

# Viability of renewable energy technologies under the Feed-in Tariff scheme in Hong Kong

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## ABSTRACT

Many countries and regions around the world have incorporated renewable energy use for the purpose of achieving resource sustainability, pollution reduction, as well as reducing the carbon footprint. Many cities around the world including Hong Kong have created Feed-in Tariff (FIT) schemes to encourage and provide incentives for renewable energy development. There is thus a need to study the feasibility of using renewable energy under the scheme. Energy generated from two prominent renewable energy technologies – solar PV and wind turbines – are studied for a hypothetical housing development in Hong Kong. To allow for increased knowledge of different types of solar panels and wind turbines that are available in the market, two different types of solar panels – the monocrystalline and amorphous silicon PV – and two different types of wind turbines – the horizontal and vertical wind turbine – are studied. The revenue that can be generated is then calculated based on a power company's FIT scheme. The payback period required for each type of renewable energy technology development is also determined. The results show that solar panels are feasible for installation within the city, and both solar panels and wind turbines are feasible for installation on outlying islands outside the city such as Cheung Chau.

**KEYWORDS** Solar Panel; wind turbine; renewable energy; energy generated; FIT; revenue; payback period

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## 1. Introduction

Renewable energy generation and use have been matters of interest for many countries both in the developed world and developing world. With an ever-increasing world population, a strain on the resources currently available will inevitably arise. Such resources include fossil fuels for electricity generation, but these are non-renewable. Therefore, it is critical to diversify the source and type of energy currently being used; this would thus include using renewable energy (Environment Bureau, 2014). Increasing the use of renewable energy would not only put less strain on the already dwindling resources that the world has for electricity generation, but would also reduce the pollution created when putting non-renewable fossil fuels into use (Union of Concerned Scientists, 2017). Furthermore, adopting renewable energy can allow Hong Kong to achieve carbon neutrality by 2050 which is a target of the HKSAR Government. Two of the more popular types of renewable energy in recent years are solar and wind for harvesting energy (KPMG, 2016). Research and consultancy studies were conducted as early as 2000 by the Electrical and Mechanical Services Department of the HKSAR Government to investigate the feasibility of wide-scale application of renewable energy technologies with a view to further improve air quality and reduce greenhouse gas emissions. Upon reviewing current technological trends and applications, and taking into account Hong Kong's

local characteristics, renewable technologies that are considered potentially feasible for wide-scale application in Hong Kong include solar power and wind power (Leung and Hui, 2003)

However, due to the large start-up costs for setting up renewable energy projects such as solar farms and wind farms, and the intermittency and unsteadiness of the electricity generated, a lot of challenges are posed for developers and investors alike. To tackle such issues, governments of countries around the world have thus created incentives for private developers to implement such projects including Feed-in-Tariff (FIT) schemes with the aim of offering long-term contracts under which renewable energy producers are paid per unit of electricity created (Couture et al., 2010). Different types of renewable technologies are offered at different rates, typically based on the cost of implementation of each technology.

Since two of the most popularly used renewable technologies are wind turbines and solar panels, this study focuses on comparing the cost and benefits of the two technologies under the FIT scheme in Hong Kong. To allow for increased knowledge of different types of solar panels and wind turbines that are available in the market, two different types of solar panels – the monocrystalline and amorphous silicon PV – and two different types of wind turbines – the horizontal and vertical wind turbine – are studied.

## 2. Overview of solar panel technology

Solar panels, or photovoltaic solar panels, absorb sunlight energy to generate electrical power. Solar panels consist of a packaged assembly of photovoltaic solar cells which make up an overall photovoltaic module (PV). Solar cells are the electrical devices which convert the energy of light directly into electricity via the process known as the photovoltaic effect. Solar farms comprising rows and arrays of solar panels, either developed on rooftops of buildings or fields of land, are very popular in many places around the world. Solar panels can now be developed on a small scale on rooftops by private homeowners, or larger scale by private industrial developers on top of factories or high-rise buildings or on tracks of land. Figure 1 shows conventional solar panels on a rooftop in Hong Kong.



Figure 1. Conventional solar panels on a rooftop in Hong Kong (Squarefoot Hong Kong, 2019).

There are five common types of solar PV modules in the commercial market, which include the monocrystalline and polycrystalline silicon cells, thin-film cells, cadmium telluride cells, and concentrated PV cells (CVP and HCVP). The majority of the solar cells used in the modules are however either wafer-based crystalline silicon cells or thin-film cells (Dirjish, 2012). The electricity is generated when sunlight-excited electrons hop across the junction between the different layers of silicon of a solar cell (Woodford, 2019). In order to calculate the energy produced in a given period from solar panels, the peak nominal power first needs to be calculated. The peak nominal power is calculated using the following formula (McFadyen, 2013):

$$kW_p = n \times W_p / 1000, \tag{1}$$

where  $n$  is the number of solar panels and  $W_p$  is the yield of the solar panel given by the ratio of the electrical power of one solar panel divided by the area of one panel. After the peak nominal power is calculated, the average energy can then be calculated using the following formula (McFadyen,

2013):

$$E_p = E_{ma} \times k \times W_p \times \eta \times A, \tag{2}$$

where  $E_{ma}$  is the measured solar radiation in a given period (in kWh/m<sup>2</sup>),  $\eta$  is the overall efficiency of the solar installation accounting for losses (such as temperature losses, tilt and orientation losses, shading losses, and inverter losses), and  $A$  is the area of the solar panels (in m<sup>2</sup>). The unit for  $E_p$  is usually expressed in kilowatt hour.

