# A Remote Sensing Study of Solar Energy Supply in Cloud-prone Areas of Hong Kong

# 太陽能供應在香港多雲地區的遙感研究

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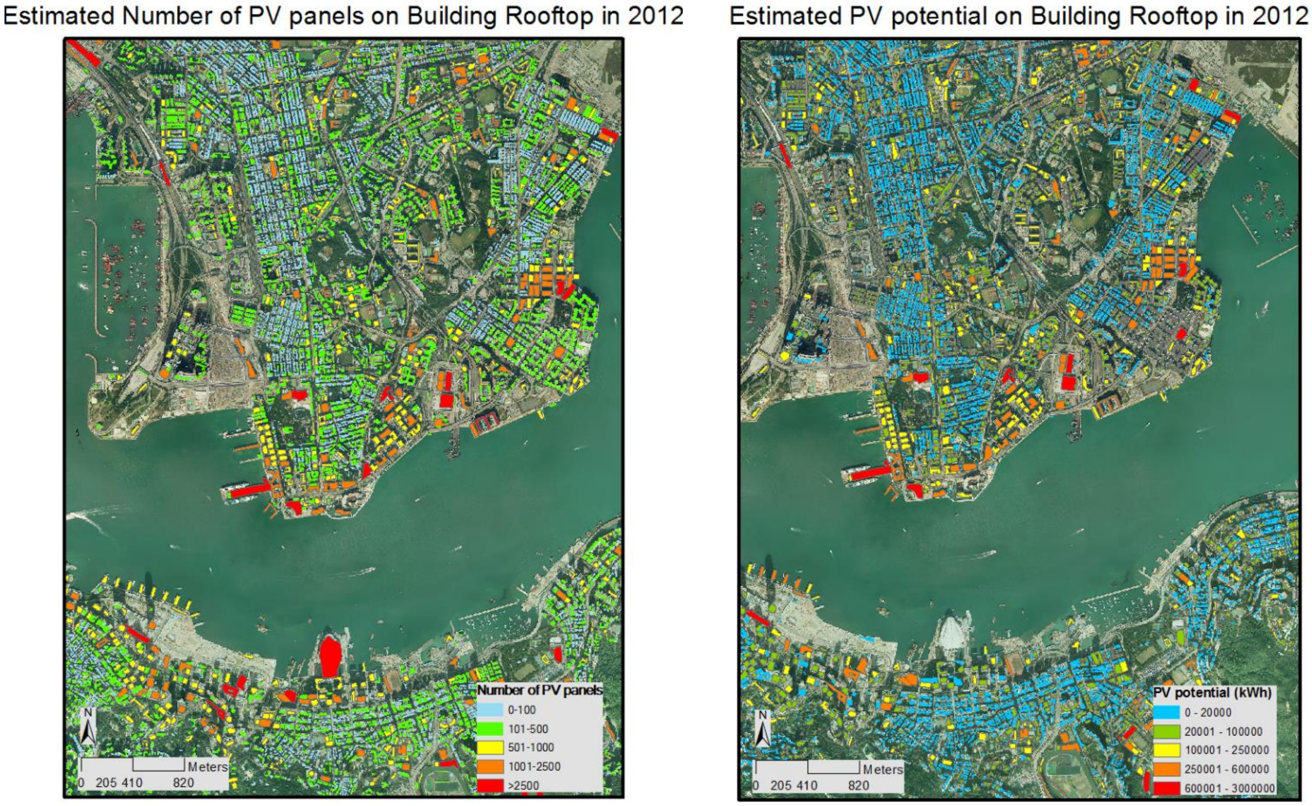
# ABSTRACT

