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Autonomous Electricity Production through Photovoltaic Systems and Environmental Evaluation: A Case Study of the Building of the Department of Landscape Architecture of the National Chiayi University

Cheng-Dar Yue[a*], Ing-Chuan Chen[b], Chio-Jing Lee[b]

[a] Associate Professor, Department of Landscape Architecture, National Chiayi University

[b] Bachelor, Department of Landscape Architecture, National Chiayi University

ABSTRACT

This study examined photovoltaic (PV) electricity generation on the rooftops of a building and neighboring parking shelter to investigate autonomous electricity supply. The self-sufficiency rate was calculated by evaluating the electricity demand and power generation from PV systems by estimating the rooftop area available for PV installation. The annual electricity output from PV systems installed on the rooftop of the studied building was estimated to be 1.2 times the total electricity consumption of the building in 2016. The annual PV power generation for both the building rooftop and parking shelters was 4.2 times the total energy demand for the building and transport, indicating that 100% renewable electricity is achievable. Surplus electricity can be fed into the grid for campus usage. A simulation of shading and PV panel installation proved to be a useful tool in allocating a suitable site for installing PV panels and in revealing their possible impacts on the surrounding environment.

Keywords: Photovoltaic system, Autonomous power generation, Environmental evaluation

1. Introduction

Transitioning from fossil fuels to renewable energy sources (RESs) is a key strategy for achieving climate protection, since the energy supply sector is the largest contributor to global greenhouse gas (GHG) emissions. Stabilizing GHG concentrations at low levels requires a fundamental transformation of the energy supply system, including the long-term substitution of fossil fuel conversion technologies with low-GHG alternatives. Most integrated modeling scenarios presented by the Intergovernmental Panel on Climate Change

* Email: cd.yue@msa.hinet.net

(IPCC) have indicated that decarbonization occurs more rapidly in electricity generation than in the industry, buildings, and transport sectors (IPCC, 2014). Decarbonizing electricity generation is therefore a key component of cost-effective mitigation strategies for stabilizing GHG concentrations at low levels.

Solar energy is widely regarded as a major RES, which in future energy systems will be able to contribute to the security of the energy supply and protection of the environment. Several reports have indicated the major contribution of solar energy to global energy needs in the long term (IPCC, 2012; WEC, 2007). The distributed energy generation from solar photovoltaics (PVs) represents a particular benefit regarding energy security.

The introduction of PV technology to the market has long been hindered by its high capital investment cost. However, during the first decade of this century, its price has dropped to between 3 and 4 USD/Wp for small-quantity buyers, and between 2 and 3 USD/Wp for large-quantity buyers. Because of these economic incentives, the application of PV power generation has rapidly increased during the past several years and might slow global warming through substitution for fossil fuel-based power generation. In addition, green roofs play an increasingly crucial role in the implementation of adaptation strategies regarding climate change because of their usefulness in reducing heat island effect, thus reducing electricity consumption from use of air conditioning. The combination of a green roof and PV system might demonstrate a considerably positive effect on the mitigation of and adaptation to climate change. This study addressed this topic by investigating a PV system design on both the rooftop area of the building and the parking shelters of the Department of Landscape Architecture of National Chiayi University for meeting local electricity demand. The objective of this study was to evaluate the electricity self-sufficiency of the building regarding PV power generation. First, site conditions in regard to the climate, land use, and user demand were investigated. PV panels were then designed. Subsequently, the electricity self-sufficiency was evaluated on the basis of the estimated electricity yield. Finally, the implications for a PV system design were proposed.

National Chiayi University is located in Chiayi City in southwestern Taiwan. The construction of the four-story building of the Department of Landscape Architecture was completed in 2007. An ancillary parking lot is located northeast of the building (Fig. 1). The department had a total of 210 students and 10 faculty members in 2013.

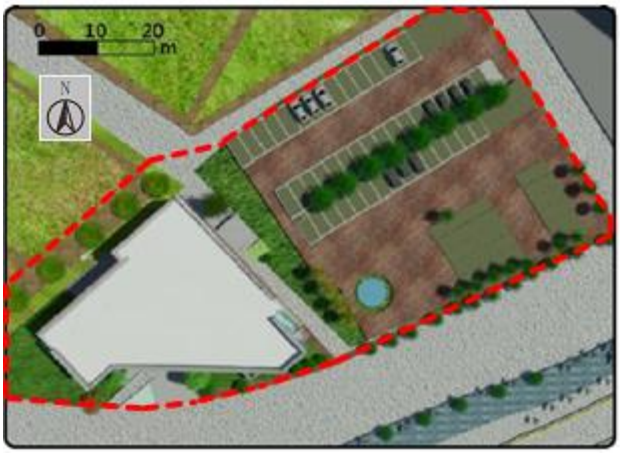

Figure 1. The studied site delimited by a dotted red line mainly comprises a building in the southwestern portion and a parking lot in the northeast portion.

2. Literature review

The achievement of energy autonomy through use of locally available RESs is becoming a target of energy policy in many parts of the world, both on national and local levels (Droege, 2009; Lund & Mathiesen, 2009; Scheer, 2006). The purposes of this policy target are energy security and the reduction of GHG emissions. Traditional centralized power supply systems have led to considerable energy loss through the electricity grid. Energy autonomy is becoming increasingly prevalent, as demonstrated by several successful cases worldwide, due to development in technology that exploits locally available RESs such as solar, wind, hydro, and biomass energy. An excellent example is the “BedZED” project at Beddington, south of London. PVs are positioned on roofs and top story windows. Roof-mounted PVs, with others on site, generate electricity that can charge up to 40 electric cars (Dunster, 2003).