The main difference between mono-crystalline solar panels and amorphous silicon solar panels is the type of material used in each type of panel. While mono-crystalline panels are made of mono-crystalline silicon (c-Si), amorphous silicon solar panels are made of amorphous silicon (a-Si) or sometimes materials with semiconductor properties known as CIGS (copper indium gallium selenide solar cells) (Solar Reviews, 2020). Although amorphous silicon solar panels generally cost less, they also have a lower efficiency compared to other types of solar panel technologies. Having a lower efficiency also means that amorphous silicon solar panels will have a lower space-efficiency. It will require more space for more amorphous silicon solar panels to generate the same amount of energy as the mono-crystalline panels. However, the space for the solar panel development is restricted in this assessment.

Over the years in Hong Kong, many village houses in the New Territories have been invested in and developed with solar panels on their rooftops by their owners. This practice has also been recently extended to institutional buildings, such as schools, in more urban and populated neighbourhoods in Hong Kong (Chan et al., 2018).

## 3. Overview of wind turbine technology

Wind turbines convert kinetic energy from wind into electrical energy. Wind turbines can also be developed as either single entities or as part of a larger wind farm with a series of wind turbines on a tract of land or around water. The incentive for developing wind turbines depends largely on the start-up costs, the efficiency of the wind farm in generating the electricity, and the rates of return. When planning to develop a wind farm, it is also imperative to know the expected power and energy output of the wind turbines to be able to determine its economic viability (The Royal Academy of Engineering, 2014). The energy available for conversion mainly depends on the wind speed and the swept area of the turbine (The Royal Academy of Engineering, 2014).

Horizontal wind axis turbines, which are the most popular and conventional type, typically consist of: two to three rotor turbine blades that convert wind energy into rotational kinetic energy; a gear box that can convert the lower speed incoming rotation motion of the rotating blades into a higher speed rotation motion; a generator that creates

electricity; and a pole and foundation structure. Figure 2 shows a series of wind turbine poles with solar panels at a power generation station in Hong Kong.



Figure 2. Series of wind turbine poles with solar panels at a power generation station in Hong Kong.

The equation to calculate the wind electrical output of a wind turbine is (Royal Academy of Engineers, 2014):

$$P = C_p \times \frac{1}{2} \times \rho \times A \times V^3, \tag{3}$$

where  $C_p$  is the turbine efficiency coefficient,  $\rho$  is the air density ( $\text{kg/m}^3$ ),  $A$  is the swept area of the rotor blade ( $\text{m}^2$ ), and  $V$  is the wind speed ( $\text{m/s}$ ).

The main difference between vertical wind turbines and horizontal wind turbines is its general wind turbine and blade orientation and the axis of rotation. The horizontal-axis turbine typically has a three-blade vertical propeller that catches the wind face-on while a vertical turbine has a set of blades that spins around a vertical axis (Papiewski, 2020). In order for the horizontal-axis turbine to work, it needs the wind to flow perpendicular to the blades. Horizontal wind turbines thus have a yaw drive that rotates the unit's direction to accommodate changes in wind direction. Vertical-axis wind turbines however run well regardless of wind direction, making them better-suited to urban areas with tall buildings where wind turbulence is a given (Papiewski, 2020). The vertical-axis design also

allows it to operate at lower wind speeds than the horizontal turbine. In other words, vertical wind turbines have lower starting torques; this however also causes them to have dynamic stability issues (Saad and Asmiun, 2014). Figure 3 shows a schematic of a horizontal wind turbine vs. a vertical wind turbine.

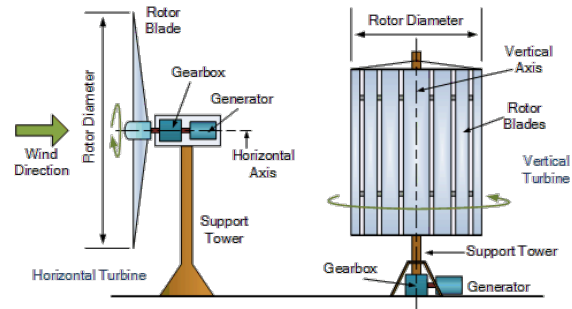


Figure 3. Schematic of horizontal wind turbine vs. vertical wind turbine (Alternative Energy Tutorials, 2015).

Vertical wind turbines work differently when generating power. Thus, the equation that is used to calculate the power generated by vertical wind turbines is also different. According to Brusca and Lanzafame (2014), the power output of a vertical wind turbine can be given as (Brusca and Lanzafame, 2014):

$$P = C_p \times \frac{1}{2} \times \rho \times 2 \times R \times h \times V^3, \tag{4}$$

where  $C_p$  is the turbine efficiency coefficient,  $\rho$  is the air density ( $\text{kg/m}^3$ ),  $R$  is the rotor radius (m),  $h$  is the blade length (m), and  $V$  is the wind speed ( $\text{m/s}$ ). Note that the output of the vertical wind turbine is also heavily influenced by the aspect ratio of the turbine, which is the ratio between the height of the turbine blade, and the turbine rotor radius. The lower the aspect ratio, the higher the efficiency.