Hong Kong is a high energy-demand city. Burning fossil fuels e.g. coal, oil and natural gas during electricity generation releases greenhouse gases and pollutants into the atmosphere. Due to the rapid scale of economic and population growth, anthropogenic greenhouse gas emissions have increased and are now higher than ever (Intergovernmental Panel on Climate Change (IPCC), 2014). The greenhouse gases will accelerate the insulating effect in the atmosphere and also are the major causative factors in global warming. The mitigation of climate change has become a major public objective, and using renewable energy is one method to achieve this. In order to encourage the usage of solar photovoltaic (PV) technology in Hong Kong, this study aims at utilizing Geographic Information Systems (GIS), Remote Sensing (RS) and airborne LiDAR technology to determine appropriate locations e.g. available rooftop areas, and total potential output power for the deployment of solar photovoltaic systems in Hong Kong. In addition, in order to derive a spatial cloud cover map for Hong Kong, geostationary satellite images from the Multi-functional Transport Satellite (MTSAT) were acquired and used for cloud mapping. The land utilization map of Hong Kong (LUM HK), digital elevation model (DEM)/ digital surface model (DSM), building GIS data and tertiary planning unit (TPU) data were also used as ancillary data.

The Solar Analyst was used to estimate solar radiation in unused areas on rooftops and areas of open spaces. The Solar Analyst generates a hemispherical viewshed for every location according to the input DSM and DEM data. Firstly, a 3 x 3 median convolution was applied for both DSM and DTM data. Then, the DSM data were resized to 3 meter resolution and input to ArcGIS software for calculating solar radiation. Solar Analyst was implemented to calculate solar energy of the entire Hong Kong territories. Several criteria were applied to filter out the unwanted pixels. After identifying the ground pixels, barriers (buffer minus 1m) on rooftops, shadows and steeply sloping pixels by decision tree classification, the optimal area of rooftop pixels could then be identified. Then, the building polygons and solar radiation map were spatially joined. Assuming that at least two solar panels should be deployed at each potential site, polygons with area less than 3 $m^2$ were then removed. More detailed descriptions of the solar model and calculation of PV potential are given in the Completion Report.

Figure 1 shows the (a) estimated number of PV panels on building rooftops and (b) estimated PV potential (unit: kWh) on building rooftops.




a. b.

Figure 1. (a) Estimated number of PV panels on building rooftops; (b) estimated PV potential on building rooftops

This research indicates that in Hong Kong, there are 309,606 buildings, of which 233,152 buildings are suitable for implementing the PV system. The total solar radiation received by building rooftops is 31 TWh in 2012 and the total potential PV output energy is about 2.43 TWh. Thus, the average output for each building is about 10.427 MWh. The maximum annual solar energy on building rooftops is about 160 GWh. The total area of PV employment on rooftop areas is about 28,643,335 $m^2$ and the average solar radiation is 1773 kWh. Residential buildings provide 648 GWh energy with utilization ratio of 64%. Commercial buildings provide 166 GWh with utilization ratio of 67% and industrial buildings provide 410 GWh with utilization ratio of 78%. This indicates that industrial buildings are capable of employing PV systems efficiently, but residential buildings can produce the largest amount of electricity. Considering the open spaces, there are about 24,217,705 $m^2$ of open spaces in Hong Kong, and some are suitable for installing PV modules. The total estimated energy in these 2,475 open space areas is about 38 TWh.

