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Exploring the potential of wind energy for a coastal state

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ABSTRACT

Adequate recognition of the wind energy potential of coastal states may have far-reaching effects on the development of the energy systems of these countries. This study evaluates wind energy resources in Taiwan with the aid of a geographic information system (GIS), which allows local potentials and restrictions such as climate conditions, land uses, and ecological environments to be considered. The findings unveiled in this study suggest a significant role for offshore wind energy resources, which may constitute between 94% and 98% of overall wind resources in Taiwan. Total power yield from wind energy could reach between 150 and 165 TWh, which would have, respectively, accounted for between 62% and 68% of Taiwan's total power generation of 243 TWh in 2007. Based on the Taiwan's current emission factor of electricity, wind energy has the potential to reduce CO_2 emissions by between 94 and 102 million ton per year in Taiwan, which is, respectively, equivalent to 28% and 31% of the national net equivalent CO_2 emissions released in 2002. However, the challenge of managing the variability of wind power has to be addressed before the considerable contribution of wind energy to domestic energy supply and CO_2 reduction can be realized.

1. Introduction

The development of renewable energy has been identified as a key strategy in mitigating climate change (IPCC, 2007). Based on observations of equivalent CO_2 emissions from the regulated greenhouse gases of CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6 over the past 30 years, fossil-fuel-induced CO_2 emissions have almost doubled during this period, while other emissions have increased moderately. Substituting renewable energy for fossil fuels is now high on the agenda in international climate and energy policy. Increased use of renewable energy will not only help mitigate global warming, but also meet future energy needs (UN, 2002).

The need for renewable energy appears particularly pressing in Taiwan, where energy supplies principally depend on imported fossil fuels and nuclear energy. Together, these accounted for 99% of the domestic primary energy supply and 95% of the energy supply for power generation in 2007. The average annual growth rate of final energy consumption from 1987 to 2005 reached 5.4%, while that of power consumption reached 6.7%. Furthermore, the demand for primary energy supply is projected to increase by 37.4% from 2005 to 2025, and it is predicted that fossil fuels will still account for 89.3% of the total primary energy supply in 2025. The amount of primary energy supply for coal and natural gas will increase by 70.3% and 179.5%, respectively, during this period (BEROC, 2005). Both the primary energy supply and the energy supply for electricity generation will increasingly depend on the use of coal and natural gas.

This increased use of coal and natural gas would lead to soaring-energy-based CO_2 emissions in Taiwan. In fact, emissions are projected to increase by 32.7%, from 272 million ton in 2005 to 361 million ton in 2025. This trend towards rapidly increasing energy consumption and heavy reliance on fossil fuels is totally incompatible with global efforts to cut CO_2 emissions.

Rising oil prices and increasing CO_2 emissions in Taiwan have recently shaken the national policy of non-nuclear energy enacted in 2003. The Minister for the Economy has recently indicated that a reevaluation of the national policy for nuclear energy may be imminent. A number of leading scientists, including a former Nobel Prize laureate in chemistry, have also stated that nuclear energy is an "indispensable evil", and appealed for the continued development of nuclear energy (Wang and Zeng, 2007). In addition, the Taiwan's newly elected President has expressed his support for rapid completion of the new nuclear power plant, and argued that electricity generation from nuclear energy is "in line with the trend worldwide to provide zero-carbon energy" (Lin et al., 2008).

Under current plans, nuclear wastes will be deposited at existing nuclear power plants after treatment; however, this has induced strong opposition from local residents. Partially treated nuclear wastes are currently deposited on Lanyu (Orchid Island) off the southeast coast of Taiwan. For this reason, the aboriginal inhabitants of this island have been judged to be "environmental refugees" by the United Nations (UN). In the Taiwan's recent past, contamination from radioactive accidents has been recorded in

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more than 1600 households, eight roads, 15 schools, and a water plant (Chang et al., 1997; Wang, 2000). Mutations in fish and the bleaching of coral reefs have also been observed in coastal areas near nuclear power plants. The deposit of nuclear wastes in Taiwan, which is subject to frequent earthquake activities, the transportation of radioactive wastes, and the potential for nuclear reactor accidents, produce incalculable risks in the expansion of nuclear energy. Despite these controversies, both the newly elected President and the majority party in the parliament support the continued development of nuclear energy.

In recent years, the issues of CO_2 reduction and energy security have driven the Taiwanese government to take steps to promote renewable energy. According to national planning, the share of renewable energy in total primary energy supply will increase from 2.4% in 2005 to 6.6% in 2025. However, the potential and significance of renewable energy in energy-economic and environmental terms are insufficiently understood in this country. This has prevented appropriate prioritization of the promotion of specific high-potential energy sources, and the inclusion of these energy sources in the long-term policy planning.

