse gas emissions, as well as encourage new industrial development [73]. For countries with well-designed renewable energy policies, substantial environmental and economic benefits have been obtained. However, considering different policy approaches leading to different outcomes, the most effective policy is necessary for a country which requires better understanding of the linkage between policy mechanisms and energy developments [45,74,75]. Target and incentive are important for an effective policy.

Targets: It is common for the national government to set targets for the contribution that renewable energies will make to meet overall energy consumption. It can be a reference for the government or public to check and measure renewable energy development progress [24,76].

Feed-in tariff (FIT) and Renewable portfolio standard (RPS): FIT and RPS emerged and were regarded as the most significant policies to promote power generation from renewable energies [73]. The FIT is a pricing policy mechanism which guaranteed the renewable energy generators a fixed price for the generated electricity [77]. The RPS is a quota system that requires power/electricity suppliers to source a certain proportion of their electricity from renewable energy [78]. It is a quantity regulation, letting the market determine a reasonable price for renewable energy technologies. The price and quantity are the two aspects of electricity generated by renewable energy. In FIT, the prices are set politically and the quantity is market driven, whereas in RPS, the quantity is established politically and the price is determined by the market.

To accelerate investment in renewable energy technologies, the FIT offers long-time contracts to electricity producers, often from 8 to 15 years, but sometimes as many as 20 to 30 years, typically according to the cost of generation of each technology [79]. The goal of feed-in tariff is to offer cost-based compensation to renewable energy producers [80].

The FIT was firstly implemented in the US in 1978 in the law of National Energy Act (NEA), which aimed to encourage energy conservation and development of new kinds of energy resources [81]. As one of the five separate Acts, the Public Utility Regulatory Policies Act (PUPRA) was established to grant a high price which was slowly dismantled by liberalized markets in the US [82]. However, in the mid-1990s, in Denmark and Germany, utilities were required to purchase electricity generated by renewable energy at a price established by the government which was regards as the second wave of FIT [83]. The utilization of FIT can compensate the renewable energy developers for the high investment as well as the environmental benefits of generation.

Trends and development related to FIT on different renewable energy resources vary from countries and regions. Taking China as an example, under series renewable energy law, for instance, The Notice on Improving the Pricing Policy for On-Grid Solar Photovoltaic Power Prices and The Notice on Improving Policy for On-Grid Wind Power Prices etc., the FIT rates for different renewable energy resources are concluded in Table 4. Regardless of the types of renewable energy resources, research indicated that FIT can effectively promote renewable energy capacity development [84–86]. See Figure 7.

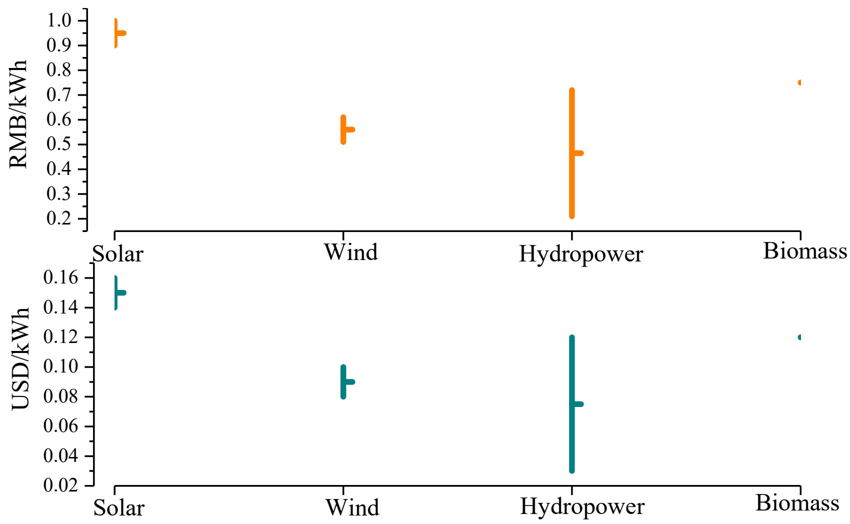

Figure 7. Feed-in Tariff rates of different renewable energy resources in China [87]. * FIT rates in China are different in different site location of power generation. In this table, a general estimation of the FIT rates range is collected. # The exchange rate is CNY1 = USD0.1564 (7th, June 2018).

