The Green Roof Team
Southern Illinois University Carbondale

NREL Solar District Cup Competition
OSU District Use Case

Team Members:

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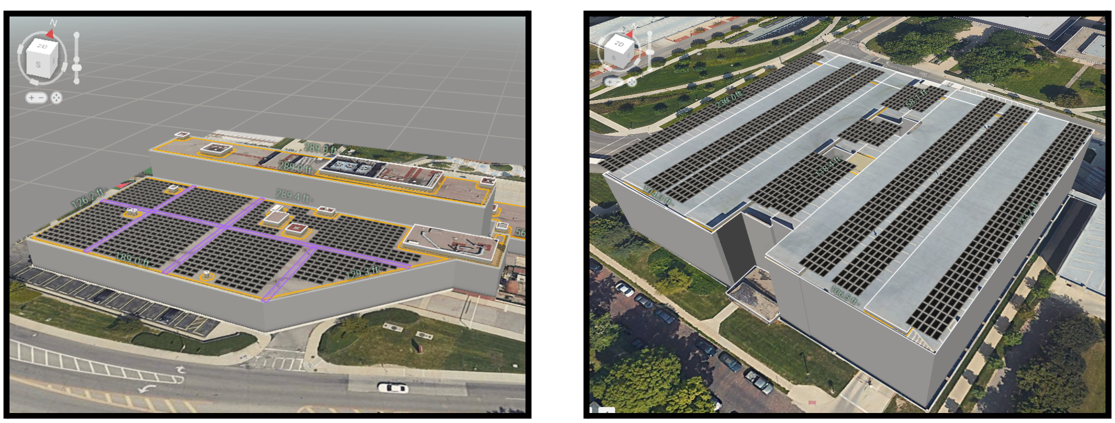
Olivia Sapp	SIU Carbondale
Stephen Shulte	SIU Carbondale

Executive Summary

The Green Roof Team is a cross-university team of undergraduate and graduate students based at Southern Illinois University Carbondale, Case Western Reserve University, Broward College, and The University of Texas at Dallas. The Ohio State University (OSU) district use case consists of ten rooftops considered by the team for a photovoltaic (PV) system. The challenge with OSU is being the largest energy-consuming area in the state, with an enrollment of 61,370 (2021) students in Columbus with a population of 880,000 people (2019). Our team designed and analyzed five PV systems, four on the medical campus and one in the Waterman Agriculture and Natural Resources, to achieve the energy-related sustainability goals outlined in their campus plans.

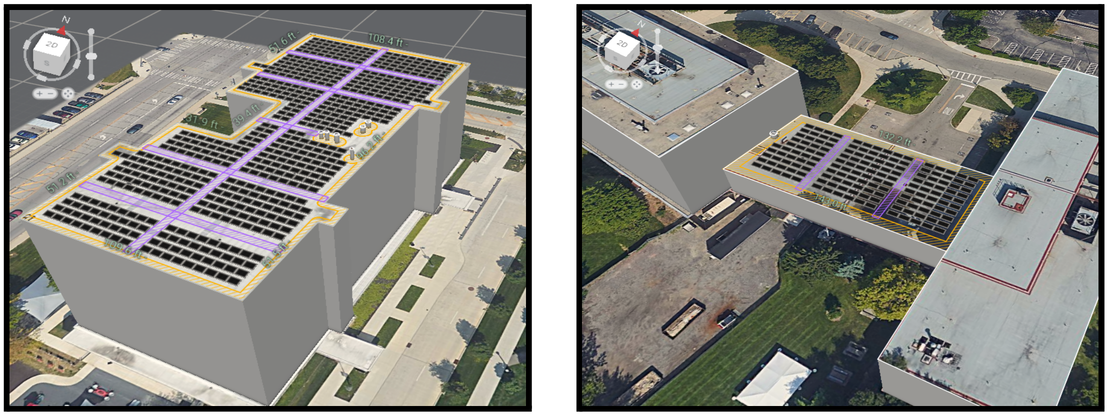
Dodd Hall was a selected site with no obstructions on the south side of the building and a large, flat rooftop area available, as shown in Figure 1 a. In addition, the site was an excellent site with no shading challenges, where we designed a 272.1 kW system producing 317MWh annually. This system will offset the building's energy consumption of Dodd Hall, the interconnection location, by 10%. The energy will be stored and supplied to the building through a battery system composed of 32 batteries. The 9th Avenue West Garage, Figure 1 b, was a selected site due to no obstructions and sizable real estate available. By adding canopy structures, we can convert solar energy into electricity and protect vehicles from the weather, such as snow; however, it provides the potential for electric vehicle charging ports in the future. The system we designed is a 497kW system producing 541MWh annually. The system will be connected to the grid.



a) b)

Figure 1. Dodd Hall (a) and 9th Avenue West Garage (b) with the solar system designed in Aurora.

