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Research article

Techno-economic evaluation of installing EV and PV combined infrastructure on Academic Institution's Parking Garages in Illinois, USA

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Abstract: The need for clean energy production is increasing due to our society's high energy consumption, decreasing fossil fuel reserves, and growing environmental issues. Implementation of renewable energy systems on university campuses would best demonstrate academic institutions' efforts to promote sustainability. In this research study, multiple locations were assessed to determine the feasibility of installing parking canopies coupled with solar photovoltaic (PV) systems and electric vehicle (EV) charging stations and to show these two systems' effectiveness if they are implemented together. We reviewed the trend and growing demand towards electric vehicles and examined different solar panels and mounts to find the most optimal combination for the suggested study sites. Through the data collection on the study sites and the utilization of simulation tools we were able to obtain estimations of these two systems at different sites, the energy production of the systems, and carbon emissions reduction potential. As a result of the proposed study, three viable locations were selected to offer PV-EV parking canopies. A cost-benefit analysis was performed at each location to provide useful energy production and financial data to determine the optimal location. The results provided insightful implications to decision makers at the university. The implementation of solar PV and EV charging stations combined gives the university the ability to implement clean, renewable energy in order to show its commitment to sustainability as well as supporting the ability of students, commuters and faculty to switch from gas powered vehicles to electric vehicles.

Keywords: photovoltaics; electric vehicles; renewable energy; solar parking canopy; sustainability

1. Introduction

The effects of climate change due to greenhouse gas emissions such as carbon dioxide are accelerating and therefore require a shift to clean energy sources. The use of fossil fuels for electricity generation and petroleum for our vehicles releases significant amounts of carbon dioxide into the atmosphere [1]. In order to mitigate these effects, we need to transition to clean renewable energy generation. Solar photovoltaics (PV) is a technology that allows us to harness the sun's energy and convert it to electricity without releasing any CO_2 into the atmosphere. The utilization of sustainable energy infrastructure on a university campus can decrease greenhouse gases and will be a step towards the transition to sustainable energy production. To further prepare and promote this transition to cleaner energy we evaluated the synergistic effect of constructing infrastructure to integrate the solar PV system into electric vehicle charging stations. The growing use of electric vehicles will require more locations and infrastructure to charge them.

Other similar cases were reviewed where solar PV was implemented on college campuses. Installations at a number of universities were reviewed including those at Arizona State University, Colorado State University, and Ohio State University. There were other universities that implemented solar PV systems but sufficient information was not available. The selected universities for review have implemented solar PV systems and had great success in generating electrical output that decreases the universities' demand for non-renewable electricity generation. Ohio State University is primarily using solar to decrease the university's carbon footprint while Hampshire College is attempting to shift to 100% renewables [2]. Many policies are being implemented at the schools to reduce their carbon emissions by a certain year. Many universities are moving to renewable sources of energy as a result.

The solar resource is one of the most important factors when siting a PV system. In order for a photovoltaic cell to produce power it is critical that photons must be striking the surface of the cell. When determining the location of a proposed PV array the solar resource must be studied on a micro scale to avoid losses. One of the largest contributors to losses in a PV system comes from shading. A study performed by Swatowska and Panek [3], compared the effects of partial and full-gray shading. The PV panel they tested produced around 66% less current with the full-gray shading, and about 60% less current with the partial shading compared to no shading at all. Significant changes in the current directly correlate to significant changes to the maximum power produced and the efficiency of the cell [3]. This information is not meant to help us determine which type of shading is better than the other, but rather to show the sheer loss of power when shading is present. Shading loss is one of the main reasons we must research the proposed location of an array on a micro scale because if we do not account for the possibility of shading, the projection numbers will be greatly skewed. While shading can hinder the solar energy output, there are still many areas with high solar resources that have yet to be examined.

One area that may have an abundance of solar resources but can simultaneously be used for other purposes are parking areas. Researchers at the Lawrence Berkeley National Laboratory explain that parking lots are an untapped resource for solar installations. According to Julie Chao at the Lawrence Berkeley National Laboratory [4], pavement makes up 35 to 50 percent of total surface area in cities, and 40 percent of that pavement is parking lots. It is also stated that the shade can keep cars cooler on hot days. For hybrids, plug-in hybrids, and electric vehicles, the effect can be even larger. By keeping cars cool on hot days, solar parking lots reduce the need for heavy air conditioning use in the vehicles.

