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Feasibility assessment of wind energy resources in Malaysia based on NWP models

Khalid Mohamed Nor, Mohamed Shaaban*,[1], Hasimah Abdul Rahman

Centre of Electrical Energy Systems, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

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ABSTRACT

There is a common belief that countries located in the doldrums with prevailing monotonous weather, characterized by light winds, cannot harness the wind for feasible energy production. This paper reexamines such a belief and presents a novel approach to assess the techno-economic potential of wind turbine generator sites in Malaysia, which lies in the equatorial, low wind speed doldrums. Dissimilar to other techniques that account for planetary-scale winds only, a numerical weather prediction (NWP) prospecting tool for mesoscale winds is used to forecast the wind characteristics. Potential sites from the forecasting studies are further investigated for economic feasibility by using a commercial wind turbine generator and a financial analysis method. From the economic analysis, it is found that unlike what is widely touted, there is an actual potential of wind energy in Malaysia, manifested through the several economically viable wind turbine generating sites.

1. Introduction

Throughout the world wind energy has the largest share in renewable energy in terms of energy production, and turbine installed capacity. The share of the global wind-energy production is dominated primarily by China, USA, Germany, India, UK, Canada, Spain, Italy, France and Portugal, which cumulatively have a total of about 86% of the world's wind turbine capacity [1]. These countries lie to the north of the equator where the prevailing winds are strong.

All winds have the same cause which is the pressure disparity that arises because of temperature differences caused by unequal heating of the Earth's surface. The circulation between 30° and 60° latitude (north and south) results in the *prevailing westerlies* blowing from the west to the east. In the Southern and Northern hemispheres and between 25° and 35° latitude, *trade winds*, from both hemispheres, blow almost constantly from easterly directions and meet near the equator. The westerlies and the trade winds are planetary-scale wind patterns and called the *macroscale winds* [2]. This is shown on the global wind map, Fig. 1, where the average wind speed in many regions of these countries is around 10 m/s.

Convergence of the trade winds from both hemispheres near the equator produces a region of low uniform pressure, and light variable winds called the *doldrums* [2]. Doldrums is characterized by frequent showers, thunderstorms, and heavy rainfall. The doldrums is located slightly to the north of the equator. Malaysia is a country situated 5° on the north side of the equator, where the average wind speed ranges from a high of 8 m/s during Monsoon season to a comfortable breeze of around 3 m/s in between the Monsoons [3]. However, apart from the macroscale winds, there are smaller-scale winds called *mesoscale winds* (time frame of minutes to hours and size of 1–100 km), which influence smaller areas and exhibit intensive vertical flow. Examples of these winds are those contributing to the formation of thunderstorms, or produced by them, tornadoes, and local winds such as land and sea breezes, gap flows, mountain and valley breezes [2]. Mountain and valley breezes develop as air along mountain slopes is heated more intensely than air at the same elevation over the valley floor.

Geographically, Malaysia comprises a Peninsular part and eastern provinces of Sabah and Sarawak (part of the Borneo island) as shown in Fig. 2. In the figure, the darker shade indicates a higher elevation. Five locations that were studied in this paper are indicated on the map. These sites are facing the Indian ocean and the South China sea at locations with a combination of mountain and valley terrain. Fig. 3 specifically displays the topography of mountains and valleys at the Langkawi island, which is one of the six locations. Malaysia has many sites, with a similarly complex terrain, that experience a significant amount of local mesoscale wind.

* Corresponding author. Tel.: +60 7 5535335; fax: +60 7 5557005.
E-mail addresses: m.shaaban@fke.utm.my, shaabaneg@gmail.com (M. Shaaban).
[1] Also with the Faculty of Engineering, Port Said University, Port Fouad 42523, Port Said, Egypt.

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Symbols and nomenclature

WTG	wind turbine generator
pdf	probability density function
NPV	net present value
IRR	internal rate of return
R	annual rate of inflation reflecting opportunity cost
TNB	Tenaga Nasional Berhad – the largest utility company in Malaysia
v	wind speed, m/s
$f(v)$	pdf of wind speed calculated annually
$P_{WTG}(v)$	the output of the WTG as a function of wind speed
3Tier	a company specializing in renewable energy risk analysis
kWh	an energy of 1 kW over 1 h which is equivalent to 3600 MJ
c	Weibull pdf scale parameter in m/s
k	Weibull pdf shape parameter

The presence of mesoscale winds, affecting local wind patterns, in Malaysia was illustrated in Ref. [4].

An early study on the potential of wind energy analyzed annual wind speed from ten meteorological stations in Malaysia using Weibull distribution [3]. Another study observed that the annual offshore average wind speed in Malaysia is between 1.2 and 4.1 m/s, where the highest potential is in the east Peninsular Malaysia with an annual resultant wind speed vector of 4.1 m/s [5]. It was reiterated that wind power has only modest potential in Malaysia due to the low wind speed characteristics it retains [6,7].