A renewable portfolio standard is a policy instrument that requires increased production of electricity from renewable energy sources. It has other common names such as renewable electricity standard (RES) in US and renewable obligation in the UK [78,88]. The difference between FIT and RPS is that the RPS program tends to encourage more price competition between different types of renewable energy. The adoption of RPS will result in competition and innovation which will deliver renewable energy at the lowest possible cost, increasing the competitiveness of renewable energy compared with cheaper fossil fuel energy sources.

RPS has been adopted in many countries, especially in the United States, which is the most successful policy that has stimulated renewable energy capacity in US combined with federal production tax credits. For example, in California, Governor Jerry Brown signed climate law mandating 50% renewable power by 2030 on October 7, 2015 [89]. For more than a decade, California has required utilities to use more renewable energy power and the previous target is 33% renewable power by the end of 2020. This target is a level the utilities are confident they will meet. The increasing target in the past years (30% by 2020, 40% by 2030, and 70% by 2040) led to a construction boom for wind farms and solar power plants, and the 50% target will stimulate renewable energy development undoubtedly.

It can be concluded that FIT performs better than RPS in the stage of cumulative wind capacity development, which can promote wind energy under a long-term effect while RPS can provide some incentives to the developers in the short run [45]. To stimulate local wind energy capacity development, it is better to combine these two policies by the government to build a more predictable investment environment.

For wind energy, effective and suitable energy policy could help to increase wind power generation as well as stimulate the energy industry. The existing successful energy policy for some countries can grant revelation and inspiration for Hong Kong's wind energy promotion. For local policy design, it is important to learn successful experiences and practices from other countries/regions. The long-term goal for Danish energy policy is: the entire energy supply including electricity, heating, industry, and transport is to be covered by renewable energy by 2050.

3.2. Wind Energy Development in Denmark

The promotion of wind power in Demark in the last three decades was very successful. It benefited from several factors, especially systematic government support, including effective economic tariff schemes and broad public support [90]. Figure 8 shows the total installed capacity of wind project in Denmark. In 2014, wind energy accounted for 39.1% of Denmark's electricity consumption.

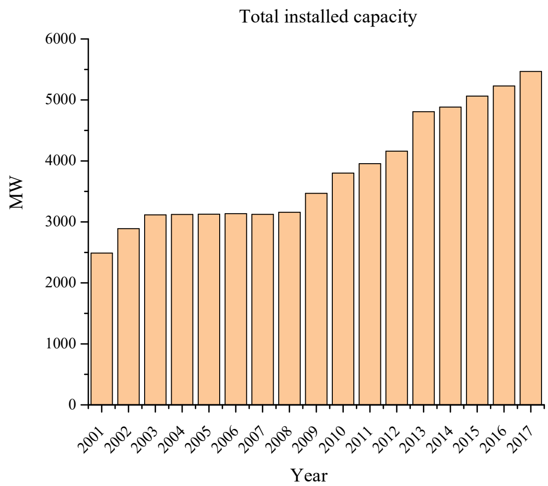

Figure 8. Total installed wind project capacity in Denmark [91].

3.3. History and Evolution of Wind Energy Policy in Denmark: 7 phases

Compared with other countries, Denmark has its unique and advantaged conditions for wind energy development. The long-standing interests in wind energy (windmills) make the wind energy in Denmark not only as an alternative energy but also a complementary source [73]. Even in the 1970s, there were many wind turbine manufacturers who had played significant roles in wind energy policy promotion and wind energy development [90,92]. Both the energy crises and the nuclear accident at Three Mile Island in 1970s provided strong impetus for wind energy development in Denmark. The policy developing history is concluded in Table 4.