Small wind turbine developments have already gained popularity in North America and Europe. Studies were conducted in Hong Kong as early as 2002 concerning wind turbine implementation viability on private rooftops in Hong Kong. According to a study commissioned by the Electrical and Mechanical Services Department in Hong Kong, rooftops on urban buildings are attractive in that they are building integrated and therefore close to the electrical load (Camp Dresser & Mckee Inc. and GHK Ltd., 2002). Although opportunities of retrofitting small wind turbines on the rooftops of buildings in Hong Kong are still limited at present, there could be increased opportunities in the future as long as such renewable energy installations comply with the region's building codes of practice and standards (Camp Dresser & Mckee Inc. and GHK Ltd., 2002). Nevertheless, the FIT scheme in Hong Kong also applies to potential wind turbine technology for private developers.

#### 4. Overview of Hong Kong’s Feed-in Tariff Scheme

In 2008, the Hong Kong government launched the following two major initiatives to enhance the increased use of renewable energy in the private sector (Yu, 2018):

- Profit tax reduction of 20% on the capital expenditure incurred on renewable energy installations for five years;
- Financial incentives for the two power companies to develop renewable energy when the scheme of control agreements came into effect in the years of 2008-2009.

However, the initiatives introduced during those years have proven ineffective. During the past decade, only 46 solar PV systems and four wind power systems have been installed by the private sector (Yu, 2018). Thus, this has called for the government to introduce a more robust system – the FIT, or Feed-in Tariff scheme to create more incentives for development within the region.

In 2018, the Hong Kong Government announced its very own FIT scheme for the promotion of renewable energy within the region. The scheme has given rise to two main power companies in the region – China Light and Power (CLP) and HongKong Electric Company (HEC) – to pay private developers for renewable energy projects in respect of each unit of electricity generated from renewable sources. The FIT scheme is applicable to solar and wind power renewable source systems with a generating capacity of up to 1 MW, and the rates will be the same for both types of systems. The two power companies will purchase the electricity produced by an approved renewable energy system developed by a developer once it is successfully connected to the company’s power grid (CLP, 2018). A smart meter will be installed to record the amount of electricity generated by the system. According to CLP, the rates that are offered are dependent on the capacity of the renewable energy system at three payment levels as shown in Table 1.

A higher capacity of the renewable energy system would require a larger development area for a larger system composed of more solar panels or wind turbines. Thus, as Table 1 suggests, a larger renewable system covering a larger area would then produce a lower dollar rate per unit produced, and a smaller renewable system covering a smaller area would then produce a higher dollar rate per unit produced.

Table 1. Capacity of the renewable energy system and the respective FIT rate (CLP, 2018).

Capacity of the renewable energy system	FIT rate (per unit)
≤ 10 kW	HK\$5
>10 kW to ≤200 kW	HK\$4
>200 kW to ≤ 1 MW	HK\$3

#### 5. Methodology and data collection technique

##### 5.1. Initial considerations and assumptions

There are couple of assumptions that have been adopted for the purpose of this analysis:

- A startup cost is estimated for each renewable technology based on the product costs from a supplier/manufacturer of the product, and the approximate labour costs of installation of the solar panel/wind turbine components.
- Since Hong Kong is a region which relatively small in size, it can be assumed that solar radiation data collected in the respective weather stations across Hong Kong can be applied to the area of interest where the arbitrary solar and wind installation is developed. Wind speed data will need to be collected at the Hong Kong Observatory at or near the site of interest since wind speed data vary according to different locations across Hong Kong.
- A size of the rooftop for a residential development needs to be chosen. The type of residential development chosen for the analysis is a private semi-detached house type as these types of developments have become more and more prevalent in recent years.

##### 5.2. Product selection for renewable energy projects

###### 5.2.1. Solar panel type selection and respective costs for mono-crystalline and amorphous (thin film) solar panels

According to a general project cost estimation for solar photovoltaics from CLP, different types of solar cells can have a different range of equipment costs for project development. The equipment cost for the project is measured in dollar value per watt of electricity produced for the whole development. Table A1 in the Appendix shows information sourced from CLP.

According to the table, the equipment cost for mono-crystalline cells is HK\$24-40/watt and the equipment cost for amorphous silicon cells is HK\$16-24/watt. The average costs for mono-crystalline cells (HK\$32/watt) and the average cost for amorphous silicon cells (HK\$20/watt) were adopted.

*Energysage*, which is a major provider of solar energy services supported and backed by the United States Department of Energy, states that the average size of solar panels used in a rooftop solar installation is approximately 1.65 m by 1 m (Energysage, 2018a). Thus, for the purpose of this study, the size of every solar panel that is used for analysis can be assumed to be 1.65 m<sup>2</sup>. The number of solar panels used for the analysis depends on the rooftop size of the private development under investigation.

Most solar panels on the market today have power

output ratings ranging from 250 to 400 watts (Energysage, 2018b). This stated power output can also be applied to both mono-crystalline cells and amorphous silicon cells adopted for this study. The average output power used for analysis can thus be 325 watts per panel. Note that there will also be losses that need to be considered for the output power.

In order to calculate the cost of equipment for the solar panels, the following procedures need to be adopted:

- Determination of the number of solar panels of the specified size that are able to fit into the area of the rooftop.
- Calculation of the equivalent amount of watts of energy produced from the number of solar panels fitted on the rooftop. This can be done by simply multiplying the number of solar panels by the nominal output of the solar panels (in watts per panel).
- Calculation of the cost of solar panel equipment by multiplying the watts of energy by the average cost of the solar panel type as referenced from CLP.

