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A GIS assessment on the feasibility of onshore solar and wind energy development in Hong Kong

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Abstract

While the government of Hong Kong has acknowledged the need to increase renewable energy contributions in its fuel mix, the implementation of renewable energy projects in the region is constrained by complex topography and limited land availability. To overcome these challenges, a pragmatic solution is devised through the use of a site suitability analysis which expedites the identification of optimal locations for renewable energy development in the region. Despite the widespread utilization of this methodology in numerous other wind/solar studies, its application is notably absent in Hong Kong.

This paper presents the development, implementation, and results of a site suitability analysis for identifying feasible rural solar and onshore wind energy sites in Hong Kong. To enable efficient analysis, a site suitability tool was created for Hong Kong that, given various development constraints, generates a suitability map for potential onshore rural wind/solar farm sites. Additionally, by utilizing both spatial and attribute data, a suitability score is allotted to each identified location, facilitating efficient comparison and ranking. These were used in this study to explore the degree to which the various criteria restrict the suitability of sites and consequently impede the progress of solar and wind energy development in Hong Kong. In order to maintain consistency with existing Hong Kong standards, the model parameters applied for each constraint were derived from benchmark values sourced from the Lamma Island Wind Turbine and Living Spring Renewable (Solar) Energy Station.

The analysis reveals that, while it is feasible to enhance electrical generation through onshore wind turbines, the potential overall capacity is unsubstantial when measured against Hong Kong's electrical demands and wind energy targets. Conversely, ample sites exist for the establishment of solar farms to generate sufficient electricity to meet Hong Kong’s solar renewable energy goals. However, their large footprint, and consideration of Hong Kong's spatial and social constraints suggests that alternative, less spatially intrusive approaches might be preferable. Consequently, this study identifies that the potential of rural solar farms and onshore wind turbines lies in their capacity to complement existing and future alternative energy sources and so foster a diversified and comprehensive energy portfolio for Hong Kong.

List of Abbreviations

AFCD: Agriculture Fisheries and Conservation Department

AHP: Analytic Hierarchy Process

CLP: CLP Holdings Limited

GHG: Green House Gas

GIS: Geographic Information Technologies

HK: Hong Kong

HK30: Hong Kong 2030+

HK50: Hong Kong 2050

HKEC: The Hong Kong Electric Company

LIWT: Lamma Island Wind Power Station

LSRES: Living Springs Renewable Energy Station

MCDM: Multi-criteria Decision Making Methods

Solar Analysis: Solar Microgrid Site Suitability Analysis

SSA: Site Suitability Analysis

Wind Analysis: Wind Turbine Site Suitability Analysis

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1. Introduction

The implementation of onshore wind and rural solar projects in Hong Kong (HK) can face challenges due to the region's complex topography and limited land availability. This was highlighted by the government in their sustainability plans through the acknowledgement that the region is short of favourable locations for utility large-scale commercial renewable energy generation (Environment Bureau, 2017).

As geographic information technologies (GIS) enable efficient spatial analysis of a region, the utilization of GIS can prove an effective solution to address these challenges. Despite the global widespread use of site suitability analysis (SSA) in determining locations for renewable energy development, published research on this practice for HK is limited[1]. A SSA leveraging GIS would rapidly identify and exclude unsuitable areas while pinpointing optimal wind and solar development sites. Consequently, conducting a publicly accessible comprehensive SSA is a simple yet effective measure to facilitate and promote the exploration and realization of wind and solar energy developments in the region.

This paper presents the development, implementation, and results of an SSA aimed at identifying feasible rural solar and onshore wind energy sites in HK, and answers the research question: 'To what extent does Hong Kong possess the potential for onshore solar and wind energy development?' At the heart of this study is the creation of an 'ArcGIS pro' tool, enabling rapid and efficient analysis of potential locations. This tool was designed to allow the user to incorporate various constraints on the suitability of sites and also calculate a 'suitability score' to enable sites to be ranked in order of attractiveness. To ensure alignment with the established principles and values of the HK government, this research employs the Lamma Island Wind Turbine (LIWT) and Living Spring Renewable Energy Station (LSRES) as foundational benchmarks for specifying constraints. Additionally, this study explores the degree to which the various criteria restrict the suitability of sites and consequently impede the progress of solar and wind energy development in HK.

[1] Please note that this statement is mostly limited to English publications as papers on the subject written in either Cantonese or Mandarin may have been overlooked due to challenges in translation.

2. Background

a. Hong Kong

In 1842, following its cession from China, HK came under British control (Chan & Young, 2015). The territory remained a British colony until 1997, at which point sovereignty transferred back to China under the "one country, two systems" principle, with HK designated a 'Special Administrative Region of the People's Republic of China'. This classification afforded HK a significant degree of autonomy and allowed it to maintain its own government and economy under the sovereignty of China (HK Gov - The Basic Law, May 2021).

Today, HK has a distinctive culture reflecting a history that encompasses a mixture of traditional Chinese and contemporary western influences (Henderson, 2001). Its economy is highly developed, having evolved into a thriving global financial hub, featuring the seventh - largest stock exchange in the world (Statista, 2023). Moreover, it is a major centre for international banking and finance (Z/Yen Group Limited, 2023), hosting numerous multinational banks and financial institutions.

Economic growth has been accompanied by a population surge in the last half century, with an estimated 7.4 million inhabitants in 2020 - an increase of approximately 90% from 1970 (World Bank, 2023). In accommodating this population expansion, the regions topography and government's land-use policies have led to a concentration of urban development on just 25% of the territory (Wang et al., 2015), leading to a preponderance of high-rise construction. These land-use policies have contributed to HK becoming one of the most densely populated places in the world (World Bank, 2023) and its status as one of the most expensive real-estate markets globally (Statista, 2023).

In contrast to its densely populated urban areas, HK has extensive natural and protected areas encompassing approximately 40% of its total territory (HK Gov, 2022). These spaces include national parks, marine parks, and nature reserves, and provide ecological refuge for a variety of species of flora and fauna. The topography of HK is generally of steep densely vegetated hills rising from narrow coastal plains with some relatively flat interior areas. These regions provide recreational outdoor activity opportunities for HK's residents, such as hiking, camping, surfing, and wildlife watching etc.

b. Electrical Energy Consumption and Green House Gas Emissions

In step with technological growth, HK's per capita electric power consumption has consistently risen over the last half century, and the growth in population has compounded this to dramatically increase the total electricity consumption of HK (World Bank, 2023). This increase in electricity consumption caused a corresponding increase in greenhouse gas (GHG) emissions, as electricity generation accounted for a substantial part of their total emission, 60.4% in 2020 (Environment Bureau, 2019).

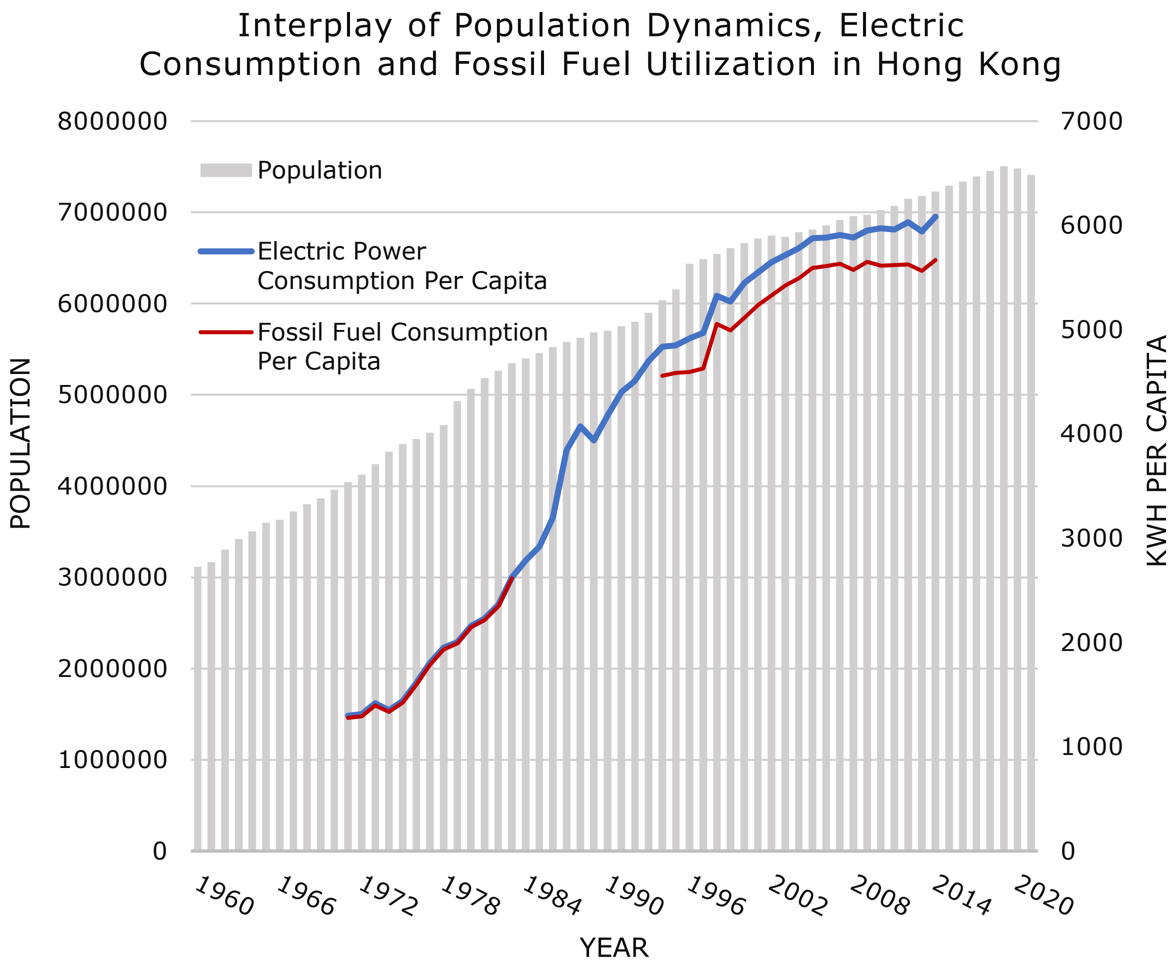

Figure 1: A bar plot illustrating the population trends in HK from 1960 to 2020, overlayed by two line charts. The first line, shown in blue, represents the annual electrical power consumption per capita (from fossil fuels and alternative sources) 1970-2014, while the second line, depicted in red, represents the electrical power consumption from fossil fuel per capita 1970-2014. The chart effectively reveals a noticeable increase in population, electricity consumption and fossil fuel consumption. Note: The data for fossil fuel consumption per capita was not available for the period between 1983 and 1994. (World Bank, 2023) (Ritchie, Roser, & Rosado, 2020).

c. Electrical Energy Generation Fuel Source

Electricity generation and distribution in HK is dominated by two major corporations: 'The Hong Kong Electric Company (HKEC)' and 'CLP Holdings Limited (CLP)' (Lam, 2004). HKE, established in 1890, is the oldest power company in HK and serves HK and Lamma Island (HK Electric, 2023). CLP, established in 1901, is the larger of the two companies serving over 80% of the HK population in both Kowloon and the New Territories (CLP group, 2020).

Over half of all GHG emissions in HK are produced from electricity generation (Environment Bureau, 2019), which in turn can be attributed to the respective fuel mixes of both energy companies. Figure 2 below illustrates CLP's and HKEC's clear reliance on gas, coal and oil, and the deficit in use of renewable energy sources. It should also be noted that the figures exclude the GHG emissions from the transportation of fuel, which, as HK heavily relies on imports for coal and oil, is also significant (EMSD, 2022).

The global consensus regarding the substantial impact of coal and oil combustion in contributing to greenhouse gas emissions is firmly established. This was demonstrated in HK where, between 2019 and 2020, an increase in utilization of gas led to a 20% reduction in coal consumption and a reduction of approximately 16% in GHG emissions. As total electricity generation only fell by 4%, the inference drawn is that significant reductions in GHG emissions can be achieved by a greater utilization of alternative energy sources to coal and oil. The current low utilization of renewable energy sources therefore suggests a vast potential for future growth and development in the industry. (Census and Statistics Department, 2020)

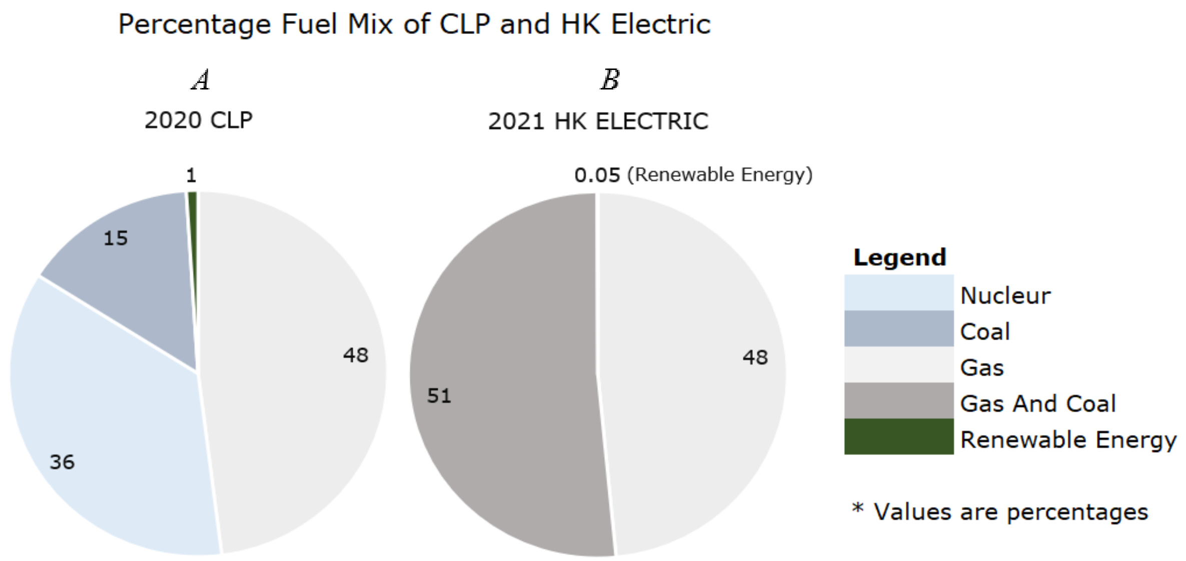

Figure 2: Two pie charts (A and B) depicting the percentage fuel mixes for CLP and HKEC in the years 2020 and 2021. Both charts highlight the notable deficit of renewable energy sources in the respective fuel mix. (HK Electric,2022)(CLP,2022).

d. Hong Kong 2030+ and 2050

Increasing the use of renewable energy sources has been identified by the HK government as a crucial element in its efforts to foster sustainable development, enhance economic competitiveness, and uplift the quality of life for its residents. This is reflected in two of the HK government's long-term development and sustainability plans, ‘Hong Kong 2030+’ (HK30) and ‘Hong Kong 2050’ (HK50).

An aim stated in HK30 is that by 2030, carbon intensity will be reduced by between 65% and 70% of 2005 levels, corresponding to an absolute reduction of 26% - 36%. One of the stated primary measures to achieve this objective is to phase out coal-fired electricity generation. (Environment Bureau, 2017).

HK50 sets a more ambitious goal for carbon neutrality by 2050. To this end, the plan states the aim to significantly increase the proportion of zero-carbon electricity from under 1% to between 7.5% and 10% by 2035, with further increases planned towards a 15% target. Additionally, the use of coal for regular electricity generation is to be phased out by 2035 and restricted solely for backup support. (Civic Exchange, 2021).

While HK30 and HK50 demonstrate that decarbonization is gaining traction in the region, the concept is not new, and future endeavours will be able to leverage the progress made and lessons learned from past and current sustainable initiatives. Notably, HK has already achieved some success in implementing wind and solar energy systems.

e. Solar and Wind Energy in Hong Kong

The development of solar energy in HK has primarily focused on small-scale applications, such as providing hot water, supplying energy to remote weather stations, and implementing modest-sized solar projects in schools and public buildings (Environment Bureau, 2017). Consequently, solar energy accounted for only 0.032% of energy consumption in 2020 (EMSD, 2022). However, although large photovoltaic projects are limited, there are notable exceptions; HK's Disneyland Resort has installed over 7,500 solar panels, creating the most extensive solar energy network in the area. Amongst others, there exists a 1MW commercial-scale solar power system on the roof of Lamma Island power station, a 1.1MW solar farm at Siu Ho Wan Sewage Treatment Works, and floating PV systems installed on the Shek Pik Reservoir and Plover Cove reservoirs (Environment Bureau, 2017) (EMSD, nd). Additionally, efforts to foster increased solar adoption are underway and notably, in 2019, the HK Government launched the "Solar Harvest" program to promote adoption of solar energy. This initiative provides subsidies and assistance to schools and welfare non-governmental organizations, aiding them in installing small-scale PV systems on their premises (EMSD, 2022).