The use of various renewable energy technologies is becoming widespread, and their impacts on our living environment have received considerable attention. The environmental impact assessment of PV power generation has been the subject of numerous studies. PV arrays on buildings do not require additional land. However, rooftop arrays are visible to neighbors (Boyle, 2004). (Chiabrando, Fabrizio, & Garnero, 2009). noted several possible impacts of installing PV panels on the surrounding landscape. Impacts such as land use, interference with flora and fauna, microclimate change, and glare and visual impact should be considered to facilitate expanding the market penetration of PV technology without causing far-reaching adverse impacts on human health and ecology (Chiabrando et al., 2009).

Ground-based, centralized PV power generation generally has a greater impact on land use than rooftop-based power generation because additional land is required. The impact on flora and fauna as a consequence of the installation and operation of the system is also a major concern. Furthermore, an impact on the microclimate may occur because of heat emission of the PV module. The module may reach a maximum temperature of approximately 70℃, which results in heating of the air surrounding the system or discomfort due to the hot surface of the module. Additionally, the conversion efficiency decreases with an increase in the temperature of the module (Skoplaki., Boudouvis, & Palyvos , 2008).

The reflection of sunlight by the surface of the PV module can cause glare. The possibility of glare should be assessed if there are potential sensitive receptors in the vicinity of the system, such as houses and roads. The visual impact of the PV module on the landscape can be assessed according to the factors of visibility, color, and fractality (Kapetanakis., Kolokotsa, & Maria, 2014). The visual impact depends on the total area of the landscape occupied by PV modules. The impact of color pertains to the contrast between the color of the PV modules and colors in the surrounding landscape, including vegetation and the sky. The fractal dimension measures the degree of artificial geometry in the natural landscape, where straight lines are absent, and the PV module, whose structures are characterized by distinct lines.

The environmental conditions around the PV panels, on the other hand, may affect their performance as well. (Früh, 2012) noted that green roofs have a positive synergetic effect with PV panels. Plants and soil raise the air humidity through the evaporation of stored water, which contributes to temperature cooling on site. This cooling effect is beneficial to PV panel performance because solar cells averagely produce approximately 0.5% less electricity with each degree of temperature higher than 25℃ under constant solar radiation. PV modules are tested at 25℃, and depending on their installed location, the heat can reduce the output efficiency of the modules by 10%–25% (Schoder, 2011). As the temperature of the solar panel increases, its output current increases exponentially, whereas the output voltage decreases linearly. Thus, heat can severely reduce the power generation of the solar panel. Heating the solar panel from 25℃ to 65℃ leads to an efficiency loss of 20%. From energy and economics perspectives, for installation in a warm climate, the temperature of the solar panel should not be excessively increased. PV modules on green roofs stay cooler than those on bare rooftops, which facilitates mitigating performance loss in PV panels caused by high temperatures.

3. Methodology

The climate, land use of the site and user demand were analyzed to determine the positions of the PV panels on the rooftops of the building and parking shelters. According to the estimated electricity supply and demand, electricity self-sufficiency was evaluated. The annual electricity output (E_e, kWh) from the PV system was estimated using the following equation (IEA, 2002; ITRI, 2005; Kaltschmitt, M., Streicher, W., & Wiese, A., 2007)

$$E_e = A_{tp} \times I \times D \times E_f \times C_o \times A_v \quad (1)$$

where E_e is the annual electricity output of the PV system (kWh/year); A_{tp} is the total PV module area (m^2); I is the global solar radiation (kW/year/m^2); D is the duration of sunshine (hours/year); E_f is the module efficiency (%); C_o is the aggregative coefficient (%); and A_v is the availability of the PV system after allowing for downtime for maintenance and unplanned outages (%).

The evaluation of PV potential was based on the following parameter assumptions:

- a module area per installation capacity of 7.7 m^2/kW (BMU, 2002);
- a global solar radiation in Chiayi of 3.6 kW/m^2/day (CWB, 2017);
- a duration of sunshine in Chiayi of 5.4 hours/day (CWB, 2017);
- a PV module efficiency of 22% (PennEnergy, 2015);
- a PV system aggregative coefficient of 75%, based on factors including temperature variation, module contamination, transmission loss, inverter efficiency, and compensation for battery charge and discharge (ITRI, 2005); and
- a 95% annual availability of the PV system, allowing for downtime for maintenance and unplanned outages (Thevenard & Pelland, 2013).

The annual electricity consumption of electric vehicles and motorcycles was estimated using the following equation:

$$E_e = P \times D \times E_k \quad (2)$$

where E_e is the annual electricity consumption (kWh/year); P is the number of passengers; D is the annual driving or riding distance (km/year); and E_k is the energy consumption of electric vehicles and electric scooters (kWh/km).

The evaluation of energy consumption of electric vehicles was based on the following parameter assumptions:

- the number of commuting days in a 36-week school year of 180 days per year; and
- energy consumption of electric vehicles and electric scooters of 15 kWh and 2.75 kWh, respectively, per 100 km (MacKay, 2009).

Carbon dioxide reduction was evaluated by replacing the values for electricity and gasoline consumption with those of PV-generated electricity according to the following parameter assumptions:

- GHG emissions from PV generators of 58 tons of CO_2 eq/GWh, based on IPCC and WEC average estimates (IPCC, 2007; WEC, 2004);
- Taiwan's overall emission factor of 0.529 kg CO_2/kWh for electricity generation in 2016 (BEROC, 2017); and
- tank-to-wheel carbon dioxide emissions from gasoline of 187 g CO_2 eq/km (WEC, 2004).

4. Site analysis

4.1 Climate

Chiayi City is located in a subtropical climate zone with a warm, monsoon-influenced humid climate. Northeasterly winds reduce rainfall during fall and winter, whereas southwesterly winds during summer and late spring bring most of the year's rainfall. Humidity is high year-round. The mean annual temperature from 1981 to 2010 was 23.1℃ (CWB, 2015). The annual average sunshine duration during that period reached 2066.7 hours, representing an excellent solar radiation condition.