Aside from the costs for the solar panels themselves, labour costs/installation costs for installation of the solar panels on the rooftop also need to be considered. According to *SUNMetrix*, another North American provider of solar energy services, the estimated installation labour cost for solar panels in cost per watt is approximately US\$0.30 US (or HK\$2.35) (SUNMetrix, 2019). The cost per watt value can be multiplied by the size of development of solar panels, in terms of the amount of watts of energy produced, to determine the total installation cost of the solar panels. The total initial start-up cost of the solar panels includes the cost of the total number of solar panels that can be fitted on a rooftop plus the labour cost for installation of all the solar panel components.

### 5.2.2. Product selection and respective costs for horizontal wind turbines

Since private wind turbine developments are still rare and relatively new in Hong Kong, there is currently no estimated range or average equipment development costs available yet from power companies in the city. Thus, wind turbine suppliers would need to be directly enquired of for an approximate equipment cost. For the purpose of this study, the type of wind turbines considered are those that can be fitted on the rooftops of private homes in Hong Kong.

A manufacturer of smaller-scale wind turbines based in Taiwan that can be fitted on the rooftops of private homes was approached for the study. Since Taiwan is in close geographic proximity to Hong Kong, wind turbine stocks purchased can be easily transported to Hong Kong. Wind turbine products from the manufacturer can also be directly

purchased from Amazon, with the price clearly listed as well. Consider Table A2 in the Appendix as a comparison with information sourced from the manufacturer.

According to the Table, a specific wind turbine (DB-1200) is one of the products that have the largest rotor diameter, which would create the greatest rotor swept area when in operation. It also has higher rated speeds of 31 mph, or 50 km/hr. A wind turbine with a larger rotor swept area and higher rated speed generates more electricity. Model (DB-1200) and model (DB-1500) have similar specifications; model (DB-1200) was however chosen over (DB-1500) because it has a lower cost at US\$999, and it also has a lower cut-in speed, meaning that it is more efficient with blades that start to turn at lower wind speeds.

The amount of wind turbines that can be put on the rooftop of a private home is also restricted by the spacing of the wind turbines. According to the United Kingdom's Department of Environment Planning Policy Statement (UKDEPPS) 18 on Renewable Energy (Annex 1, A16), it is recommended that wind turbines be positioned so that the distances between them are between 3-10 rotor diameters (Planning and Environmental Policy Group, 2009). The British Department's policy also notes that the recommended spacing is a compromise between compactness, while minimising the capital cost, and also at the same time lessening the energy loss through wind shadowing. The stated policy was also implemented for this study for wind turbines to be placed on the rooftop of the private home considered in Hong Kong. The total cost of the development is based on the total number of wind turbines that are able to be placed on the rooftop of the private home based on the spacing recommendations for turbines.

According to the manufacturer, wind turbines can be installed by the developer themselves, owing to their kit's mechanical simplicity. Thus, the installation costs for the wind turbine development can be ignored. There is, however, a cost associated with the mounting of structural supports for the wind turbines. The manufacturer offers a tower kit auxiliary product that includes a mounting pole which allows developers to install the wind turbines directly on a rooftop. The tower kits cost US\$499. The total start-up cost of the wind turbines includes the cost of the total number of wind turbines fitted on the rooftop plus the required auxiliary mounting equipment cost to install all the wind turbine components.

Note that the cut-in speed for the wind turbine adopted is 4.5 mph (or 2.0 m/s and 7.2 km/h). The cut-in speed for a wind turbine is defined as the minimum wind speed needed for the wind turbine blades to start to rotate and generate power. Thus, on dates with any recorded wind speeds below 2.0 m/s (or 7.2 km/h) from the Hong Kong Observatory records electricity cannot be generated.

### 5.2.3. Product selection and respective costs for vertical wind turbines

Due to the geographical proximity and convenience of supply, products were chosen from a vertical wind turbine manufacturer based in Mainland China. The manufacturer supplies a variety of vertical wind turbines at different rated powers. Table A3 in the Appendix shows the product selection of vertical wind turbines based on their rated power. The table lists the physical and mechanical properties of each product.

A horizontal wind turbine with a rated power of 1.2 kW was chosen for the study. For comparison, a vertical wind turbine (DG-1000H) with a similar rated power (1kW) was chosen. From enquiries made with the manufacturer directly, the cost of the vertical wind turbine chosen including all its required equipment is US\$1,317. According to the manufacturer, the wind turbines can be installed by the developer themselves. Thus, installation costs for the wind turbine development can be ignored.

The cut-in speed for the vertical wind turbine is 2.0 m/s (or 7.2 km/h), which is the same as the horizontal wind turbine adopted in this study. Thus, on dates with any recorded wind speeds below 2.0 m/s from the HKO records electricity cannot be generated.

### 5.3. Meteorological data collected from the Hong Kong Observatory

The Hong Kong Observatory is a weather forecast agency in Hong Kong that provides weather forecasts and various assessment services to the public in the city. Forecasts and assessments include solar radiation and wind speeds collected every month of the year. The data are collected at various weather stations throughout Hong Kong.

The King's Park Weather Station (KPWS) is one of the two stations in Hong Kong that records Global Solar Radiation. Since Hong Kong is a region which is relatively small in size, it can be assumed that solar radiation data collected in KPWS can be applied to the area of interest where the arbitrary solar installation was to be developed. As per the wind speed data, although many different weather stations across Hong Kong record this type of data, the Cheung Chau weather station was chosen as Cheung Chau is an outlying island and the winds there are comparatively stronger than in the city. If the analysis results are ideal, Cheung Chau may indeed be chosen as a location where an arbitrary wind turbine installation can be developed.

