Proceedings of the 8th Annual World Conference
of the Society for Industrial and Systems Engineering,
Baltimore, MD, USA
October 17-18, 2019

Techno-Economic Feasibility of Rooftop Photovoltaic Systems over Gas Stations in New York State

Y.M. Alwesabi, Y. Wang, and S.W. Yoon

Department of Systems Science and Industrial Engineering
State University of New York at Binghamton,
Binghamton, NY, USA

Corresponding author's Email: yongwang@binghamton.edu

Abstract: This paper aims to study the techno-economic feasibility of rooftop photovoltaic (PV) solar energy systems over gas stations in New York State (NYS). This study provides an estimation of the potential total electricity generation from solar systems. Real data of four case studies in four different geographical regions (Manhattan, Hamilton, Syracuse, and Niagara) in NYS are collected. The feasibility study of grid-tied systems is conducted. The National Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) software is used to compute annual energy production for each PV system. The results show that all four gas stations are economically feasible, which is a positive indicator of adopting solar energy in the four regions. The four selective gas stations can produce 135,207 kWh, 144,183 kWh, 109,660 kWh, 157,321 kWh, respectively per year. The average energy production of the four stations (11,383 kWh) is higher than the average demand (8,149 kWh) per month. It is found that the four gas stations can provide fully self-power for eight months (from March to September) and more than 60% for other months. The payback period ranges between 6.1 and 7.2 years without incentives. The results show that solar systems can save $24,048, $25,101, $20,748, and $26,645 per year, respectively, for these four cases. The studied systems are feasible and will yield tangible financial benefits.

Keywords: Feasibility Study, Photovoltaic (PV), Solar Energy, Gasoline Stations, New York State

1. Introduction

Solar energy is one of the fastest-growing energy sources in the world according to the International Energy Agency (IEA) report (Araújo et al., 2019). NYS aims to produce 50% of the total energy through renewable sources by 2030 and reduce greenhouse gases (GHG) emissions by 40% (NYS of Opportunity, 2018). NYS has a target of generating 3,000 megawatts (MW) of PV solar energy by 2023. In 2017, a total of 972 MW was installed in NYS and another 1,119 MW in the process (EIA, 2018). In 2018, NYS committed $1.4 billion to the development of 26 renewable projects authorized by the NYS Energy Research and Development Authority (NYSERDA), 22 of which were solar farms. Different criteria have been considered including geospatial, political, and socio-economic characteristics of clean energy adopters when policymakers review and approve a new clean energy project (Araújo et al., 2019; IRENA, 2018).

Solar energy has been utilized to power commercial buildings, residential buildings, and electric vehicles (EVs). For example, solar energy has been powering hospitals, schools, factories, prisons, hotels, and apartments (Good et al., 2019). Recent research efforts have studied parking lots with solar systems to generate electricity for electric vehicles (EVs) (Nunes et al., 2016; Sun et al., 2018).

Alghoul et al. carried out an economic feasibility study of solar energy integration in gas stations (Alghoul, et al., 2018). Among several petroleum companies, Petronas was selected for the study in Malaysia in Alghoul's work. Their simulation showed potential electricity generation of 136 GWh/year across Malaysia. They also reported that the generated solar power was applicable to charge EVs. However, this idea is not practical because it will require a significant change in customer behaviors (it is difficult for a driver to wait hours just for charging an EV). Instead, it could be better to reserve the generated power for self-use or to feedback into the power grid. French oil company Total confirmed to install a total of 200 MW of solar panels across 5,000 stations. The United Arab Emirates announced in 2017 to install solar panels over the roof of new gas stations (SNT, 2018).

Human behaviors play an important role in the propagation of renewable energy (Araújo et al., 2019). Studies have shown that the immediate surroundings of an installed solar system have a higher probability of installation as well (Graziano & Gillingham, 2014). As a result, installing solar modules over the roof of gas stations will lead to several co-benefits, such as encouraging neighbors to go green, decentralizing grid load, utilizing unused roof area, and reducing pollutants.

This paper aims to study the techno-economic feasibility of rooftop photovoltaic (PV) solar energy systems over gas stations in NYS. This study provides an estimation of the potential total electricity generation from solar systems. According to the authors' best knowledge, this is the first such study being conducted in NYS. The research result will help commercial implications in energy planning and management. It will also contribute to early diffusion of renewable energy, decentralize grid load, reduce carbon dioxide, and gain financial benefits.