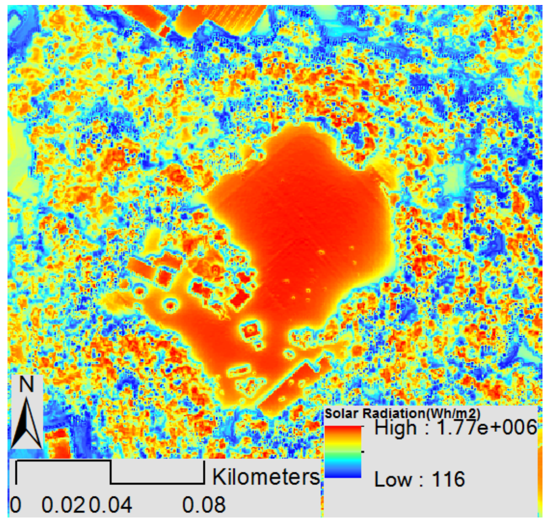
In 2012, the Hong Kong residential electricity consumption is 41,188 TJ, commercial usage is 102,440 TJ, industrial usage is 11,283 TJ, and the annual street light consumption is 390 TJ. Thus overall, the Hong Kong's total electricity consumption is 161,528 TJ. Electricity generated at local plants is 139,506 TJ and 42,508 TJ is imported from China. There are 20,487 TJ due to system loss and 6,616 TJ exports to mainland China. System loss includes energy losses in electricity generation, transmission and distribution. It also includes electricity consumed within the electricity companies. The estimated PV potential is calculated as 2.66 TWh on building rooftops and 2.88 TWh in open space areas. The total electricity output is 5.54 TWh. Supposing all the rooftops have deployed the PV systems in Hong Kong, the potential energy can cover 5.9% of the city's total consumption and 6.9% of local electricity generation in Hong Kong. If PV systems are implemented in all open spaces, this will contribute 6.4% of the total consumption and 7.4% of local electricity generation in 2012. Supposing PV systems are deployed at the buildings in Government, Institution and Community facilities, the estimated output is 511.7 GWh. This covers 1.1% of total consumption and 1.3% of local electricity generation in 2012. More details of different types of buildings, their PV potentials, and average utilization ratios are given in Table 1.

| Type of Buildings (temp structure excluded) | Total PV potential (GWh) | Average utilization ratio |
|---:|---:|---:|
| Residential buildings | 648 | 64% |
| Commercial/Business & Offices | 166 | 67% |
| Industrial buildings | 410 | 78% |

Table 1. Summary of different types of buildings, their potential PV and utilization ratio

Although some promising results have been observed, there are still some limitations and uncertainty in this study. The accuracy of the insolation model could be improved if more ancillary data were provided. The solar model was processed using a 3 m resolution DSM. This may not be adequate to estimate all detailed objects on rooftops. For achieving higher accuracy estimation, a DSM with higher resolution, e.g. 0.5 meter, should be adopted, but this may require longer computer processing time. In this study, the average PV potential has been validated with observation data from the Hong Kong Observatory (Figure 2). Since the solar model from ArcGIS does not account for cloud cover, a discrepancy of the average solar radiation between the solar model and the Hong Kong Observatory is observable. More ground observation data of solar radiation measurements should be collected in order to refine and modify the numerical model, and further work on integrating the cloud probability map with the solar model will be conducted in the near future.

a.

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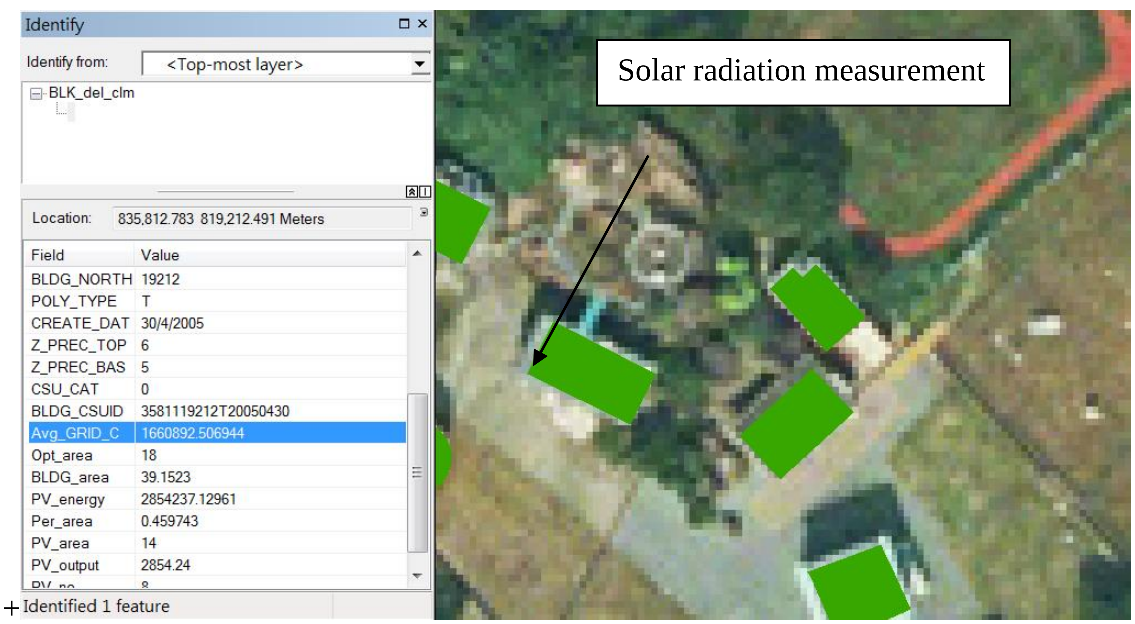