Daily global solar radiation and mean wind speed data recorded in 2018 at the Hong Kong weather stations were obtained through a data enquiry via the Hong Kong Observatory website. Data points of each day of the whole of 2018 were collected. The solar radiation data and wind speed data obtained were used to calculate the total amount

of electricity created throughout 2018 for the type of solar panel and wind turbine selected respectively. The amount of revenue generated based on the FIT scheme for each renewable energy technology could then be calculated.

### 5.4. Rooftop of private home for analysis

Regarding the private development of solar panels, more particular focus can be put on the development of solar panels for private houses whose owners can benefit directly from the FIT scheme. Most of the private houses, or semi-detached houses, in Hong Kong are clustered in and around the New Territories region. "Small Houses" started being developed in the New Territories region of Hong Kong in the 1970s. Under the Buildings Ordinance, a small house is defined as a building that shall not exceed three storeys or 27 ft in height and the maximum roofed-over area of the house shall not exceed 700 sq ft (Hopkinson and Lao, 2003). For the purpose of this study, a 700 sq ft (~65 m<sup>2</sup>) roof area could thus be adopted for the renewable energy development in focus. A certain number of solar panels and wind turbines would be fitted to the 700 sq ft rooftop of the residential housing and the amount of energy produced by each type of equipment was analysed case by case.

#### 5.4.1. Solar panel placements

Based on the assumptions made earlier, the size of every solar panel that was used for analysis can be assumed to be 1.65 square metres. Online software, Google Sketchup, was used to visually model the solar panels on the small house's residential rooftop (8062 mm x 8062 mm) studied. Note that a 1 metre by 1 metre corridor space around the edge of the rooftop was created for access around the rooftop. If the solar panels are placed side by side near the centre of the rooftop, a total of 18 solar panels can be placed on the rooftop. The solar panels were placed at a tilted angle on the rooftop for better sunlight exposure. According to CLP, solar panels shall be placed at an inclination angle of 22.5° in Hong Kong to achieve the best results (CLP, 2016). Note that losses due to solar panel tilt and orientation have been considered. Refer to Figure 4 for the solar panel placements on a Small House rooftop.

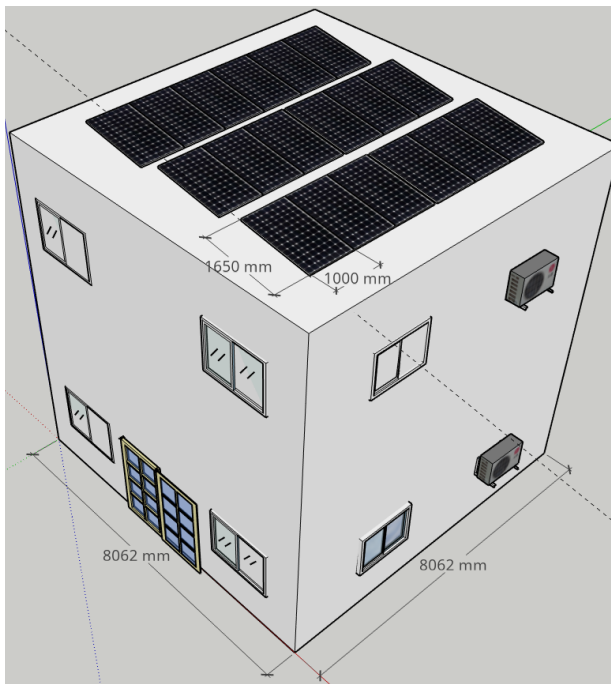


Figure 4. Solar panels on a small house rooftop.

**5.4.2. Wind turbine placements**

According to the assumptions made earlier, UKDEPPS 18 was adopted for this project. For analysis, wind turbines should thus be positioned so that the distances between them are between 3-10 rotor diameters. Model (DB-1200), which was the chosen wind turbine for this project, has a rotor diameter of 1709 mm. Wind turbines were placed at least a metre away from the edge to leave space for proper anchorage and maintenance. Four wind turbines could be placed on the rooftop of each placed near the corners; this arrangement allowed a maximum of three rotor diameters in distance in between each wind turbine. Refer to Figure 5 for the wind turbine placements on a Small House rooftop.

It is also important to note that vertical wind turbines are not governed by the same minimal spacing requirements as stated for horizontal wind turbines. There is currently no recognised universal guideline for spacing requirements in particular for vertical wind turbines. Thus, this will allow vertical wind turbines to be packed closer together in developments, thereby saving more space (Saad and Asmiun, 2014). For the purpose of this project, the spacing used for horizontal wind turbines was however also applied to vertical wind turbines for easier comparison.

