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Wind resource assessment for urban renewable energy application in Singapore

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ABSTRACT

In highly urbanized and energy intensive countries like Singapore all possible avenues for power generation need attention. In this context, rooftop installations of both solar and wind energy are of particular interest for Singapore, especially because of Singapore's condition of land limitation. Decentralized and distributed energy sources such as rooftop wind and solar installations have numerous advantages. However, the potential for wind energy is not fully understood in built-up areas and thus not fully exploited. Hence it is important to study wind flow patterns in built-up areas and also develop technologies tuned for these conditions. The demand for technologies that deliver energy for low flow wind conditions is of paramount importance to Southeast Asia region and especially to Singapore. In this paper, two measurement systems, namely stationary rooftop wind mast and mobile Light Detection and Ranging (LiDAR) profiler, have been discussed. Measured wind data from various sites across Singapore using have also been presented. Wind roses, Weibull distribution, roughness lengths and other statistical analyses were carried out to understand the prevailing wind characteristic, which is used for evolving the basic criteria for economic viability of roof top wind turbines in the tropical conditions of Singapore.

1. Introduction

Singapore's installed electricity generation capacity is 12.5 GW, which is almost entirely derived from fossil fuels [1]. Household electricity consumption is 15% of the total electricity consumption and consumption by commercial and services sector is 37%. Singapore is committed to reducing its emissions by 7%–11% below 2020 business-as-usual levels [2]. Hence, decentralized and distributed energy sources such as rooftop wind and solar installations require due attention in terms of resource estimation and techno-economic evaluation. Based on the space availability in Singapore, maximum cumulative capacity of rooftop photovoltaic installations is estimated to be 5 GW_p by 2030, with 80% of the installed capacity on rooftops and facades [3]. However, the potential for wind energy is not fully understood in built-up areas and hence not fully estimated. In order for Singapore to achieve this goal and to diversify the energy mix, several government agencies are working with Institutes of Higher Learning and local SMEs. National Environment Agency (NEA) owns and maintains several met masts that measure the surface wind across the island nation. But this data is inadequate to estimate the wind potential for the installation of rooftop wind turbines in densely urbanized Singapore. Housing Development Board (HDB) of Singapore, a government body responsible for public housing in Singapore, has been working with the Energy Research Institute at Nanyang Technological University (ERI@N) to study the feasibility of rooftop wind turbines in Singapore. Hence, ERI@N has developed two wind measurement systems for Singapore, namely remote sensing and mobile LiDAR measurement system and rooftop standard anemometry measurement system with wireless data transfer capabilities. ERI@N is the first and so far the only institute in Singapore that conducts wind measurement campaigns in the region using SODAR (SOnic Detection and Ranging) and LiDAR wind profilers.

Singapore has a wet equatorial climate with fairly uniform mean monthly temperatures between 26 °C and 28 °C throughout the year [4]. Singapore's weather can be classified into four seasons. These four seasons are the Northeast Monsoon (December to early March), the Southwest Monsoon (June to September) and two relatively short inter-monsoon seasons. Singapore experiences light and variable winds during the transition between these

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seasons [5]. Wind power is affected by the monsoon weather pattern [6]. Singapore's weather is characterized by high humidity and frequent rainfall [7]. Singapore receives a considerable amount of rainfall throughout the year. The mean monthly rainfall can be between 150 mm and 275 mm depending on the season [4].

Fig. 1 indicates the locations where ERI@N either has permanent masts for long term wind measurements or has undertaken LiDAR campaigns for short-term measurements. Green ‘rhombus’ markers indicate the four HDB rooftops where wind measurement masts have been installed. In this paper, wind measurements of over two years (2012–2014) from the three sites viz. Woodlands Crescent, Pandan Gardens and Marine Drive have been presented and discussed. Results of short-term LiDAR campaigns undertaken at Sentosa and SSC Tanah Merah have been presented, especially to understand the roughness lengths in various direction sectors and turbulence intensity variation with increasing wind speeds. A stripped down techno-economic analysis has been presented for the case of small wind turbine installation.

2. Urban wind energy potential

Urban areas include considerable turbulence and local aberrations. Urban wind energy problem has two main aspects: One, understanding of flow pattern within the lowest urban canopy layer where individual building affects the flow; Two, vertical extrapolation of wind in roughness and inertial sublayers. Wind characteristics such as surface drag, vertical shear profile and turbulence intensity are affected by the roughness lengths of the urban canopy. Estimation of spatially averaged wind profile for urban surface sublayer and roughness sublayer has been discussed in Ref. [8]. In Ref. [9] Ishugah et al. discuss three methods to estimate surface roughness in urban areas viz. Davenport classification, morphometric and meteorological methods. Giovanni and Sauro [10] have discussed in detail the effect of roughness length and wind shear coefficients on the Annual Energy Yield (AEP) for three coastal sites in Southern Italy. Hee-Chang and Tae-Yoon [11] discuss the wind resource assessment of a wind energy site in Jeju Island and spectra analysis of wind data.