The remainder of the paper is organized as follows. The proposed approach, including PV system components, system design, feed-in tariff, and the mathematical model, is demonstrated in Section 2. Section 3 describes case studies. Results of the case studies are shown in Section 4. Finally, the conclusions are drawn in Section 5.

2. Proposed Approach

This study aims to evaluate the techno-economic feasibility of a PV-Grid system. Table 1 shows the solar system parameters. There are many different petroleum companies located in NYS, such as Mobile, Sunoco, Shell, and BP.

Table 1. The solar system parameters

RA_S	The actual net roof area of installed panels over one station m^2	$PVC_{ann.S}$	Annual produced PV energy (kWh/ year) by one station
RA_{avg}	The average net roof area of one station m^2	SI_{ann}	Annual system income from ($/year)
$Panels_{total}$	Number of installed panels over one station	SR	Selling rate of the PV system to the grid ($/kWh)
Pd	Power density (W/m^2)	Pb_{ann}	Annual Payback period
d	The difference between RA_S and RA_{avg}	$Strings_{No}$	Number of parallel strings
PVC	PV capacity of RA_S (kW)	LC	Levelized cost (real)
$Modules_{No}$	Number of modules per string	NPV	Net present value

We demonstrate the methodology using the same assumptions in Table 2. The exact addresses of the four case studies in Manhattan, Hamilton, Syracuse, and Niagara are not explicitly reported for confidentially. They have total roof areas of 357 m^2, 432 m^2, 339 m^2, 455 m^2, respectively.

Table 2. The system assumptions

Variable	Assumption	Variable	Assumption
Shading & losses		**System cost**	
Shading	-	Module price	$ 0.47/Wdc
Monthly soiling losses	5%	Inverter price	$ 0.08/Wdc
AC losses	1%	Balance of system (BOS)	$ 0.30/Wdc
Model degradation rate	0.2%	Installation labor	$ 0.36/Wdc
Financial parameters		Installation margin & overhead	$ 0.10/Wdc
Project debt	No loan, no debt	Total install cost	$ 1.95/Wdc
Analysis period	25 years	O&M fixed annual cost	$ 200/year
Inflation rate	2.5%	**Incentives**	
Real discount rate	6.4%	Tax credit	0
Nominal discount rate	9.06%	Investment based incentive (IBI) by state	50 %
The federal income tax rate	21%	**Electricity rate**	
State income tax rate	6.57%	Metering & billing	Net energy metering
Property tax rate/year	1%	Selling rate	$0.12/kWh
Sales tax	5%	Buying rate	$ 0.20/kWh
Annual insurance rate	1% of the installed cost	Fixed monthly charge	$18.34
Depreciation	5-year MACRS		

2.1 PV System Components

The proposed solar system consists of several main components, including solar modules, bidirectional inverters, installation labor, and BOS. BOS includes electrical work and structural work. BOS cost varies depends on different factors, such as the geographical place, the number of installed panels, and the year (Fu et al., 2018). To determine the commercial PV system cost, our proposed systems fall within the first category ($1.95 per watt DC) based on the gas station capacity, see (Fu et al., 2018). SAM software has a database for modules, batteries, inverters, and their features. United Renewable Energy D7K400H8A module has been selected for the all four gas stations, 401.136 Wdc maximum power and 1.98 m^2 area. Due to different rooftop areas and different power capacities of the four gas stations, different inverters have been selected, see Table 3. The value, 34130.9*2 means two inverters of max power 34130.9 is chosen.

Table 3. The systems inverters

Inverter/gas station	Manhattan	Hamilton	Syracuse	Niagara
Name	SMA America: STP 33-US-41 [480V]	SMA America: ST42 [240V]	SMA America: STP 60-US-10 [400 V]	SMA America: STP30000TL-US-10 [480V]
Max power (Wdc)	34,130.9*2	43,963.8*2	61,130.8	30,592.3 *3
Efficiency	97.544%	96.024%	98.2%	98.3%

2.2 PV System Design

The proposed system is designed into parallel strings where each string consists of many modules. This design allows for maintenance or replacement with a gap d, see Eq. (1). The inclination of modules plays an important role in energy production as it is varied from region to region and season to season (Sarhan et al., 2019). As a result, the sensitivity analysis is performed to select the best angle for each location by considering the latitude value.

2.3 Feed-in Tariff

The average electricity price in NYS in February 2019 is 20 cents (U.S. Bureau of Labor Statistics, 2019). The feed-in tariff (FIT) rate in NYS is 12 cents (NYSEDRA, 2019), which represents the selling rate (SR) back to the local grid. The net metering in NYS allows users to store their surplus energy in the grid and retrieve as needed. At this case, the battery option can be avoided to save more money.