Wind energy has a minor presence in HK, with small-scale projects predominating. One exception is the LIWT of HKEC, which stands out as the first and only commercial-scale wind power station in HK (EMSD, nd). The single turbine has a rated power output of 800KW, a hub height of 46m, a rotor diameter of 50m, and became operational in 2006 (EIA, 2004). Multiple objectives motivated the power station's development, including showcasing the potential of wind power in HK, promoting environmental awareness through educational initiatives, engendering the development of local expertise for future wind energy utilization, and providing electrical energy to the local grid (EIA, 2004). After the completion of the LIWT, HK saw little further progress in wind energy development. However, recent years have seen interest increase, with HKEC and CLP actively exploring the feasibility of establishing offshore wind farms with anticipated completion in the second half of this decade (HK Electric, 2022) (Hong Kong Offshore Wind Limited, 2009).

Within HK30 and HK50, the government projects that, by 2035, solar energy will meet approximately 1-2% of HK's electricity demand, while wind energy could contribute between 3.5% and 4%. Realizing these goals necessitates a concerted effort to harness novel technologies, build upon existing infrastructure and most importantly locate and develop new wind and solar energy sites (Environment Bureau, 2017) (Civic Exchange, 2021).

3. Aim and Research Question

This study aims to assess the feasibility of developing solar and wind energy in HK, along with estimating the potential energy production derived from these sources. Given the complex social and environmental factors amidst urban and offshore development, this study's scope is constrained to onshore rural environments. Within the context of geographical, technical, and societal limitations and constraints, this research addresses the following question: "To what extent does HK possess the potential for rural onshore solar and wind energy development?"

To answer this question, and as a secondary objective in its own right, a bespoke ArcGIS Tool for HK has been developed that serves as a site suitability model, capable of accommodating various spatial scenarios and development constraints. The tool/model has been developed with the intention of being released as an open-source resource, which can be tailored to meet the specific requirements of interested parties for conducting further investigations into solar and wind energy development in HK. It should be noted that user updates, such as the integration of more accurate (up-to date) climate data, is recommended to refine the models' calculations. To promote informed decision-making, the model will utilize factors that, alongside technical considerations, reflect the interests and priorities of HK residents.

4. Study Area

The study area encompasses the entirety of the Hong Kong Special Administrative Region of the People's Republic of China. Located along the south-eastern coast of China at the mouth of the Pearl River Delta, HK's territory comprises Hong Kong Island, the New Territories, Kowloon Peninsula, Lantau Island, and over 261 outlying islands, see figure 3 below.

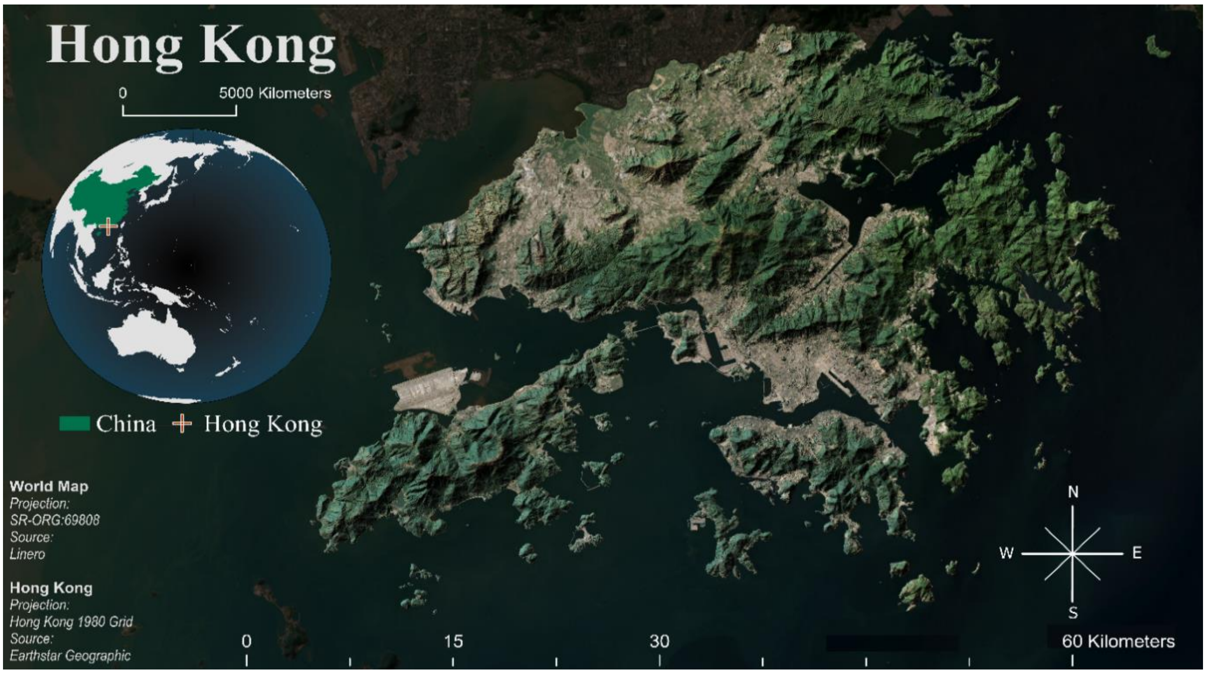

Figure 3: HK Special Administrative Region of the People's Republic of China.

5. <u>Literature Review</u>

The insights obtained from previous site suitability studies were applied in the development of this study. By assimilating their successful methodologies, a comprehensive framework was established that could effectively accomplish the objectives of this study and address the unique characteristics and challenges of HK. The following presents a concise overview of eight studies central to the direction of this study. Additionally, a brief examination on the key findings and methodologies of other relevant studies is also provided.

a. Site Suitability Analysis Literature

i. Identification and Selection of Potential Sites for Onshore Wind Farms Development in Region of Murcia, Spain. (Sánchez-Lozano et al., 2014)

This study focused on the identification and selection of potential sites for onshore wind farm development in the Region of Murcia, Spain. It employed GIS and multi-criteria decision making methods (MCDM) to evaluate and rank feasible sites. The research incorporated legal restrictions and various criteria, such as wind speed, area, slope, and proximity to airports, roads, power lines, and cities. The study utilized two models, lexicographic order, and the 'ELECTRE-TRI' methodology, to assess site suitability.

ii. Developing and Applying a GIS-Assisted Approach to Locating Wind Farms in the UK. (Baban & Parry, 2001)

Baban & Parry's study on UK wind farm site criteria pre-Brexit highlighted the lack of consistent national standards. They emphasized the impact of government regulations like 'Planning Policy Guidance,' crucial for meaningful site suitability studies. Collaborating with various organizations, they conducted a comprehensive survey, revealing the significance of physical, economic, environmental, and resource factors in turbine site suitability. Using two methods—equal weighting and graded weighting—the researchers combine these factors to create a suitability map ranging from 0 (ideal locations) to 10 (unsuitable locations)

iii. GIS-based site suitability analysis for wind farm development in Saudi Arabia. (Baseer et al., 2017)

Baseer et al assessed the suitability of potential wind energy sites throughout Saudi Arabia by considering various climatic, economic, aesthetic, and environmental factors. These factors included wind patterns, road accessibility, proximity to the electrical grid, and safe distances from settlements and airports. The establishment of criteria constraints such as buffer zones, exclusion zones, and suitability scores for each criterion was based on prior published literature. The study employed an analytic hierarchy process (AHP) to assign weights to the criteria based on their relative significance. Additionally, the study conducted a literature review to assess key criteria utilized in various studies for wind turbine suitability analysis.

iv. Site Selection for Large Wind Turbines using GIS. (Bennui et al,2017)

Bennui et al utilized GIS and MCDM techniques to pinpoint viable wind turbine sites in Thailand. Their evaluation process factored in technical and non-technical elements, spanning physical, economic, social, environmental, and political aspects. They employed ten spatial data layers, including urban areas, community zones, landmarks, scenic spots, airports, highways, wind potential, surface roughness, elevation, and water bodies. Identification of unsuitable zones involved exclusion criteria like high elevation, steep slopes, and proximity to communities or tourist sites. Decision-makers assigned weights to criteria via pairwise comparisons, feeding these into an AHP to generate an overall suitability score function, ensuring a consistent assessment of each criterion's significance.

v. Use of Multicriteria Analysis and GIS for Selecting Sites for Onshore Wind Farms: The Case of Andros Island (Bili & Vagiona, 2018)

This study proposed a comprehensive methodology for selecting onshore wind farm sites on Andros Island, Greece. The methodology consisted of four stages: 1) gradually excluding unsuitable areas based on exclusion criteria, 2) considering minimum distances from incompatible zones, 3) excluding areas with existing renewable energy infrastructure, and 4) removing polygonal areas smaller than 300,000m² or 0.3km² to ensure economic viability. The evaluation of eligible areas involved criteria such as wind velocity, slope, distance from the road network, distance from the electricity grid, and social acceptability. The study employed AHP for pairwise comparisons to determine the weights of these criteria.

vi. The Future Scope of Large-Scale Solar in the UK: Site Suitability and Target Analysis. (Palmer et al., 2019)

This study took a comprehensive three-phase approach focused on determining the site suitability of solar panels in the UK. The researchers implemented a systematic method that involved selecting and combining relevant criteria, evaluating solar resources, and examining network connection constraints. To assess solar resources, the study interpolated from satellite-based estimations and used measurements of global horizontal irradiation from meteorological stations. The analysis also considered grid connection constraints by assessing bulk supply points availability and proximity to existing distribution lines. Through a boolean overlay method, multiple criteria were combined to create a site suitability map. Additionally, the study evaluated the impact of each criterion on available land and estimated the potential capacity for solar farms in the UK. The study highlighted the importance of considering planning permission and grid constraints to ensure accurate estimation of the potential solar farm area. Additionally, the study conducted a literature review to assess key criteria utilized in various studies for solar suitability analysis.

vii. Environmental Decision-Support Systems for Evaluating the Carrying Capacity of Land Areas: Optimal Site Selection for Grid-Connected Photovoltaic Power Plants. (Arán Carrión et al., 2008)

The study developed a comprehensive model that integrates multiple criteria and methodologies to optimize grid-connected photovoltaic power plant site selection. It combines MCDM, AHP, and GIS. The model considers environmental factors (solar irradiance, climate data, topography), locational criteria (electrical infrastructure proximity, accessibility), and climate criteria (weather patterns, solar radiation). The study underscores the significance of integrating multiple factors to comprehensively evaluate and prioritize suitable areas for solar installations.

viii. Assessing Socially Acceptable Locations for Onshore Wind Energy using a GIS-MCD Approach. (Harper et al., 2019)

This study developed a predictive model for identifying suitable locations for onshore wind turbine projects by considering both resource availability and planning acceptance likelihood. Social, technical, and legislative restrictions were assessed to determine site suitability, which was accomplished through the use of GIS and MCDM. The results underscored the pivotal role of planning acceptance in a project success. To ensure a thorough analysis, the study employed a multi-layered framework consisting of three main criteria categories: exclusion zones, economic viability, and social acceptability. Exclusion zones consider legislative restrictions and areas avoided by wind developers. Economic viability includes wind speed and proximity to the national power grid. Social acceptability considers factors like population density, protected natural areas, local demographics, and political composition. Acknowledged limitations encompassed data availability, resolution, and non-geospatial factors (like planning processes and local engagement). The researchers suggested prioritizing enhanced data quality, accommodating land cover variations, and assessing impacts on electricity transmission networks. They emphasized the importance of region-specific planning acceptability data for wider international applications.

ix. Other Notable Studies

Watson et al. employed MCDM to evaluate land suitability for wind and solar farm development. The analysis incorporated two types of layers: binary layers for identifying unsuitable regions and factor layers for assessing suitability using specific variables. They found that 60% of the region was deemed unsuitable for development due to environmental constraints. A study by Li employed a multi-criteria system, encompassing ecological, environmental, and socio-economic factors, to conduct a wind resource analysis. This system included 26 sub-criteria, such as sensitivity to nature reserves and distribution of wind energy. AHP and fuzzy logic was utilized to weight and rank these criteria. Ifkirne et al. analysed optimal sites for onshore wind farms in France, weighing six key factors: wind speed (38%), protected areas (26%), proximity to electrical substations and roads (13% each), and land topography, focusing on slope and elevation (5% and 3%, respectively). An estimated 6.98% of the research area was determined as potential sites for wind turbine installation. Brewer et al. examined site suitability for utility-scale solar projects in the Southwestern USA. A key finding of the study is that using social preference data in a SSA greatly reduces suitable areas for solar projects, saving time, money, and resources in site selection.

b. Literature Review Insights

The papers reviewed above (*4a)* served as the basis for the design of this study. Building upon their collective findings and groundwork, several key points emerged that shaped the approach and methodology used herein.

Firstly, the majority of the studies utilized similar criteria during their decision-making processes, highlighting the accepted relevance of these criteria for the site suitability analysis. As a result, the present study recognized the prominence of these criteria and utilized them in its own model. i.e., slope, elevation, distance from airports etc.

The development of a site suitability model for wind/solar farms in HK should follow a structured and objective decision-making process. In accordance with the papers 4a*: I,III, IV, VI, VII* this study will use a MCDM methodology, specifically AHP, to comprehensively evaluate criteria through pairwise comparisons. By utilizing this approach, the model can effectively assess the relative significance of the various factors ensuring a rigorous and systematic process.

It was also noted that numerous papers suggested that the model should consider constraints specific to the local context. These include factors such as protected areas, existing infrastructure, local laws, and land use. By incorporating these considerations, the model could identify suitable locations that minimized environmental impacts and avoided conflicts with existing land uses, cultural values, and local legislation. This approach ensured that the chosen sites are feasible and realistic.

Another important aspect highlighted in the literature is the significance of ensuring that the selected sites align with the overall values and priorities of HK. Consequently, understanding the needs, concerns, and perspectives of stakeholders is vital. This participatory approach fosters inclusive decision-making, enhances the legitimacy of the model, and increases the chances of its long-term success and acceptance. In response to this, the model utilized diverse and up-to-date public spatial data enabling effective local analysis. Additionally, it was designed to enable users to easily modify the decision influencing parameters, enabling the speedy determination of outcomes acceptable to all stakeholders.

6. Site Suitability Model

a. Model Overview

A Python script tool was developed for Esri - ArcGIS Pro to assess site suitability for wind and solar development in HK. The tool allows the input of a variety of criteria and associated parameters that enable a user to define their specific requirements and refine the output results. Identified locations can then be ranked using a weighting scheme specified by the user. All generated output data and results automatically organized into folders within the user's current ArcGIS project folder, ensuring easy access and management.

i. Parameters

Parameters encompass the customizable analysis choices accessible to users. These options come in the following types: project specific parameters, constraints, buffer values, weightings, normalization values and technical parameters.

- *Project specific parameters* dictate the selection of features incorporated into the analysis.
- *Constraints* are either user specified minimum and maximum values for a given criterion, or areas that are selected to be included/excluded from the analysis. Constraints are applied in the initial Boolean analysis stage and any site that violates a criterion constraint is excluded from further analysis.
- *Buffer Values* are used to specify a "buffer zone" surrounding a specific area/feature.
- *Weightings* and *normalization* values are used to calculate a site suitability score based on the weighted average of the selected criterion scores for that site.
- *Technical parameters* control the implementation of the analysis.

ii. Scalability

The model's design prioritizes adaptability and scalability, facilitating easy adjustments for updates. This flexibility ensures the model's long-term effectiveness in strategic planning as new data, future technological advances, expanding requirements and new model functionalities can be seamlessly integrated into the model.