A system that would allow further exploration of a parking area would be one that identifies the site in detail and array arrangement. In the article, *Assessment of Large Scale Photovoltaic Power Generation from Carport Canopies*, Alghamdi, Bahaj and Wu [5] explain their parking lot site assessment methodologies, which will allow our team to replicate this assessment this on the parking areas at Illinois State University in Normal, Illinois. The researchers developed a methodology, specifying, "we have developed an approach based on geographic information system…" [5]. This is applicable globally for site selection and PV array configuration. They also conducted a case study using these methodologies on a college campus which has a similar footprint for parking areas compared to many urban cities. The results found by the researchers show that less than 1% of parking areas are affected by shading from surrounding structures. Since this research was done mostly in the Middle East, we must conduct further research to make sure that the methodology is applicable to our geographic location in Illinois, USA. By looking at their case study on a college campus, this will allow us to see where is the best spot to utilize a solar PV canopy on our campus. With the opportunity for solar PV and parking areas to coexist, electric vehicles could also benefit by having the ability to charge on site.

Electric vehicles (EV) and their charging stations are on the rise with solar PV, and the charging systems must ultimately make sense economically for both the supplier and consumer of the electricity. The implementation of EV charging stations is an ongoing project that New York City (NYC) is actively supporting. To promote the use of electric vehicles and support the existing demand, NYC has decided to implement Electric Vehicle charging stations. These charging systems were placed in 40 New York City valet parking garages with one to four stations in each garage [6]. The number of stations was dependent upon the demand in that area. The CEO of CarCharging, Michael D. Farkas described the need for EV charging, "It is imperative for drivers who do not have access to a dedicated charging system, have the access to public charging infrastructure" [6]. Beam Charging, the company that installed the charging systems, allows customers two options for making payments. The first option is unlimited charging which will cost the customer $98/month, while the second option is pay as you use and that will cost the customer $0.48/kWh with a one-time payment of $9.95 [6]. Each garage can be monitored to see how many vehicles are using the charging stations per month and an app allows customers to see which stations are available and which ones are in use. With utilization increases in the future, New York City, CarCharging, and Beam Charging hope to implement these EV charging stations all over as an increase in electric vehicles is expected. For this project to be successful, the infrastructure needs to be in place throughout the whole area.

Although Illinois State University has already assessed the feasibility of solar PV on campus [7], none of the previous investigations have assessed the feasibility of combined solar PV and EV charging stations and their combinatory effects. The rising number of electric cars projected on the road in the future and the declining price of solar PV have shown the need for the assessment to evaluate the technical as well as the economic analysis of multiple locations on campus specifically on parking garages. This investigation utilized a quantitative method involving a number of tools that can evaluate the sites' solar resource and assess techno-economic feasibility of the combined solar PV and EV charging stations.

2. Methodology

Three different solar module types were evaluated to compare in our modeled electrical production estimates, which are shown in Table 1. SolarWorld SW 290 mono-crystalline PV modules are one of the cheapest modules manufactured in the USA. The SW 290 costs $0.69/Watt or $200/panel and has an efficiency of 17.47%. Another module selected was one of the cheapest modules manufactured outside of the US. This Chinese manufactured solar panel is called the Trina Solar TSM-255PD05.08 and costs $0.59/Watt or $151/panel with an efficiency of 15.76%. We chose these modules to compare the economic effects of the newly placed solar import tariff. The last PV module selected was the one with the highest efficiency commercially available on the market. It is the SunPower SPR-X22-460-COM modules and it has an efficiency of 22.29% and it is not manufactured in the US. We needed to further research the SunPower modules to obtain accurate pricing. While researching the solar PV modules, the selected modules' performance data were collected to estimate the system production potential in a solar performance model.

Table 1. Solar PV panel specifications.

Solar PV panel	Cost	Efficiency	Manufactured in	Cost after tariff
SolarWorld SW 290 Mono	$0.69/Watt	17.47%	USA	$0.69/Watt
Trina Solar TSM-255PD	$0.59/Watt	15.76%	China	$0.77/Watt
SunPower SPR-X22-360	$1.23/Watt	22.29%	China	$1.60/Watt

The study methodology was broken into two sections, a data collection and an analytical assessment. For the data collection, we first assessed the locations with the most potential for installing EV charging stations. We then performed a preliminary assessment of the locations using PVWatts software and performed a thorough shading analysis of each location. Next, we determined the current electric rates and available incentives, obtained information regarding the PV modules we will compare, obtained estimates of the canopy structure costs, and simulated the PV system using System Advisor Model (SAM). The analysis methodology for the electric vehicle charging station consisted of obtaining information regarding electric vehicle market forecasts, and the different types and most commonly used EV chargers. We then used this information along with our projections from the data collection to analyze the carbon emissions mitigated, compile cost-benefit analysis of each system, and an analyze the optimal method to combine PV systems and EV charging stations.