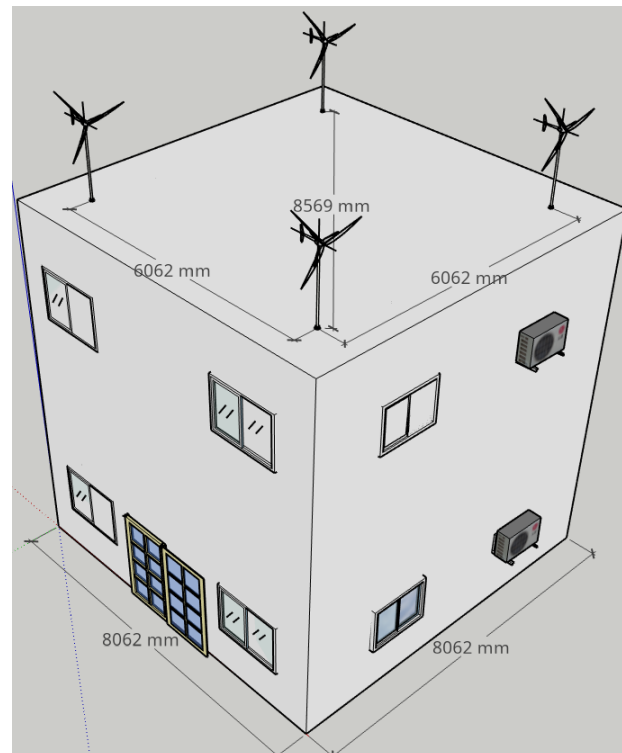


Figure 5. Wind turbines on a small house rooftop.

**6. Energy generated from the renewable technologies**

Daily solar radiation and wind speed data from the Hong Kong Observatory for all months in 2018 were used to calculate the energy generated (in kWh) for the mono-crystalline and amorphous silicon solar panel developments and wind turbine horizontal and vertical developments respectively. Figure 6 shows the energy generation trends for each renewable energy technology throughout 2018.

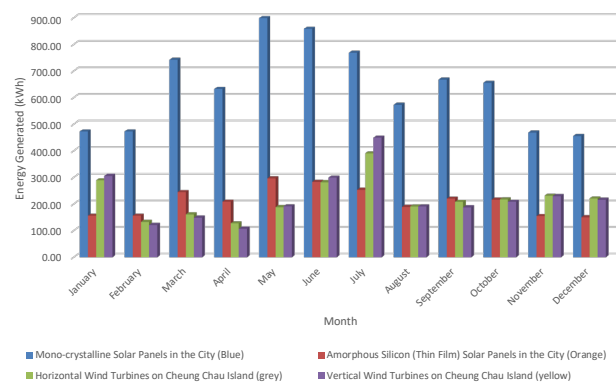


Figure 6. Monthly energy generated (kWh) from the renewable energy installation in 2018.

**7. Revenue generated from the FIT Scheme and tariffs for each renewable technology**

The revenue, in Hong Kong dollars, generated for each type of the following renewable energy developments: A) the mono-crystalline solar panels and amorphous solar panels and B) the horizontal wind turbines and the vertical wind turbine, was calculated. The FIT rates referenced were based on CLP’s specifications. Figure 7 shows the revenue generation trends for each renewable energy technology throughout 2018.

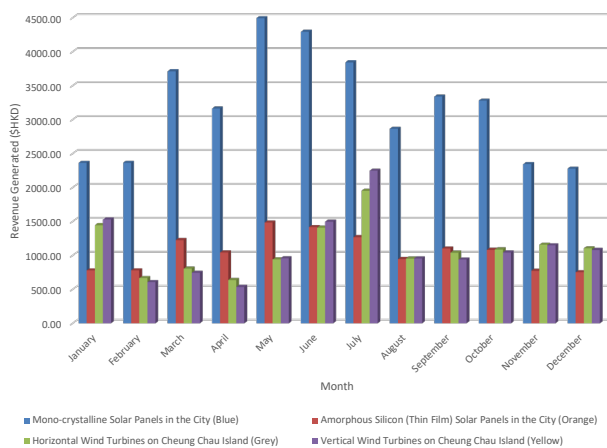


Figure 7. Monthly revenue generated (HK\$) from the renewable energy installation in 2018.

**7.1. Payback period based on revenue generated from each renewable technology type**

Calculating the payback period determines the number of years required for the revenue generated from the FIT of a renewable energy system to offset the initial cost of investment. In other words, the payback period is able to assess how quickly an investment might be paid back and whether the investment is likely to be recouped within the expected lifetime of the project (Rashford et al., 2013). Note that a simple payback method was used for this project to calculate the payback period; this method disregards the following: the time value of money, energy price escalation, variable rate electricity pricing, and alternative investment options.

The following equation calculates the simple payback period (Rashford et al., 2013):

$$Payback (years) = \frac{Initial Cost}{Annual Production * Value - O\&M}, \quad (5)$$

where the Initial Cost is the total price (\$) paid for the renewable energy installation, *Annual Production* is the amount of energy produced per year (kWh/year), *Value* is the FIT rate (\$/kWh) offered by CLP for the renewable energy installation, and *O&M* is the operations and

maintenance required for the installation every year (\$/year). Figure 8 shows the intersecting year in which the cumulative revenue would overtake the initial cost for mono-crystalline and amorphous silicon solar panel developments.

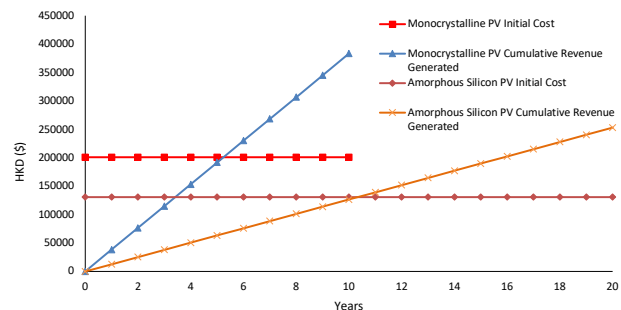


Figure 8. Cost offset for mono-crystalline and amorphous silicon solar panel development.

