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Evaluation of the development potential of rooftop solar photovoltaic in Taiwan

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ABSTRACT

Because of extensive exploitation, fossil fuels are gradually becoming depleted and global warming issues are increasing. Therefore, all nations must develop alternative energy resources to reduce the potential risk of exhausting the available fossil fuel energy supply and to resolve environmental degradation.

The amount of sunlight and installed power capacity are crucial factors that influence solar photovoltaic (PV) efficiency. Among domestic and international studies, numerous scholars have proposed various installed power capacity assessment models, which typically calculate areas based on sub-fields, ground floors or per capita. However, an evaluation of the potential of solar PV power generation on rooftops indicated that the shadow effect caused by building structures substantially influence the amount of installed power capacity. This study aims to effectively compute the shadow areas (shaded areas) on rooftops. By using the Hillshade module, the buildings' elevation data and the solar azimuth and altitude angles at different hours were calculated to obtain the hourly sun/shade grayscale values. The grayscale values were then integrated into binary images to calculate the shadow areas on rooftops.

This study suggests that the rooftop solar photovoltaic installation capacity is some 12,428.5 MW and power generation capacity 15,423.75 GWh in Taiwan.

1. Introduction

1.1. Background

Energy is an indispensable element of production input during a nation's economic development. Without an adequate and steady supply of energy, economic development is severely affected. The domestic production of fossil fuels in Taiwan has always been minimal. Coal mining briefly flourished, but currently, only a small amount of natural gas and gas distillate is produced in Taiwan [1].

Over the years, the increasing demand for all energy sources currently used by nations, including fossil fuels such as oil, coal, or natural gas, or radioactive energy such as nuclear energy, has caused prices to skyrocket; moreover, the gradual depletion of resources has caused the imminent exhaustion of energy stores worldwide. In addition, the tangible and intangible pollution produced during energy conversion processes poses a severe risk to the environment. Therefore, the development of alternative energy resources is a necessary direction for all nations, and the use of renewable energy (also called green energy) has become a goal for all advanced nations. Taiwan is an island with a scarcity of self-produced energy; 98% of the energy consumed is imported [2]; thus, the security and stability of the energy supply requires consideration. Renewable energy will play an increasingly essential role in the future, and among these, solar energy is the most common and inexhaustible.

In fact, Taiwan is rich in renewable energy reserves. Located in a subtropical region and surrounded by oceans, sunlight can be considered one of the most abundant resources in the country. The Tropic of Cancer passes through Central Taiwan; therefore, with long hours of sunlight and a small angle of sunlight deflection, sunshine is plentiful. It is estimated that 1.7×10^{11} kW/h of solar energy reaches Taiwan's surface daily [3].

In recent years, the standard of living of the Taiwanese people has increased, and the peak load during summer months has been

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increasing annually. This has caused a potential supply shortage crisis in Taiwan's power market, leading to policies of brownouts or rolling blackouts. If the power generation characteristics of PV systems could match the peak demand in the Taiwan area, this would assist in alleviating peak loads.

Skyscrapers in cities often cast shadows on one another. The formation and timing of shadows are related to the position of the sun, which varies according to location and seasonal changes. Furthermore, the power generated by PV panels (also called solar cells) is related to solar insolation. Therefore, geographic information systems (GIS) can be used to calculate and analyze insolation levels, sunshine durations, and rooftop surface areas. Considering the mutual shadowing by buildings, the rooftop areas of urban buildings suitable for installing PV modules can be analyzed to estimate the area suitable for installing PV panels. These results can be used as a reference in future solar energy developments or investments.

1.2. Research objectives

The following have been performed in current studies for calculating domestic PV potential: empirically measuring one building or one local area (comprising approximately a dozen buildings or a city block), calculating image or vector data by using a GIS, or calculating from land use zoning data, surface area, or per capita area. However, in estimating rooftop PV potential, the shadows caused by buildings will substantially affect the installed power capacity.

For this study, insolation and sunshine duration data from the solar radiation of typical meteorological years were obtained from the Central Weather Bureau and data regarding building layers were collected from the research area (the Yongkang District in Tainan). A GIS was used to calculate and analyze these data. The different azimuth and elevation angles of the sun in the research area were calculated and their effects on the shadowing of the buildings in the area were analyzed. The height differences among the buildings and resulting rooftop surface area shadowed was determined. The surface area that can be used for power generation was calculated and PV power generation was estimated.