The rooftop area of the building on site is unshaded for the entire year, and it is therefore highly suitable for solar electricity generation. Parts of the parking lot nearest to the building are shaded by it in the afternoon. A software simulation (3ds Max; Autodesk, Inc., San Rafael, California, U.S.) conducted in this study indicated that the shading was differently located according to different hours and seasons, with the greatest shading effect occurring before the sunset of the winter solstice (Fig. 2 and Fig. 3).

The analysis of the shading effect at different hours in each season indicated that the sun is located on the south side of the building from autumn to spring. The parking lot is rarely shaded in summer, when solar irradiation is strong, whereas the shading effect is evident before the sunset of the winter solstice (Fig. 4).

4.2 Land use

The studied site mainly comprises a building and parking lot. The building of the Department of Landscape Architecture is situated in the southwestern part of the site, with an ancillary parking lot located in the northeast part (Fig. 1). A small pond is located at the south side of the parking lot.

4.3 Building construction

The four-story building of the Department of Landscape Architecture is constructed using reinforced concrete. The floor area of the building is 731.86 m^2. This allow PV panels to be installed on the rooftop area without construction safety concerns.

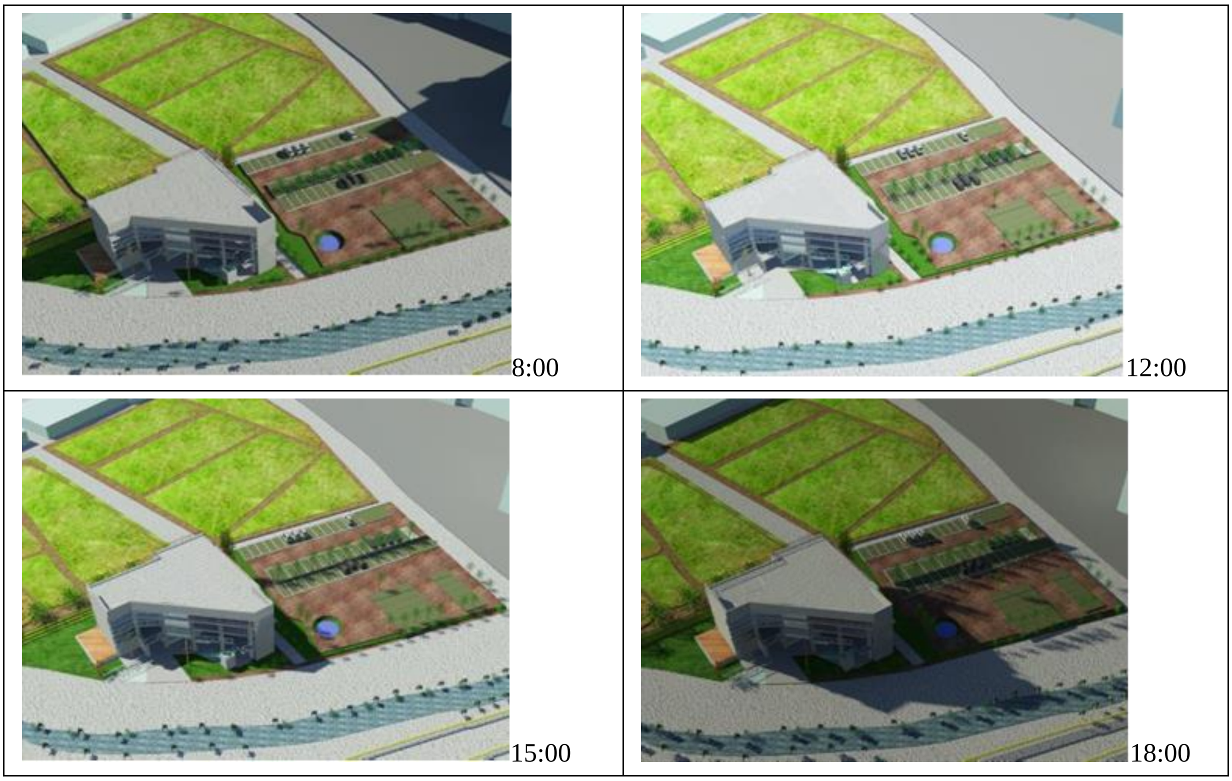

Figure 2. Simulated shadow positions during the summer solstice.

