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Life cycle cost of photovoltaic technologies in commercial buildings in Baja California, Mexico

J.F. Armendariz-Lopez [a], A. Luna-Leon [b], M.E. Gonzalez-Trevizo [c, *], A.P. Arena-Granados [d], G. Bojorquez-Morales [b]

[a] Institute of Engineering, Autonomous University of Baja California, Blvd. Benito Juárez S/N Unidad Universitaria, Mexicali, Baja California, 21270, Mexico
[b] Faculty of Architecture and Design, Autonomous University of Baja California, Blvd. Benito Juárez S/N Unidad Universitaria, Mexicali, Baja California, 21270, Mexico
[c] Faculty of Architecture, Michoacan University of Saint Nicholas of Hidalgo, Francisco J. Mújica S/N, Col. Felicitas del Río, cd. Universitaria, Morelia, Michoacan, 58030, Mexico
[d] Mendoza Regional Faculty, National Technological University, Rodriguez 273, Mendoza, Mendoza, M5502AJE, Argentina

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ABSTRACT

The appropriate use of photovoltaic technologies is essentially based on the identification of the available solar resource at the location in which they will be installed and the energy demand concerned. The purpose of this paper is to identify the geometric orientations that provide the best life-cycle cost for a multi-crystalline photovoltaic module, in order to supply electric energy for commercial buildings in three locations in Baja California, Mexico. The energy production of photovoltaic technologies was estimated on TRNSYS® according to a Typical Meteorological Year (TMY) simulated through spatial interpolation methods in Meteonorm®. Energy generation was compared in different orientations and inclinations of the photovoltaic array, its cost was calculated from the grid of the Federal Electricity Commission of Mexico. As a result, it was observed that in the city of Mexicali (hot-dry climate) the highest cost-benefit factor (3.17) and the shortest return on investment (13.02 years) was reached. The results showed that the multi-crystalline silicon photovoltaic cells represent a feasible investment option when installed in commercial buildings.

1. Introduction

There is an increasing concern for environmental issues, depletion of energy resources and their supply difficulties. As a result, governments tend to focus increasingly on the dissemination of technologies that exploit renewable energy sources [1].

Solar energy is the most abundant, inexhaustible and clean of all existing energy resources [2]; due to this, solar-based systems have notably increased their popularity as an alternative to reduce the consumption of fossil fuels and greenhouse gas emissions [3].

The solar energy applications go beyond power generation and water heating, common applications are useful for heating, steaming, drying and dehydration processes; preheating, concentration, pasteurization, sterilization, lavage, cleaning, chemical reactions, amongst others [4]. This energy, is suitable to supply electricity in the residential, commercial or industrial sector, but especially in remote or rural communities. The potential of solar energy on earth surface is near 1.8×1011 MW, which is 10,000 times greater than the global energy consumption [5].

Irradiance on earth's surface during the day is not uniform, because this depends on aspects, such as solar zenith angle, the length of the day, air turbidity, water vapor content in the air and the type and amount of clouds.

The Solar irradiance data on horizontal surfaces are commonly measured by meteorological services in stationary solar conversion systems throughout weather stations. However, in order to estimate the irradiance on tilted surfaces with high accuracy, several numerical models have been developed [6–9].

Thus, there are databases built up from satellite measurements, where models of solar radiation are embodied within geographical information systems (GIS); based on empirical equations, these may provide fast and accurate radiation on different regions, taking

* Corresponding author.
E-mail addresses: josefrancisco.armendariz@gmail.com (J.F. Armendariz-Lopez), anibal@uabc.edu.mx (A. Luna-Leon), gonzalez_marcos@ucol.mx (M.E. Gonzalez-Trevizo), aparena@gmail.com (A.P. Arena-Granados), gonzalobojorquez@uabc.edu.mx (G. Bojorquez-Morales).

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into account the tilting surface orientation and shading effects. Although these methods provide information at continental level or even globally, they can also generate wrong predictions, especially where there are mountain ridges where the shading of the surface can cause significant fluctuations in irradiance.

Some of the best known databases are the European Solar Radiation Atlas (ESRA), the Surface meteorology and Solar Energy (SSE) from NASA, as well as the one provided by National Renewable Energy Laboratory (NREL), the high-resolution information available from SolarGIS and finally the Photovoltaic Geographical Information System (PVGIS) which includes free information of Europe, Africa and Asia [10–14].

This paper focuses on the solar resource analysis for three different locations in Baja California, Mexico; Mexicali (Lat. 32° 39′ N, Long. 115° 29′ W) with a hot-dry climate, San Felipe (Lat. 31° 02′ N, Long. 114° 50′ W) with a hot-humid climate and Tijuana (Lat. 32° 32′ N, Long. 116° 58′ W) with a temperate climate. Later, a study of the economic feasibility of the multi-crystalline silicon photovoltaic systems in commercial buildings for the locations cited was evaluated.

2. Antecedents

2.1. Photovoltaic module orientation for optimum power production

Several studies have been made to estimate the PV power stations in different latitudes. Yan et al. [15] found that the optimum tilt angle for this systems in Brisbane, Australia (Lat. 27.28° S), is 26° oriented due north. Randall et al. [16] showed that the optimal annual performance of monocrystalline PV array on field conditions in London, England is achieved with a south orientation and tilt angle of about 30°. Yet, at the same time, when the orientation was 45° due south–east, the output energy was near 95.7% regarding the optimum orientation and slope annual performance.