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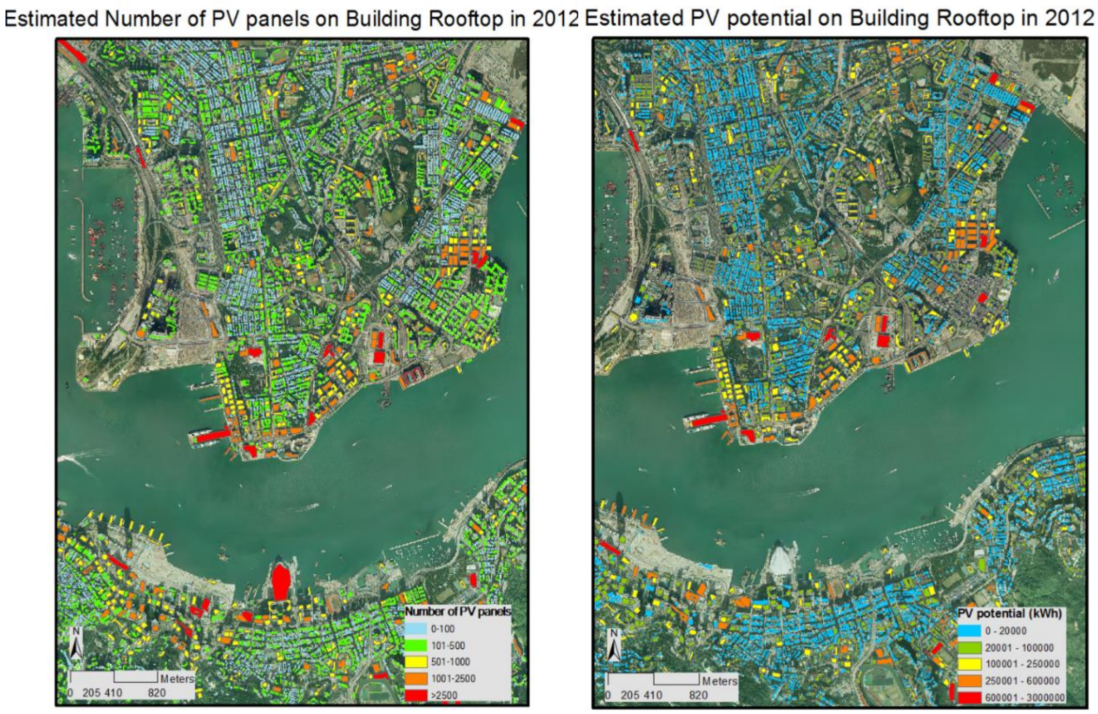
Figure 2. (a) True-color image; (b) insolation map of the King's Park; (c) the estimated solar radiation of solar radiation equipment at King's Park