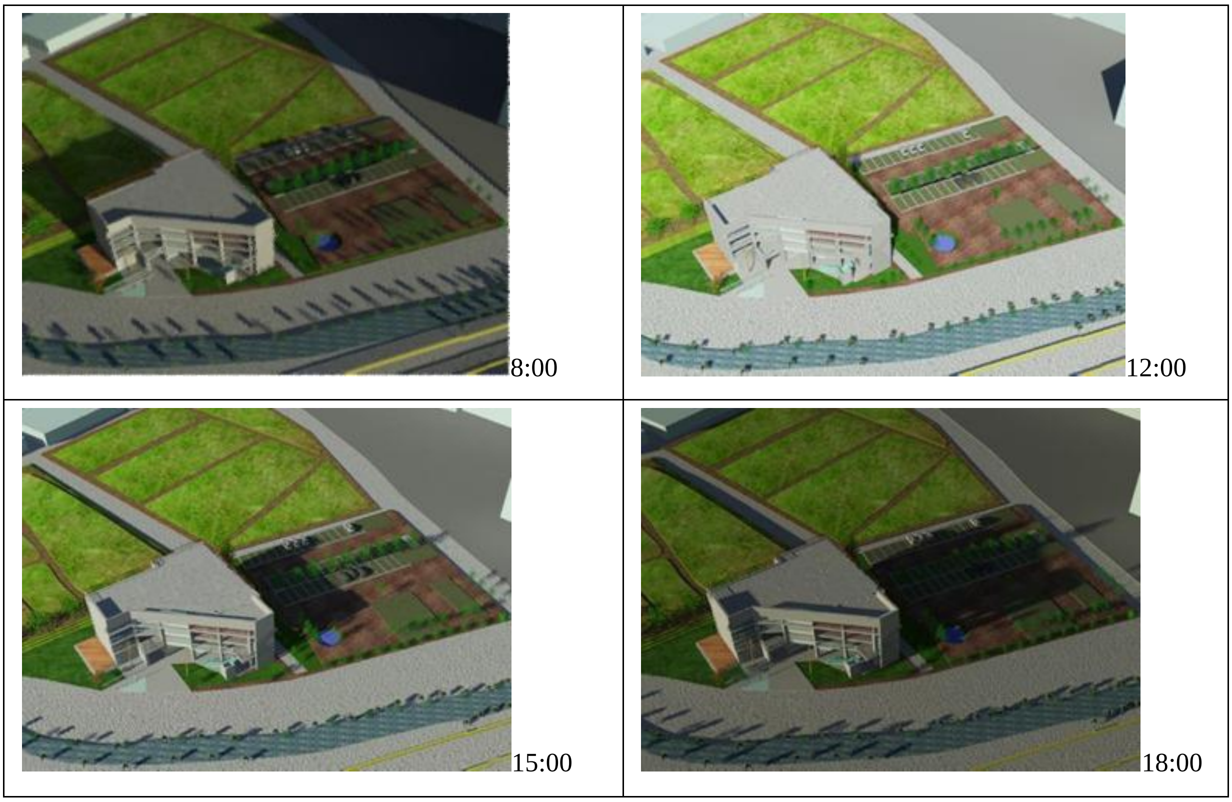

Figure 3. Simulated shadow positions during the winter solstice.

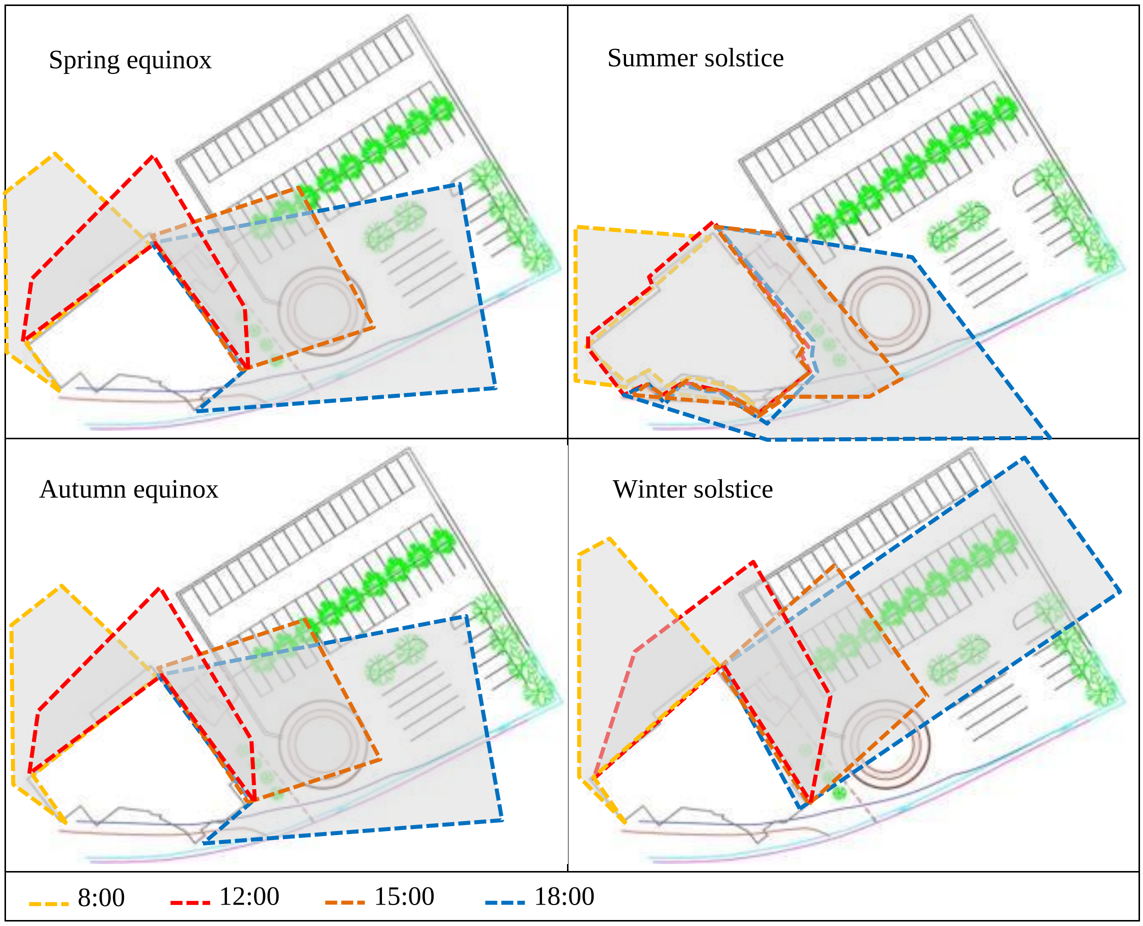

Figure 4. Simulated shadow positions for different times and seasons.

4.4 Functional demand

The flat building roof was unused. The parking lot is principally unshaded, causing a considerable heat burden on car and bike users year-round. Shading of the parking lot would therefore be beneficial and can be integrated with the installation of PV panels.