Scalability was achieved through the development of a versatile python script toolbox, which provides a streamlined process for updating, removing, or adding new parameters and data to facilitate continuous evolution and enhancement of the model. This is achieved through a modular design, where each sectional analysis is separate, and generates individual directories that house their analysis results. Only two layers and two field labels are then required from this directory (per section) to direct the boolean and ranked analysis.

iii. Data

The model uses pre-configured datasets stored within its directory. The inclusion of any dataset is optional save for the model's core data components which consist of two binary raster layers used to define the study area. All datasets can be edited by users if required.

iv. Bespoke vs Pre-Built

This study explored pre-existing suitability toolsets, such as a version in ArcGIS Pro's Business Analyst Toolbox. Despite these, it was decided to develop a bespoke tool for HK; as custom functionalities could then be integrated, the back-end analysis could be fine-tuned according to this study's needs, and parameters could be made versatile. Moreover, a bespoke tool can be designed to prioritize user-friendliness, catering to non-GIS experts and thus enabling simple operations without specialized knowledge - an aspect lacking in many alternative tools. Collectively, these aspects enable a bespoke model to better fulfil the requirements of potential users and the objectives of this study, and hence were the primary drivers in the development of this study's model.

v. Model Stages

There are five unique stages in the model's application and analysis. These are outlined in figure 4 below.

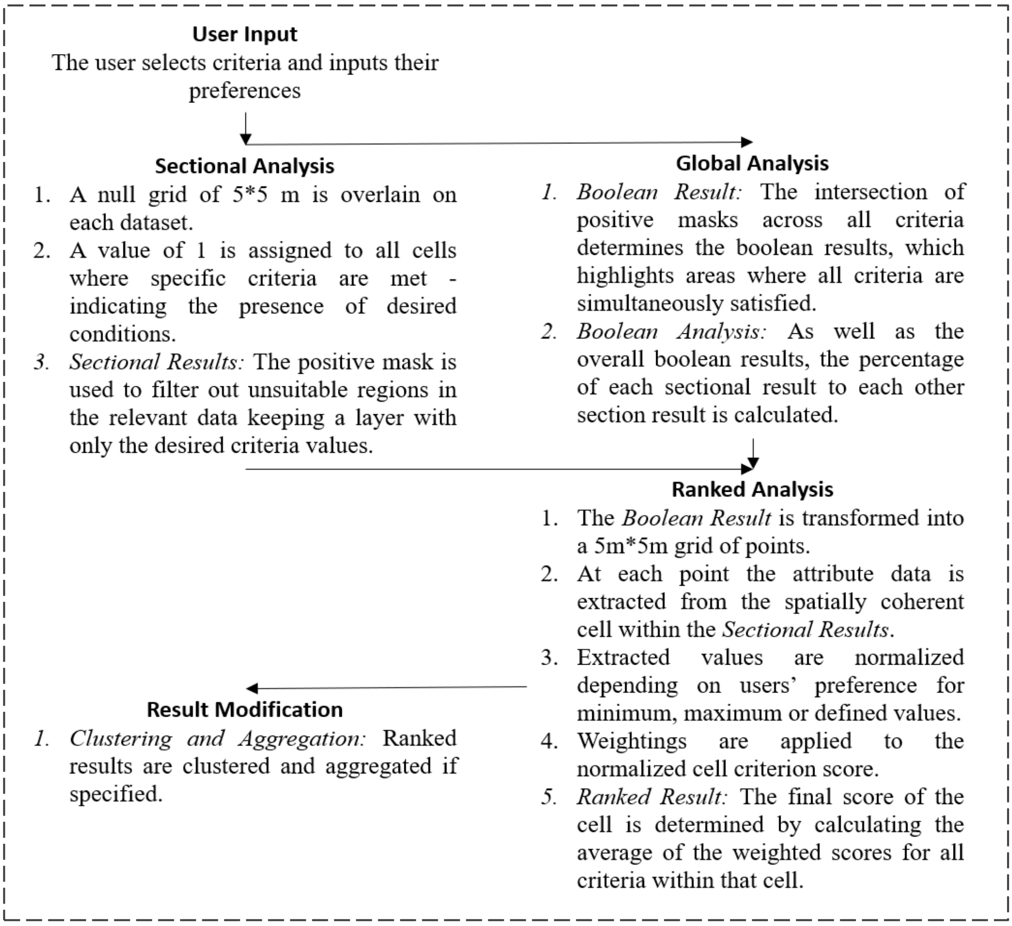

Figure 4: (left) Outline of the site suitability model analysis.

b. Criteria Selection

To determine suitable criteria, this study drew upon existing studies that evaluated wind turbine site suitability and solar site suitability, specifically the studies described above in the literature review (Section 4A) and a study by Wimhurst et al (Wimhurst, Nsude, & Greene, 2023). Similar criteria that occurred in many of the studies were grouped into distinct categories, where each category served as a specific data area to explore within the context of HK. The categories derived from this process were: 'Wind Speed', 'Solar Potential', 'Elevation', 'Slope', 'Temperature', 'Land Use', 'Nature and Conservation', 'Terrestrial Habitats', 'Distance from the coast', 'Proximity to Electrical Grids', and 'Proximity to the Road Network'. Additionally, in recognition of the association between avian conservation and wind turbine sites, a separate category for this was specifically designated within the wind turbine tool, distinct from the category Nature and Conservation. For each category, the data/datasets most appropriate to HK were used as the representative criteria for that category within the model.

The final outcome was a set of criteria and associated datasets that this study determined to be the most representative of criteria employed in previous studies elsewhere and established practices, as well as being suitable in terms of the values and priorities of HK.

c. Criteria Overview

The following section describes the technical aspects of each criterion included in the base tool.

i. Wind Speed

Data Source: Daily mean wind speed data (km/h) was collected from the HK Observatory from 2000 to 30th April 2023 for 29 locations across the territories and pre-processed to obtain monthly and yearly site averages (Data.Gov.hk, 2023). Values for other points were inferred by interpolating the recorded data to produce a continuous wind speed surface (for the user specified period)

Model Parameters: The tool enables the user to specify whether the model uses daily, monthly, or annual average windspeeds, the minimum and maximum wind speed constraints and an interpolation parameter.

Interpolation: The interpolation process employs the inverse distance weighted method – a method chosen for its simple implementation and use, ease of scaling and computational efficiency (Mapscaping, 2023). If multiple months for analysis are selected, the data is averaged across all the chosen periods before interpolation.

ii. Elevation

Data Source: A 5-meter DTM covering the entire administration area of HK was obtained from data.gov.HK, an open-source data library coordinated by the Office of the Government Chief Information Officer (Data.Gov.hk, 2022).

Model Parameters: The tool enables the user to set minimum/maximum elevation constraints.

iii. Solar Potential

Data Source: An evaluation of solar radiation distribution was conducted using the ArcGIS 'area solar radiation' tool, which incorporates multiple factors including sun position, terrain characteristics, atmospheric conditions, specific time parameters, and both the direct and diffuse elements, for every point on the input surface. The output is a raster layer of regional global radiation (WH/m2)[2].

The solar radiation tool was supplied with the 5-meter DTM described above (5.g.ii-Elevation). Temporal settings were configured from sunrise to sunset on significant astronomical event dates, namely the summer solstice, winter solstices, and equinoxes. This was done to ensure a comprehensive evaluation of solar variability throughout the year, as these days mark the extremes and medium duration of daily solar length. To facilitate interpretation and utilization of the results, the data obtained was normalized to percentage values of the maximum for all solar events.

Model Parameters: The tool enables the users to define the minimum acceptable thresholds for solar potential at the summer solstice, winter solstice and equinoxes.

iv. Temperature

Data Source: Daily maximum temperature (^{O}C) data was collected from the HK Observatory from 2000 to 30th April 2023 for 29 locations across the territories and pre-processed to obtain monthly and yearly site averages (Data.Gov.hk, 2023). Values for other points are inferred by interpolating (please refer to section *5.g.i - Wind Speeds - Interpolation*) the recorded data to produce a continuous temperature surface.

Model Parameters: The tool enables the user to specify whether the model uses monthly, seasonal, or annual average temperatures, the minimum and maximum temperature constraints, and an interpolation parameter.

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[2] The total solar radiation received from the entire hemisphere above a specific location on the Earth's surface, including direct sunlight, diffuse radiation, and ground-reflected radiation.

v. Avian Conservation

Data Source: Regional bird species and abundance count was obtained from the Wild Tracks Webpage and converted to raster grid tiles with a resolution of 1km. This data had been collected through bird surveys conducted in 2016-2019 (breeding and wintering seasons). The collection was organised by the staff from the Hong Kong Bird Watching Society using voluntary bird surveyors, surveyors from Ho Koon Nature Education cum Astronomical Centre, and students from the College of International Education of Hong Kong Baptist University. (Hong Kong Bird Watching Society, 2022).

Model Parameters: The tool enables the user to select which season to consider, which of either bird abundance and/or bird species to include, the constraint maximum values and whether the data should be transformed by truncating to the maximum value of the interquartile range - this is done to facilitate percentage comparisons, mitigating the impact of the extreme range of values in the data.

vi. Slope

Data Source: A 5-meter resolution raster depicting slope (degrees) was created using the DTM described above (5*.g.ii-Elevation)*.

Model Parameters: The tool enables the user to set minimum and maximum slope constraints.

vii. Proximity to Road Network

Data Source: Line road data was obtained through Esri China HK and sourced from HK's Transport Department. Underground roads were removed from the dataset. A raster of HK was created and the minimum euclidian distance of its cells to the nearest road calculated. (Hong Kong's Transport Department,2023)

Model Parameters: The tool enables the user to set minimum and maximum distances to the road network as constraints.

viii. Proximity to Electrical Grid

Data Source: A static map produced by CLP Power (CLP, 2023) on their transmission system in the New Territories and Kowloon was manually digitized.

Model Parameters: The tool enables the user to define buffer zone sizes around specified features so that only areas within these zones are included in the final analysis.

Additional Information: The provided data does not encompass the electrical infrastructure of HKEC situated on HK Island, Ap Lei Chau, and Lamma Island, or the low voltage transformers scattered throughout the territories. Consequently, the incorporation of this criterion into the model is predominantly for localized analysis within CLP managed regions.

ix. Proximity to Coast

Data Source: A HK raster was generated, where each cell contains the minimum Euclidean distance from that cell to the edge of the study area (Hong Kong boundary) – please refer to '*5.A.iii -Data*'

Model Parameters: The tool enables the user to select the size of buffer zone that denotes the minimum distance from the edge of the study area (coast) that is considered suitable for solar and wind development.

x. Nature and Conservation

Data Source:

- The following datasets were obtained via Esri China HK and sourced from the Agriculture, Fisheries, and Conservation Department (AFCD) (AFCD, 2023):
  - *Sites of scientific interest*
  - *Priority sites for enhanced conservation*
  - *Conservation areas*
  - *Fish culture zones*
  - *Ecologically important streams*
- Beach data: A beach dataset supplied by Esri China HK (AFCD, 2022) was transformed into a polygon shapefile by manually tracing the consistent area surrounding the point locations using satellite imagery.
- Marine reserves: A polygon shapefile representing marine reserves was acquired from Esri China HK. This dataset was found to be incomplete and necessitated manual updates. This was undertaken via geo-referencing the dataset to align with a static map of "Marine Reserves" (AFCD, 2023) made available online by the AFCD.
- Country parks: Geographical data on country parks in HK was derived from the land-use dataset (refer to *5.g.xii – Land use*) and geo-referenced to a static map of the country parks sourced by the AFCD (AFCD, 2022).

Model Parameters: The tool enables the user to select which of these areas (and the size of any buffer zones around them) should be excluded as potential sites.

xi. Terrestrial Habitats

Data Source: Habitat data was sourced from a study by the Chinese University of HK (Kwong et al., 2022). The study utilized machine learning classification algorithms applied to satellite imagery to identify and map 21 distinct habitat types across HK.

Model Parameters: The tool enables the user to select which terrestrial habitats (and the size of any buffer zones around them) should be excluded as potential sites.

xii. Land Use

Data Source: Land use data in HK was obtained through Esri China HK and sourced from the HK's government 'Outline Zoning Plans Planning Scheme Area'. The data on country parks was incomplete and so removed from this dataset to be recreated as its own layer (refer to *5.g.x – Nature and Conservation*). (Town Planning Board,2022)

Model Parameters: The tool enables the user to select which land use (and the size of any buffer zones around them) should be excluded as potential sites. Additionally, due to the abundance of data, an option for grouping similar land use types is available.

d. Criteria Normalization

To enable the comparison and weighting of specific criteria, the values of selected features intended for ranking were normalized on a scale of 0 to 100. This normalization process considers their respective values in relation to either a user defined value or the maximum and minimum values for each feature within the dataset. If higher values indicate a higher degree of site suitability than the following equation is employed:

Normalized Cell Value = 100 (Cell Value - Minimum criteria Value)/ (Maximum criteria Value - Minimum criteria Value)*

However, if lower criterion values are preferable e.g., proximity to the grid, the equation is modified as follows:

Normalized Cell Value = 100(1- (Cell Value - Minimum criteria Value)/ (Maximum criteria Value - Minimum criteria Value))*

Normalisation enables the tool to pursue the objective of maximising the normalised criteria regardless of whether a high or low value of the original criterion is preferable e.g., Wind speed (high) versus proximity to roads (low).

e. Criteria Weighting Method

The model enables criteria weighting to be defined according to either of two methods: AHP and the Direct Weighting Method. In either, each criterion is given a user defined weighting to represent its relative importance to the other criteria or a default value of 1 representing no difference in significance.

The Direct Weighting Method is a simplistic approach that assigns independent isolated weights to each criterion indicating their individual significance. This enhances its user-friendliness but, as it does not consider the relative importance or relationship between criteria, its evaluation is limited (Odu, 2019).

AHP involves systematically comparing categories in pairs and assigning weights based on their relative importance. This method considers the interdependencies and relationships between the categories, leading to a more consistent and accurate evaluation (Odu, 2019).

The result of either method yields a percentage weighting for each selected criterion. The percentage weighting for a criterion is multiplied by the normalized value of that criteria's value for a specific cell to provide a criterion suitability score for that cell. The sum of all criterion suitability scores for a particular cell then gives the overall attractiveness of that location based on all its criteria values.

f. Model Outputs

The model outputs results corresponding to each stage of the analysis. First, it generates 'Boolean Sectional Results' which reveal suitable regions satisfying the constraints for each individual criterion employed in the model. By combining these sectional results, the model produces an overall 'Boolean Result' specifying the areas which satisfy all constraints. The third output, "Boolean Analysis" is a text file containing the percentage contributions of each criterion to the overall boolean result, as well as the interactions between criteria.

Within the boundaries of the 'Boolean result', the model generates a gridded point dataset (where each point represents a 5*5m cell) and calculates the relative suitability of each location in comparison to others through the 'Suitability Score' i.e. the weighted average of the suitability scores of each of the criteria applied to that specific cell.

Finally, the ranked result can be clustered and/or aggregated. Clustering groups the resulting sites by distance from other sites, aggregation removes any sites not part of a group of 2 by 2 cells. This is undertaken to ensure that each potential location has a large enough (surrounding) area to facilitate solar or wind development.

7. <u>Site Suitability Analysis Methodology</u>

a. Constraint/Buffer Values - Primary Sources

The results of this study rely heavily on the determination of appropriate constraint/buffer values. As no standard values exist generally, and in order to align with HK's policies and priorities, the constraint values were derived from two distinct HK case studies: the LIWT and the LSRES. The former was selected as it represents the sole commercial wind turbine in HK (EIA, 2014) and hence is the only exemplar project this study can draw on. LSRES was chosen as, considering HK’s limited space, this study views microgrid farms to have more potential than larger variants. Since LSRES has already proven its commercial viability (Wang et al, 2019) and was successfully implemented in a confined environment (an island), this study considers it an exemplary model for potential solar farms to emulate. It is assumed that the original values and priorities that influenced the decision-making process for these projects are still significant and relevant in the present context.

b. Criteria Parameter Values

This section discusses the parameter values utilized in the assessment of wind and solar site suitability in HK. Please note that a table of values for each criterion’s parameter are shown in Appendix 2.

i. Wind Speed

Wind turbines are subject to technical limitations that establish specific minimum and maximum wind speeds for their operation but, within this range, higher wind speeds generally correspond to higher energy generation (Farm Advisory Service, 2023).

Yearly average wind speed is used in this study as it includes daily and seasonal variations, encompassing both high-intensity and calm periods. This offers a more informative estimation of long-term suitability for wind power generation than daily or monthly wind speeds.