Figure 1 represents a flowchart of the data collection methodology process for this research study. The three locations for the site assessments are the three parking garages on the ISU campus. First, we used Google Earth [8] to get an overhead view of the three locations to get an idea of their layout and size. Figure 2 represents the screenshots of the satellite images of all three garages. Then, we obtained preliminary production estimates from PVWatts to give us an idea of each site's electrical production potential. PV Watts estimated the S. University Street garage output to be around 3 GWh/year, the School Street garage output to be around 1.2 GWh/year, and the N. University Street garage output to be around 783 MWh/year. The differences are primarily due to the differences in size between the three parking garages. Subsequently, we performed shading analysis at each site. We utilized the Solmetric Suneye to obtain the data. At the N. University Street garage, we compiled results from four different micro-locations on top of the garage which provided us with an average solar access of 99%.

At the School Street garage, we analyzed five different micro-locations to provide an average solar access of 99% as well. At the S. University Street garage, the largest of the three garages, we analyzed the shading losses for ten different micro-locations on the property and obtained an average solar access of 97%. The sun-path chart diagrams are not presented as all the assessed sights show no or very low shaded spots.

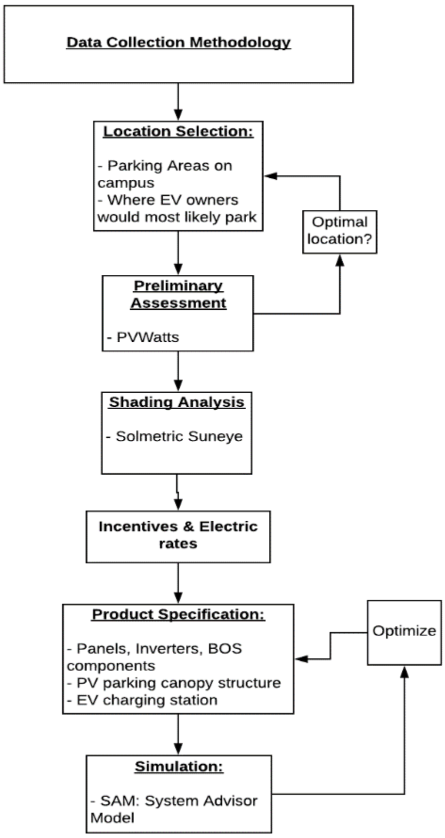

Figure 1. Data collection methodology flowchart.

Figure 2. Aerial views, from left to right: S. University Street Garage, School Street Garage, N. University Street Garage.

After performing the shading analysis, information regarding the hardware costs were collected to be entered into System Advisor Model (SAM). We also obtained estimates from several sources regarding the costs of the PV parking structure. One source showed the total installation costs of a PV parking canopy to be between $2.10/Watt and $2.50/Watt. This price includes modules, inverters, other Balance of System (BOS) components, and the installation costs. The suggested system costs are used here primarily for comparison and research purposes and should not be used for commercial projects or consultation purposes.

We reviewed the growing electric vehicle market by looking at the current market status and future forecasts. This information has shown us the exponentially increasing electric car stock in the world. Other information we have found about electric vehicle growth are announcements made by vehicle companies and manufacturers regarding their goals in electric vehicle sales for the next couple years. We also investigated the different types of EV chargers available and the most commonly used type for commercial charging. There are Level 1, 2, and 3 chargers, with Level 2 being most commonly used for applications like ours.

Lastly, we obtained information about current incentives and the newly implemented import tariff on foreign-manufactured solar panels. The tariff on imported solar panels is 30% for the first year and decreases by 5% for the next three years. This will help us provide accurate financial projections.

A breakdown of our other systematic approaches can be seen in Figure 3 as the analytical methodology. The electrical production amount from the PV systems were estimated through the energy performance model and then this was then used to project carbon emission reduction potential from the suggested PV systems. The suggested method was established based on the amount of clean energy production and the required electrical energy to be used by the EV charging stations. Then we compared it to how much carbon emission we would get from fossil fuels if the gasoline-powered vehicles were not replaced with EVs.