Table 4. Wind energy policy developing history of Denmark.

Phase No./Time	Description
Phase 1: First Energy Plan, (Dansk Energipolitik)/1976	• Aim: reduce dependence on imported oil (90% on oil in 1973). • "Sketch for an energy plan in Denmark" 1976; • "Energy for the future: alternative energy plan" 1983; • Wind turbine is still too costly with a capacity of 55 kW.
Phase 2: Second Energy Plan (Energiplan81)/1981	• Function: Simulate the growing of energy production. • Introduced subsidies for the construction and operation of WTs while increase the taxes imposed on oil and coal. • Incentive offered to families for generation power for their community. • Capital grants of up to 30% of the installation costs. • Two orders of 100 MW wind power issued in 1985 and 1990 and 200 MW in 2000.
Phase 3: Third Energy Plan (Energi 2000 [87]), Feed-in tariff/1990	• The first energy plans in the world without nuclear power. • Targets: reducing CO_2 emissions by 20% in 2005 with providing 10% of electricity from wind turbines by 2005 [86]. • Fixed feed-in tariff: 85% of the retail electricity rate by 1992 [87]. • A refund of carbon tax for the first 5 years of operation. • Public hearings prior to any actual applications for turbine siting, was a significant help in getting public acceptance [87].
Phase 4: Fourth Energy Plan (Energi 21)/1996	• Target: RE provide 12–14% consumption in 2005, 35% by 2030. • Offshore WF was set as a further planning regulations an additional 750 MW of OWP (five offshore WF) in 1998. • A net exporter of energy.
Phase 5: Electricity market liberalisation/(1999–2008)	• In 1999, liberalise Denmark's electricity market by 2002. • FIT was abandoned in 2004 and introduced a RPS mechanism [88]. • The WP development stagnated, only 129 MW in 2004–2008. • 'Energy policy statement of 2008 to address climate change' increased the development with a funding of EUR135 million/year [89].
Phase 6: Rejuvenation and strengthening of the wind sector/2009–2012	• New target: Increase the utilization of RE to 20% of energy consumption by 2011 and the reduction of total energy consumption of 2% by 2011 and 4% by 2020 based on 2006. • Installation increase to 3482 MW [90]. • Environmental premium: for onshore wind: DKK 0.25/kWh for the first 22,000 full load hours. • For offshore, 0.45–0.52 DKK/kWh for first 10 years [91,92]. • For new offshore wind since 2009, the premium plus market will not exceed (depending on location) DKK 0.518 or DKK 0.629/kWh for up to 10 TWh with 20 years of grid connection. The maximum subsidy of systems financed by utility companies is DKK 0.353/kWh. An additional DKK 0.023/kWh was provided during the whole lifetime of the turbine to compensate for the cost of balancing [92]. • 'Energy Strategy 2050' in 2011 aim to achieve independence from coal, oil and gas by 2050, 50% from renewable energy by 2020 [93].
Phase 7: Rapid development stage/2013-now	• Electricity production from renewables accounted for 53.4% of Danish domestic electricity supply in 2014 and in which, 38.8% from wind power [94]. • CO_2 emissions have been reduced by 32.6% since 1990 [94]. • A feed-in premium of DKK 0.25/kWh for onshore wind and the a feed-in premium of DKK 0.25/kWh [95]. • Integration of wind power in the energy system is the key barriers to wind energy development in this stage

3.4. Experiences from Denmark

Important conclusions can be drawn from the Danish experience: both the FIT and public attitude are important for the wind energy development.

For FIT, the wind energy tariff depends on several factors: the location of the project (onshore/offshore), the start data of operations, and the number of full-load delivered. A market price element, a compensation for balancing, and a government subsidy, are included in the tariff. The wind energy market reacted closely to the tariff. It can also be observed from Figure 8 that, after the FIT was abandoned in 2004, the market reaction to the abandoned FIT was that the wind power capacity declined rapidly (500 MW to over 3000 MW from 1993 to 2004 while only 129 MW from 2004 to 2008) and the wind market stalled until 2008, when a new support framework was introduced [93].