Respecting industry norms, the minimum threshold was set at 9km/h (2.5 m/s), corresponding to the typical wind speed at which wind turbines can initiate power generation. As the average wind speeds in all regions of HK do not surpass 90 km/h (25 m/s) (the upper threshold or cut-off point commonly set or most wind turbines) the maximum threshold was set to the maximum value in the data. (Farm Advisory Service, 2023).

Wind speed is not considered in the assessment of solar site suitability as PV sites are generally built to a standard which allows them to resist wind speeds well beyond the maximum wind speeds experienced in HK.

ii. Solar Potential

Maximizing solar potential is crucial for enhancing electricity generation from solar farms. As HK's relatively small land area results in minimal fluctuations in its local solar radiation, the primary factor affecting solar potential is topography as areas with steep terrain face restrictions due to shading, impacting the feasibility of solar installations in these locations.

Solar potential during both the winter and summer solstices was used in order to integrate seasonal solar variations into the site evaluation results. A benchmark was established by matching the constraint values to those observed at LSRES, requiring a minimum solar potential of 60 and 40 percent for each period, respectively.

Solar potential is not considered in the assessment of wind site suitability as it has no impact on wind turbine efficiency or site suitability.

iii. Elevation

Higher elevations typically experience stronger wind currents (Irwin, J.S, 1979) and solar intensity (Panjwani et al, 2014), leading to increased energy generation. However, extreme elevations can pose challenges in accessing sites for construction, maintenance, repair and may face legal restrictions.

Owing to the privatization of data from the Civil Aviation Department, this study was unable to determine specific legal elevation restrictions. Instead, this study prioritises the assumed (and simplified) benefits of higher elevations versus the potential construction cost increases due to the anticipated advantages of improved wind (Irwin, J.S, 1979), temperatures, solar potential (Panjwani et al, 2014), and enhanced consistency/reliability in energy generation. Additionally, the variability in construction/maintenance costs is difficult to estimate, due to their dependence on the influence of local features e.g., roads. Consequently, this study takes the view that focusing on energy output and reliability will yield more practical and effective insights than incorporating unsound estimates of construction/maintenance costs.

With the highest peak in HK being 958m, this is adopted as the maximum elevation. To counter potential flooding risks, a minimum elevation of 10m is set.

iv. Temperature

Elevated temperatures compromise the efficiency of solar panels, leading to a decrease in the output voltage and, consequently, a reduction in power generation (Alrwashdeh, 2018). Despite this, irradiance boosts output. Hence, even on a hot sunny day, a significant amount of solar energy can still be harnessed, albeit at a diminished efficiency rate. Therefore, when planning the location of a solar farm, it is advantageous to prioritize areas with lower temperatures but high sunlight exposure to optimize the balance between irradiance and heat-induced efficiency loss.

Consequently, the ranked analysis will prioritize areas with cooler conditions to optimize the overall performance of the solar panels. As 25 degrees Celsius is typically taken as the cut-off for non-degraded efficiency (Biwole et al., 2013) we determine optimum areas by referencing only to months with a HK average temperature above 25 degrees namely: April to November. For this period the maximum and minimum temperatures constraints are set to max/min in the dataset respectively, with a preference for lower values.

v. Avian Conservation

Regions exhibiting either a significant concentration of bird species or a plentiful population of birds in their vicinity are less favourable for wind turbine development due to potential habitat disruption during construction and the ongoing risk of bird fatalities from collisions with turbine blades post-construction. (Leung et al, 2012). HK sees a notable influx of migratory birds during winter, preserving these species entails keeping wind development away from locations abundant with birds during this season. In spring, the emphasis turns to safeguarding bird populations by avoiding areas with the greatest variety of species, prioritizing biodiversity conservation (Jay, K, 2022).

To prevent excessive disturbance or exploitation of ecosystems while still allowing for controlled human activities and development, this model sets the constraint maximums as the spring species count and winter abundance count found at LIWT, namely 64 and 33 respectively.

It should be noted that avian conservation has not been included in the assessment of solar site suitability. Construction is typically less impactful, and birds are less likely to be harmed by such systems. Additionally, the parameters outlined in the habitats and nature, and conservation sections effectively prevent the selection of crucial migratory or breeding grounds as locations for solar development.

vi. Slope

Slope impacts the cost and complexity of construction, with relatively flat terrain requiring less excavation and grading work, resulting in reduced costs and minimal impact of construction on the local environment (Xu et al., 2020). Due to these practical considerations the optimal choice of wind turbine sites strives to minimize slope (Xu et al., 2020). Analysis of the LIWT site reveals slopes ranging from 2 to 8 degrees. However, literature indicates that a slope of 8 to 16 degrees is viable (Ifkirne et al., 2022). To address the challenging terrain in HK, this study adopts a 10-degree maximum slope threshold to achieve a balance between minimizing slope and accommodating the topographical constraints of HK's undulating terrain. A preference for locations with minimal slope is applied in the ranked analysis.

Although solar farms encounter similar construction challenges related to slope as wind turbine development, certain inclines can potentially reduce the land area required for a solar installation (Bakirci, 2012). At HK's latitude (23°N) the mid-day solar elevation in HK varies between approximately 40° in midwinter and 90° in midsummer. It is preferable to ensure that the sun's rays are perpendicular to the solar panel's surface as much as possible since optimizing the tilt angle of the solar panel to align with the sun's rays can significantly enhance electricity output (Bakirci, 2012). In the case of HK, the ideal tilt angle for optimal performance is determined to be around 20° (Siraki & Pillay, 2012). However, this approach poses a challenge when deploying panels on flat land, as panels located 'behind' others would be shaded unless they were appropriately 'spaced apart'. This would result in any given number of panels requiring a larger land area than would otherwise be the case. In contrast, sloping terrain allows panels to be positioned "up slope" of each other thus avoiding the shading effect. A 20-degree slope consequently facilitates optimal land use while maximizing solar efficiency.

Since PV panels can nonetheless effectively be deployed on level ground, this research adopts a minimum slope threshold of 0 degrees. To strike a balance between optimum land management, solar efficiency and increased construction expenses, the maximum slope is constrained to an angle of 20 degrees. Due to variations in land availability and construction limitations across different areas, the cost-benefit for a steep or gentle slope is specific to each location and cannot be applied across all of HK. As a result, slope is solely incorporated in the Boolean Analysis and not weighted.

vii. Proximity to Road Network

Adequate road infrastructure is essential for the construction, maintenance, and repair of wind turbines and solar grids. Consideration of the proximity of the site to existing road infrastructure is therefore critical for reducing costs and minimizing the environmental impact of any additional access road construction. At the same time, separation is often required between public roads and the sites to ensure the security of both the site and road users (Xu et al., 2020).

A generalized guideline for ensuring safety and reducing potential risks for wind turbines involves maintaining a distance between the turbine and roads that surpasses the turbine's overall tip height by at least 10% (Central Bedfordshire Council 2022). With LIWT serving as a reference turbine, its 61-meter tip height suggests a clearance of at least 67 meters to ensure safe clearance. In the solar analysis, due to the low probability and insignificance of potential risks, no minimum road clearance distance is set.

Environmental and economic considerations suggest minimizing the distance of development sites to access roads. To avoid substantial construction, the literature review in section *4a* suggest a maximum range of 1000m to 5000m. Due to HK's complex topography, a construction at the lower end of this range is still likely to be a substantial undertaking. To accommodate the demands for adaptable development in remote areas whilst addressing the challenges of HK's landscape, this study sets its upper limit to 500m acknowledging though this is below suggested guidelines, it remains significant considering HK's topography.

viii. Proximity to Electrical Grid

A site's proximity to the electrical grid is important as it directly reduces transmission losses and so improves energy efficiency while cutting down on infrastructure expenses. Moreover, proximity plays a key role in lessening environmental impact by decreasing the requirements for developing expansive power line networks.

Although data is available for much of HK, vital areas such as HK Island lack public data. Consequently, this study is unable to consider the proximity to the electrical grid in its analysis, as its inclusion would distort results.[3]

[3] Please note that while this study did not use this parameter, its inclusion in the model is intended to assist users conducting localized studies within regions encompassed by the electrical grid dataset.

ix. Proximity to Coast

Coastal winds and waves transport salt-laden sea spray over 100 meters inland, causing accelerated corrosion at solar and wind energy site. This corrosion leads to increased maintenance costs, decreased operational efficiency, and reduced lifespan (Takle et al., 2007). Avoiding coastal regions for the placement of solar and wind sites is a straightforward approach to mitigate these effects but restricts available construction space.

Determining the optimal distance from the coastline is complex and requires careful consideration of various factors, including prevailing wind direction, average wave size, and the characteristics of the terrain between the sea and renewable energy infrastructure (Takle et al., 2007). This study noted the positioning of the LIWT to be 328 meters from the coast and the LSRES to be 50m. It is inferred that these distances can be deemed acceptable, and they therefore served as a reference point for their respective SSA. It should be noted that once the threshold distance from the coast has been reached, any additional distance away from coastal regions provides negligible further benefits. As a result, distance from the coast is only be incorporated in the Boolean Analysis.

x. Nature and Conservation

Numerous international conventions, local legislation, and guidelines establish requirements for safeguarding species and habitats. Consequently, the construction of solar or wind farms in protected areas or their immediate vicinity is unlikely to receive planning approval (HK Planning Department, 2020) due to the environmental harm that can occur during and post construction, as well as the infringement on areas of natural beauty and public recreation. For these reasons, the following features and their surrounding areas were considered unsuitable areas for development in both the solar and wind analysis.

- *Beaches*
- *Conservation Areas*
- *Country Parks*
- *Ecologically Important Streams*
- *Fish Culture Zones*
- *Marine Reserves*
- *Priority Sites for enhanced conservation*
- *Sites of Special Scientific Interest*

Please refer to Appendix 2 for the size of the applied buffers around each feature. This study employs a preference for larger distances from these locations in both the solar and wind ranked analysis.

xi. Terrestrial Habitats

Valuable ecological habitats and their immediate surroundings are typically considered unsuitable for development projects due to the potential environmental damage during and post construction. Moreover, specific habitats may hinder the efficiency of a solar or wind site or may simply be incompatible. The following features and their surrounding areas were identified as unsuitable for development in both the solar and wind analysis:

- *Artificial Hard Shoreline*
- *Artificial Pond*
- *Green Urban Areas*
- *Mangroves*
- *Marsh and Reed Beds*
- *Modified Water course*
- *Natural Rocky Shorelines*
- *Urban Areas*
- *Reservoirs*
- *Seagrass Beds*
- *Soft Shores*
- *Woodlands*

Please refer to Appendix 2 for the size of the applied buffers around each feature. It should be noted that once the buffer distance around a habitat has been reached, any additional distance away from the habitat yields minimal additional advantages. Consequently, Terrestrial Habitat and their buffers will contribute solely to the Boolean Analysis.

HK's remaining habitats, all of which are deemed suitable for development, comprise:

- *Agricultural land*

  Already transformed for human use, these areas offer ample space without significantly affecting sensitive ecosystems. However, disruption to this land type should be minimised due to its important role in food production. Consequently, such land is better suited for wind turbines, which, post development, have minimal impact on the land's use for agriculture.

- *Mixed barren land, bare rock, and soil*

  The presence of the LSRES and LIWT on these habitats demonstrates the suitability of these areas for renewable energy development. Moreover, their lack of diverse plant and animal communities makes them less ecologically sensitive and so ideal for sustainable energy projects.

- *Grassland*

  The simplified ecosystem structure of grasslands allows for minimal ecological interference while maximizing the potential of wind and solar energy generation, owing to the lack of obstructions which might cause wind shadows or solar shading.

- *Shrubland, Shrubby Grassland and Woody Shrubland*

These are the dominant habitat types around LIWT and, given their relatively small ecological impact and poor land use compatibility, can be very well suited to energy development projects.

- *Rural plantations*

Due to the dominance of a limited number of commercially valuable plant species, areas dedicated to rural plantations typically have lower biodiversity than natural ecosystems. Given selection and management practices that mitigate potential ecological risks, these regions can be suitable locations for renewable energy installations.

xii. Land Use

Areas currently serving significant regional or local purposes are considered unsuitable for the development of wind and solar projects. Additionally, certain types of land might impede the effectiveness of a solar/wind site and/or not be compatible with the construction of such sites. As a result, the following land types and their adjacent areas were identified as unsuitable for development in both the solar and wind analysis:

- *Airport*
- *Coastal Protection*
- *Commercial*
- *Commercial/Residential*
- *Comprehensive Development Area*
- *Cultural Features*
- *Drainage Channel*
- *Government, Institution or Community*
- *Historical Feature*
- *Inlet*
- *Land Development Corporation Development Scheme Plan Area*
- *Major Road and Junction*
- *Marine Basin*
- *Nullah*
- *Pedestrian Precinct / Street:*
- *Pedestrian Street*
- *Railway*
- *Recreation*
- *Recreation Priority Area*
- *Residential*
- *River Channel*
- *Sea*
- *Touristic Features*
- *Typhoon Shelter*
- *Urban Renewal Authority Development Scheme Plan Area*
- *Vessel Anchorage / Sea Channel*
- *Village Type Development*
- *West Kowloon Cultural District Development Plan Are*

Please refer to Appendix 2 for the applied buffers around each feature. It should be noted that once the buffer distance around a feature has been reached, any additional distance away from the habitat yields minimal additional advantages. Consequently, Land Use features and their buffers contribute solely to the Boolean Analysis.

The remaining land use types in HK are considered suitable for development and consist of:

- *Green urban areas*

  LIWT is situated in a greenbelt, suggesting that greenbelts are deemed appropriate for renewable energy development projects.

- *Open space and open storage areas*

  These areas offer abundant space and typically encounter fewer conflicts with other land uses. However, the specific suitability of such areas should be evaluated on a case-by-case basis.

- *Industrial areas*

  Energy projects in industrial zones can be advantageous due to the existing infrastructure and potentially lower visual impact. However, careful consideration should be given to conflicts with industrial operations.

- *Undetermined and other specified land uses*

  To avoid potential unnecessary limitations to its search area, these areas were incorporated. However, it is crucial to emphasize that additional analysis would be necessary to definitively confirm their suitability and effectiveness.

c. Criteria Weightings

Establishing criteria weightings is a critical step in evaluating a site's suitability score. While there is no universally accepted weighting scheme, numerous studies have developed their own weighting schemes based on their objectives, methodologies, and available data. This study will base its applied weights on an established weighting scheme proposed by Arán Carrión et al (Arán Carrión et al, 2008). The table below lists these relative weights.

Table 1: Relative weights determined by Arán Carrión et al. The entry in any cell specifies how significant the criteria category to the left of the cell in the first column is compared to the criteria above the cell in the first row e.g., Orography is 0.35 times as important as Environment. (Arán Carrión et al,2008)

Category	Environment	Orography	Location	Climate
Environment	0.12	0.09	0.15	0.12
Orography	0.35	0.26	0.25	0.19
Location	0.04	0.05	0.05	0.06
Climate	0.59	0.77	0.46	0.58

i. Weight Modifications

To ensure a more appropriate fit to the criteria used in this study, the weights above were modified as follows:

- In the original study conducted by Arán Carrión et al., weights for minimizing proximity to areas of natural significance were not included. This omission was due to the study's focus solely on regions classified as ecologically low value, rendering such a weight unnecessary. In order to include these specific features within the scope of the current study, an additional category "Conservation" was created and assigned equal weight to the orography category. By aligning the weights of conservation and orography, the study ensures regions of ecological importance are also given appropriate significance in the analysis.
- The spatial temperature range in HK is fairly uniform, which raises concerns about the justification for assigning it the significant weight associated to its placement in the climate group. Instead, this study chooses to minimise the significance of temperature in the ranked result by removing it from the pairwise calculations and assigning it a weight of 1%.

ii. Solar vs Wind Analysis Weights

Though originally developed for assessing solar site suitability, the *Arán Carrión et al* weighting scheme will be utilized in both the solar and wind analyses. This decision is here justified by noting that the criteria applied in both analyses, such as in nature and conservation, possess inherent and consistent significance for both solar and wind, and that the relative priority of criteria in Carrión et al. weighting scheme are in alignment with established priorities for turbine development. Furthermore, given the comprehensive nature of this analysis, wherein criteria weights can only be broadly generalized (due to the size and complex terrain of HK), this study found it valid to maintain the weighting scheme across both analyses.

d. Additional Settings

An aggregation of four was applied in both analyses to remove isolated cells and leave only a collection of sites that had a regularly shaped minimum area of 100 square meters.