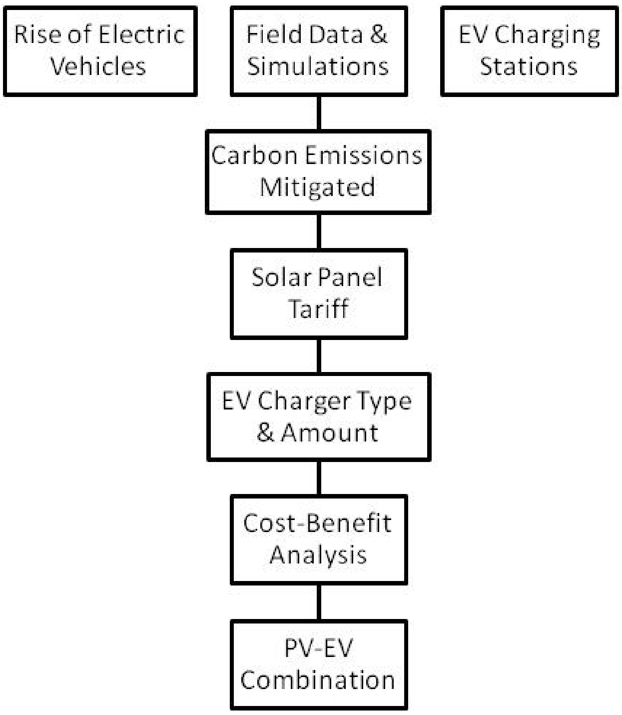

Figure 3. Analytical methodology flowchart.

Next, we researched what the new solar panel tariff that was implemented earlier this year. The newly imposed tariff is a 30% increase on solar modules that will fall each year by 5%. We chose two panels that were manufactured outside of the United States based on the efficiency as well as the price to show the effect of the tariff. The Trina Solar TSM 255-PD panels from China increase in price from \$0.59/W to \$0.77/W. The Solar Power SPR-X22-360 panels also from China increase in price from \$1.00/W to \$1.30/W. The effect the tariffs had on the panels impacted the study because if the tariff had not been imposed, the Trina solar panels would have had the lowest cost. Instead, the American made SolarWorld SW 290 Mono panels now have the lowest cost at \$0.69/W.

The electric vehicle chargers were selected based on the size of the garage and how much energy was generated through the PV system. When we calculated the data, we used how that the amount of energy that was projected to be generated and how many EV chargers it would be able to sustain. We found 3 chargers which are commonly used today. The charger selection in Table 2 consists of three different chargers and their corresponding costs: One Super Charger and two Level 2 chargers. Based on the electric vehicles that are projected on the road in the future and now, we decided to keep the common Level 2 chargers while also including the quick charging Super Charger for those who do not have much time.

Table 2. EV chargers specifications.

Type	Level	Cost	Full Charge (E–100)
ClipperCreek HCS-40 (7.7 kW)	2	\$2,161	4–8 hours
ClipperCreek HCS-60 (11.5 kW)	2	\$2,499	2–6 hours
ChargePoint Express250 (DC56kw)	Super Charger	\$5,650	30mins for 80% charge

The cost benefit analysis that we conducted was to find the payback period as well as the levelized cost of energy (LCOE). We used the cost of the complete solar system for each location and calculated the annual electrical energy generated to estimate the time it would take for the system to pay for itself. The LCOE allowed us to see the lifetime costs divided by the lifetime energy production. The LCOE is one of the most useful calculations because it quantifies the costs and production into a value that can be easily compared with electricity prices. The LCOE and payback calculations were performed in SAM using the following equation with the discount rate of 5% typical for a non-profit institution.

$$LCOE = \frac{\sum_{n=1}^{n=25} NPV(Cap + Fin + O\,\&\,M)}{\sum kWh} \quad (1)$$

Finally, we analyzed the best process on combining a PV system with EV charging stations. We started by finding the electricity prices through the University which allowed us to determine the best approach, whether to directly charge the EV stations or to send the electricity to the grid and purchase the electricity at the retail rate. We performed calculations based on the PV system LCOE to found out which approach makes the most economic sense.

3. Results and discussion

3.1. PV system analysis

The analysis of the PVWatts, as well as the shading analysis with Solmetric Suneye technology, allowed us to input all of the relevant statistics into SAM. The results of the analyses concluded that the location best suited for a solar PV canopy with the suitability of EV charging station installation would be the South University garage. This was determined based on a combination of energy generated, shading analysis, and what garage was best suited for the EV charging stations. After analyzing the data we decided that the best panels for the canopy would be the SolarWorld SW 290 Mono. This was determined based on the annual energy production, payback period, total cost, and LCOE of the system. The final outcomes for each of the three potential system locations are summarized in Tables 3, 4, and 5.

Table 3. S. University street PV system results.

Panel	Annual Energy	Total Cost	Payback Period	LCOE (nominal)
SolarWorld SW 290 Mono	2,684,804 kWh	$4,219,096	14.1 years	8.23 c/kWh
Trina Solar TSM-255PD	2,596,160 kWh	$4,377,722	15.3 years	8.78 c/kWh
SunPower SPR-X22-360	2,633,113 kWh	$5,969,971	20.6 years	11.32 c/kWh

Table 4. N. University street PV system results.