# 本文摘要

香港是一個高能源需求的城市。發電過程中，煤、石油、天然氣等化石燃料的燃燒會向大氣排放大量的溫室氣體與污染物。由於經濟與人口的急速增長，人為溫室氣體的排放已達到歷史最高位，並呈持續增長趨勢（IPCC, 2014）。溫室氣體吸收及阻止熱能往外傳送，造成地球暖化的現象，這正是全球變暖的主要成因。減輕氣候變化已經成為大眾共同的議題。利用可再生能源是減輕這現象的方法之一。為了鼓勵香港地區對太陽能光伏（PV）發電技術的使用，本次研究旨在綜合利用地理資訊系統（GIS）、遙感（RS）以及機載雷射雷達（LiDAR）技術在全港尋找合適的屋頂可用位置、可用空置地放置太陽能光伏板，並估算香港太陽能光伏系統潛在的輸出能量。對地同步衛星影像(MTSAT)將用於生成香港雲量空間圖。除此之外，香港土地利用圖（LUM HK）、數字高程模型（DEM）/數字表面模型（DSM）、建築物 GIS 資料以及規劃單元（TPU）將作為本次研究的輔助數據。

Solar Analyst 在本次研究中用於估算屋頂及空地等未使用地方的太陽日照及太陽能光伏潛力。它可以根據輸入的 DSM 與 DEM 數據生成每個位置相應的半球可視域。首先，將 3*3 的中值卷積應用於 DEM 與 DSM 數據。接著，將 DSM 數據的空間分辨率調整為 3 米，並輸入 ArcGIS 軟體計算太陽輻射。這樣，利用 Solar Analyst 可以實現對整個香港地區的太陽能計算。其次，通過設定一系列的標準可以剔除不符合要求的像素。決策樹分類方法可以識別出地面，屋頂圍欄、陰影與陡峭斜坡等，剩餘的最合適屋頂像素則可以被找出。建築物矢量圖和太陽日照圖可以按空間進行合併。假設每個可用的位置需要放置至少兩塊太陽能板，面積小於 3 平方米的

地方就需要被剔除。有關太陽日照模型的討論以及光伏潛力的估算將在完成報告具體介紹。圖 1 (a)展示估算的建築物屋頂可放置的太陽能光伏板的數量。圖 1(b)是相應的太陽能光伏潛力。




a. b.

圖 1. (a)建築物屋頂太陽能光伏板數量；(b)建築物屋頂太陽能光伏潛力

研究表明，香港地區共有 309,606 座建築物，其中適合放置太陽能光伏系統的有 233,152 座。2012 年建築物屋頂接收到的總太陽輻射為 31 TWh，潛在的總太陽能光伏輸出能量約為 2.43 TWh。因此，每個建築物的平均輸出能量為 10.427 MWh。屋頂接收到的年太陽能最大值為 160 GWh。太陽能光伏佔用的屋頂總面積約為 28,643,335 平方米，平均太陽輻射 1773 kWh。住宅區提供 648 GWh 能量，利用率為 64%；商業區 166 GWh，利用率為 67%；工業區則提供 410 GWh 能量，利用率為 78%。這闡明工業區可以有效地使用太陽能光伏系統，但是住宅區可

以提供最多的電能。針對空地地區，香港空地共計 24,217,705 平方米，部分適合安裝太陽能光伏模塊。2,475 個空地可以產生的能量估計有 38 TWh。

在 2012 年，香港住宅區耗電量為 41,188 TJ，商業區消耗 102,440 TJ，工業區消耗 11,283 TJ，而街燈年消耗為 390 TJ。因此，香港 2012 年總耗電量為 161,528 TJ。本地發電廠共發電 139,506 TJ，另外 42,508 TJ 來自於中國大陸。20,487 TJ 為系統損耗，另有 6,616 TJ 輸出至中國大陸地區。系統損耗包括在生產、傳輸與分配電能的過程中造成的能量流失，同時也包括在發電企業內部的電能消耗。屋頂區域估算的太陽能光伏潛力為 2.66 TWh，空地區域為 2.88 TWh。假設香港所有的屋頂或空地都放置太陽能光伏系統，產生的能量可以分別覆蓋總消耗的 5.9%或 6.4%，且分別佔香港發電量的 6.9%或 7.4%。假設在政府、公共設施與社區建築安置太陽能光伏系統，估計總輸出量在 511.7 GWh，佔總耗電量的 1.1%，佔發電量的 1.3%。其他類型的建築物、以及對應的太陽能光伏潛力及平均利用率可見表 1。

| Type of Buildings (temp structure excluded) | Total PV potential (GWh) | Average utilization ratio |
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表 1. 不同類型建築物太陽能光伏潛力與平均利用率

