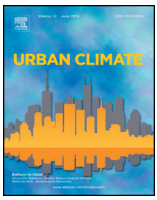
Urban Climate 17 (2016) 1–19

Contents lists available at ScienceDirect

Urban Climate

journal homepage: http://www.elsevier.com/locate/uclim



A method to estimate the potential of rooftop photovoltaic power generation for a region

Jihui Yuan [a,*], Craig Farnham [a], Kazuo Emura [a], Siqiang Lu [b]

[a] Graduate School of Human Life Science, Osaka City University, Osaka, Japan
[b] College of Architecture and Environment, Sichuan University, Chengdu, China

ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 8 January 2016
Accepted 9 March 2016
Available online xxxx

Keywords:
PV power generation
Potential
Aerial photo data
Solar radiation
Roof utilization

ABSTRACT

At present, solar energy is receiving heightened attention as a potentially widespread approach to sustainable energy production, and the study of photovoltaic (PV) technology has expanded globally. The amount of PV power generation is growing quickly. This paper proposed a method to calculate the rooftop PV potential for a city or region by estimating the total useful roof area for PV installations and incident annual solar radiation. The aerial photo data of a city and pixel analysis techniques with a C++ program were used to estimate the rooftop PV potential of an example case, Osaka City, Japan in this study. The total useful area of PV system is estimated as 42,000,000 ± 9,000,000 m^2 in Osaka. If the efficiency of PV power generation is assumed to be a value of 0.20 in this contribution, PV power generation could supply about 56% of the entire electrical power demand in the commercial sector, about 12,400,000 MWh/year, or could supply about 34% of the entire electrical power demand in the commercial and industrial sectors, about 20,300,000 MWh/year.

1. Introduction

The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts, such as ozone layer depletion, global warming, climate change, etc. The global contribution from buildings toward energy consumption, both residential and commercial, has steadily increased to between 20% and 40% in developed countries, and has exceeded the other major sectors: industrial and transportation (Lombarda et al., 2008). A dramatic spread and expansion of

* Corresponding author at: Graduate School of Human Life Science, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan.
E-mail addresses: yuanjihui@hotmail.co.jp (J. Yuan), farnham@life.osaka-cu.ac.jp (C. Farnham), emura@life.osaka-cu.ac.jp (K. Emura), lusiqiang@scu.edu.cn (S. Lu)

http://dx.doi.org/10.1016/j.uclim.2016.03.001
2212-0955

Nomenclature

I_{inc}	Global solar radiation of an inclined plane [kWh/m^2]
I_{inc}'	Incident global solar radiation for the useful area of PV system [kWh/ m^2/year]
I_s	Direct solar radiation onto the normal plane [kWh/m^2]
I_d	Diffuse solar radiation onto the horizontal plane [kWh/m^2]
I_g	Global solar radiation onto the horizontal plane [kWh/m^2]
i	Solar incident angle [°]
θ	Inclination angle [°]
h	Solar altitude [°]
A	Solar azimuth [°]
μ	Azimuth of the roof [°]
ρ_g	Albedo of the ground (−)
γ_{max}	Inclination angle of PV system with the largest total daily solar radiation [°]
γ	Inclination angle of PV system [°]
φ	Latitude [°]
δ	Declination [°]
S_u	Useful area of PV system set on the rooftop of 1 km square sample [m^2]
S_h	Horizontal projection area of the roof [m^2]
S_o	Obstacle area of the roof [m^2]
S_s	Shaded area of the roof [m^2]
a	Obstacle coefficient of the roof [−]
b	Shape coefficient of the roof [−]
m	Proportion of number of units [−]
U	Utilization ratio of the roof due to different style of roofs [−]
G	Gradient elongation rate of the roof [−]
P_s	Annual PV power generation [kWh/year]
F	Efficiency of PV power generation [−]
n	Net sunlight proportion coefficient [−]
C_{is}	Proportion of the solar panel subject to any shading [−]
R_s	Proportion of the area of C_{is} that receives sunshine, integrated over the course of the day as the shadows move [−]
C_{os}	Proportion of no shade zone [−]

renewable energy is essential. With increasing attention toward carbon-neutral energy production, solar electricity is receiving heightened attention as a potentially widespread approach to sustainable energy production. The global solar electricity market is currently more than $10 billion/year, and the industry is growing at more than 30% per annum (U.S. Department of Energy, 2005).

In cities, space is limited, so placement of photovoltaic (PV) panels is usually only possible on rooftops. Various parameters have to be considered when installing grid-connected PV systems (Eltawil and Zhao, 2010; Singh, 2003), as some buildings' roofs are more suitable than others, regarding the received solar irradiance. Solar potential is one of the more reliable metrics for finding the most suitable surfaces for PV systems' installations. Some of the more important parameters to be considered in solar potential estimation are: geographic location, surface topography, influence of atmospheric attenuation by molecular absorption and Rayleigh or Mie scattering, and shadowing effects from surroundings (Lukac et al., 2014). The solar potential can generally be defined as the potential suitability of a given surface for a PV system's installation, evaluated by the total or average-daily estimated irradiance the given surface receives throughout the year (Lukac et al., 2013).

The Agency for Natural Resources and Energy (ANRE) reported that sources of electric energy in Japan included crude oil, coal, natural gas, nuclear power, hydropower and renewable energy. However, nuclear power, which accounted for about 30% of Japan's electric supply, was almost entirely shut down in the