The electricity consumption of the building was 121,905 kWh in 2016 (NCYU, 2017). Apart from the summer vacation from July to September, the electrical load is high between April and October, when air conditioning is typically used (Fig. 5). The expenditure for electricity is a considerable financial burden for the department.

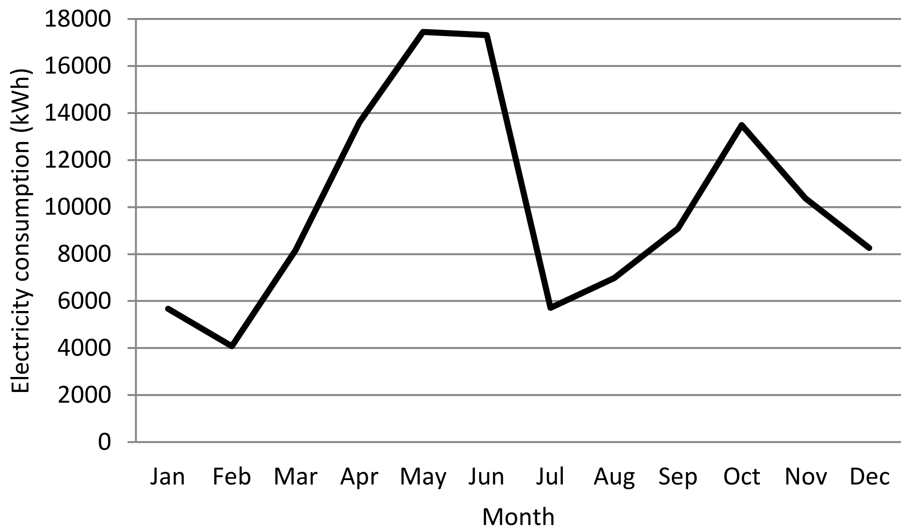

Figure 5. Averaged monthly electricity consumption of the building of the Department of Landscape Architecture from 2012 to 2016 (NCYU, 2017).

5. Allocation of PV panels

Installing PV panels on both the rooftop of the existing building and the proposed parking shelters is intended to avoid additional land use in the studied area. Since the sun is situated on the south side of the building during most of the year, the PV panels were allocated to the south parts of the building rooftop area (Fig. 6). Plants were situated beneath the PV panels on the building rooftop. A balcony was constructed on the northern corner of the rooftop. A practice farm was placed between the PV panels and the balcony.

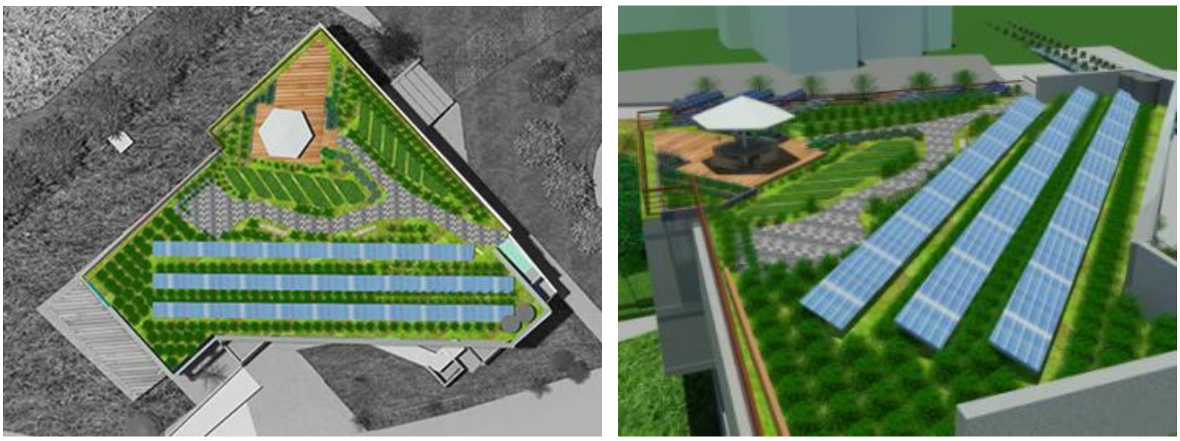

Figure 6. Simulated rooftop plan (left) and perspective (right) for integration of the PV system and green roof.

Because the western part of the parking lot is shaded from solar irradiation by the building in the afternoon, a buffer zone was allocated between the parking lot and building. Parking shelters for cars and bikes with mounted PV panels were allocated to the eastern part of the parking lot (Fig. 7). In total, 18 parking spaces for cars and 232 for bicycles were provided.


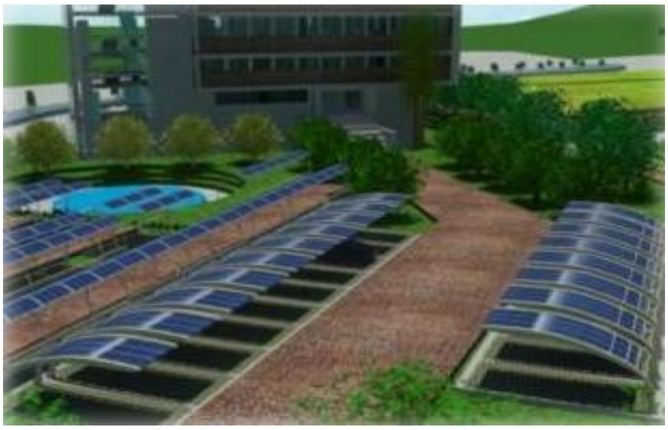

Figure 7. Plan of the parking lot with 18 and 232 parking spaces for cars and bicycles, respectively (left), and the perspective of the parking shelters in the parking lot (right).