Asl-Soleimani et al. [17] evaluated the experimental performance of photovoltaic modules in Tehran, Iran (Lat. 35.71°N) using mono-crystalline modules with different tilt angles 0°, 23°, 29°, 35° and 42°, and two multi-crystallines, 16 mono-crystallines and one of thin film with a tilt angle of 45°. Results indicated that the maximum production of photovoltaic energy is reached with a tilt angle of 29°.

Hussein et al. [18] calculated via computational simulation, that maximum annual production for monocrystalline arrays is reached at south orientation and at a tilt range between 20° and 30° in Cairo, Egypt (Lat. 30° N). It also showed that east orientations produced a higher amount of annual energy than west orientations, was also identified that the horizontal arrangement obtain 95% of the optimal annual value for energy production.

Nakamura et al. [19] identified that energy production of monocrystalline modules installed in Shizuoka, Japan (Lat. 34.45° N) decreased one percent for a cell with horizontal arrangement regarding a tilted surface with a slope of 30° and oriented due south. Other studies have conducted more detailed analyzes to identify the optimum configuration for each month of the year. Kacira et al. [20] evaluated the optimum orientation and tilt for PV modules installed in Sanliurfa, Turkey (Lat. 37° N), the results were compared with the gain of a system of dual axis solar tracker.

Optimum inclinations varied around the year, with a minimum value of 13° in June and a maximum of 61° in December. The increased uptake of radiation of the tracking system was 1.1% higher over the year compared to the optimum setting for every month and 3.9% higher when it was compared to the latitude of the location.

Mondol et al. [21], indicated through numerical simulation that the highest energy production in maritime climate in Northern Ireland (Lat. 54° N) was achieved with a 30° tilt angle, oriented due south; although the optimum tilt angle changes throughout the year between 10 and 70°. Benghanem [22] found that the optimum tilt angle for PV systems around the year in Medina, Saudi Arabia (Lat. 24.28° N) was almost the same as the latitude of the location.

Kaldellis et al. [23] noted that to satisfy certain energy demands, is not essential the increase of the system capacity, but the tilt angle and orientation must fit the annual consumption pattern of the particular case. In this respect, Kaldellis y Zafirakis [24] experimentally analyzed tilted surfaces of 0°, 15°, 30°, 45°, 60° y 75° during 20 days in summer in Athens, Greece (Lat. 37.58° N); this research concluded that tilted surface of 15° produced the highest amount of electricity in summertime.

Hiraoka et al. [25] examined the performance of photovoltaic technologies installed with a tilt angle of 26.51° due south (monocrystalline), 26.51° due north (multi-crystalline and amorphous silicon cells) and horizontally (amorphous silicon cells) in Shinga, Japan (Lat. 34.51° N).

The results showed that the annual data of all orientations represent approximately 70% compared to the data of the south facing panels. The amorphous silicon cell arranged horizontally had the best performance in summer, while the south-facing monocrystalline technology had the best performance in winter.

Useful considerations come up with concepts for cross-comparison, such as Performance Ratio (PR), which refers to the ratio of the energy of a PV plant that is actually available for export to the grid after deduction of thermal and conduction losses, regardless of location. That is to say; the PR is a factor that describes the existing relationship between real and theoretical output power of a photovoltaic system, this parameter – for example-have resulted a powerful tool to compare an enormous amount of facilities studied by Leloux et al. [26].

Various authors have compared PR values from several PV technologies in Chipre throughout different climate seasons. Results shown that monocrystalline technology has the best performance in winter, along with CIGS and CdTe, but these two with a shorter breadth [27]. Some others evaluate experimental results of grid-connected PV systems finding an average PR of 77.28% in mono-crystalline silicon cells [28].

Meanwhile, the International Energy Agency (IEA) [29] has developed a set of guidelines for the development of life-cycle assessment of photovoltaic technologies through the Photovoltaic Power Systems Program (PVPS) where sets the PR to consider are site-specific or a default value of 75%–80% roof and ground mounted, installed in optimal orientation and tilt (Hyung et al. [30], Mason et al. [31] and Pfatischer [32]).

It is considered that a photovoltaic plant has a high performance when the performance ratio exceeds 80%. Overall performance ratio increases with the decrease in temperature and the monitoring of photovoltaic systems for early detection of defects. This means that with good ventilation and large-scale installations increased performance is obtained.

2.2. Economic feasibility of photovoltaic modules

Some studies have conducted comparative economic feasibility between different countries. Muhammad-Sukki et al. [33] showed that in the residential sector, despite having a higher installation cost, Japan requires less time to recover the investment (7.70 years) than the UK (7.80 years) and Germany (12.32 years).

Similarly, in the non-residential sector, Japan has the highest installation cost; however, payback period of the investment is about eight years long for Japan, while for the UK and Germany is over nine years. Pillai et al. [34] identified that residential photovoltaic systems interconnected to the electric grid in India obtain a