Panel	Annual Energy	Total Cost	Payback Period	LCOE (nominal)
SolarWorld SW 290 Mono	785,459 kWh	$1,241,740	13.5 years	8.28 c/kWh
Trina Solar TSM-255PD	758,903 kWh	$1,287,190	14.7 years	8.83 c/kWh
SunPower SPR-X22-360	772,517 kWh	$1,760,204	19.8 years	11.37 c/kWh

Table 5. School street PV system results.

Panel	Annual Energy	Total Cost	Payback Period	LCOE (nominal)
SolarWorld SW 290 Mono	996,523 kWh	$1,566,286	13.6 years	8.23 ¢/kWh
Trina Solar TSM-255PD	963,487 kWh	$1,624,919	14.8 years	8.78 ¢/kWh
SunPower SPR-X22-360	976,910 kWh	$2,215,314	20.0 years	11.32 ¢/kWh

When sizing each garage for the number of EV chargers we considered the size of the garage and the production of the PV system. We aimed to place as many chargers in each garage as possible based on the total demand of the chargers and the production of the PV system. We needed to keep in mind the time of day that the PV production occurs. We wanted the PV system to be able to sustain the power required by the chargers throughout an average work day (i.e. 8AM–4PM) so that the impact on the existing electrical consumption would be minimized.

As can be seen in Table 6, we chose to install three different types of EV chargers. This is because the demand capacity of the three chargers varied which allowed us to closely match our PV system capacity with them.

We decided the optimal amount of EV chargers to be installed at the South University Street garage will be 20. As shown in Table 6, the total power demand from the 20 EV chargers operating at one time is 273 kW. We can see based on Figure 4 that on average, the PV system would be able to sustain all chargers operating at the same time through 6 AM to 5 PM in the summer, and 8 AM to 3 PM in the winter.

Table 6. EV Charger Selection—S. University Street.

Charger	# of chargers	Chargers demand capacity
ClipperCreek HSC-40 (7.7 kW)	12	92 kW
ClipperCreek HCS-60 (11.5 kW)	6	69 kW
Chare Point Express 250 (56 kW)	2	112 kW
Total	20	273 kW

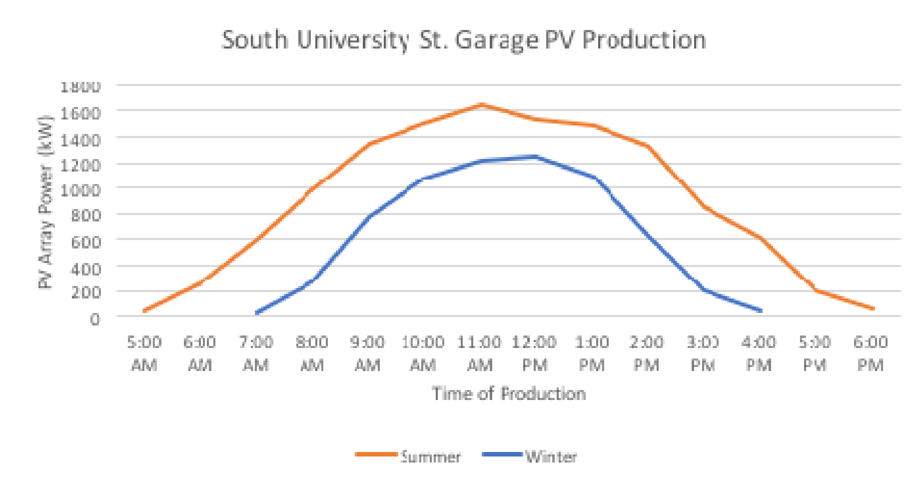

Figure 4. Daily PV Production—S. University Street.

We decided the optimal amount of EV chargers to be installed at the North University Street garage will be 10. As shown in Table 7, the total power demand from the 10 EV chargers operating at one time is 136.5 kW. Figure 5 shows that on average, the PV system would be able to sustain all chargers operating at the same time from 5 AM to 6 PM in the summer, and 7 AM to 4 PM in the winter.

Table 7. EV Charger Selection—North University St.

