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Integration of optimal combinations of renewable energy sources into the energy supply of Wang-An Island

Cheng-Dar Yue*, Chung-Sheng Chen, Yu-Chen Lee

Department of Landscape Architecture, National Chiayi University, No. 300, Syuefu Rd., Chiayi City 60004, Taiwan, ROC

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ABSTRACT

This is a case study of Wang-An Island's energy demands and potential renewable energy sources (RESs). Optimal integration of RESs was simulated using the EnergyPLAN model. The RES evaluation indicated an annual production potential of 458.1 GWh, which substantially surpassed local energy requirements of 22.3 GWh. The potential of yearly electricity generation from RESs of 299.7 GWh apparently outnumbers local electricity demand of 6.4 GWh as well, indicating that 100% renewable electricity would be achievable if surplus electricity can be stored and then reused during an electricity deficit. Electricity production from fully exploited RESs is able to supply only 5.8 GWh of electricity mainly caused by mismatches in times of electricity demand and production. The integrated optimization can supply 3.7 GWh of electricity. A deficit of 2.68 GWh can be compensated for through electricity storage or biomass energy. Although the total amount of generated renewable electricity during the whole year cannot yet satisfy the total amount of yearly demand, electricity storage can help to satisfy most of the electricity needs for the year.

1. Introduction

Transitioning from fossil fuels to renewable energy sources (RESs) is a key strategy for achieving climate protection and energy security. Concerns over whether RESs are sufficiently meeting energy requirements, or whether electricity production fluctuations from RESs damage grid security, have prevented numerous governments from extensively integrating renewable energy into national energy systems worldwide. Remote islands often provide ideal feasibility study conditions for building self-sufficient energy systems, because of lower population density, fewer energy-consuming activities on the demand side, and extensive undeveloped land or coastal areas available for RES utilization on the supply side. In this context, Wang-An Island was used to study the feasibility of building a self-sufficient RES system.

Wang-An Island is located west of Taiwan and consists of two islets: Wang-An islet and Jian-Jun-Ou islet (Fig. 1). In 2010, the island comprised 1308 households and a total population of 3289. Wang-An Island forms part of the Penghu Archipelago, and exhibits excellent solar radiation and wind resources (Fig. 2), which provide favorable RES utilization conditions. Recognizing this potential, the local government intends to actively exploit RESs to establish a low-carbon island example for the entire country. According to a global database that supplies mean wind speeds from January 2000 to December 2009 for a hub height of 100 m as a guide for establishing offshore wind farms, there are 19 potentially viable offshore wind farm sites in the Taiwan Strait, based on a mean wind speed of 11.72–12.02 m/s [1]. Taiwan's government and the state-owned power company, Taipower, intend to use the Peng-Hu Archipelago as a base for exploiting the abundant offshore wind energy in the Taiwan Strait to supply clean energy through underwater cables to Taiwan, a country in which 98.2% of the total energy consumption was supplied by imported fossil fuels and uranium in 2011. A project to lay 59 km of 161-kV double loop underwater cable between Peng-Hu Island and the main island of Taiwan, each with a 200-MW capacity, is already in progress, at a cost of US$ 570,000,000.

Although Wang-An's abundant RESs have strong potential from an economic perspective, the degree to which various RESs can be integrated, and the ability of combined renewables to meet demand, are topics that have yet to be fully explored. This study addressed these topics by using the EnergyPLAN model to simulate electricity production from various types of RES. First, data necessary for modeling were gathered, including energy demand,

* Corresponding author.
E-mail address: cd.yue@msa.hinet.net (C.-D. Yue).

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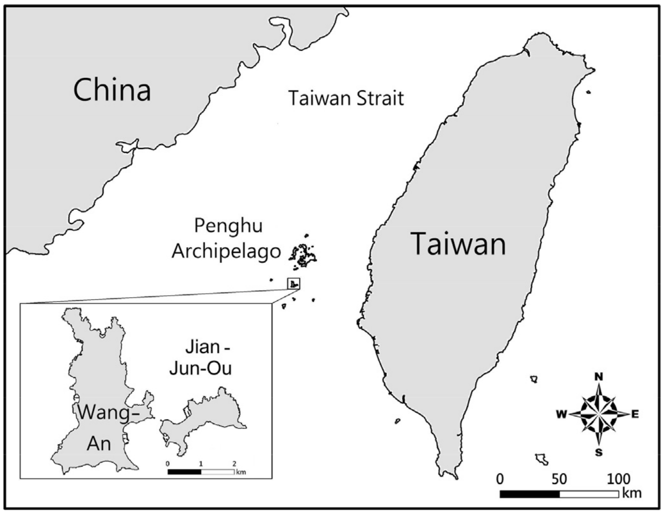

Fig. 1. Geographic location of Wang-An Island.