Besides the effective policies, the public had quite a significant role in wind energy development [94]. In 2009, the Danish Wind Industry Association conducted a survey on the Danish public's opinion on energy production in the future. Results showed that 91% of the population thinks that Denmark should expand the use of wind power and 85% support the wind energy expansion in their local areas [95]. Not surprisingly, this extensive support has a long historical standing in the period of consumer-owned windmills. In addition, the extensively liberalized and privatized Danish electricity markets have also facilitated wind energy installations [96–98].

It is also worth mentioning that universities and research institutions are important partners for the Danish wind industry, i.e., Risø National Laboratory for sustainable energy in Technical University of Denmark (DTU) [99], Danish Wind Industry Association [100] etc.

The Danish government was Europe's first country to bring in large subsidies for wind energy, including the feed-in-tariff system. Effective policies in Denmark were successfully replicated in Germany. Denmark is also one of the first countries to use environmental taxation to reduce air pollution and CO_2 emissions and to support renewable energy development.

The enabling conditions for wind industry development in Denmark attributed to the following aspects:

1. Effective rule of law and transparency in the administrative and permitting processes: A coherent and long-term policy framework has been in place for 30 years;
2. A clear and effective pricing structure (combination of market price and premium ensures);
3. Effective industrial development strategy-energy plans;
4. Provisions for access to the grid: priority access is guaranteed to renewable energy producers;
5. Expression of political commitment from government (e.g., targets);
6. A functioning finance sector (for example, most Danish offshore wind project are financed by utilities.); and
7. Public acceptance.

4. Suggestions for Hong Kong for Wind Energy Development

To stimulate the wind power development in Hong Kong, three aspects should be paid attention to, they are economics, public attitude, and political factors.

4.1. Economics

Surveys show that both the government and power companies in Hong Kong react less for wind energy development because the high investment and long-time payback and also, the public do not want to pay HKD 1.8–2.3 per unit for wind power while the electricity price now is HKD 1/kWh. Thus, how to reduce the cost of energy (COE) is the main issue for Hong Kong when planning wind projects. With the maturation of technologies, wind project cost decreases [101,102]. When planning wind projects in Hong Kong, the following factors should be considered:

1. Based on the National Renewable Energy Laboratory (NREL)'s report, the turbine cost of onshore and offshore wind project is 68% and 32% of the total capital [103]. So, the selection of a wind turbine which can produce significantly more power than other devices at the same wind speed is essential. For example, select turbines with new blade types, new control technologies, longer and lighter blades, or installed with taller wind towers, etc.
2. In Hong Kong, it was proved that there is great wind power potential with suitable geographical conditions for wind energy development [43]. At the stage of project planning, the location selection is important for the power generation of the project. Thus, windy locations with long-term wind resources observation and analysis are indispensable essential.
3. Reducing the operating cost can also significantly help to reduce the COE of wind energy. After the location is determined with specific turbines selected, the turbine layout optimization should be conducted and from which, the optimal turbine layout pattern can be obtained with higher power generation and decreased turbine interactions, and thus, the minimum COE can be obtained.

4. Other considerations, such as financing costs, site-specific characteristics, availability, and cost of skilled labor, transportation and logistics, and other factors, should be considered.

4.2. Public Attitude

Public attitude and social acceptance for wind energy is another important challenge. The public is always in a conflict and dilemma situation when facing the choice between wind turbines and landscape. In Great Britain's study [104], this phenomenon is called a "green to green" dilemma, which means that locals living nearby a planned wind project have to choose between a global good and the local bad. They know that the wind project can reduce CO_2 emissions, but they have to face the negative impact of turbines on the local landscape. Other studies [105–107] have also shown that public attitude towards wind projects based on broader factors relating to environmental, aesthetic, and socioeconomic dimensions. After considering all factors affecting the public attitude, it can be concluded that wind projects with minimal environmental impact and contribution to local economies, which are aesthetically pleasing, will be socially accepted. Factors contributing to society's acceptance of a wind project include the ownership of the wind project, local information on the project, local network, as well as integration of the wind project developers.