2.4 Mathematical Model

The net roof area of one station as noted in sub-section 2.2 is obtained by Eq. (1).

$$RA_{avg} = Strings_{No} * Modules_{No} * \ Module\ area + d, \tag{1}$$

The required number of installed solar panels over the rooftop of one station can be obtained by Eq. (2).

$$Panels_{total} = Strings_{No} * Modules_{No} \tag{2}$$

The PV power density is the ratio of watts to the area of that selected panel ($^{w}/_{m^2}$), see Eq. (3).

$$\text{Power density} = \frac{watts}{area} \tag{3}$$

The total capacity of the estimated roof area for one station yields the following equation.

$$PVC = Panels_{total} * module\ power\ capacity \tag{4}$$

Equation (5) computes the annual income of the proposed system, which is computed in the form of multiplying the total annual energy by selling price.

$$SI_{ann} = PVC_{ann} * SR \tag{5}$$

3. Case Studies

We perform four case studies located in four different regions in NYS, Manhattan, Hamilton, Syracuse, and Niagara, respectively. Each gas station has a different rooftop area and different global horizontal irradiation. The four selective regions are presented in different geographical parts in NYS to have a good representation of potential solar energy diffusion in NYS. The red color is used to highlight the selected regions, see Figure 1. The SAM software (SAM, 2018) is used to compute the annual energy as well as a sensitivity analysis. Solar irradiation and other weather data can be extracted easily from SAM.

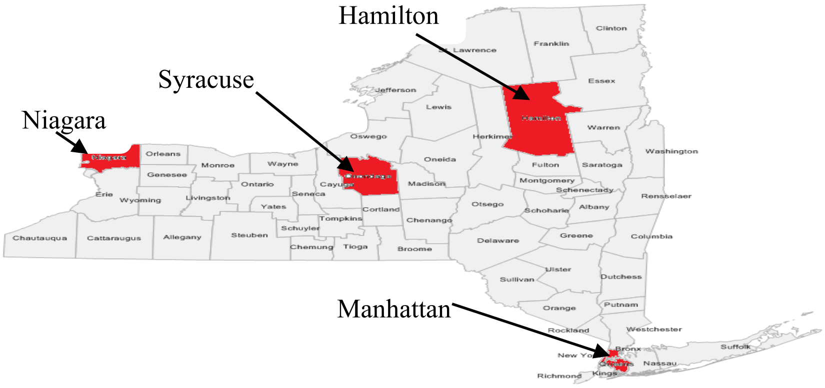

Figure 1. The selective regions in NYS are highlighted by the red color

Google Earth is used to compute the net rooftop areas of the selected gas stations. The accuracy of length and width is based on the Google Earth measurement tool. As a result, decimals are rounded. It is worth to mention that not all roof areas are square or rectangle. The roof area includes not only the areas that covering the gas pumps but also the corresponding building where the cashier works in.

The estimated consumption of electricity is obtained through the SAM database. There is no such loading data for gas stations, so an alternative prototype data of standalone retail (TMY3 file) is chosen with slight scale adjustment. The current selected load is on average 8,149 kWh per month.

It is known that some factors are critical in economic feasibility evaluation. First, sunlight plays an important role in annual energy production associated with Global Horizontal Irradiance (GHI). The second main part is the overall installation cost. Third, the electricity rate that assists in determining the payback period. The system design parameters are shown in Table 4.

4. Results

The actual simulation results of the four gas stations are extracted from the SAM software, see Table 5. The payback period of the four stations ranges between 6.1 and 7.2 years without any incentives and between 3.6 and 4.2 years with 50% incentives. The rooftop area and GHI are important factors to determine energy production. For example, the gas station in Niagara has higher energy production because of its larger rooftop area compared to the other three gas stations. The proposed solar systems can save $24,048, $25,101, $20,748, and $26,645 at year 1 for the four gas stations in Manhattan, Hamilton, Syracuse, and Niagara, respectively.