Figure 9 shows the intersecting year in which the cumulative revenue would overtake the initial cost for horizontal and vertical wind turbine developments.

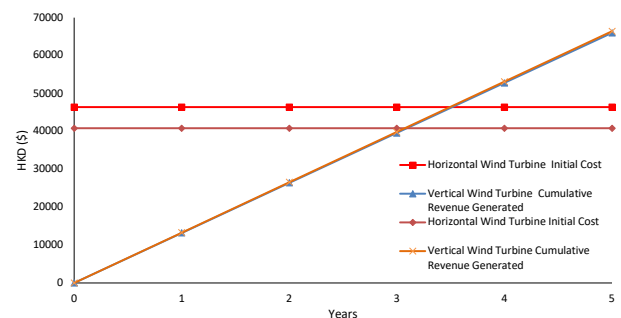


Figure 9. Cost offset for horizontal and vertical wind turbine development on Cheung Chau.

**8. Comparison and discussion**

The initial start-up cost of solar panels is a lot higher than that of wind turbines. The large price difference is due to the fact that the costs of installing the wind turbines are nil; the specified wind turbine systems are simple enough to be self-installed. The residential development in which the renewable energies are fitted also limits the number of wind turbines that can be installed. Solar panels on the other hand require the necessary expertise for installation; thus, there will be an associated installation labour cost. The residential development in which the renewable energies are fitted also allows a decent amount of solar panels to be installed.

There is a substantial difference between the energy that is created from mono-crystalline solar panels in particular compared to all other renewable energy technologies. The reason behind this is that mono-crystalline solar panels in general yield more energy compared to

wind turbines; the possibility of having more solar panels installed on the rooftop of a residential development compared to wind turbines also compounds the amount of energy that can be generated. The solar panels studied in this project are also more mechanically efficient than wind turbines, meaning that the former suffer from less energy losses compared to the latter. Aside from the mechanical properties of the renewable technologies that play a role, the general climate in Hong Kong is also a big factor. The global solar radiation that the city receives as recorded by the Hong Kong Observatory is a lot more stable than the wind that the city receives. Thus, with a more favourable climate for solar panel applications, mono-crystalline solar panels are deemed to have better energy yielding results. It is also important to note that mono-crystalline PV are a lot more efficient than amorphous silicon PV in terms of the energy per unit that can be generated.

The FIT rates offered by CLP for both solar panel and wind turbine installations is HK\$5 per unit if the capacity of the system is equal to or below 10 kW. The output power of the solar panel development is 5850 W (or 5.85 kW) and the total output power of wind turbines is 4800 W (or 4.8 kW). Since both power values are less than 10 kW, the highest FIT rates (i.e. HK\$5/kWh) that will be offered can be applied to both types of renewable energy installations. In other words, the revenue gains of renewable energy technologies are thus completely dependent on the size of the renewable energy development and the energy that each development generates. As specified earlier, since mono-crystalline solar panel developments generate a lot more energy than all other renewable energy technologies considered in this study, the FIT revenue generated by a mono-crystalline solar panel development is thus a lot more as well.

The payback period was also calculated for both types of renewable energy developments. Although the mono-crystalline solar panel is able to yield a lot more energy and earn a lot more FIT revenue, the payback period calculated for it is longer compared to that of the horizontal and vertical wind turbine developments. This is due to the fact that wind turbine developments have lower start-up costs. It is thus faster to pay off wind turbine developments developed on outlying islands such as Cheung Chau. However, this does not apply to the case of areas within the city, which will have a much longer payback period (Tsui, 2020).

## 9. Conclusion and recommendation

Overall, although a mono-crystalline solar panel development was found to yield higher energy gains and earn more FIT revenue, it has a higher payback period than horizontal and vertical wind turbine developments. Thus, wind turbine developments should be selected as the better option for a developer to develop a renewable energy installation on the rooftop of an average private house if

it is situated on outlying islands in Hong Kong such as Cheung Chau. The mono-crystalline solar panel should, however, be selected as a better option for installation on the rooftop of an average private house in other areas in the city such as the New Territories in Hong Kong. Noting that the payback period of the mono-crystalline solar panel is not much longer than the wind turbine for the case of Cheung Chau, it is also suitable for all outlying islands as well. It is important to note that wind is expected to not be as prevalent in areas closer to city centres due to shielding effects, but solar radiation is consistent in many geographical areas in and around the city. Installing the appropriate type of renewable energy in different areas in Hong Kong after taking into account the climate conditions is thus required for developers to benefit the greatest from the FIT scheme provided by the Hong Kong Government. It should be noted that mono-crystalline PV is a better option for solar panel development than amorphous silicon PV due to its higher efficiency. Generally, amorphous silicon solar panels are not suitable for most residential situations where space is limited since amorphous PV requires a lot more space to produce the same amount of energy than mono-crystalline PV does.

Global radiation sources in Hong Kong are abundant and stable, and based on this study, a mono-crystalline solar panel development is able to generate an abundance of energy in the city. Solar panel technology themselves are also very reliable, with breakdowns very uncommon. The solar panel industry in Hong Kong is very mature, with many contractors and suppliers available to provide the equipment and installation. Thus, owners will be able to easily acquire professionals to help them develop solar panel renewable energy installations on their properties as they wish.