6. Energy self-sufficiency

The total area available for PV panel installation on the rooftops of the building and parking shelters approximated 130.9 m^2 and 369.6 m^2, respectively, with a total installation capacity of 65 kW. By using Eq. (1), the annual electricity output from PV systems on the rooftop area of the building was estimated to be 145,592 kWh, which is 1.2 times the total electricity consumption of the building of 121,905 kWh in 2016.

$$E_e = A_{tp} \times I \times D \times E_f \times C_o \times A_v$$
$$= 130.9 \times 3.6 \times 5.4 \times 365 \times 22\% \times 75\% \times 95\%$$
$$= 145{,}592 (kWh)$$

Considering the area of parking shelter roofs available for PV panel installation, with a potential yield of 411,082 kWh per year, the total annual electricity yield of the building and parking shelters is 556,674 kWh. This yield is 4.6 times the total electricity demand of the building of 121,905 kWh in 2016, which indicates that the electricity generated by PV panels on the building rooftop and parking shelters would substantially surpass the electricity requirements of the building.

$$E_e = A_{tp} \times I \times D \times E_f \times C_o \times A_v$$
$$= 369.6 \times 3.6 \times 5.4 \times 365 \times 22\% \times 75\% \times 95\%$$
$$= 411{,}082 (kWh)$$

$$(145{,}592 + 411{,}082) / 121{,}905 = 556{,}674 / 121{,}905 = 4.6$$

The preceding estimation of electricity self-sufficiency did not consider the charging of electric cars and scooters by PV systems. According to results from a questionnaire distributed by the Department of Landscape Architecture in 2013, 14 faculty members and students commuted by car, with an average driving distance of 16 kilometers per person per day; 124 faculty members and students used motorcycles, with a riding distance of 10 kilometers per person daily. Using Eq. (2), annual electricity consumption by electric cars was calculated as follows.

$$E_e = P \times D \times E_k$$
$$= 14(person) \times 16(km / day / person) \times 36(week) \times 5(day / week) \times 0.15(kWh / km)$$
$$= 6{,}048 (kWh)$$

By using the same equation, the annual electricity consumption of electric scooters was estimated to be 6,138 kWh.

$$E_e = P \times D \times E_k$$
$$= 124(person) \times 10(km / day / person) \times 36(week) \times 5(day / week) \times 0.0275(kWh / km)$$
$$= 6{,}138 (kWh)$$

$$6{,}048 + 6{,}138 = 12{,}186 (kWh)$$

In total, the electricity consumption by electric vehicles and scooters for commuting purposes amounts to 12,186 kWh per year. The annual PV power generation of 556,674 kWh on the building rooftop and parking shelters is 4.2 times the total energy demand of 134,091 kWh for the building and transport, indicating that 100% renewable electricity is achievable. Surplus electricity can be fed into the grid for campus usage.

$$556{,}674 / (121{,}905 + 12{,}186) = 556{,}674 / 134{,}091 = 4.2$$

7. Environmental evaluation

7.1 Carbon dioxide reduction

PV power generation has the potential to reduce GHG emissions by replacing the fossil-based energy that is currently used for electricity generation and vehicular traffic. GHG emissions from PV generators comprise approximately 58 tons of CO_2 eq/GWh, according to IPCC and WEC average estimates (IPCC, 2007; WEC, 2004). On the basis of Taiwan's overall emission factor of 0.529 kg CO_2/kWh for electricity generation in 2016, replacing conventional electricity generation with PV power generation to meet the annual demand of the studied building (121,905 kWh) would reduce the level of CO_2 emissions from 64.5 tons to 7.1 tons—an 89% reduction.

$$121{,}905(kWh)\times 0.529(kg/kWh)\div 1000 = 64.5(tons)$$

$$121{,}905(kWh)\times 58(ton/GWh)\div 10^6 = 7.1(tons)$$

$$(64.5-7.1)\div 64.5\times 100\% = 89\%$$

According to the assumption that the tank-to-wheel CO_2 emissions from gasoline are 187 g CO_2 eq/km, CO_2 emissions from gasoline-consuming cars and scooters are estimated to be 15.2 and 84.6 tons/year, respectively, whereas those from electric cars and scooters are estimated to be only 350.8 and 356 kg/year, respectively. Replacing cars and scooters using conventional combustion engines with those using PV-generated electricity would reduce the annual level of CO_2 emissions from 99.925.3 kg to 706.8 kg—a 99% reduction. For countries with high per capita CO_2 emissions from fuel combustion, such as Taiwan (10.65 tons compared with the OECD member average of 9.18 in 2015) (IEA, 2017), solar PVs exhibit strong potential to reduce national CO_2 emissions.

$$187(g/km)\times 16(km/day/person)\times 14(person)\times 365(day)/10^3$$
$$=15{,}289.1(kg/year)$$

$$187(g/km)\times 10(km/day/person)\times 124(person)\times 365(day)/10^3$$
$$=84{,}636.2(kg/year)$$

$$58(ton/GWh)\times 6048(kWh/year)/10^3$$
$$=350.8(kg/year)$$

$$58(ton/GWh)\times 6138(kWh/year)/10^3$$
$$=356(kg/year)$$

$$[(15,289.1+84,636.2)-(350.8+356)]\div(15,289.1+84,636.2)\times 100\%$$
$$=(99,925.3-706.8)\div 99,925.3\times 100\%$$
$$=99\%$$

7.2 Modulation of the microclimate

The temperature of PV panels may reach approximately 70℃, which results in heating of the air surrounding the system. Plant life and green roofs can serve to cool not only the PV panels but also the microclimate on site. Considering that planting greenery under the PV panels should prevent shading, extensive use of short, drought-enduring sedum would be ideal. The distance between roof greenery and the PV module should be at least 30 centimeters to prevent the plants from obstructing the solar module as they grow. In the parking lot, trees should be planted in the buffer zone and along the rim of the parking lot so that no shading can obstruct the PV panels on the parking shelters.