儘管本項目取得了一系列的研究結果，本項研究仍然存在著一些局限性與不確定性。如果可以獲得更多的輔助資料，日照模型的準確性可以進一步提高。研究中利用 3 米分辨率的 DSM 數據模擬得到太陽日照模型，但用於估算屋頂全部細節並不合適。為了提高估算的準確性，0.5 米的 DSM 更適合，但相對地，需要更長的電腦處理時間。在本研究中，平均太陽光伏潛力將與香

港天文台的觀測資料進行對比驗證（圖 2）。由於 ArcGIS 產生的太陽模型沒有考慮雲量，由太陽日照模型和香港天文台得到的平均太陽日照值存在著一定的差異。更多的地面太陽日照觀測值可以用來改進數位日照模型，而未來的研究方向將著重在如何將雲概率圖與太陽模型互相結合。

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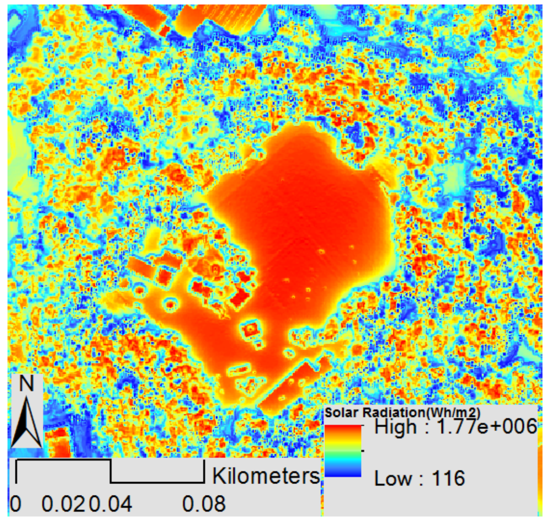


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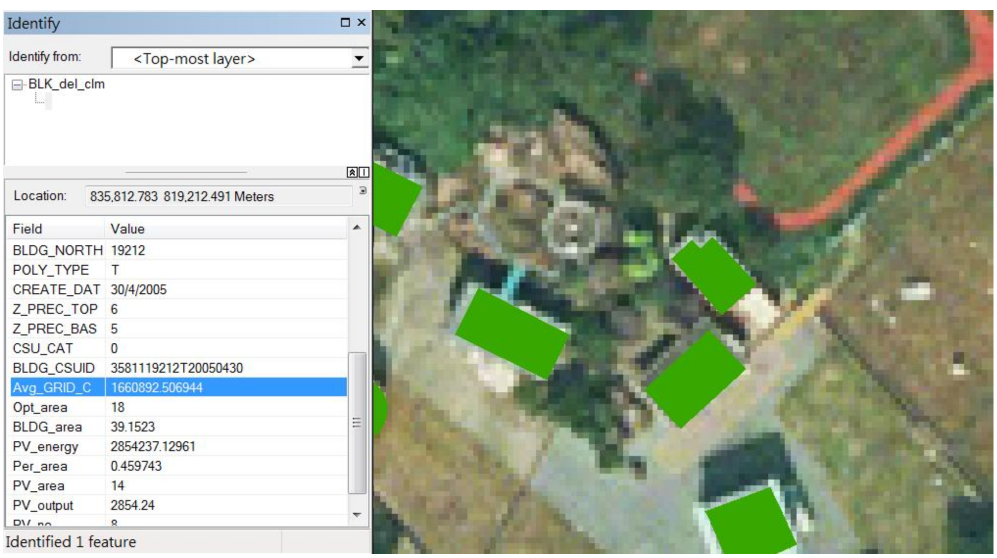