Additionally, clustering was applied in the wind analysis, with a minimum cluster distance of 250m - equivalent to 5 times the rotor diameter of the LIWT (Göransson, 2023). Each cluster represents an area of land where the placement of a turbine anywhere within its vicinity would influence the placement of other turbines within that vicinity. Conversely, turbines in one cluster have no influence on turbines in another. A clustering of 5m was applied in the solar analysis to group all adjacent cells into the same cluster.

e. Post Analysis Processing

To ensure that the sites located in the study were at least as attractive as those already in service, sites that had lower scores than the minimum score of the reference sites were removed from the final result. Additionally, in the solar analysis this was extended to also exclude clusters that had an area smaller than the LSRES.

Given the computational complexity of estimating the optimum distribution of wind turbines within suitable areas and with a separation distance of 250m, a Monte Carlo simulation was applied. Points with a proximity constraint of 250m are randomly generated in all clusters and the number of such points per cluster recorded. This was repeated 100 times and the maximum value recorded for each cluster used as a lower bound of how many turbines could be constructed in that cluster. The sum across all clusters is therefore an estimate of the minimum number of turbines that could be developed in HK.

f. Buffer Values

The criteria of Nature and Conservation, Land Use, and Natural Habitats necessitate the establishment of buffer zones surrounding exclusion areas to mitigate the risk of wind/solar development occurring in inappropriate proximity. These buffer values are related to regional policy and so no universally accepted values exist. To validate the suitability of buffer values for HK, this study based its values on the LIWT and LSRS. In instances where data was insufficient, relevant literature was referenced. Citeria that exhibit similar characteristics were were grouped and assigned buffer zones of the same size.

1. Securing approval for turbine installations close to ecologically significant areas is improbable due to the potential ecological impact. Defining an appropriate buffer zone around these valuable ecological and conservation sites is usually specific to each case. This study resolves this issue by employing a standardized 505-meter buffer around such ecologically valuable sites, equal to the distance between the LIWT and its nearest conservation site.

2. The nearest buildings outside the immediate area of the LIWT are approximately 250 meters away. Project reports (EIA, 2014) considered that, in regard to noise pollution, this is sufficiently far away to prevent significant disruption. However, such dwellings are small and appear uninhabited, as the closest substantial residential dwellings are actually 445m way, this value is used as a buffer around all residential areas. While disturbances from solar farms are minimal, a 50-meter buffer is implemented to address any potential public concerns and prevent shadows from nearby structures impacting solar efficiency.

3. Safety guidelines advocate a minimum distance between turbines and nearby structures, such as roads or railways, to prevent serious injury in case of turbine structural failure. The common guideline for suitable separation is tip height plus 10 percent, which in the case of LIWT gives a value of 67m (Central Bedfordshire Council 2022).

4. To pre-emptively avert any possible conflict between wind turbines and aircraft operations, wind turbines are prohibited in close proximity to airports This study will follow the modal distance in a review by Baseer et al. which dictates a minimum buffer of 3000 meters around airports as a safety standard.

5. Marine environments need to be protected from construction debris and other associated pollution runoff. Project reports state the LIWT is situated 170 meters away from a service reservoir and surrounded by streams within a range of 230 to 500 meters (EIA, 2014), a conservative value of 170m was adopted as a guideline for acceptable construction distances from aquatic environments for both solar and wind development.

6. In order to protect visual aesthetics and protect culturally significant locations, this study draws from Bertsiou et al. and Giamalaki & Tsoutsos and employs a 500 meter buffer for turbines and a 200 meter buffer for solar grids surrounding these sites.

g. Scenarios

In order to address the unique challenges posed by HK's complex environment and limited space, two scenarios were used to assess the feasibility and potential of solar and wind energy while safeguarding environmental protection and respecting the priorities and values of HK.

- **Scenario 1**: This accommodates all the constraint conditions to identify optimum suitable sites for solar and wind energy projects. Given the restricted space available in the region and the complexity of its environment, it is anticipated that the results of this scenario will be limited but have minimum impact on protected/reserved areas.
- **Scenario 2**: This scenario maintains the same constraints as Scenario 1 other than removing the buffers associated with the criteria Nature and Conservation, Land use and Natural Habitats. These specific buffers delineate zones deemed unsuitable for development primarily due to societal preferences and environmental protection rather than essential logistical requirements for turbine/solar deployment. Consequently, these areas may possess potential viability for solar/wind development and their exclusion enables identification of all potential sites, irrespective of existing environmental/social policies. The sites identified in this scenario will be more numerous than in scenario 1, but have significant impact on protected/reserved areas.

Scenarios 1 and 2 are used to facilitate an evaluation of the feasibility of implementing solar and wind development under ideal environmental and social conditions within HK's limited space. A comparison of the results from these scenarios provides insights into the compromises and trade-offs that may need to be considered and leads to the identification of the primary factors contributing to potential limitations. This can be used to pinpoint potential buffer adjustments that effectively balance fulfilling HK's renewable energy objectives against minimizing associated damages. Although this study recommends caution in reducing buffers, it notes that such requirements may arise in situations where prioritizing energy production is paramount.

By comparing the output of the specific criterion results, the impact of the buffer zones can be evaluated. If there is minimal variation between Scenario 1 and Scenario 2 for a particular criterion it implies that the buffers in place for that criterion are not significantly restricting and can be maintained or potentially increased. Conversely, if Scenario 2 yields a substantial increase in available sites, it indicates that the existing buffers are significantly restrictive and buffer adjustments may be necessary - albeit at the expense of areas with natural and/or social value.

8. <u>Results</u>

a. Boolean Analysis - Scenario 1

In the wind analysis, the criteria: Wind Speed, Elevation, Avian Conservation (Winter Abundance), and Coastal Distance are identified as the least limiting factors in determining site suitability, meeting the specified constraints across over 78% of the area (see column headed "HK" in figure 6). Conversely, Slope, Nature and Conservation, Distance to Road Networks, and Avian Conservation (Spring Species), significantly limit potential sites to 29.92%, 30.27%, 36.42% and 44.06% (respectively) of the region. Each of the land type criteria limits potential suitable area to approximately half of HK's total area, 43.21% and 57.05% for Land Use and Terrestrial Habitats.

In the solar analysis-scenario 1, the majority of criteria used in the model prove relatively unrestrictive. Temperature, Coastal Distance and Elevation satisfy the constraints in approximately 80% of the study region, while Terrestrial Habitats, Land Use and Slope do so in 62.73%, 72.36% and 55.77%. The primary constraints are identified as the Solar Potential (33.88%) and Nature and Conservation (39.74%).

b. Scenario 1 vs Scenario 2

The total percentage of land suitable for wind and solar development under scenario 1 is 0.03% and 1.56%, respectively. As anticipated, the removal of buffers in scenario 2 resulted in the expansion of viable areas. Potential wind and solar areas experienced increases of 623% and 91% respectively, translating to absolute gains of 0.16% and 1.43%, and a final total percentage of 0.19% and 2.99%. As Land Use, Nature and Conservation, and Terrestrial Habitats were the only criteria with buffers, this increase is entirely attributable to these three criteria.

- In scenario 1, the Nature and Conservation criterion greatly restricted suitable locations in HK, permitting just 30.27% of the land for wind turbines and 39.74% for solar farms. However, in scenario 2, there was a notable improvement in results, marked by a 21.86% expansion in potential area for wind turbines and a more moderate increase to 52.13% for solar farms.
- The Land Use criterion proved relatively unrestrictive in scenario 1, with 43.21% and 72.36% of HK eligible for developing turbines and solar farms respectively. However, eliminating buffers (scenario 2) resulted in a notable expansion of 37.77% for turbine development and a slight increase of 8.62% for solar.
- Terrestrial Habitats proved relatively unrestrictive in scenario 1, with 57.05% and 62.73% of HK eligible for wind and solar development, respectively. In scenario 2, there was a moderate increase of 14.77% for turbine development and 9.09% for solar.

A

Wind

Scenario 1	WS	ELE	SLP	LU	CD	RN	WB	SB	TH	NC	Hong Kong Total Area
WS	100.00	80.73	64.18	85.63	73.99	76.09	82.54	90.29	80.85	73.44	**78.28**
ELE	83.76	100.00	48.21	91.01	87.32	89.68	82.53	85.70	85.24	65.75	**81.21**
SLP	24.54	17.76	100.00	13.56	27.75	18.68	27.40	20.46	29.87	51.26	**29.92**
LU	47.27	48.42	19.58	100.00	43.24	42.29	45.59	63.34	44.89	20.94	**43.21**
CD	74.03	84.21	72.63	78.38	100.00	85.37	77.44	73.22	82.19	71.72	**78.32**
RN	35.41	40.22	22.74	35.65	39.71	100.00	36.17	32.85	33.84	27.14	**36.42**
WB	95.99	92.51	83.36	96.04	90.01	90.38	100.00	98.62	93.75	91.65	**91.03**
SB	50.82	46.50	30.13	64.59	41.19	39.73	47.74	100.00	46.50	33.82	**44.06**
TH	58.93	59.89	56.96	59.28	59.87	53.01	58.76	60.20	100.00	70.30	**57.05**
NC	28.40	24.51	51.85	14.67	27.72	22.55	30.48	23.23	37.30	100.00	**30.27**
										Overall Results	**0.03**

B

Scenario 2	WS	ELE	SLP	LU	CD	RN	WB	SB	TH	NC	Hong Kong Total Area
WS	100.00	80.73	64.18	79.57	73.99	76.09	82.54	90.29	79.08	72.41	**78.28**
ELE	83.76	100.00	48.21	87.42	87.32	89.68	82.53	85.70	79.46	71.33	**81.21**
SLP	24.54	17.76	100.00	20.30	27.75	18.68	27.40	20.46	33.60	45.46	**29.92**
LU	82.32	87.17	54.95	100.00	81.86	93.63	81.67	89.46	76.87	63.94	**80.98**
CD	74.03	84.21	72.63	79.17	100.00	85.37	77.44	73.22	77.18	74.00	**78.32**
RN	35.41	40.22	22.74	42.11	39.71	100.00	36.17	32.85	33.06	32.50	**36.42**
WB	95.99	92.51	83.36	91.81	90.01	90.38	100.00	98.62	91.65	88.68	**91.03**
SB	50.82	46.50	30.13	48.68	41.19	39.73	47.74	100.00	44.76	32.30	**44.06**
TH	72.56	70.27	80.65	68.18	70.77	65.19	72.31	72.96	100.00	77.69	**71.82**
NC	48.22	45.79	79.19	41.16	49.25	46.51	50.78	38.21	56.39	100.00	**52.13**
										Overall Results	**0.19**

C

Solar

Scenario 1	SP	ELE	SLP	LU	CD	RN	TMP	TH	NC	Hong Kong Total Area
SP	100.00	26.17	46.00	27.13	33.31	34.78	33.23	35.97	43.11	**33.88**
ELE	62.73	100.00	68.31	89.58	84.14	81.31	81.19	84.29	68.73	**81.21**
SLP	75.73	46.91	100.00	46.34	55.14	57.42	55.76	54.67	70.29	**55.77**
LU	57.94	79.82	60.13	100.00	72.44	71.04	72.34	70.78	47.49	**72.36**
CD	93.76	98.81	94.28	95.46	100.00	96.32	95.33	97.44	94.16	**95.36**
RN	61.04	59.53	61.22	58.37	60.05	100.00	59.44	55.79	66.63	**59.46**
TMP	98.11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	**100.00**
TH	66.60	65.10	61.49	61.36	64.10	58.86	62.71	100.00	71.53	**62.73**
NC	50.57	33.63	50.08	26.08	39.24	44.54	39.73	45.32	100.00	**39.74**
									Overall Results	**1.56**

D

Scenario 2	SP	Elevation	SLP	LU	CD	RN	TMP	TH	NC	Hong Kong Total Area
SP	100.00	26.17	46.00	28.26	33.31	34.78	33.23	37.26	40.43	**33.88**
ELE	62.73	100.00	68.31	87.42	84.14	81.31	81.19	79.46	71.33	**81.21**
SLP	75.73	46.91	100.00	48.64	55.14	57.42	55.76	57.39	68.34	**55.77**
LU	67.54	87.17	70.62	100.00	80.76	81.68	80.96	76.87	63.94	**80.98**
CD	93.76	98.81	94.28	95.10	100.00	96.32	95.33	95.66	93.75	**95.36**
RN	61.04	59.53	61.22	59.97	60.05	100.00	59.44	56.36	67.81	**59.46**
TMP	98.11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	**100.00**
TH	78.99	70.27	73.90	68.18	72.04	68.08	71.80	100.00	77.69	**71.82**
NC	62.20	45.79	63.87	41.16	51.24	59.45	52.11	56.39	100.00	**52.13**
									Overall Results	**2.99**

WS: Wind Speed, **SA:** Solar Potential, **Ele**: Elevation, **SLP**: Slope, **LU**: Land Use, **CD**: Coastal Distance, **RN**: Road Network, **TMP**: Temperature, **TH**: Terrestrial Habitat, **NC**: Nature and Conservation, **WB**: Avian Conservation – Winter Abundance, **SB**: Avian Conservation – Spring Species Count.

Figure 6: A collection of four tables (A: wind – scenario 1, B: wind – scenario 2, C: solar – scenario 1, D: solar – scenario 2) presenting the intersection of suitable areas between different criteria for each scenario, as well as the percentage of land deemed suitable for wind or solar development across the entire territory of HK. Each cell in this matrix states the proportion of its row's category's suitable area that also meets the suitability requirements of its column category.

c. Ranked Suitability Scores

Figures 7 and 8 depict the distribution of the site suitability scores in scenarios 1 and 2 for both the wind and solar analyses. Eliminating buffers in scenario 2 results in a rise in score counts across all ranges, notably showing substantial growth in the 20% to 40% range for the wind analysis and the 14% to 30% range in the solar analysis. Additionally, the range of scores in the wind analysis increases by 29%. These findings indicate that, while there is some increase in the number of high-scoring sites, particularly in the wind analysis, the primary effect of removing buffers is a noticeable rise in the count of relatively low scoring sites.

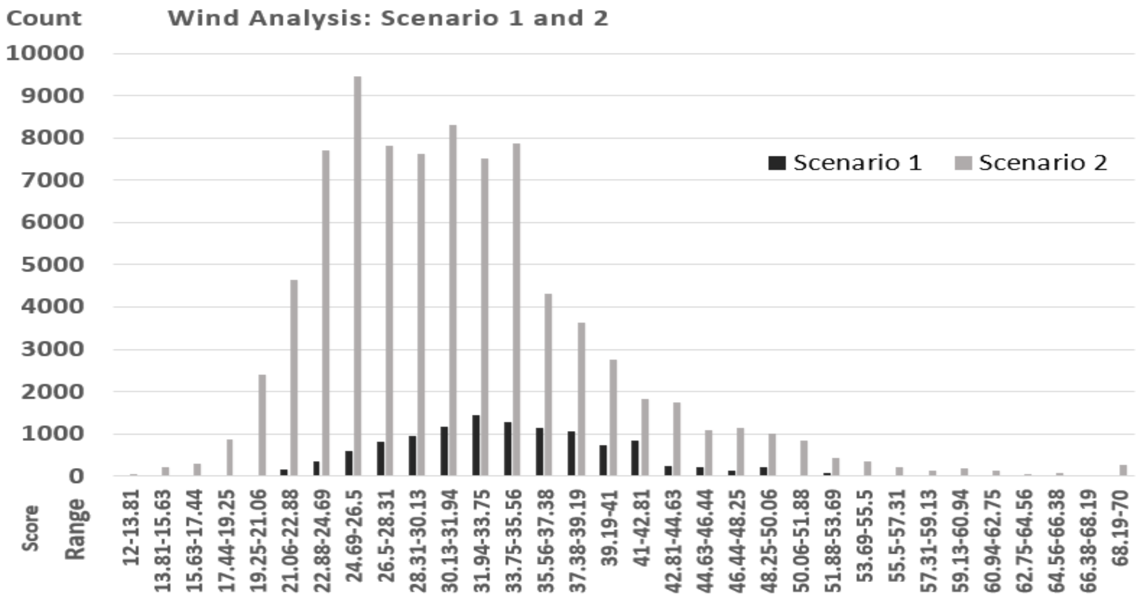

Figure 7: Distribution of scores among ranked results from scenario 1 and 2 of the wind analyses.