7.3 Visual impact of PV panels

The effect of glare is first assessed by determining whether there are potential sensitive receptors in the vicinity of the PV systems. A three-story building located southwest of the studied building and a parking lot for motorbikes located southeast of it are the only possible receptors (Fig. 8). Since the PV panels on the building rooftop are not visible to the neighboring building, roads, and parking lot because of their height, there are no potential sensitive receptors. Concerning the possibility of glare caused by the PV panels on the parking shelter, there is a greater number of potential receptors in the vicinity because its PV panels are closer to the ground than those on the building rooftop. Mitigation measures at both reflector (e.g., diffusive reflection coatings) and receptor sites (e.g., plant shadings) are applicable.

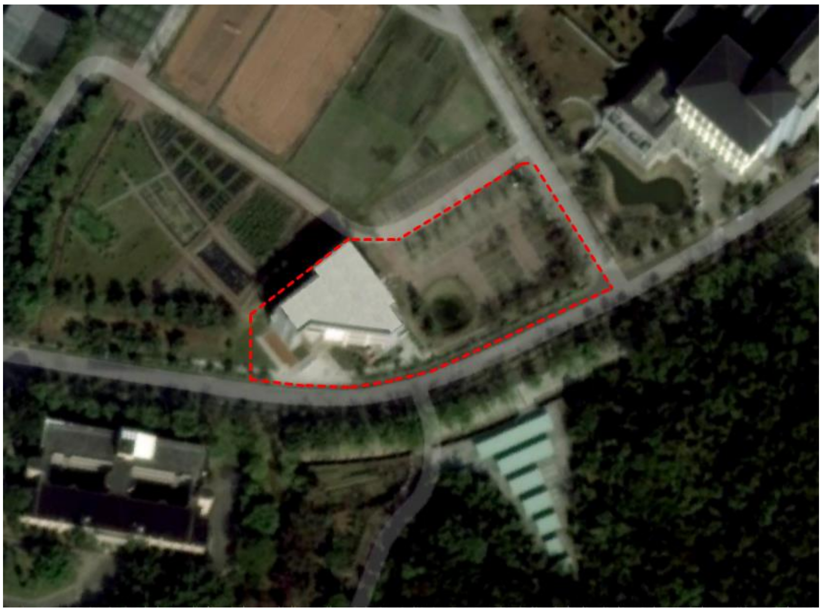

Figure 8. Aerial photograph of the studied building and parking lot, delimited by the dotted red line.

To mitigate the visual impact of PV panels on the parking shelter, curved surfaces were integrated into the surrounding environment by adding trees. To limit aesthetic impact and achieve rudimentary color congruity, mild coloration of the PV crystals, with a hue approximating the background color of the trees, was applicable. Tree fencing was placed around the PV panels to limit their visibility from outside.

7.4 Implications for the environmental management of PV power generation

Currently, many installations of PV panels do not involve planting under and around PV panels to yield cooling effects, thereby increasing the efficiency of the PV system. Furthermore, the blending of PV panels into surrounding environment is likewise seldom considered. Numerous parking lots are not sheltered from sunshine. Leaving cars exposed to strong irradiation, particularly in tropical and subtropical regions such as Taiwan, leads to frequent use of car air conditioning, an increase in fuel use and air pollution, and physical discomfort among vehicle users. The PV system designed for building rooftops and parking shelters demonstrated its effectiveness in mitigating climate change through the generation of low-carbon electricity. In addition, the integration of PV panels with green roofs and parking shelters displayed potential to facilitate adaptation to global warming through microclimatic modulation of building rooftops as well as parking lots.

8. Conclusions

The annual electricity output from PV systems on the rooftop area of the studied building was estimated to be 145,592 kWh, which is 1.2 times the total electricity consumption of the building of 121,905 kWh in 2016. The total annual electricity yield of the building and parking shelters available for PV panel installations is 556,674 kWh, which is 4.6 times the total electricity demand of the building. Furthermore, the annual PV power generation of 556,674 kWh on the building rooftop and parking shelters is 4.2 times the total energy demand of 134,091 kWh for the building and transport, indicating that 100% renewable electricity is achievable. Surplus electricity can be fed into the grid for campus usage.

This study indicated that PV panels can be allocated in consideration of solar irradiation according to on-site investigations of the climate and land use. The simulation of shading and PV panel installation using 3ds Max in this study proved to be a useful tool in determining a suitable site for the installation of PV panels and in displaying the possible visual result of the established facility. Visual simulation and evaluation is recommended for every licensed application of PV panel installation, enabling methods for assessing the aesthetic impact to be applied to facilitate the smooth integration of PV systems into the surrounding environment.

9. Future Research Directions

This study provides valuable information on solar PV configurations; however, some limitations of the present study may be addressed in future studies. First, power losses that occur in the vehicle and building systems while charging electric vehicles were not considered in this study. Energy losses between the grid connection point and the vehicle battery vary depending on factors such as battery state of charge and charging current. Future analyses may include these factors to enhance the accuracy of their technical and economic evaluations.

Second, this study adopted a commonly used methodology to estimate carbon emission reduction that involves calculating the difference in the amount of carbon emission between methods that use the traditional technology and those adopting a low-carbon technology. Another approach to evaluate carbon emission reduction is to calculate the carbon footprint of an organization, which can be measured by conducting a greenhouse gas emission assessment. Once the size of a carbon footprint is determined, a strategy can be devised to reduce it, such as technological developments, carbon capture, and consumption strategies. Such investigation could provide insight into various strategies to reduce net carbon emission.