Table 4. The system design parameters

Item	**Manhattan**	**Hamilton**	**Syracuse**	**Niagara**
RA_{avg}	357 m^2	432 m^2	339 m^2	445 m^2
RA_S	348.5 m^2	427.7 m^2	316.8 m^2	443.5 m^2
$Modules_{No}$	16	9	16	16
$Strings_{No}$	11	24	10	14
$Panels_{total}$	176	216	160	224
Pd	202 w/m^2	202 w/m^2	202 w/m^2	202 w/m^2
d	8.5 m^2	4.3 m^2	22.2 m^2	1.5 m^2
PVC	70.4 kW	83.2 kW	64 kW	89.6 kW
SR	\$0.12	\$0.12	\$0.12	\$0.12

Table 5. Simulation results

Item	**Manhattan**	**Hamilton**	**Syracuse**	**Niagara**
$PVC_{ann.S}$	135,207 kWh	144,183 kWh	109,660 kWh	157,321 kWh
LC	8.07 ¢/kWh	9.27 ¢/kWh	9.06 ¢/kWh	8.81 ¢/kWh
NPV	\$77,711	\$57,072	\$60,782	\$64,524
Pb_{ann}	6.1 years	7.2 years	6.5 years	7.1 years
Electricity bill without system (year 1)	\$19,779	\$19,779	\$19,779	\$19,779
Electricity bill with system (year 1)	-\$4,270	-\$5,323	-\$969	-\$6,867
Net saving with the system (year 1)	\$24,048	\$25,101	\$20,748	\$26,645
Net capital cost	\$79,618	\$168,612	\$124,898	\$174,857

It's important to understand the monthly energy production of the solar system at each gas station. The monthly solar energy production will help determine whether solar energy is sufficient, or grid energy is required at what percentage. The four average monthly productions of the four gas stations are 11,267 kWh, 12,015 kWh, 9,138 kWh, and 13,110 kWh, respectively. We found out that the average energy production is higher than average load energy, which gives confidence for implementing these projects practically. Figure 2 shows the relationship between energy production and load energy, and then the cumulative excess energy. It is observed that solar energy can cover the entire demand from March to September for all the four locations, while demand may be more in the rest months. It is noticeable that the gas station in Manhattan can provide fully self-power.

5. Conclusions

The main conclusion is that utilizing existing gas stations has a promising future with many co-benefits such as zero infrastructure, accessible locations, decentralizing grid load, self-power production, and supplying local grid by solar energy. Four cases of studies have been conducted in different geographical areas in NYS to shed light on the large-scale diffusion of solar energy. Each of the four gas stations has been simulated separately due to their different rooftop areas and GHI values. The results show that all four gas stations are economically feasible within a payback period ranges between 6.1 and 7.2 years without incentives. The average monthly productions of the four gas stations are higher than the average monthly demand. The proposed solar systems can save \$24,048, \$25,101, \$20,748, and \$26,645 at year 1 for the four gas stations in Manhattan, Hamilton, Syracuse, and Niagara, respectively.

Although the obtained results are limited to specific regions, the proposed methodology can be applied and customized to solar energy systems of other regions. Demand response is one of the future research potentials to address the imbalance between PV power supply and gas station demand.