There can be significant increase of wind speed at specific locations due to concentration effect of buildings [12]. Hence, estimation of wind parameters is more complicated in built up areas. Sara Louise Walker [13] has discussed in detail various methods of estimating urban wind resource. Wind potential in urban areas can be evaluated using standard anemometry at the site, computational fluid dynamics (CFD) simulation and wind tunnel experiments on the physical model of the building and the surrounding area [14]. A combination of two of these methods is employed to verify the results. A CFD simulation of wind flow around simple building and subsequent wind tunnel measurements to verify CFD simulation have been discussed in Ref. [15]. A method describing a combination of CFD and measurements from a single anemometer for wind energy assessment has been discussed in Ref. [16]. Subsequent to a thorough understanding of the flow patterns, various wind energy systems suitable for exploiting wind potential in that specific urban environment can be considered [17].

D. Elliott and D. Infield [18] have studied the effect of averaging time wind measurements on turbine energy capture prediction and turbulence intensity calculation. The AEP for low wind speed

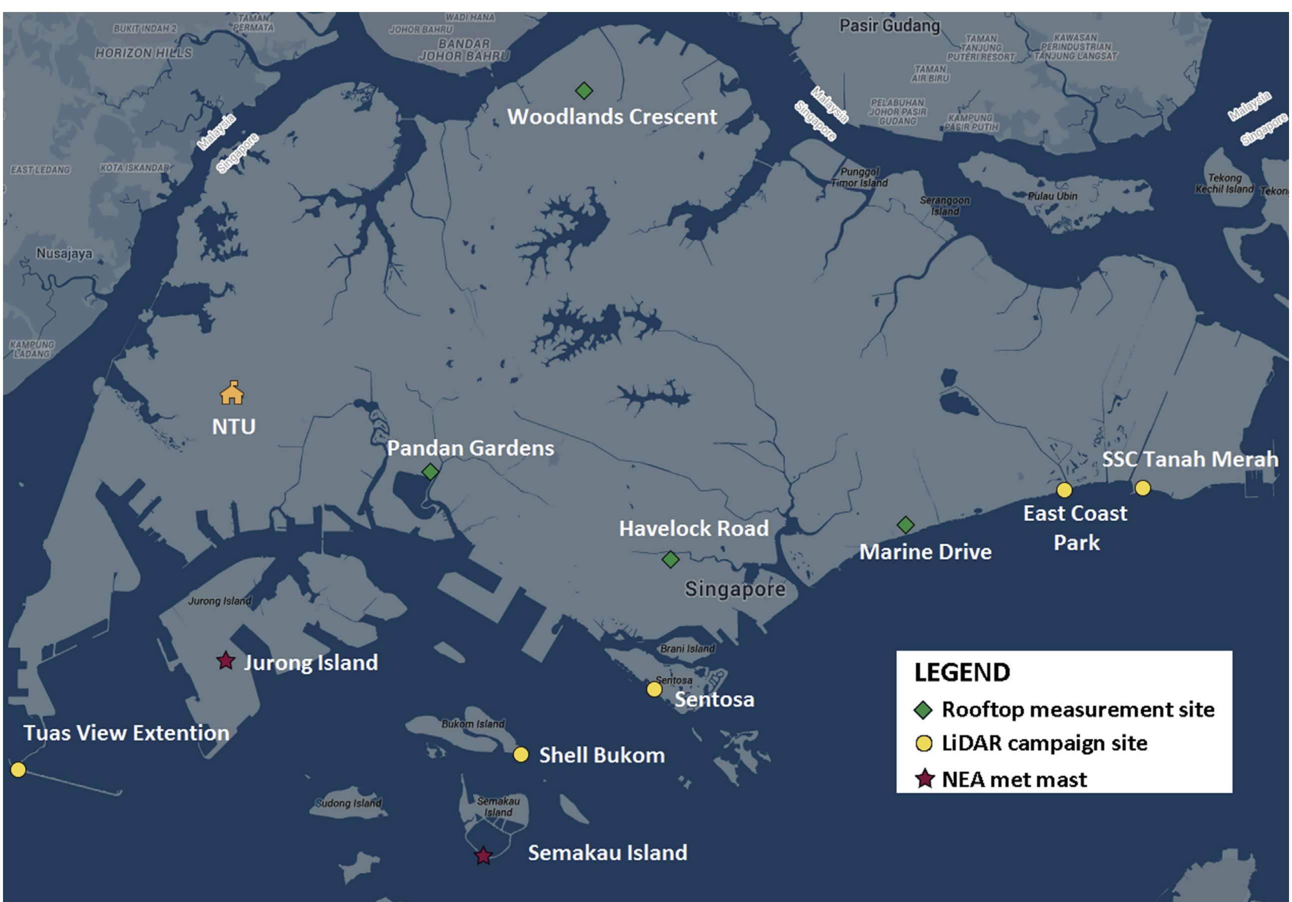

Fig. 1. ERI@N's wind measurement sites in Singapore.