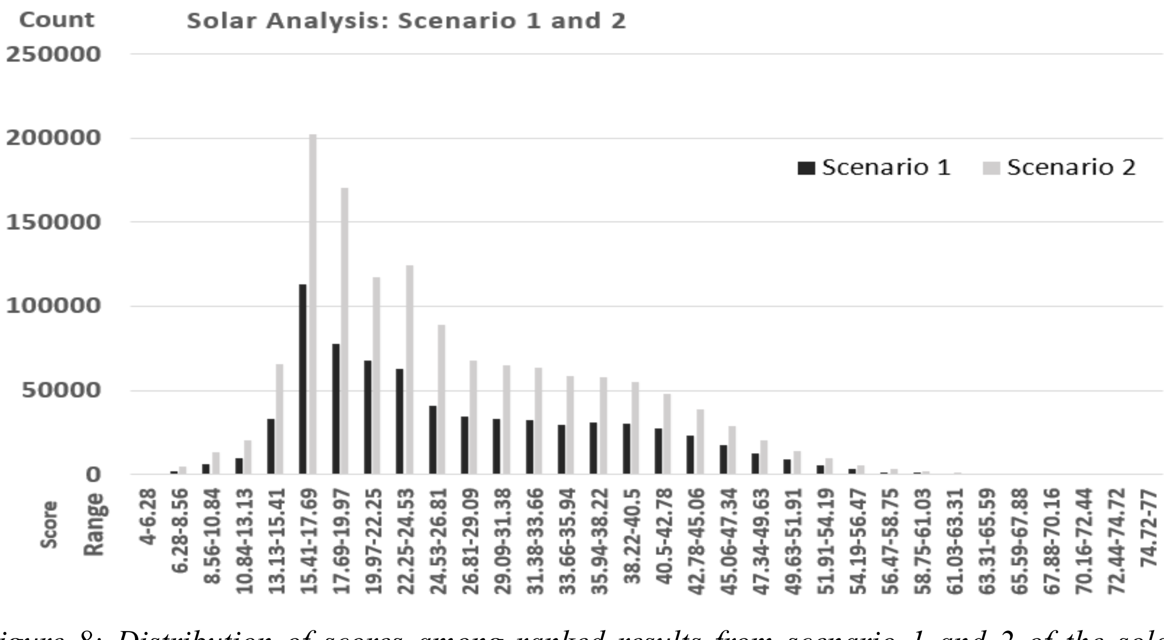

Figure 8: Distribution of scores among ranked results from scenario 1 and 2 of the solar analyses.

d. Wind Analysis Site Results

The results show that under scenario 1, 0.03% of HK's territory is suitable for developing wind turbines under the defined constraints. The suitability scores centered around the LIWT range from 22.2 to 29.9. Post processing filtering of sites with scores less than the minimum score in the vicinity of LIWT left 11,396 potential sites located in 45 clusters. Due to the proximity of sites within clusters, it was estimated that only 117 turbines with adequate separation between them could be developed.

Figure 9 displays the distribution of the 117 turbine sites identified in this analysis along with their corresponding scores. Analysis of satellite imagery and DTM's indicates that numerous identified sites are well-suited for turbine placement - situated on hill peaks surrounded by low shrubbery. However, the feasibility of construction is less evident, as the complex mountainous terrain may create significant logistical hurdles that will have to be addressed on a case by case basis.

The majority of the 117 sites are concentrated into 3 clusters around Tsing Shan Firing Range/Black Peak Hinterland (Area A), "Fa Peng Teng" (Area B) and west of "Fo Tang,"(Area C); additionally, the island Hei Ling Chau (Area D) stands out as having two highly scoring clusters.

- Area A is characterized by an ample availability of densely located suitable sites. As the area already has existing industrial infrastructure, the aesthetic degradation from turbine placement would be less significant. Additionally, this suggests the likely presence of nearby electrical substations which could receive the turbines output.
- Area B benefits from its close proximity to a major road network. However, some turbines sites are situated on existing walking trails, which would need to be rerouted. Additionally, the region is relatively mountainous, and many sites may be difficult for construction vehicles to access.
- The majority of sites in Area C are located in valleys, making them unsuitable for turbine development due to potential wind shadows caused by the valley sides. Moreover, the presence of residential buildings in the area suggests a possible mislabelling in the land use dataset. The ridge tops in the region seems more favorable for turbine placement, however their remote location and lack of access make construction appear impractical.
- Area D exhibits a mixed potential for turbine development, with several locations receiving high-ranking scores and benefiting from excellent connectivity to local road networks. A few sites are in close proximity to correctional facilities (which were unlabelled in the data).

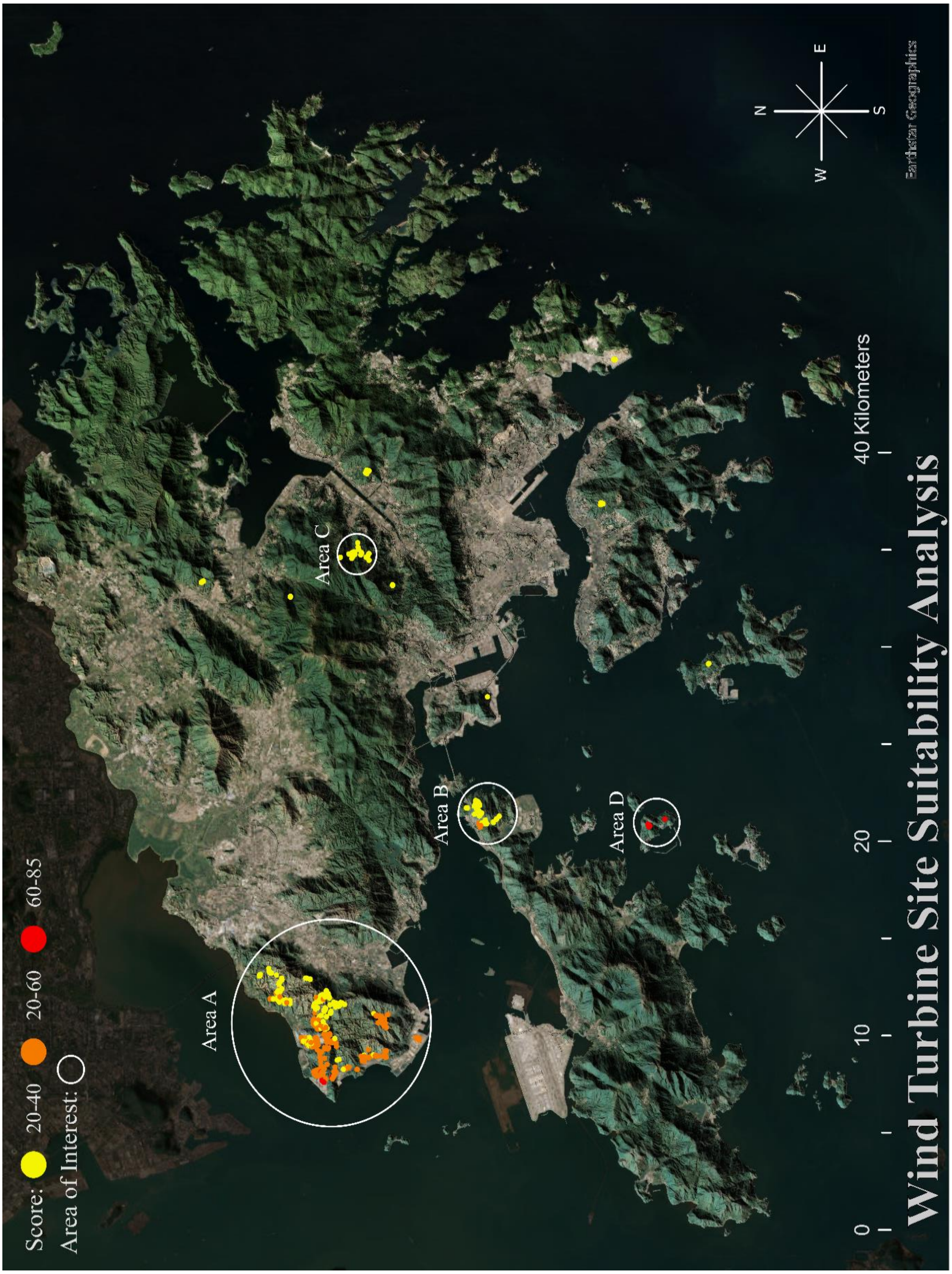

Figure 9: Distribution of cluster centroids and mean score in the wind analysis. Notable groupings of clusters are marked as areas of interest. Image Source: EarthStar Geographics

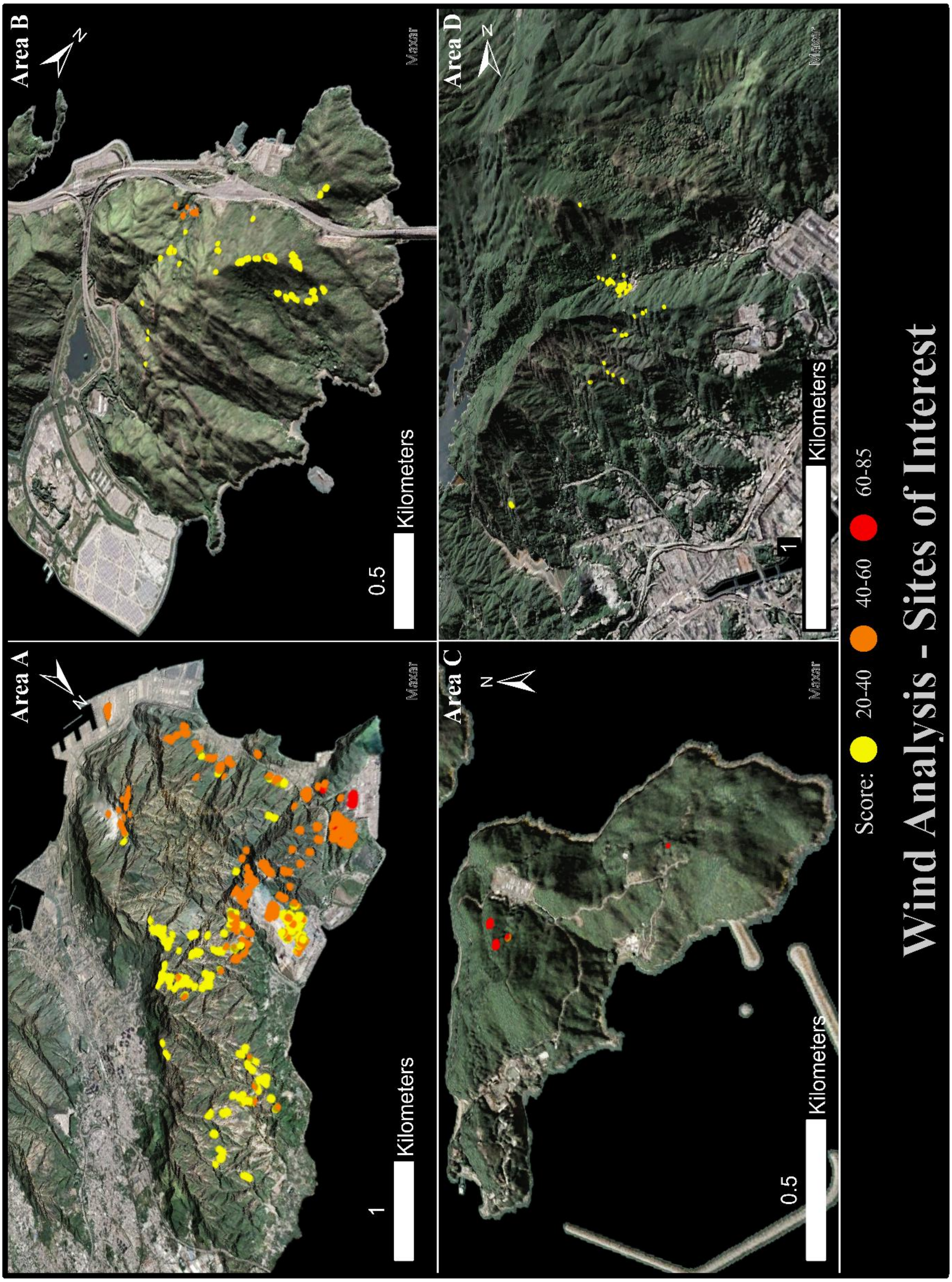

Figure 10: Distribution of cluster centroids and mean score in the areas of interest from the wind analysis, refer to figure 9. Image Source: Maxar

e. Solar Analysis Site Results

The model identified 1.6% of HK's land area as suitable for the development of solar farms under the defined constraints. The range of suitability scores around the LSRES is 13.9 to 18.46. Post processing filtering of sites with scores less than the minimum score in the vicinity of LSRES, and clusters with an area less than that of the cluster located on the LSRES (726m^2) left 377,107 potential sites in 1,975 clusters. Considering the total area of these clusters (9,427,675m2), it is estimated that a total of 12,986 solar microgrids, with attributes similar, or superior to the LSRES, could potentially be built in HK.

Figure 12 displays the distribution of solar clusters and their corresponding mean scores. The clusters are widely dispersed across HK, with a notable concentration in the Northern Territories. Towards central and lower HK, the prevalence of solar sites reduces, although sites in these regions exhibit relatively higher scores. A visual review suggests that the model's assessment of site suitability is well supported with a considerable number of sites situated near industrial areas or locations that have little aesthetic value due to the presence of existing infrastructure.

A notable issue in the results in that a few of the solar sites are found in urban regions. This is likely a result of false representation of urban areas in the *Land Use* data set. Consequently, a small proportion of urban-based sites (estimated to be under 1% of total sites) can be disregarded due to their obvious unsuitability for solar farms, see figure 11 below.

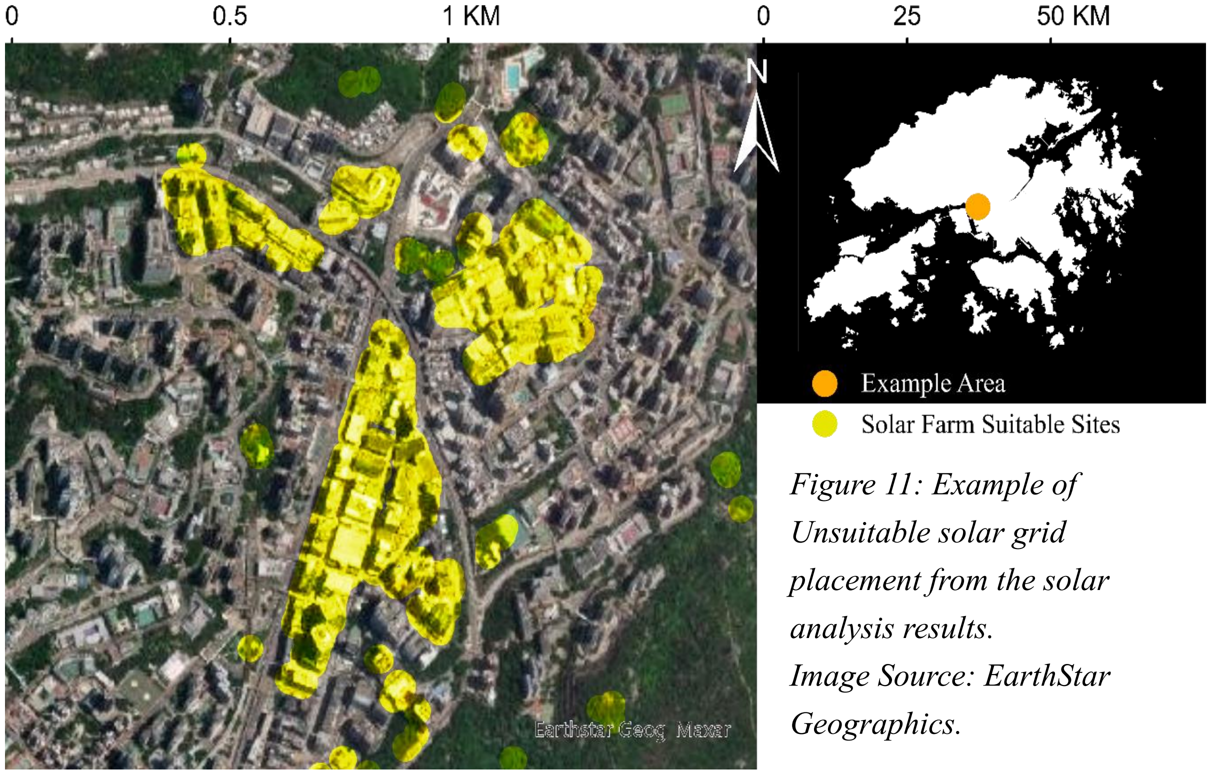

Figure 11: Example of Unsuitable solar grid placement from the solar analysis results. Image Source: EarthStar Geographics.

