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Spatial energy predictions from large-scale photovoltaic power plants located in optimal sites and connected to a smart grid in Peninsular Malaysia

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ABSTRACT

In order to make accurate energy predictions for large-scale photovoltaic (PV) systems connected to a smart grid, it is first necessary to identify the very specific locations that are required for their long-term optimal operation. Multi-criteria evaluation techniques are often applied for different site selection studies. This study discusses the past, present and future condition of solar PV application in Malaysia. The study also uses the optimal site definition model (ODM) and GIS to select sites for the installation of large-scale PV power plants that will be connected to a smart grid, and to predict their technical potential and carbon emission reduction, based on optimal sites in Peninsular Malaysia. The outcome of the study reveals that policies and strategies being adopted by Malaysia government are significantly improving the solar PV application for energy sustainability. However, on the other aspect, the results show that 10,092.08 km^2 (7.64%) of the area under study is suitable for large-scale PV plant installation. If even half of the potential sites are used, with an installed capacity of 756.91 GW, we predict a total electricity generation potential of 1,343,527.9 GWh/yr with an annual carbon emission reduction of 846,422.56 kt-CO_2/yr in Peninsular Malaysia. Based on predicted national energy consumption in 2030, this study shows that about 8 times future annual energy consumption could be met if PV plants with an installed capacity of 756.91 GW are set up in Peninsular Malaysia. Similarly, the study predicts an improvement of 1.6 times the annual carbon emission reduction, based on predicted carbon emissions for 2020. Therefore, the implementation of large-scale PV applications is technically and environmentally viable in Peninsular Malaysia and tropical countries as a whole.

Contents

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1. Introduction

Currently, efforts to integrate renewable energy (RE) sources into existing electricity sources are global ambitions, with particular attention being paid to solar and wind alternatives. The impacts of overwhelming greenhouse gas emissions on the climate from conventional energy sources together with growing energy demands have led to the acceptance of solar photovoltaic (PV) technology across the globe. PV systems convert sunlight energy into electrical energy without using mechanical activities [1–3]. Developed countries like Italy, Greece, Germany, and others, have developed remarkable solar PV applications at different scales (both grid-connected and off grid) [4]. However, PV development in developing nations like Malaysia is progressing at a slower rate despite the abundance of solar sources.

Recently, efforts to promote the development of RE resources have increased in Malaysia due to rises in the annual amount of carbon dioxide (CO_2) that is being emitted and to growing energy demands (1). Reports emerging from international and local environmental agencies reveal that in Malaysia alone 226,988.90 kt-CO_2/yr of CO_2 are discharged into the atmosphere, as of 2013 [5]. In addition, uncertainty about the sustainability of conventional energy sources to produce electricity has become more worrying, with possible depletion predicted by the year 2046 [6,7]. These factors have highlighted the urgent need for proactive measures to integrate RE sources such as solar and wind into the national energy generation mix.

Malaysia has good solar insolation with about 4–5 kWh/m^2/day and the average amount of sunshine is recorded in the range of 4–8 h daily [8,9]. Based on this, the Malaysian government has initiated several policies to promote RE applications to compliment the energy generation mix. The eighth Malaysian plan aimed at an initial RE contribution of 5% to complement the generation mix by 2005. The tenth national strategic plan (2006–2010) aimed at an RE capacity of 300 MW connected to the national grid across Peninsular Malaysia. In addition, a 40% reduction in CO_2 emissions, relative to the 2005 level, was the suggested target for 2020 [10] (see details in Section 2.).

A major requirement for successful large-scale PV installations of this size (i.e., 300 MW) is the location of optimal sites that will provide optimal output. However, the multiple criteria involved in decision making make this a complex task [11,12]. In addition, sites with apparently higher solar source potential are not always suitable for PV plant installations when considered in parallel with economic, climatic and environmental factors [13–15].

Geographic information systems (GIS) have been widely used as decision-support tools to provide solutions to difficult decision-making problems similar to this type. For instance, Janke [16] identified suitable sites for solar or wind farms using a multi-criteria and GIS-modeling approach. In their study, Charabi and Gastli [17] proposed developing the first geographical mapping models to select the most suitable sites for different PV technologies in Oman using a multi-criteria approach. Sener [18] identified suitable locations for landfill using GIS and the analytical hierarchy process (AHP). Lozano et al. [19] used a combination of GIS and multi-criteria decision-making (MCDM) methods to determine the optimal location of a PV solar power plant in southeast Spain. A similar study conducted by Uyang [14] identified optimal sites for solar farms using GIS and AHP. In southeast Spain, using GIS and the ELECTRE-TRI multi-criteria method, Lozano et al. [20] analyzed the potential locations for a solar farm in the municipality of Torre Pacheco. In Andalusia, Carrion et al. [11] conducted research to select optimal sites for grid-connected PV power plants by integrating GIS and AHP.

This study proposes the use of a GIS tool to select optimal sites for large-scale PV power plant installations that will be connected to a smart grid. The study will also use these data to predict energy generation potential, installation capacity, and potential CO_2 emission reductions in Peninsular Malaysia.

2. Progress in sustainable power generation in Malaysia

2.1. Generation mix

Currently, Malaysia is implementing its fifth fuel diversification