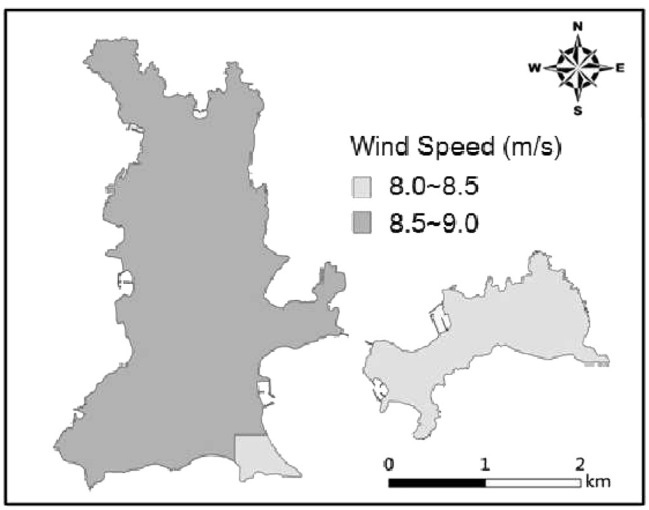

Fig. 2. Distribution of mean annual wind speeds from 2008 to 2010 in Wang-An at a height of 80 m based on hourly numerical simulation [2].

potential RESs, hourly electricity production using RESs, and the electricity production costs. Wang-An's energy system was then modeled by inputting these data into EnergyPLAN to simulate hourly electricity production from RESs. Finally, the combination of RESs was optimized from both a technical and marketing perspective.

2. Methodology

2.1. Overview of methodology

An overview of the methodology adopted in this study is provided in Fig. 3. The procedures are described below.

(1) Local demand for electricity, thermal energy, and transportation fuels were investigated.
(2) The RES potential was evaluated based on local land use and geographical conditions.
(3) Hourly data on wind energy and solar photovoltaic (PV) electricity generation systems were derived from operational wind turbines and PV systems, and hourly data on wavelength and amplitude for wave energy evaluation were derived from a marine meteorological measuring station.
(4) The electricity generation cost analysis was based on the power plant costs, fossil fuel prices, CO_2 costs, and feed-in tariffs for RES power generation.
(5) Wang-An's energy system was modeled using EnergyPLAN, through the input of energy demand, RES potential, data on hourly RES electricity production, and electricity production costs.
(6) The accuracy of the model was examined by comparing average monthly electricity demands simulated by the EnergyPLAN model with the actual average monthly electricity demand on Wang-An in 2010.
(7) Hourly electricity generation from fully-exploited RESs was simulated using the hourly electricity generation data from operational wind turbines and PV systems in 2010, and the installation capacity was derived from the evaluation of potential described above in (2). The hourly data on wavelength and amplitude for 2010, collected by a marine meteorological measuring station, were used to derive hourly power output based on the power matrix of a Pelamis wave generator.
(8) The RES combination was optimized for electricity production from a technical perspective by identifying the combination with the least excess electricity production. The combination was optimized from a market perspective by matching supply and demand at the lowest cost. The combination was optimized from an integrated perspective by considering both technical and market requirements.

2.2. The EnergyPLAN model

The EnergyPLAN model is an energy system analysis tool designed for analyzing regional or national energy systems. It uses data regarding a system's energy conversion capacities and efficiencies and the availability of fuels and RESs. It calculates how the electricity and heat demands of a complete system are met hourly. It has been used in numerous energy system analysis activities, including the design of 100% renewable energy systems [3]. The inputs are distributed into hourly values using actual historical demand and production distribution data for related demands and sources [4].

The EnergyPLAN model was also used to analyze large-scale integration of wind power and PV and wave power into a Danish reference energy system. The possibility of RES integration into the electricity supply was discussed regarding the ability to avoid excess electricity production. The purpose was to identify optimal combinations from a technical perspective [5].

Duić et al. reported renewable energy integration into an insular energy system using an H_2RES model that balanced the hourly time series of water, electricity, heat, and hydrogen demand, as well as the appropriate storage and supply in any user-defined period [6,7]. Because the export of excess electricity production of Wang-An Island through underwater cables might be a realistic future option, rather than the conversion of excess electricity to hydrogen, the EnergyPLAN model was more suitable for analyzing RES integration in this study than the H_2RES model was.

The EnergyPLAN model was capable of simulating electricity supply and demand on an hourly basis with a higher time resolution than other energy system models, such as LEAP and MESSAGE, on a 1- and 5-year basis, respectively. These features make EnergyPLAN favorable for the combined energy systems analysis required for this study.

The rapidly increasing electricity production from distributed RESs brings about the challenge of coordinating the electricity