The objective of this study was to use GIS technology to estimate the installed power capacity levels and power generation potential of four rooftop PV systems to provide the government with a reference for the promotion of PV systems.

2. Literature review

2.1. Building rooftop shadowing in studies of photovoltaic installation potential

Because PV installation potential has become a theme in international energy and sustainable development, substantial research has been conducted on this topic both domestically and internationally. Building rooftop shadowing in studies of PV installation potential was explored, and the relevant literature is summarized here:

Wiginton et al. [4] quantified the rooftop PV power generation potentials of regional renewable energy policies. Southeastern Ontario was used as an example. To determine available rooftop surface area, five steps were implemented to estimate the total rooftop PV power generation potential, including the geographical division of the region, sampling, deducing the relationship between rooftop area and population, reduction of shading and other uses, and conversion to power and energy outputs. It was discovered that the relationship between roof surface area and population was 70.0 m^2/capita (±6.2%). When rooftops had appropriate solar cell coverage, the potential peak PV power output in the region was 5.74 GW, which is 157% of the peak power demands of the area. This signifies that deploying rooftop PV throughout the province would satisfy 30% of Ontario's energy needs.

Ordonez et al. [5] analyzed rooftop PV capacity in Spain's Andalusia region. In 2006, the residential sector in Andalusia consumed 12,320 GW. If PV arrays were installed on all the residential rooftops in the region, the PV capacity was estimated to be 9.73 GW/y, and the rooftop surface area was 265.52 km^2. With these specifications, 78.89% of all energy demands could be met. By implementing the measures proposed in the study, the sustainable development of energy required by Andalusian residents would be feasible.

Bergamasco et al. [6] considered roof-top integrated PV systems. The assessment of the PV energy potential passes through the evaluation of the roof surface area available for installations. In the present paper, a methodology for estimating the PV solar energy potential is presented, together with its application to the Piedmont Region (North-Western Italy). The roof area suitable for solar applications is calculated through the analysis of available GIS data. However, Bergamasco et al. [7] has been computed on a given cartographical dataset, and the real roof surface available for PV installations has been evaluated through the assumption of representative roofing typologies and empirical coefficients found via the visual inspection of satellite images. In order to overcome this arbitrariness and refine our methodology, in the present paper we present a brand new algorithm to compute the available roof surface, based on the systematical analysis and processing of aerial georeferenced images (ortho-images). The algorithm, fully developed in MATLAB®, accounts for shadow, roof surface available (bright and not), roof features (i.e. chimneys or walls) and the azimuthal angle of the eventual installation. Here we apply the algorithm to the whole city of Turin and process more than 60,000 buildings. The results achieved are finally compared with our previous work and the updated PV potential assessment is consequently discussed.

Vardimon [8] estimated the usable area of rooftops in Israel by using orthoimages to extract building layer images. GIS data were used to calculate the available rooftop area. The annual rooftop PV electricity production was equivalent to 32% of annual national consumption and was feasible for long-term application.

Yue et al. [9] estimated the domestic rooftop surface area suitable for the installation of solar energy systems based on insolation data from throughout Taiwan and integrating GIS data. The power generation and thermal energy potential of all cities and counties in Taiwan were estimated. The total thermal energy potential of all of Taiwan was found to be 25 TWh/y, and the electricity potential was found to be 236 TWh/y. Investment returns and other financial

Table 1
Taiwan's development potential regarding PV resources.

Research unit	Development potential
Energy Commission, Ministry of Economic Affairs [10]	5250 MW
Taiwan Power Company [11,12]	Theoretical reserves: 11,730 MW Developed capacity: 4131 MW
Institute of Nuclear Energy Research [11]	6166 MW
Chen et al. [13]	52,000 MW $\left(65\,\frac{\text{TWh}}{\text{y}} \div \frac{1250\ \text{kWh}}{\text{y}} = 52\ \text{GW}\right)$
Bureau of Energy, Ministry of Economic Affairs [14]	2855 MW
Lin [15]	3758 MW
Yue et al. [16]	28,880 MW $\left(36.1\,\frac{\text{TWh}}{\text{y}} \div \frac{1250\ \text{kWh}}{\text{y}} = 28.88\ \text{GW}\right)$