Charger	# of chargers	Chargers demand capacity
ClipperCreek HCS-40 (7.7 kW)	6	46 kW
ClipperCreek HCS-60 (11.5 kW)	3	34.5 kW
Charge Point Express 250 (DC 56 kW)	1	56 kW
Total	10	136.5 kW

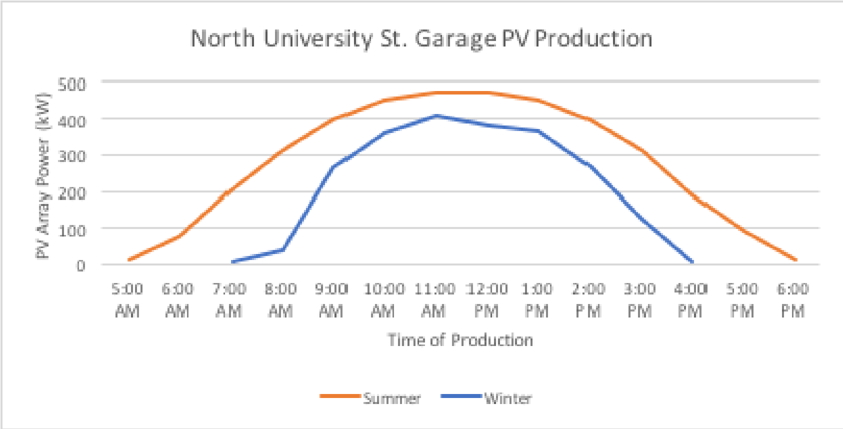

Figure 5. Daily PV Production—North University St.

For the School Street garage, it was determined that the optimal amount of EV chargers will be 12. As shown in Table 8, the total power demand from the 12 EV chargers operating at one time is 156 kW. We can see based on Figure 6 that on average, the PV system would be able to sustain all chargers operating at the same time from 5 AM to 6 PM in the summer, and 7 AM to 4 PM in the winter.

Table 8. EV Charger Selection—School St.

Charger	# of chargers	Chargers demand capacity
ClipperCreek HCS-40 (7.7 kW)	7	54 kW
ClipperCreek HCS-60 (11.5 kW)	4	46 kW
Charge Point Express 250 (DC 56 kW)	1	56 kW
Total	12	156 kW

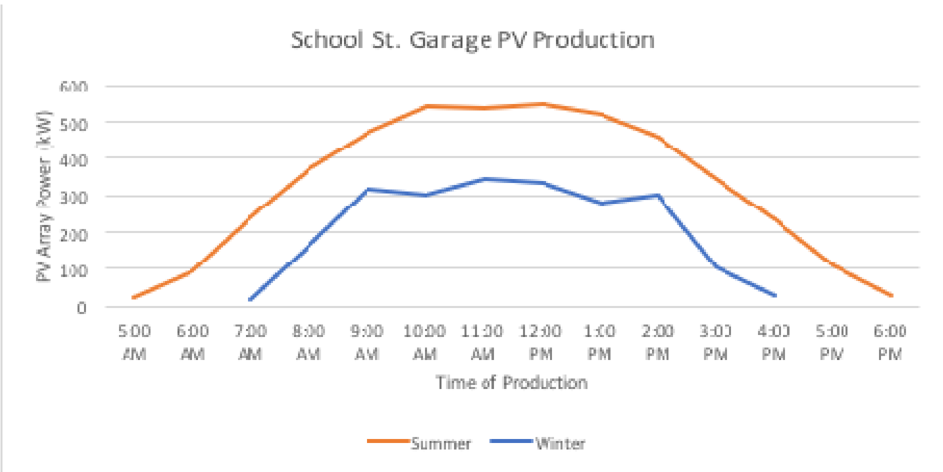

Figure 6. Daily PV Production—School St.

After we determined how many EV chargers would go in each garage we could calculate the total cost of the PV-EV systems. The total costs of the systems were found using the total cost of the

PV systems using the SolarWorld panels and the total installed cost of the EV chargers at each garage. The results can be seen in Table 9.

Table 9. Total systems costs.

Garage	# of Charging Stations	Total Installed Cost of Chargers	Total Combined PV-EV System Cost
South University St.	20	$52,226	$4,271,322
School St.	12	$30,773	$1,597,059
North University St.	10	$26,113	$1,267,853

3.2. Combined PV-EV analysis

To find the most cost-effective way to combine the PV system and the EV charging stations, we considered a variety of options: 1) PV direct to grid approach, and 2) using a PV to EV direct connection. As shown in Figure 7, the PV system would be directly connected to the grid. The electricity that is produced will be sold to Ameren at 2.3 ¢/kWh. When the chargers are in use, the energy is bought back from Ameren at 6.5 ¢/kWh. The other option is to connect the PV system directly to the EV chargers. This can be seen in Figure 8. Any excess energy that is produced will be sold to the utility to be distributed elsewhere.