Exploring the potential of renewable energy sources has therefore become an urgent issue in the Taiwan's energy and climate policy. Among all renewable energy sources, wind energy particularly stands out, due to its resource potential and market maturity. In order to quantify domestic wind energy potential, the Energy Commission of the Ministry of Economic Affairs (ECMEA), a governmental agency in charge of national energy policy in Taiwan, commissioned the National Central University (NCU) and the Industrial Technology Research Institute (ITRI) to conduct a joint study to evaluate nationwide wind resources. In this project, wind resources were evaluated by taking the hourly wind data from 1996 to 2000 for the whole Taiwan and calculating them with the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model (known as MM5). The calculated average values of wind data were then modified using data observed from 144 meteorological stations throughout the country with the Wind Atlas Analysis and Application Program (WAsP) software. With these procedures uniform for all areas of the country, a wind atlas was plotted and officially published by the ECMEA for the purpose of providing academic and business communities with database of nationwide wind energy, as presented in Fig. 1. This wind atlas is used in the presented study to estimate large-scale wind energy potential as a reference for framing national energy policy. For investment in wind power generation on a specific site, detailed investigation of wind data over one year would be necessary to ensure investment effectiveness. Such an investigation goes beyond the scope of this study.

Fig. 1 illustrates the distribution of mean annual wind speeds at a height of 50 m from 1996 to 2000 in Taiwan, and indicates that wind resources in Taiwan are concentrated principally in the north-western and south-eastern offshore areas around the main island. For onshore wind energy, there are restrictions in both wind resource and the amount of land available on this island, where the national population density reached 638 person/km^2 in 2007 and two-thirds of the territory is covered by mountainous terrain. An investigation of wind energy potential is, therefore, essential to grasp how wind energy may contribute to supplying clean energy for meeting domestic needs.

Against this background, this study attempted to investigate the potential of wind energy and its probable contribution to the domestic energy system. With geographic information system (GIS)-based analyses, wind energy was evaluated according to actual local land uses to provide more-accurate information to policy-makers and investors as a basis for decision-making. This information is indispensable if decisions are to be made which will build a sustainable energy system, while ensuring climate protection and a long-term energy supply.

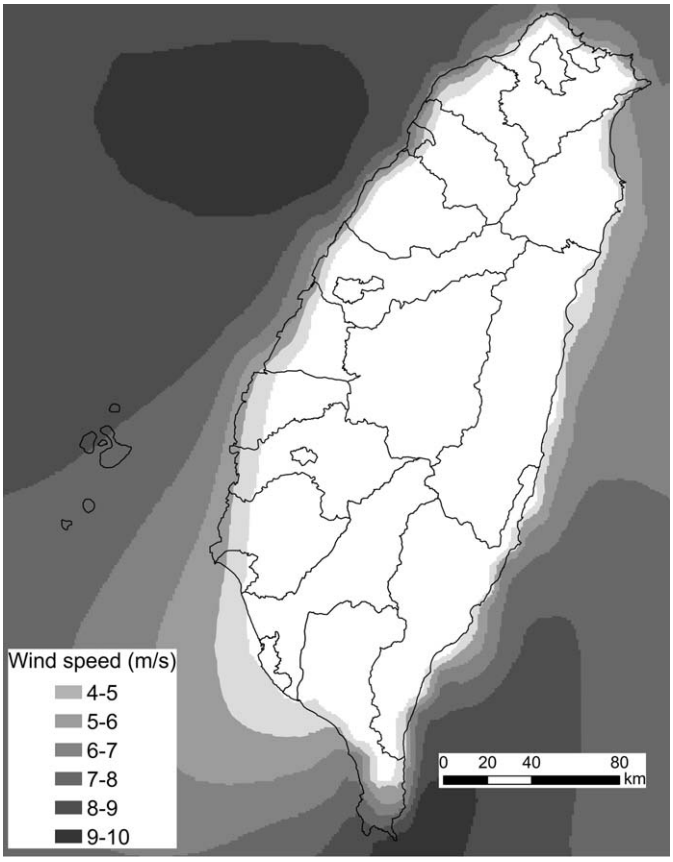

Fig. 1. Distribution of mean annual wind speeds from 1996 to 2000 in Taiwan in m/s at a height of 50 m (*Source*: NCU, 2005).

2. Methodology for evaluating energy potentials

The evaluation of wind potential in this study was based on the wind atlas presented in Fig. 1. The methodology adopted is described below.

2.1. Onshore wind energy

This study evaluated wind energy sources with the aid of a GIS according to actual local conditions. This allowed the assessment to consider local potentials and restrictions such as wind speeds, land uses, and ecological environments. In accordance with recommended guidelines for wind turbine installation (Burton et al., 2001; EWEA, 2003; Kaltschmitt and Wiese, 1994; Voivontas et al., 1998; Yue and Wang, 2006), the evaluation of onshore wind energy was conducted in this study using the following procedures.

(1) The potential was evaluated by considering the following restrictions:
- a minimum allowable mean annual wind speed of 5 m/s over the years from 1996 to 2000 at a height of 50 m;
- a minimum distance from urban-planned districts of 500 m;
- a minimum distance from rural districts of 250 m;
- a minimum distance from forest districts of 250 m; and
- a minimum distance from ecological conservation areas of 250 m.