For Hong Kong, two activities can help to achieve local acceptance of wind project, as provided below:

1. Providing information and involving the public in the decision-making process and the actual project development and design process: for example, organizing seminars or workshops on the environmental and economic benefits of wind projects and also, a public enquiry on the impact on the local landscape, etc.
2. Encouraging local ownership or financial participation in the projects, including:
    - Promoting local ownership: fund support for local groups or encourage wind projects to offer certain percent of ownership to locals;
    - Compensation for loss of value of real property: financial compensation to individual property owners;
    - Providing fund support to locals, for example, enhancement of local scenic and recreational values.

4.3. Political Factors

As the policy maker, the government should propose effective wind energy policy. In designing or adjusting wind energy policies, multiple goals should be taken into consideration together for the government. For Hong Kong, reducing oil dependence and carbon emissions to improve the air quality, relieving power supply pressure, setting up a new industry, as well as providing new job opportunities, are beneficial. Therefore, the proposed energy strategy will include, but not be limited to the following items:

1. Proposing the Hong Kong Renewable Energy Law and setting up targets of wind electricity share from renewable energy, especially from wind energy in Hong Kong. Both a long-time and short-medium time target should be proposed and the target of 2–3%, which is out of date, should be totally abandoned.
2. Subsidy polices with detailed incentives and subsidies are appreciated:
    - A fixed feed-in tariff: considering the large initial investment of a wind project, a higher fixed feed-in tariff can stimulate enthusiasm of investors. Previous incentives on wind projects, such as 11% of the average renewables net fixed assets was permitted to return' from SCA proposed in 2008 can give experiences when determining the incentives.

- A continual supplement to the market price can make wind energy competitive with other traditional power until wind project technologies has matured enough to obtain a lower cost.
- Environmental protection tariffs can be imposed on non-renewable energy resources.

3. When the policies are established, periodical evaluation on the socio-economic influences of the proposed policies should be conducted to ensure the policy effective; for example, regular seminars or workshops with public surveys held by the government or community can help policy-makers achieve immediate feedback for policy adjusting.

5. Conclusions and Policy Implications

In this paper, a comprehensive analysis of Hong Kong's wind energy from power potential to development constraints is conducted with the experiences from other countries as well as suggestions for local wind energy promotion. Detailed conclusions can be summarized as follows:

1. The power potential of wind energy in literature which is divided into three types (land, high-rising building and offshore wind) is reviewed. Great wind power potential in Hong Kong can be observed and concluded as to which represents a large part of annual electricity consumption.
2. The offshore wind power potential using field measured offshore wind data in the proposed offshore wind farm by Hong Kong Electric Co., Ltd. is conducted in this paper. Results show that the offshore wind power potential is estimated to be 14,449 GWh, which occupied 32.02% of electricity consumption in 2017.
3. The electricity market and power structure in Hong Kong is also reviewed with the existing policy related to wind energy development. Conclusions can be made that the renewable energy target in Hong Kong set in 2006 of 2–3% is out of date and until now, there is no specific policy on wind energy.
4. Wind energy utilization in Hong Kong is limited, although its potential has proved to be significant. The lack of effective policy for wind energy development in Hong Kong is the main constraint. The government, power companies, and public react little to wind project development.
5. The histories and evolutions of wind energy policies in Denmark are reviewed and discussed. It is concluded that both the detailed incentives, such as FIT and public attitude, are important for wind energy development.
6. Based on successful experiences in Denmark, suggestions are proposed for Hong Kong to develop wind energy. Economics, public attitude, and political factors are the three main aspects which can stimulate wind power development in Hong Kong. Detailed information and suggestions for these three aspects were investigated.

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