Finally, 3Dmax was used to simulate the shading and PV panel installation. Additional research can be conducted using other tools to facilitate these tasks. For example, Revit, a building information modeling software, allows users to design a building and its components in 3D and access building information from the database of the building model. Autodesk Ecotect Analysis is an environmental analysis tool used to simulate building performance. It combines analysis functions with an interactive display that presents analytical results directly within the context of the building model. These tools provide ideal opportunities to simulate the design of a building and analyze its environmental performance.

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References

1. BEROC (Bureau of Energy of the Republic of China) (2017). Emissions factor of electricity generation in Taiwan 2016. Retrieved from (http://web3.moeaboe.gov.tw/ECW/populace/content/ContentDesc.aspx?menu_id=5426).
2. BMU (2002). Entwicklung der Erneuerbaren Energien (Development of renewable energy). Bundesministerium fuer Umwelt, Naturschutz und Reaktorsicherheit (BMU) (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). Retrieved from (http://www.bmu.de).
3. Boyle, G. (Ed.) (2004). *Renewable Energy: Power for a Sustainable Future*. Oxford University Press, Oxford, UK.
4. CWB (Central Weather Bureau) (2015). Climate Statistics. Central Weather Bureau, Taipei, Taiwan.
5. CWB (Central Weather Bureau) (2017). Climatological data annual report 2016. Central Weather Bureau, Taipei, Taiwan.
6. Chiabrando, R., Fabrizio, E., & Garnero, G. (2009). The territorial and landscape impacts of photovoltaic systems: Definition of impacts and assessment of the glare risk. *Renewable and Sustainable Energy Reviews*, 13 (9), 2441-2451.

7. Droege, P. (Ed.) (2009). *100 Per Cent Renewable: Energy Autonomy in Action*. Routledge, Oxford, UK.
8. Dunster, B. (2003). Perspectives on innovation: Housing. Patricia Pyton.
9. Früh, S. (2012). Gruendach und Photovoltaik - Gemainsam gegen den Klimawandel. *Solarzeitalter*, 2, 87-91.
10. IEA (International Energy Agency) (2002). *Potential for Building Integrated Photovoltaics*. IEA Report PVPS T7-4.
11. IEA (International Energy Agency) (2017). *Key world energy statistics.* IEA, Paris.
12. IPCC (2007). *Mitigation of Climate Change*. Cambridge University Press, Cambridge, UK.
13. IPCC (2012). *Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, UK.
14. IPCC (2014). *Climate Change 2014 Mitigation of Climate Change.* Cambridge University Press, Cambridge, UK.
15. ITRI (Industrial Technology Research Institute) (2005). Design of Solar Photovoltaic System. Retrieved from (http://solarpv.itri.org.tw/).
16. Kaltschmitt, M., Streicher, W., & Wiese, A. (2007), *Renewable Energy - Technology, Economics and Environment*. Springer, Berlin, Germany.
17. Kapetanakis, I.A., Kolokotsa, D., & Maria, E.A. (2014). Parametric analysis and assessment of the photovoltaics' landscape integration: Technical and legal aspects. *Renewable Energy*, 67, 207-214.
18. Lund, H., Mathiesen, B. (2009). Energy system analysis of 100% renewable energy systems - The case of Denmark in years 2030 and 2050. *Energy*, 34 (5), 524-531.
19. MacKay, D. (2009). *Sustainable Energy —without the Hot Air*, UIT, Cambridge, UK.
20. NCYU (National Chiayi University) (2017). Statistics of electricity consumption. National Chiayi University, Chiayi, Taiwan.
21. PennEnergy (2015). SolarCity unveils world's most efficient rooftop solar panel. Retrieved from (http://www.pennenergy.com/articles/pennenergy/2015/10/solarcity-unveils-world-s-most-efficient-rooftop-solar-panel.html?cmpid=EnlDailyPowerOctober52015&eid=290973536&bid=1192710).
22. Scheer, H. (2006). *Energy Autonomy: The Economic, Social and Technological Case for Renewable Energy*. Earthscan, New York, USA.
23. Schoder, T. (2011). How Solar Panel Temperature Affects Efficiency. Website of CivicSolar: https://www.civicsolar.com/support/installer/articles/how-solar-panel-temperature-affects-efficiency.

24. Skoplaki, E., Boudouvis, A., & Palyvos, J. (2008). A simple correlation for the operating temperature of photovoltaic modules of arbitrary mounting. *Solar Energy Materials and Solar Cells*, 92, 1393-1402.
25. Thevenard, D., & Pelland, S. (2013). Estimating the uncertainty in long-term photovoltaic yield predictions. *Solar Energy*, 91, 432-445.
26. WEC (World Energy Council) (2004). Comparison of Energy Systems using Life Cycle Assessment. Would Energy Council, London.
27. WEC (World Energy Council) (2007). 2007 Survey of Energy Resources. Would Energy Council, London.

建築物自主式太陽光電發電潛力與環境評估
—以嘉義大學景觀系館為例

余政達 [a*]、陳應傳 [b]、李秋靚 [b]

[a] 國立嘉義大學景觀學系 副教授

[b] 國立嘉義大學景觀學系 學士

摘要

本研究檢視建築物與附屬停車棚頂裝設太陽光電板達到自主電力供應的潛力，藉由估算可裝設光電板面積計算發電量，再與電力需求整合評估自給自足率。每年建築物屋頂太陽光電潛力為 2016 年建築物電力需求的 1.2 倍。每年建築物屋頂與車棚頂太陽光電潛力為建築物與交通電力需求的 4.2 倍，顯示 100%再生電力可以達到，多餘電力可饋入校園電網使用。遮蔭與太陽光電裝置的模擬，經驗證可作為配置光電板合適安裝地點、檢驗對周遭環境影響的有效工具。

關鍵詞：太陽光電系統、自主式發電、環境評估

* 通訊作者：余政達
Email: cd.yue@msa.hinet.net