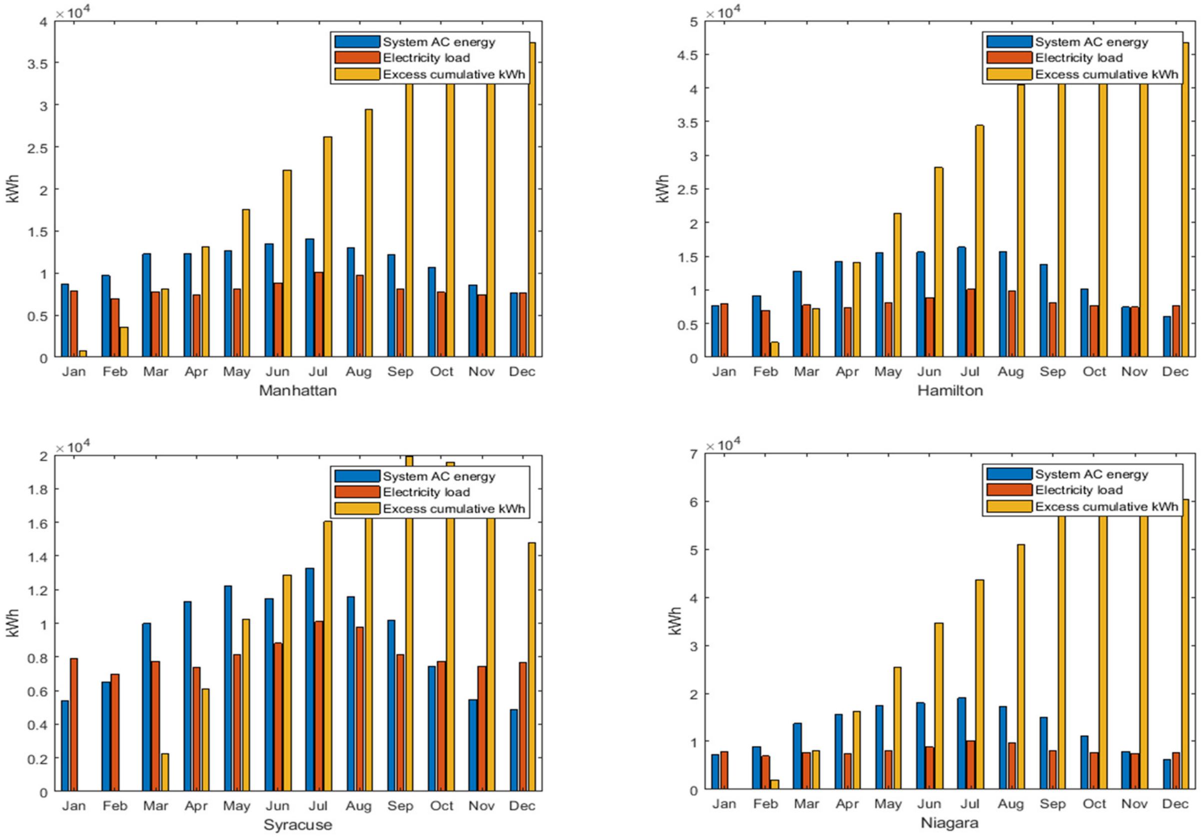

Figure 2. Monthly energy, load, and cumulative excess energy of the four gas stations

6. References

Alghoul, M., Hammadi, F., Amin, N., & Asim, N. (2018). The role of existing infrastructure of fuel stations in deploying solar charging systems, electric vehicles and solar energy: a preliminary analysis. *Technological Forecasting and Social Change, 137*, 317-326.

Araújo, K., Boucher, J. L., & Aphale, O. (2019). A clean energy assessment of early adopters in electric vehicle and solar photovoltaic technology: Geospatial, political and socio-demographic trends in New York. *Journal of cleaner production, 216*, 99-116.

EIA. (2018). Renewable Energy in New York. Retrieved from: https://www.eia.gov/state/analysis.php?sid=NY.

Good, C., Shepero, M., Munkhammar, J., & Boström, T. (2019). Scenario-based modelling of the potential for solar energy charging of electric vehicles in two Scandinavian cities. *Energy, 168*, 111-125.

Fu, R., Feldman, D., & Margolis, R. (2018). US Solar Photovoltaic System Cost Benchmark: Q1 2018. Retrieved from: https://www.nrel.gov/docs/fy19osti/72399.pdf.

Graziano, M., & Gillingham, K. (2014). Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment. *Journal of Economic Geography, 15*(4), 815-839.

IRENA. (2018). *Global Energy Transformation*. Abu Dhabi, UAE.

Nunes, P., Figueiredo, R., & Brito, M. C. (2016). The use of parking lots to solar-charge electric vehicles. *Renewable and Sustainable Energy Reviews, 66*, 679-693.

NYS of Opportunity. (2018). The Energy to Lead. Retrieved from https://static1.squarespace.com/static/576aad8437c5810820465107/t/5797fc26cd0f68be0b7d241e/1469578279961/2018-nysep-vol2-enduse.pdf.

NYSEDRA. (2019). Net metering. Retrieved from:

https://www.nyserda.ny.gov/Researchers-and-Policymakers/PowerGeneration/Net-Metering-Interconnection.

SAM. (2018). National Renewable Energy Laboratory. from Golden, CO. Retrieved from: https://sam.nrel.gov/download.

Sarhan, A., Hizam, H., Mariun, N., & Ya'acob, M. (2019). An improved numerical optimization algorithm for sizing and configuration of standalone photo-voltaic system components in Yemen. *Renewable Energy, 134*, 1434-1446.

SNT. (2018). Solar on Gas Stations to Provide Power to Local Homes in South Korea.

Sun, G., Yu, M., Liao, D., & Chang, V. (2018). Analytical exploration of energy savings for parked vehicles to enhance VANET connectivity. *IEEE Transactions on Intelligent Transportation Systems, 20*(5), 1749-1761.

U.S. Bureau of Labor Statistics. (2019). Average prices of electricity per kWh. Retrieved from: https://www.bls.gov/regions/new-york-new-jersey/news-release/averageenergyprices_newyorkarea.htm.