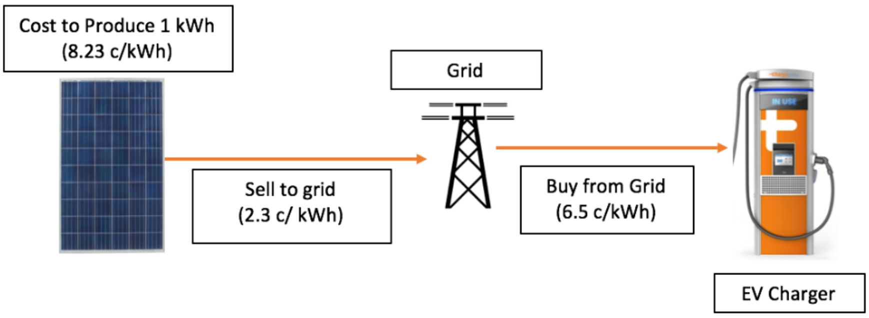

Figure 7. PV direct to grid approach.

With this approach, it would cost $0.1243/kWh to charge an EV during PV production hours.

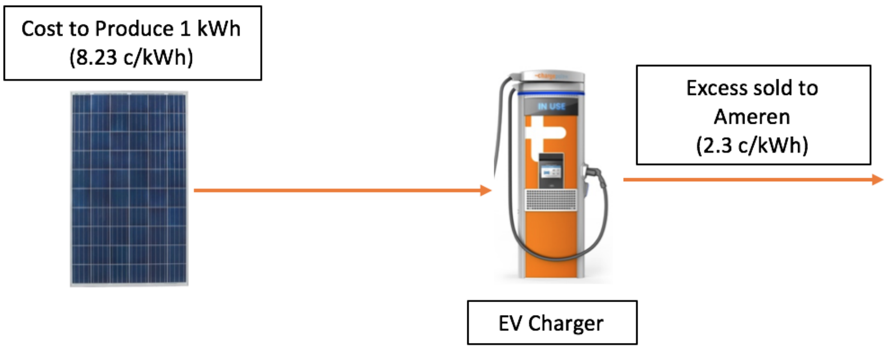

Figure 8. PV to EV direct connection approach.

The approach used in Figure 8 would cost $0.0823/kWh (which is the PV system LCOE) to charge an EV during PV production hours. A theoretical example considering both connection possibilities on a summer day is demonstrated as follows.

The 12 chargers at the School Street garage being used simultaneously will have an energy demand of 156 kW, as seen in Table 8. For this example, we assume that the 12 chargers are running at 75% of their total demand (117 kW) from 6 AM to 5 PM (11 hours) that day which makes the total consumption of 1,287 kWhs on a given day.

The energy production model estimates an average day in July to produce approximately 3,800 kWh during the hours between 5 AM and 6 PM. This garage's PV system has an LCOE of 8.23 ¢/kWh.

For the consideration of PV to EV direct connection, PV system feeds directly to EV chargers. The total cost of electricity produced this summer day would be $312.74 based upon the total electrical production and rate. The EV chargers consume 1287 kWh during this day causing an excess of 2,513 kWh.

This remaining electricity will be sold back to the grid for an estimated rate of 2.3 ¢/kWh. The revenue from selling the excess electricity back to the grid would be $57.80.

We combine the costs and revenues to determine the total cost of producing electricity for this day. With the direct PV to EV approach, the total cost of producing electricity for a summer day would be $254.94.

For the other case where PV system is directly connected to the utility's grid, the EV chargers consume electricity directly from the grid. The total cost of electricity produced this summer day would be the same as the case abovebut with this approach, all of this energy that is produced by the PV system is sold directly to the grid at the rate of 2.3 ¢/kWh. Revenue from selling to the grid is reduced at $87.40. With this approach, the EV chargers consume the electricity directly from the grid. We must repurchase the electricity from the grid for the chargers' consumption. The cost of electricity from the grid is 6.5 ¢/kWh. The total cost of the EV chargers consuming 1287 kWh for this day is $83.66

Subsequently, we combine the costs and revenues to determine the total cost of producing electricity for this day. According to the calculation the total cost will be $309.

With the direct to grid method, the total cost of producing electricity for a summer day would be $309. The direct PV to EV method for an average summer day would produce a total cost of $254.94, which is $54.06 cheaper than the PV direct to grid method. In this example, the PV direct to EV method is 17.5% cheaper than the PV direct to grid method.

3.3. Parking pass analysis

According to Hybrid Cars Dashboard [9], in December of 2013 there were approximately 180,000 total EVs in the U.S. and in 2016 there were about 770,000 EVs. The U.S. EV stock is now around 4 times larger than it was in 2013. In an article on Green Car Reports, Edelstein [10] stated there were a total of 300 EVs on the road in Normal, IL in December of 2013, while the population that year was 53,837. With those numbers, 0.55% of the residents in Normal, IL own an electric vehicle. The population of Normal, IL today is 54,264, very close to the population in 2013 [11]. If we take the 2013 data showing 0.55% of residents in Normal that own an EV and multiply it by 4 to account for the growth of EVs in the U.S. then we get 2.2% of Normal residents who own an EV in 2016.