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圖 2. (a)真彩色影像；(b)京士柏公園日照圖；(c)位於京士柏公園的太陽日照儀器估算太陽日照值

# POLICY IMPLICATIONS AND RECOMMENDATIONS

Hong Kong, as a metropolitan city with a service-oriented economy, needs large amounts of energy to support economic activities. However, if energy consumption continues to escalate, projected carbon dioxide emissions generated for the year 2015 are expected to grow by 59% from the year 2000 level (EMSD, 2011). The terms "New Energy" or "New and Renewable Energy" have been highlighted in the Energy Saving Plan for Hong Kong's Built Environment 2015-2025+. It has been emphasized that Government will take the leadership in photovoltaic installation for Government projects after 1 October, 2015, and all other Government buildings should incorporate renewable energy technologies as far as reasonably practicable (Energy saving plan, 2015).

It is also worth noticing that in some regions, the renewable energy industry has developed successfully with the support of Government policies. Solar power is a rapid growing industry in China. In 2011, the construction of the world's largest solar farm - the 200 MW Huanghe Hydropower Golmud Solar Park was completed. It is expected that the country's total installed solar capacity will grow to 1,800 MW by 2020 (Ma, 2013).

In the context of these developments, this study examined unused areas on rooftops and open space areas, for potential supply of solar energy in different sectors of land uses in Hong Kong. Results suggest that a tremendous amount of potential energy can be received by PV systems, and can support 5.9%, 6.4%, 1.1% of total electricity consumption in 2012, with the deployments on all appropriate rooftops, open spaces, and building rooftops of Government, Institution and Community facilities, respectively. The effective usage and planning of PV deployment will help to reduce Hong Kong's reliance on fossil fuels and reduce greenhouse gas emission.

The following recommendations for encouraging and promoting usage of solar energy can be considered.

- In the assessment of BEAM plus, 1 to 5 credits where the minimum percentage of 20% to 100% of the building footprint being covered/used by PV panels respectively and/or other renewable power facility generation will be given, in order to encourage the usage of renewable energy. Since some areas on rooftops are always under the shadow e.g. areas near barriers or water tanks, a simple estimation based on the percentage of building footprint may not be realistic. A guideline of estimating appropriate potential areas for PV deployment should be established, e.g. this study developed a decision tree method while considering inappropriate areas such as areas near barriers, shadows, steeply slopes, and areas less than 3 $m^2$.

- This study demonstrates the potential energy from PV systems on building rooftops of Government, Institution and Community facilities. It is also aligned with Government policies, e.g. all new schools and educational buildings irrespective whether air-conditioning is provided or not, should aim to have at least 1% of electricity consumption for their general power and lighting provided by renewable energy as far as reasonably practicable (Energy saving plan, 2015).

- Subsidy may be considered for commercial, residential and industrial buildings for deploying PV system on rooftops, since our findings illustrate that industrial buildings are capable of employing PV system efficiently with more spaces, and residential buildings with the largest number of buildings can produce the largest amount of electricity. These can provide financial support and incentive for the building owners to deploy PV system.

- Our research group has started to investigate the feasibility of deployment of PV system on building wall facets. A three-dimension model of Kowloon peninsula has been established, and a preliminary study of estimating the solar radiation on high-rise buildings has been conducted (Figure 3). Thus, the PV system on wall facets can support the electricity of individual households with proper energy saving battery, e.g. Powerwall by Tesla.

Powerwall is a home battery for charging the electricity generated from solar panels. More research study will be carried out by our research group in the phase 2 public policy research study, if any.


Figure 3. Three-dimensional solar insolation model of Kowloon peninsula (case study at the Hong Kong Polytechnic University, Hung Hom)

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