Although small wind turbines prove to be efficient enough when they are developed on rooftops in outlying islands such as Cheung Chau, it is still a very nascent technology in Hong Kong. The wind turbine technology is also restricted by geographical location. If wind turbines are placed closer to city centres where there are high-rise buildings, it will greatly affect the ability of the turbines to turn because the tall buildings in the city will cause wind shielding effects; these effects will block winds that flow in and around the regions within the city where the wind turbines are located. If the turbines do not turn at a sufficient frequency, then it will greatly hamper their ability to yield energy. Small wind turbine developments in Hong Kong are also in their infancy and many professionals in Hong Kong do not have much experience in regard to wind turbine installations.

Wind turbines are also recommended for larger developments, where large tracts of land are available for an actual wind farm to allow ample placement of such equipment. Large wind turbines are more preferable as well, as they have a much higher output power. Larger wind turbines are taller, and they will be able to capture more wind to turn the turbine blades. It is also important to

note that it may also be more desirable for the wind turbine developments to be situated offshore or more closely to shores. As in the case demonstrated for Cheung Chau, winds are stronger around bodies of water and it will help wind turbine developments yield more energy.

Lastly, there are also various uncertainties and factors that may affect the energy payback periods which may be worth considering in future studies. These include depreciation of the dollar value, and deterioration of the mechanical equipment over time and quality of the materials used in the systems.

## Appendix

Table A1. Solar Photovoltaic (PV) comparison in Hong Kong (CLP, 2016).




	Mono-crystalline (Crystalline)	Poly-crystalline (Crystalline)	Amorphous silicon (Thin-film)
			
<b>Manufacturing method</b>	Made from a single continuous crystal lattice structure	Silicon wafers are produced by casting or by forming thin ribbons directly from the silicon melt	Use a homogeneous layer of silicon rather than a crystal structure
<b>Cell efficiency</b>	20% - 25%	10% - 24%	6% - 9%
<b>Equipment Cost</b>	HK\$24 - 40/watt	HK\$24- 40/watt	HK\$16 - 24/watt
<b>Advantages</b>	Highest efficiency	<ul style="list-style-type: none"> <li>• Cheaper than mono-crystalline cells;</li> <li>• Simpler and less energy-intensive to manufacture than mono-crystalline cells</li> </ul>	<ul style="list-style-type: none"> <li>• Cheaper than crystalline cells;</li> <li>• Can be used on curved and flexible surfaces;</li> <li>• Lightweight</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>• Complicated and relatively expensive to manufacture;</li> <li>• Heavy weight compared to thin-film installation</li> </ul>	<ul style="list-style-type: none"> <li>• Less efficient than mono-crystalline cells;</li> <li>• Heavy weight compared to thin-film installation</li> </ul>	<ul style="list-style-type: none"> <li>• Less efficient than crystalline technologies</li> </ul>

Table A2. Horizontal wind turbine products from the manufacturer based in Taiwan.





	(DB1500) 1500W 24V 60A Wind Turbine Generator kit	DB-1200 1200W 24V 42A Wind Turbine Generator kit	(DB-600) 600W Wind Turbine Generator kit	(DB-400) 400W 12V Wind Turbine Generator kit
				
<b>Rated Power</b>	1500 W	1200 W	600 W	400 W
<b>Rated Speed</b>	46 ft/s	31 mph	31 mph	46 ft/s
<b>Voltage system</b>	24 V	24 V	12 V & 24 V auto-detect	12 V
<b>Cut-in wind speed</b>	5.6 mph	4.5 mph	4.5 mph	6.7 mph
<b>Suggested battery capacity</b>	200 A or larger	100 A or larger	100 A or larger	50 A or larger
<b>Number of blades</b>	3	3	3	3
<b>Rotor diameter</b>	5.6 ft	5.6 ft	4.3 ft	4 ft
<b>Weight</b>	33 lbs	33 lbs	26 lbs	22 lbs
<b>Cost</b>	US\$1,500	US\$999	US\$549	US\$399

Table A3. Vertical wind turbine products from the manufacturer based in Mainland China.

Model	DG-800H	DG-1000H	DG-1500H	DG-2000H	DG-3000H	DG-5000H	DG-10000H	DG-20000H
Rated power	800W	1kW	2kW	2kW	3kW	5kW	10kW	20kW
Max power	830W	1.2kW	2kW	2.2kW	3.5kW	5.5kW	12kW	23kW
Rated voltage	48V	48V	48V/96V	48V/96V	96V/120V	120V/220V	360V	360V
Start-up wind speed	2m/s	2m/s	2m/s	2m/s	2m/s	2m/s	2.5m/s	2.5m/s
Rated wind speed	12m/s	12m/s	12m/s	12m/s	12m/s	12m/s	12m/s	12m/s
Survival wind speed	35m/s	35m/s	35m/s	35m/s	35m/s	35m/s	35m/s	35m/s
Wheel diameter	2m/s	2.2m	2.55m	2.55m	2.85m	3.6m	5.8m	7.6m
Wheel height	2.2m	2.4m	2.8m	3m/2.6m	3.5m/3m	4.5m/4m	8m/6m	10m/9m
Number of blades	5							
Blades material	Casting aluminum alloy	Reinforced glass fiber				Casting aluminum alloy		
Generator type	Three phase permanent magnet AC synchronous generator							
Control system	Electromagnet							
Working temperature	-40oC~80oC							

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