We can use these numbers to help us estimate the amount of EVs possible on ISU's campus. An article by Forbes [12] states that there are currently 20,760 students at ISU. The article also states that the faculty to student ratio is 1 to 18, which equals 1,166 members of the faculty. The combined number of students and faculty on ISU's campus is about 21,900. To estimate the number of EVs on campus we multiply the 21,900 faculty and students by the 2.2% of Normal residents who own an EV. The product comes out to be 482 potential EV owners on ISU's campus, which is an optimistic estimation. It is difficult to accurately estimate the number of EVs on campus because most college students may not have a car at all, let alone a newer vehicle like an EV. Given these variables, in order to make our analysis more realistic we estimate the number of EVs on campus to be 125.

The reason we estimated the possible number of EVs on campus is to analyze how revenue from the garage parking passes affects the entire system. We decided to offer two different garage parking passes, a Level 2 EV pass and an All Access pass. We chose to do this in an attempt to maximize parking pass revenues. As can be seen in Table 10, we based our parking pass rates on the current $419 annual rate that ISU charges. The Level 2 EV pass is $100 more than the standard parking pass and includes free access to all Level 2 chargers. The All Access pass has a cost of $575 and allows free usage of both Level 2 chargers, and Super Chargers. Hourly rates are set for those who do not have a Level 2 EV pass or All Access pass.

Table 10. Garage parking passes.

Type of Pass	Annual Cost	Cost of Charge: Level 2	Cost of Charge: Super Charger
Standard Pass	$419	$1/hr	$5/hr
Level 2 EV Pass	$519	$0	$5/hr
All Access Pass	$575	$0	$0

Out of the 125 estimated EVs on campus we will assume 100 of them purchase the Level 2 EV parking pass and 25 purchase the All Access pass. In Table 11, the effects of the parking pass on revenues are shown. The value for the additional revenue from each pass is calculated by subtracting the cost of a standard garage parking pass, $419, from the costs of the EV passes. This parking pass cost structure provided the system with an additional $13,900 of revenue for the first year. The amount of EVs will continue to grow by each year and so will the amount of parking passes purchased.

Table 11. Parking pass revenues.

Type of Parking Pass	# of Passes Purchased	Additional Revenue from Each Pass	Annual Revenue from Each Pass
Level 2 EV Pass	100	$100	$10,000
All Access Pass	25	$156	$3,900
Total	125		$13,900

To analyze the long-term economic effects of this growing revenue we estimated projections for the first 5 years of the PV-EV system. Assuming 125 EV owners purchase parking passes in the first year, the number of parking passes purchased in the following years will be calculated based on the national EV market share rate. The EV market share rate is the percentage of electric vehicles sales compared to the total vehicle sales in a year. A report by EV Adoption [13] has stated that the EV market share in 2016 was 0.90%, in 2017 it was 1.16%. Projections by EV Adoption [13] show the EV market share in 2018 will be 1.93%. We can multiply the estimated 125 EVs on campus by the national market share rate to project the amount of EVs on campus for a future year. This calculation can be seen in Table 12. This parking pass cost structure is projected to accumulate about $73,700 in revenues by the 5th year of the system's life.

Table 12. Parking passes accumulating revenues.

Year	# of Passes Purchased	Next Year's EV Market Share Projection*	Annual Revenue	Total System Revenue
2017	125	1.96%	$13,900.00	$13,900.00
2018	127	2.73%	$14,172.44	$28,072.44
2019	131	3.75%	$14,567.20	$42,639.64
2020	136	5.47%	$15,123.20	$57,762.84
2021	143	7.81%	$15,950.44	$73,713.28

*Projections retrieved from EV Adoption [13].

4. Conclusion

In our research, we analyzed three possible locations to determine the feasibility of installing parking canopies coupled with solar photovoltaic (PV) systems and electric vehicle (EV) charging. We studied the trend and growing demand towards electric vehicles as well. We have come to multiple conclusions using our methodologies for finding the best solutions for PV solar panels and EV charging stations at each parking garage location. Based upon the analyses performed we have found that the South University Street garage would provide the largest amount of renewable generation while the School St. garage provide the shortest payback period.

The final recommendation would depend on the overall goals and budget of ISU. With the exponentially increasing electric vehicle market projections along with the declining price of solar PV, combined PV-EV systems will be emerging quickly. The future work can address the charging mechanism of the EV as an on-site energy storage to support the intermittent PV generation. The results of this research can assist Illinois State University and the Town of Normal to make an informed decision to implement clean energy infrastructure into their sustainability efforts.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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