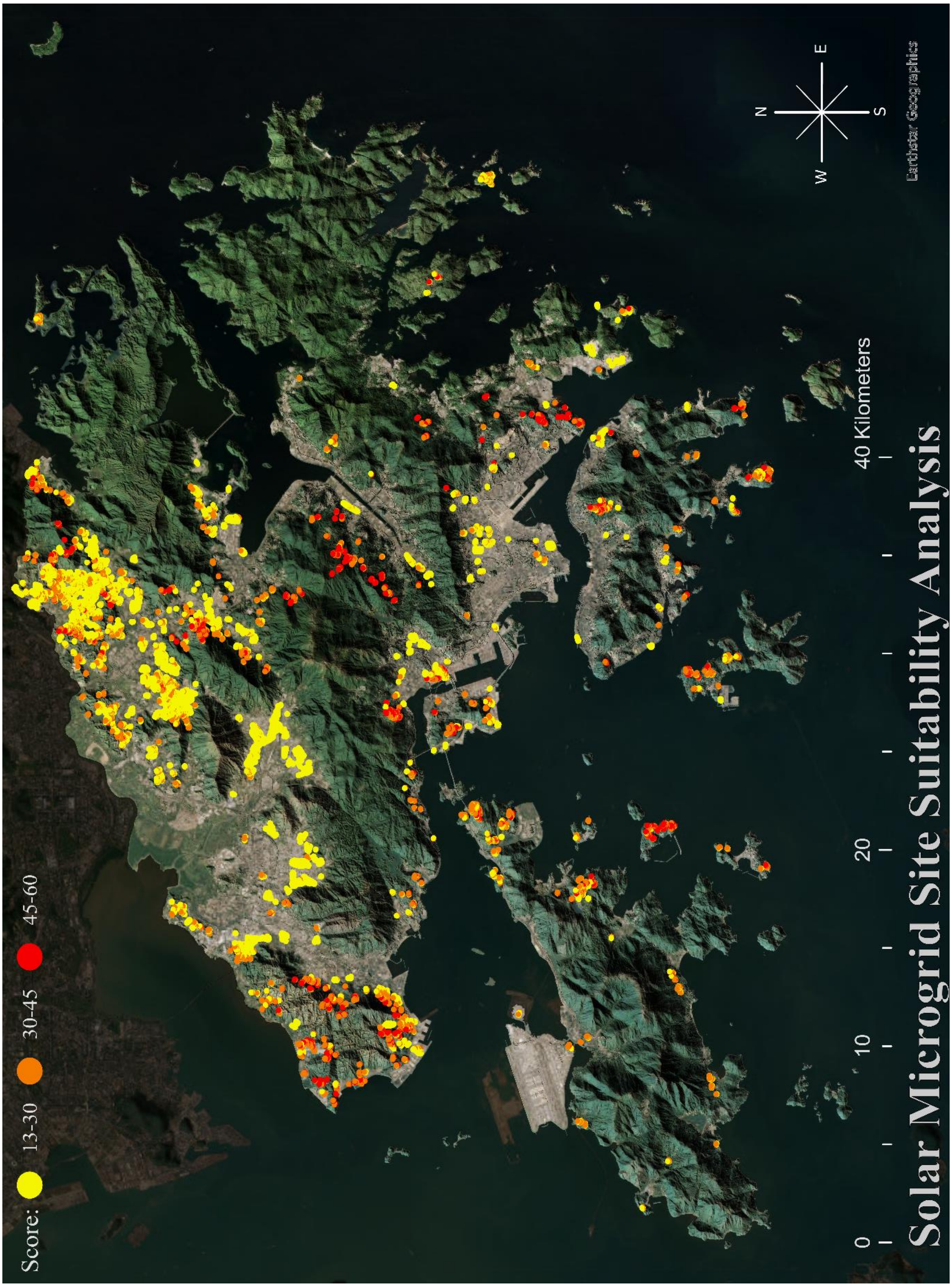

Figure 12: Distribution of cluster centroids and mean score from the solar analysis. Image Source: EarthStar Geographics.

9. <u>Discussion</u>

a. Model Limitations

Certain limitations in the analysis should be taken into consideration when interpreting the results.

Firstly, the accuracy of the data varies between datasets. Although a substantial portion was sourced from governmental bodies, it is often proved to be incomplete or inaccurate. This issue was particularly evident for 'urban regions' in the Land Use dataset which in some instances (an estimated 1% of the data) was misclassified as agricultural land. Fortunately, the infrequent occurrence of such cases, and the interwoven nature of misclassified features with accurate ones meant that the surrounding buffers in these areas often effectively rectified any errors. However, as noted in the solar analysis results, there were some instances of urban areas being included in the final result. As these errors were infrequent, no action was taken to mitigate them, however this study notes that potential solutions for this issue could entail opting for more accurate privatized data over governmental sources and/or manually correcting the data using satellite imagery. It is worth noting, however, that this latter approach might introduce more errors than it resolves due to the complexity and size of the data.

The interpolation of wind speed and temperature across HK is over simplified and fails to consider the influence of localised factors on these criteria, for example: the formation of wind shadows, shade in mountainous terrains, urban heat sinks, surface roughness etc. Additionally, the accuracy of the results from interpolation decreases towards the edges of the study area due to the increasing scarcity of data points in these regions. The approach utilized in this study represented the most effective short-term solution for integrating wind speed and temperature into the model. However, it's important to highlight that integrating accurate climatic models in forthcoming updates would notably augment the accuracy of the analysis. As such, this will be a key priority for any future revisions.

The accuracy of the model results is limited by the exclusion of geological characteristics (wind turbines require stable foundations) and the location of electrical infrastructure in the analysis. As the geology of the land and proximity to electrical infrastructure can significantly impact the feasibility of renewable energy projects, an analysis of such features would be necessary for confirming the suitability of any particular site. It should be noted that the limitation arising from the omission of consideration of the proximity of electrical infrastructure varies across different regions. In isolated areas, this could be particularly consequential due to the likelihood of requiring substantial construction to support the development of energy sites. Conversely, for sites in close proximity to urban or industrial areas, the impact of this limitation might be less pronounced because of the higher probability of suitable electrical infrastructure being readily available.

The study took the criteria values implicit in the development of the LIWT and LSRES as representative of the HK administration’s current standards and criteria. However, this study notes these values may have evolved due to technological advances or conservation initiatives and may no longer be current. Therefore, it is recommended that future research in this area undertakes thorough investigations to verify their data regarding construction practices is current e.g., through actively engaging with relevant HK government departments.

This study recognises that a generalised weighting scheme is not ideal and highlights the potential for a more customized weighting system when undertaking more localized studies. This should be a finely tuned weighting scheme directed by local knowledge and legislations, which accounts for distinct environmental characteristics and social preferences. This can be achieved by involving local stakeholders, experts, and affected parties to gain valuable insights regarding the significance of each criterion. Additionally, it's imperative to transparently communicate the criteria weights and the decision-making process to these stakeholders, encouraging validation and seeking feedback to ensure a comprehensive and inclusive approach. Avenues of communication for such discourse could include surveys, interviews, and/or workshops.

Finally, the feasibility of every site can only be affirmed through case by case validation in a case-by-case manner, as identified sites may have issues invisible to the data, preventing solar/wind development. The model outputs should therefore be considered as an optimistic situation and may be an overestimation of the actual solar and wind potential in the region.

b. Considerations for Solar and Wind Energy Sources in Hong Kong

On sites identified in this study where solar and wind energy are both viable, consideration should be given to their relative long and short term impacts.

Solar power has a comparatively small environmental impact during construction and integrates into natural surroundings relatively seamlessly, with negligible disruption to ecosystems and minimal risks to local wildlife (Taylor et al., 2019). Furthermore, the near-silent operation of solar farms minimizes disturbances to the environment and makes them an ideal option for locations adjacent to nature reserves and parks (Obaideen et al., 2021).

Where space is restricted, wind energy has the capacity to emerge as a more potent energy source than solar, due to better power to area efficiency. As an illustration, the output of LIWT, whose area is less than 1000m^2, is approximately 10 times the output of LSRES - which has an area of 7260m^2. However, erecting wind turbines presents greater challenges, and their construction can have a more significant environmental impact (Pearce-Higgins et al., 2012). Nonetheless, once installed, wind turbines have a relatively small physical footprint and can coexist with livestock and nearby agricultural activities, facilitating a harmonious combination of energy generation and sustainable land use practices (Groth & Vogt, 2014).

Accessibility is crucial in keeping wind turbine development logistically viable, as their installation and maintenance demand specialized machinery and skilled workers. This typically hinges on their proximity to transportation networks and suitable infrastructure (Walford, 2006). This study notes that should the air lifting of components to construction sites become more economically attractive, wind energy could become more viable. While rare, a standout example is the use of helicopters to transport a turbine from sea level to a height of 1200m on Grouse Mountain, Canada (GrouseMountain.com, 2009). Conversely, solar panels offer adaptability, and can be more easily placed in challenging and remote environments reducing the necessity for extensive road and infrastructure development (Patel & Beik, 2021) - this is of particular relevance given HK's mountainous terrain.

Another vital aspect to consider is the economic viability of these two resources. Solar panels are relatively cheap, rendering solar energy more affordable and competitive. Moreover, solar panels require low maintenance, contributing to their cost-effectiveness over the long term (Obaideen et al., 2021). On the other hand, wind turbines have a higher initial installation cost but can offer competitive long-term costs due to their potential for higher energy production. However, maintenance tends to be more intricate and expensive, reducing their overall economic viability (Patel & Beik, 2021). As these issues are very specific to the particular economic circumstances of HK, they are out of scope of this study which focusses only on identifying the location of potential sites. Nonetheless, the results obtained in this study are highly relevant as inputs within such economic calculations.

c. Potential Energy Generation from Onshore Turbines and Solar Farms

The study estimates that HK can accommodate 117 additional wind turbines and 12,986 solar farms, each able to produce at least as much as the output of the LIWT or LSRES, respectively. The LIWT has an estimated output of 0.7TWh per annum (EIA, 2014), implying a combined output for the additional wind turbines of 81.9TWh annually. The LSRES generates 0.067TWh annually (Wang et al., 2019), suggesting a total output of 863.6TWh for all identified solar sites.

The HK government aims to increase renewable energy's share in electricity generation from under 1% to 7.5% - 10% by 2035 (Civic Exchange, 2021). By 2035, the goal is for solar energy to meet about 1-2% of electricity demand and wind energy to contribute 3.5% - 4% (Environment Bureau 2017). In 2022, HK's total electricity generation amounted to 36,091TWh, while total consumption was 44,765TWh (Census and statistics department, 2022). Assuming, energy generation and consumption remain around these levels, the wind turbine sites located in this study could potentially account for 0.23% of the total electricity generation (and 0.18% of consumption), while solar power could account for 2.40% and 1.93% respectively. However, compared to projection of electricity consumption rising to 61,500TWh by 2050 (WWF, 2015), these proportions fall to 0.13% and 1.40% for wind and solar.

Consideration must also be given to increases in efficiency through technological developments. When the LSRES was completed in 2012, its solar cell performance was limited by the technological capabilities of that time. Although the exact efficiency number is not revealed, a connected project in close proximity demonstrated an efficiency of 9.09% (CLP, 2015). In contrast, modern commercial solar cells usually attain efficiencies ranging from 13% to 47% (NREL, 2023). This indicates that if a contemporary solar array of similar scale were to be established, its energy production could potentially surpass that of the LSRES by a factor of 1.4 to 5.1, leading to a contribution of solar of 2.56%-7.14% of 2050 consumption, more than meeting HK30 goals.

Contemporary construction of turbines similar to LIWT would also benefit from advances in technology enabling more efficient power generation. However, the degree of improvement is complex to generalise, given the need to consider multiple factors in order to accurately assess efficiency (Barthelmie & Jensen, 2010). Consequently, an estimation of the increased power generation from a modern turbine is not discussed into this study.

While these results provide strong support for the attainability of the solar HK30 targets, the wind energy targets seem less attainable without technological developments. To improve the feasibility of this objective, expanding the pool of potential wind turbine sites by easing development constraints might be necessary, however, this could be costly to the environment and impinge on valued areas in HK.

d. Buffer Adjustments

Increasing the count of sites (and so potential energy generation) can be achieved through the use of alternative criteria values in the SSA. A comparison of scenarios 1 and 2 shows the impact of restrictions imposed by buffers on the criteria: Nature and Conservation, Land Use, and Terrestrial Habitats. This indicated whether compromises could be made on the buffer zones around these areas to reduce the area of land excluded as potential sites within the analysis. The findings are described below.

- The buffers associated with the Nature and Conservation criterion are relatively restrictive in their current form, and their reduction can lead to a meaningful increase in wind and solar potential in HK. However, this study recognises that benefits gained from such adjustments are at the expense of an increased potential for environmental harm. Consequently, to ensure the preservation of the environment and minimize negative impacts, adjustments or reductions in these buffers should be kept minimal.
- The Land Use criteria saw the largest relative expansion in the wind analysis, and the smallest in the solar analysis. Given the substantial land area meeting the Land Use constraint on solar development in scenario 1, reducing the buffer is deemed unnecessary and could introduce excessive leniency into the model, potentially compromising its effectiveness. Conversely, reducing the buffers in the wind analysis is shown to almost double the number of viable locations, increasing wind energy potential in HK.
- The findings on Terrestrial Habitats indicate that the associated buffers have a moderate impact on limiting the potential areas for wind and solar development. By eliminating or reducing these buffers, there is an opportunity to expand the options for wind turbine and solar panel placement. However, as with the Nature and Conservation criterion, this may result in environmental damage, which, given the already considerable size of the area suitable under this criterion, may be considered an unnecessary risk.

The comparison of scenarios 1 and 2 indicates that removing the criteria buffers can lead to a significant increase in the number of potential sites by a factor of 2 and 6 for wind and solar development respectively. However, it is important to note that the quality of many of these additional sites tends to be low (refer to figure 7 and 8) and reducing buffers increases the potential for environmental harm. In the solar analysis, the already substantial number of potential sites and their collective energy potential argues against the need for buffer adjustments. However, the results from the wind analysis show that the number of identified sites is insufficient to meet HK's targets, and large increases could be obtained by buffer adjustments, particularly in the Land Use criterion. It should be noted that this study recommends that any adjustments be made on an area by area basis to limit any excessive risks to the environment specific to that region.

e. Other Renewable Energy Systems in Hong Kong

This research concentrated exclusively on rural solar microgrids situated in un-developed spaces and onshore wind turbines with conventional three-blade designs. However, the results of this study suggest that increasing the share of renewable energy in electricity generation to between 7.5% and 10% by 2035 will require energy sources that go beyond these typical implementations.

Due to the limited land availability in HK, there has been proactive exploration and development of solar energy sources in unconventional locations. These include repurposed landfills and solar installations on water bodies (Environment Bureau, 2017). Additionally, the government is actively promoting solar energy on buildings, as exemplified by the release of the HK urban solar irradiation map (EMSD, 2022) and research conducted by *Peng et al*, which projected that the widespread installation of solar panels on rooftops could yield an annual solar energy output ranging from 2.66TWh to 5.98TWh, equivalent to approximately 5.9% to 13.4% of HK's overall electricity consumption (Peng et al, 2013).

Technological progress in wind turbines has led to a diverse array of alternative designs. These encompass vertical axis turbines and biomimetic designs inspired by nature. Vertical axis turbines offer scalability and multi-directional wind capture (Ragheb, 2011) while biomimetic turbines derive efficiency from natural principles (Whittlesey,2010) (Chu, 2018). Integrating these systems into HK's energy system could enhance the appeal of onshore turbines as a viable choice due to potential simplifications in the construction process, a wider range of suitable placement sites, and/or increased energy output.

Additionally, offshore wind energy holds significant promise for HK, with approximately 360 square kilometres available for offshore wind farm development (Gao et al, 2014). Offshore wind farms offer improved electricity generation, benefiting from stronger and more consistent winds compared to onshore sites, while also having minimal impact on the terrestrial skyline and land use. Additionally, they can be simpler for construction and maintenance due to their clustered construction and more direct accessibility (He et al, 2020). Currently, CLP has proposed a 250MW offshore wind farm in southeastern HK (Carbon Tracker, 2022) (HK Offshore Wind, 2006) and HK Electric has proposed a 150MW offshore wind farm southwest of Lamma Island (HK Electric, 2022) (EIA, 2009). It is estimated that these sites could annually produce 466TWh (TGS, 2021) and 400TWh (HK Electric, 2022) respectively - a combined equivalent of 2.39 % and 1.93% of HKs total energy generation and consumption in 2022.