Most of the published studies on wind energy potential in Malaysia used data from existing weather station network operated by the Malaysian Meteorological Department (MMD) [3,5–7]. The measuring tower is 10 m high above ground level, and is typically installed at specific locations such as airports, ports and areas with high density population. These low-lying sites should, on the contrary, be avoided altogether during the search for suitable low speed wind turbine generator sites. Generally, such sites do not receive strong mesoscale winds, and thus the measurement is for the global-scale doldrums' winds (or macroscale winds). Indeed, the measured wind speed normally agrees with the global wind map shown in Fig. 1. Mesoscale wind is a significant compound of the wind regime in Malaysia that contributes substantially to maintain the wind circulation all year round [4]. Failure to account for mesoscale winds can be flagrantly inaccurate in wind resource assessment in Malaysia. Furthermore, measuring wind speed below turbine hub heights and extrapolating these measurements, assuming a constant wind shear, can lead to critical errors in predicting the energy production [8].

One of the suggestions arising from the early studies, is the application involving small-scale wind turbines to provide electricity to the relatively undeveloped East coast of Peninsular Malaysia and offshore islands; which are not connected to the national grid [3,5]. In 2007, the Malaysian Government under joint venture partnership with the State Government of Terengganu and Tenaga Nasional Berhad (TNB), which is the largest and very dominant electric utility in Malaysia, have embarked on a project of integrating power supply at the Perhentian Island. The project consisted of installing two wind turbines, solar farm (solar panel), generator and battery. The reported energy produced was not encouraging [9], for reasons that will be discussed later in this paper.

From the published studies and reports, it can be concluded that the previous research initiatives on wind energy in Malaysia were not comprehensive enough. Most of the studies estimate energy output from the annual average wind speed. This is grossly incorrect as the wind-turbine output is proportional to the cubic function of the wind speed. A practical wind turbine has a discontinuous output at the cut-in speed as well at the cut-out speed. Therefore, a better estimation of wind energy potential has to be based on the total

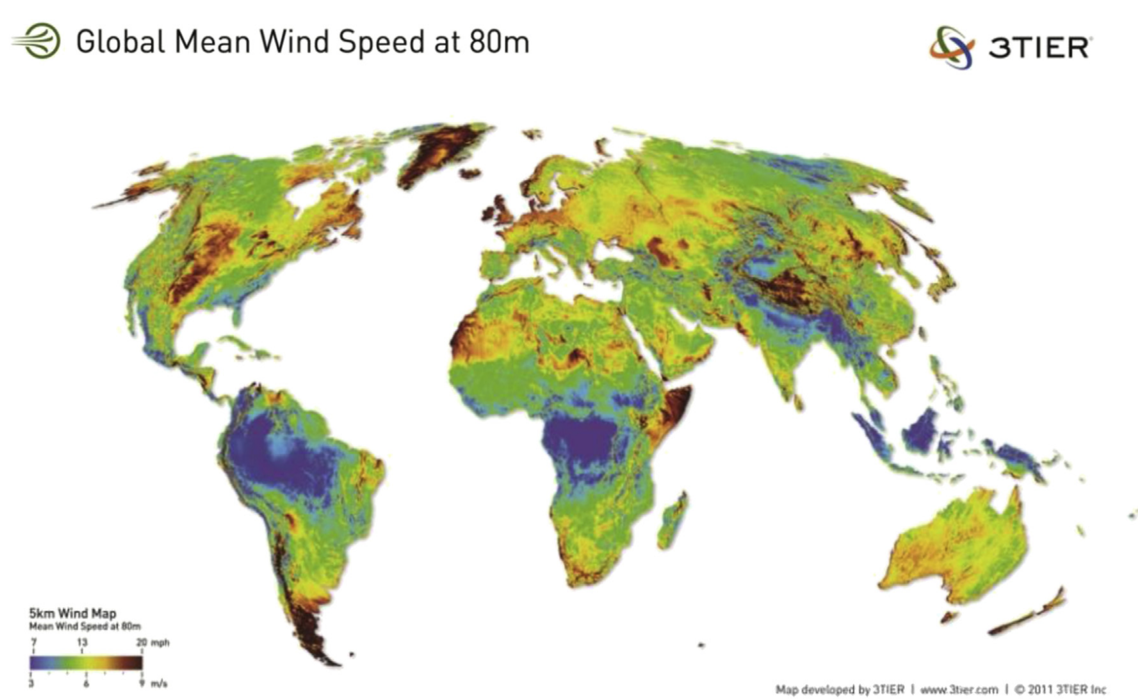

Fig. 1. Global wind map.