In addition to solar and wind energy, other types of renewable energy sources exist that could be further harnessed to meet the growing demand for sustainable energy in HK. Hydropower, marine and waste-to-energy systems play a central role in this context.

HK possesses two hydropower systems. The 500KW Tuen Mun Water Treatment Works was finalized in February 2017 and stands as HK's inaugural large-scale hydropower system. Subsequently a hydropower installation with a capacity of 65 KW was established at the Sha Tin Waterworks to supply the operational capability of the water treatment facility. The output of these systems results in an annual electricity generation of around 3TWh and 0.36TWh, respectively. (Lo, 2017) (Water Supplies Department, 2021)

Despite the success of these hydropower systems, the scarcity of suitable rivers with the necessary water flow and elevation in HK hinders the likelihood of larger-scale hydroelectric power generation (EMSD, 2023). Furthermore, similar initiatives would encounter notable challenges due to factors such as environmental concerns, logistical complexities, and the regulatory considerations associated with constructing such facilities. Nevertheless, there exists specific areas where the implementation of relatively small hydroelectric facilities could be feasible - however a significant growth in the use of this technology seems unlikely (EMSD, 2023)(Environment Bureau, 2017).

HK's coastal geography and its extensive territorial waters position it favourably for the utilization of both tidal and wave energy. The theoretical maximum daily tidal energy capture per unit area has been calculated for various tidal measurement stations across HK, with an average potential of 0.00139MWh/m^2/yr (EMSD, 2023). While there are no operational commercial-scale facilities, ongoing research endeavours signify an increasing interest in investigating and utilizing these marine energy sources. However, the relatively modest electricity generation, in comparison to other renewable sources, confines the contributions of these systems to a minor portion to the region's energy fuel mix.

Although the capacity for harnessing hydroelectric and marine energy sources is restricted, the success of waste-to-energy facilities has been evident. In 2020, waste-to-energy systems accounted for 80.3% of all renewable energy consumption (EMSD, 2022). These systems have substantial potential as they offer a means to address the city's waste management predicaments as well as producing green electricity. By capitalizing on waste-to-energy facilities, HK can effectively mitigate landfill capacities and harness energy from organic waste and sewage sludge. Notable facilities such as O Park 1 and O Park 2 (currently in construction) employ anaerobic digestion to transform 200 and 300 tonnes of food waste into biogas daily, leading to an annual electricity generation of 14TWh and 24TWh respectively (Wong, 2022). Additionally, T Park, a sewage sludge treatment facility, is capable of processing up to 2,000 tonnes of sludge per day and generating an estimated 0.730TFWh annually (Arup, ND). Furthermore, the (under-construction) I·PARK 1 is designed to accept 3,000 tonnes of municipal solid waste daily and is projected to produce approximately 480TWh annually (Higgins, 2013). These facilities as have significant potential to play a major role in contributing to HK’s renewable energy generation capabilities.

f. Potential of Solar Farms and Onshore Wind Electricity Generation in Hong Kong

Although, solar and wind generation in HK is currently limited, this study has identified numerous locations suitable for the deployment of solar farms and wind turbines, highlighting their potential for expansion.

Solar farms have a high potential in HK, as evidenced by the identification of 12,986 potential solar farm sites. The combined capacity of these sites is sufficient to achieve HK's solar energy targets and, by adopting more advanced solar cell technologies, these targets could even be exceeded. Consequently, when focusing solely on energy output, the integration of solar farms emerges as an effective solution with the capacity to substantially enhance HK's renewable energy output.

The feasibility of expanding HK's current onshore wind turbine utilization was demonstrated through the identification of 117 suitable sites. However, while this represents a substantial increase compared to the current deployment of onshore wind turbines, their impact on overall energy generation was found to be marginal. The collective output of all these turbines would contribute only 0.23% to the 2050 targets, leaving a shortfall of 3.27-3.77%. Although increasing the number of sites, and thus electrical capacity, could be achieved by reducing buffer constraints, this would still be insufficient as the land area suitable under scenario 2 was determined to be approximately 6 times the area under scenario 1. This suggests, that even without buffer constraints, the electricity output from onshore turbines would still leave a significant shortfall. Thus, although onshore wind turbines are a viable option for generating additional energy in HK, their role is likely to be a minor one in enhancing the region's renewable energy generation capabilities.

The extent of expansion of solar and wind also depends on the benefits they can offer to the people of HK, balanced against the degree to which their implementation might disrupt the current social and environmental norms. A major challenge in progressing energy initiatives in HK is the limited available space, exacerbated by complex spatial constraints like housing shortages and high land costs (Hui, Lam, & Ho, 2006) (Peng & Wheaton, 1994). Therefore, justifying the land required for the development of wind turbines and solar farms becomes a challenging proposition if better suited alternatives exist.

The potential of wind and solar can consequently only be evaluated in the context of the potential of other types of renewable energy. While this study doesn't delve deeply into a comparison of such systems compared with solar and wind options, it acknowledges the possibility that advantages in these technologies, could diminish the demand for solar and wind development.

For instance, an alternative strategy to solar farms is to prioritize the installation of PV systems in urban and unconventional spaces (i.e. lakes). This approach could be attractive as it circumvents the limitations imposed by the region's spatial constraints and avoids further erosion of rural space. Given the urban nature of much of HK's landscape, this strategy holds particular promise and could be optimized by integrating these systems into newly constructed structures, allowing for a seamless incorporation into the supply networks. As previously shown, these systems could provide between 2 and 4 times as much solar power as all the rural solar sites identified in this study, without causing damage to the natural landscape.

Even in the scenario where turbines were permitted within buffer zones, their cumulative capacity would still fall short of meeting HK's wind targets. It is evident therefore that the deficit in onshore wind capacity must be compensated for by offshore wind developments. The anticipated capacity from these projects would be approximately ten times greater than that of onshore installations. Given this and the fact that offshore turbine sites can be constructed on a large scale (compared to piece meal onshore) it would seem sensible to focus development on offshore wind rather than onshore.

It may therefore seem that new onshore turbines and rural solar farms are unlikely to play any role in HK. However, their true potential lies in their capacity to supplement existing and future energy sources, thereby contributing to a diversified and well-rounded energy portfolio. They should be employed to compensate where other renewable energy systems, notably rooftop solar, offshore wind, and energy-to-waste systems, fall short in meeting HK's energy needs. Additionally, given the extended timeline required for the establishment of these alternative systems, rural solar farms and onshore wind energy can emerge as the more viable options for addressing short-term needs.

In light of this, rural solar farms and onshore wind turbines should be located either in places where they can supply nearby isolated communities or where they can make use of poor quality land areas and provide a backup/diversified generation capability. In such cases, due to their ability to generate significant energy while possessing a relatively small footprint, onshore wind turbines are deemed the preferred choice wherever feasible, with solar farms located on the remaining low land-quality areas. However, given the large number of potential solar sites identified in this study and the relative simplicity of their installation, this study anticipates a prevailing inclination toward solar farms as the preferred solution over wind turbines in meeting HK's renewable energy requirements.

10. Conclusion

This research has determined the feasibility of implementing onshore wind turbines and solar farms in Hong Kong. To facilitate this analysis, an ArcGIS tool was developed to efficiently identify suitable locations. Although the degree of accuracy was limited by inaccuracies in the base data, the tool successfully pinpointed appropriate areas for potential development and demonstrated its effectiveness as a valuable tool for rapidly and effectively identifying and ranking sites based on a variety of criteria, weights, and preferences.

Given Hong Kong's unique spatial limitations, this study emphasized the need for innovative strategies to leverage the benefits of adopting renewable energy sources. Onshore wind turbines appeared to be a promising choice due to their efficient land utilization and substantial energy production potential. However, this study determined that only 117 locations are suitable for their deployment. Furthermore, their utility would be somewhat offset by construction expenses and logistical challenges, and their total capacity would only constitute a minor portion of Hong Kongs wind energy target with the remaining balance needing to be met, either by technological improvements in efficiency, or notably offshore wind developments.

Solar energy offers a versatile alternative and this study found numerous suitable sites throughout Hong Kong. Based on the efficiency of the Living Spring Renewable Energy station, it was calculated that utilising all these sites would produce electricity in excess of that required by HK50. Although such solar farms would have the potential to fulfil Hong Kong’s solar energy targets, the alternative of placing solar panels in urban areas would produce more electricity at a lower environmental cost. Furthermore, while solar is simpler to implement, its generational capacity is smaller than wind turbines with the same spatial footprint. Given Hong Kong’s spatial constraints, the development of solar farms in rural locations is thus viewed as a less attractive option than onshore wind. Despite this, the sheer abundant availability of potential solar sites found in this study is likely to drive their adoption.

Rather than being the main solution, this study finds that the true potential of rural solar farms and onshore wind turbines lies in supplementing and diversifying existing and future energy sources, thereby contributing to a well-rounded and robust energy portfolio. Additionally, they should also be employed to bridge the gaps in situations where other more potent renewable energy systems like rooftop solar, offshore wind, and energy-to-waste systems are less viable. The sites best suited for fulfilling these roles will be among those identified in this study and by utilizing their site suitability scores, it becomes possible to precisely determine which amongst these sites should be given precedence for further development

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12. <u>Appendix 1 – Buffer Value Key</u>

As many of the criteria exhibit similar characteristics - they were grouped and so assigned buffer zones of the same size. This appendix contains the keys used to specify the size of buffers around features.

Table 2: Legend for buffer key values and descriptions.

Key	**Buffer (m)**	**Description**
ResC	10	A compensation for potential 'fuzziness' in boundaries arising from inaccuracies in resolution.
SolMit	50	To address any potential public concerns and prevent shadows from nearby structures impacting solar efficiency. Refer to section *6.f - 2*
Safety	67	Ensure adequate separation between wind turbines and infrastructure. Refer to section *6.f - 3*
Aquatic	170	Protects marine environments from construction debris and other associated pollution runoff. Refer to section *6.f - 5*
SolVal	200	To protect visual aesthetics and culturally significant locations. Refer to section *6.f - 6*
Noise	445	Prevent noise pollution from wind turbines. Refer to section *6.f - 2*
Eco	505	For protecting ecologically significant areas during and post development. Protection Refer to section *6.f - 1*
Protec	500	To protect visual aesthetics and culturally significant locations. Refer to section *6.f - 6*
Aviat	3000	Used to avert any possible conflict between wind turbines and aircraft operations. Refer to section *6.f - 4*
X	NA	Parameter not utilised

13. Appendix 2 – Parameter Values

The parameter values utilized in the assessment of wind and solar site suitability are stated in the following table. For normalization parameters, "Max" signifies a preference for high values in that category, while "Min" signifies a preference for low values. “None” implies the category was not used in the ranked analysis, and so not normalized. It should be noted that, apart from the buffer zone sizes, the criteria constraints remain the same across all scenarios. For the category’s Nature and Conservation, Terrestrial Habitats and Land Use, the value of buffers can be determined by cross referencing their label against the key in appendix 1.

Table 3: Parameter values applied in the model.

Wind Speed

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
Period: Yearly Minimum Threshold: 9kmh Maximum Threshold: Maximum value appearing in the data for period (35km/h) Normalization: Max IDW Power: 2	NA

Solar Potential

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
NA	Winter Solstice: 64 Summer Solstice: 40 Equinox: X Normalization: Max

Temperature

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
NA	*Minimum Temperature*: Maximum value appearing in the data for period (28C) *Maximum Temperature*: Maximum value appearing in the data for period (32C) *Normalization:* Min

Elevation

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
Minimum Threshold: 10m Maximum Threshold: Maximum value appearing in the data (958m) Normalization: Max	Minimum Threshold: 10m Maximum Threshold: Maximum value appearing in the data (958m) Normalization: Max

Slope

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
Minimum Threshold: 0 degrees Maximum Threshold: 10 degrees Normalization: Min	Minimum Threshold: 0 degrees Maximum Threshold: 22 degrees Normalization: None

Proximity to Road Network

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
Minimum Threshold: 67m Maximum Threshold: 500m Normalization: Min	Minimum Threshold: 10m Maximum Threshold: 500m Normalization: Min

Proximity to Electrical Grid

Wind Site Suitability Analysis	*Solar Site Suitability Analysis*
NA	NA

Proximity to Coast

Wind Site Suitability Analysis	Solar Site Suitability Analysis
Minimum Threshold: 323m, Normalization: None	Minimum Threshold: 50m Normalization: None

Avian Conservation

Wind Site Suitability Analysis	Solar Site Suitability Analysis
Season: Winter Count: Abundance Constraint Maximum values: False Minimum value: 33 Normalization: Min Season: Spring Count: Species Constraint Maximum values: False Minimum value: 64 Normalization: Min	NA

Nature and Conservation

Type of Site Suitability Analysis:	**Wind**	**Solar**
Feature	*Buffer (Meters)*	
Beaches	Noise	SolVal
Conservation Areas	Eco	SolVal
Country Parks	Noise	SolVal
Ecologically Important Streams	Aquatic	Aquatic
Fish Culture Zones	Aquatic	Aquatic
Marine Reserves	Aquatic	Aquatic
Priority Sites for Enhanced Conservation	Eco	SolVal
Sites of Special Scientific Interest	Eco	SolVal

Terrestrial Habitats

Type of Site Suitability Analysis:	**Wind**	**Solar**		**Wind**	**Solar**
	Buffer (meters)			*Buffer (meters)*	
Agricultural Land	X	X	Natural Rocky Shoreline	ResC	ResC
Artificial Hard Shoreline	ResC	ResC	Natural Watercourse	Aquatic	Aquatic
Artificial Pond	Aquatic	Aquatic	Reservoirs	Aquatic	Aquatic
Bare Rock and Soil	X	X	Rural Plantation	X	X
Green Urban Area	X	X	Seagrass Bed	Eco	SolVal
Grassland	X	X	Shrubland	X	X
Marsh and Reed Bed	Eco	SolVal	Shrubby Grassland	X	X
Mangrove	Eco	SolVal	Soft Shore	ResC	ResC
Mixed Barren Land	X	X	Woodland	0	0
Modified Watercourse	Aquatic	Aquatic	Woody Shrubland	X	X

Please Note:

Due to the widespread and dense distribution of the "Woodland" habitat across Hong Kong, the model was run with no buffer zone around this habitat to avoid the significant restrictions this would impose.

Table continues on next page.

Land Use

Type of Site Suitability Analysis	Wind	Solar		Wind	Solar
	Buffer (meters)			*Buffer (meters)*	
Cultural Features	Protec	SolVal	Open Space	X	X
Touristic Features	Protec	SolVal	Open Storage	X	X
Historical Feature	Protec	SolVal	Other Specified Uses	X	X
Airport	Aviat	ResC	Other Specified Uses (Amenity Area)	X	X
Agriculture	X	ResC	Pedestrian Precinct / Street:	Noise	SolMit
Coastal Protection	ResC	ResC	Pedestrian Street	Noise	SolMit
Commercial	Safety	SolMit	Railway	Safety	ResC
Commercial/Residential	Noise	SolMit	Recreation	Noise	SolMit
Comprehensive Development Area	Noise	SolMit	Recreation Priority Area	Noise	SolMit
Drainage Channel	Aquatic	Aquatic	Residential	Noise	SolMit
Government, Institution or Community	Noise	SolMit	River Channel	Aquatic	Aquatic
Green Belt	X	X	Sea	Aquatic	Aquatic
Industrial	X	X	Typhoon Shelter	Safety	SolMit
Inlet	ResC	ResC	Undetermined	X	X
Land Development Corporation Development Scheme Plan Area	Noise	SolMit	Urban Renewal Authority Development Scheme Plan Area	Noise	SolMit

Type of Site Suitability Analysis	Wind	Solar		Wind	Solar
	Buffer (meters)			*Buffer (meters)*	
Major Road and Junction	Safety	ResC	Vessel Anchorage / Sea Channel	Aquatic	Aquatic
Marine Basin	Aquatic	Aquatic	Village Type Development	Noise	SolMit
Nullah	ResC	ResC	West Kowloon Cultural District Development Plan Area	Noise	SolMit

The end.

Thank you.