McCampbell Hall, seen in Figure 2 a, was a selected site due to no obstructions near the building resulting in significant shading on the real estate. The system is a 191 kW system producing 224MWh annually stored in a battery system of 9 batteries. This system will offset the building's energy consumption of McCampbell Hall, the interconnection location of the interconnections, by 17%. Newton Hall, Figure 2 b, was a selected site despite the buildings to its east and west and the trees to the south. The proposed site has significant shading potential. The system designed is a 67.4kW system producing 71MWh annually. With a battery system containing 11 batteries, this design will offset the building's energy consumption of Newton Hall, the interconnection location, by 6%.



a) b)

Figure 2. McCampbell Hall (a) and Newton Hall (b) with the solar system designed in Aurora.

Figure 3 shows the agrivoltaic system at Waterman Agriculture and Natural Resources, this site contained several trees and a sloped landscape, and we identified cattle on site. The system is a 2MW system producing 2,334MWh annually. While this system will be connected to the grid and not offset by a specific building, the annual production accounts for 22% of our system's cumulative energy production.

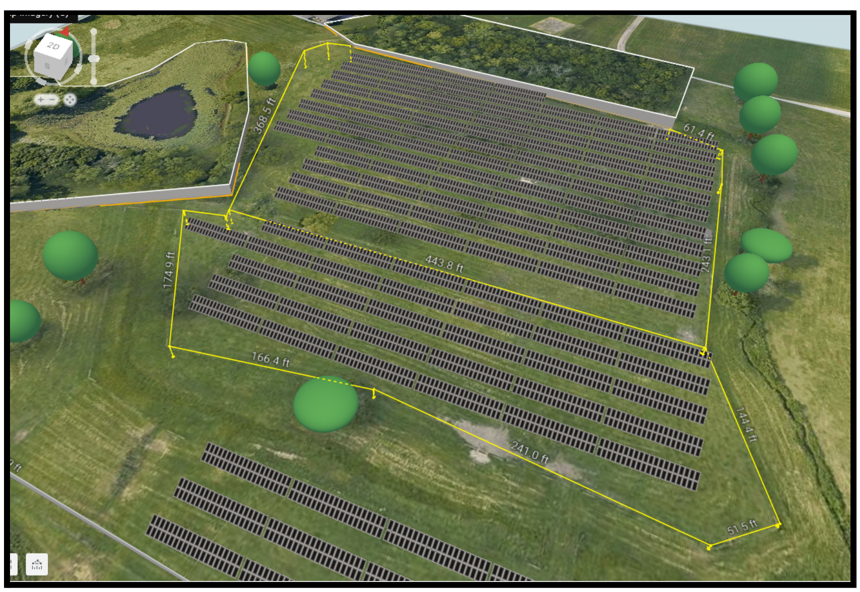


Figure 3. Agrivoltaic System simulated at the Waterman Agriculture and Natural Resources.

Table 1. System size, annual production, and PPA price per kWh.

Site Location	System Size (kW)	Annual Production (kWh)	PPA Price per kWh
9th Avenue West Garage	497	541,227	$2.54
Agrivoltaic System	2,000	2,334,951	$1.90
Dodd Hall	272.1	316,990	$2.57
McCampbell Hall	191.0	223,292	$2.45
Newton Hall	67.4	71,003	$2.75
Total	**3,027.5**	**3,487,463**	**$12.21**

All the design was carefully made using professional techniques related to positioning, spacing, and assembling the arrays of PV systems. In addition, the choice of the sites, number of cells, types, and brands of components was made, focusing on the best cost-benefit for the district, maximizing the efficiency.

This design was checked by professionals such as a solar energy specialist from Supplied Energy and C.H. Electrical. The professional help primarily validated and offered suggestions for Aurora Solar's conceptual design, especially keeping in compliance with national standards and regulations. All that professional attitude when developing the design guarantees the outstanding quality of our design.

Team Introduction

The team participating in the competition is a sub-team of the Green Roof Team based at SIU Carbondale but contains several team members attending other universities. From Southern Illinois University Carbondale, Olivia majors in Electrical Engineering; Nelson and Aaron major in Mechanical Engineering; Stephen is an Electrical Engineering student. Hein represents Case Western Reserve University, also a Mechanical Engineering major. From the University of Texas at Dallas, Gustavo is doing a Ph.D. in Mechanical Engineering.

In our second year of existence, we have improved our communication skills as a virtual engineering team. One tactic we used for communicating is using a Matrix of Responsibility seen in Figure 6 for visually delegating roles of the project ranging from the different topics such as the conceptual design, analysis, finance, and project management.

Tasks	Video Link	Nelson Fernandes	Gustavo Felicio Pernci	Aron Taylor	Hein Htet Aung	Stephen Schulte	Olivia Sapp	Ichiro Pineiro
Secondary Field of Interest								
Heatspring - Module 1								
Lesson 1 - Warm Up Workshop 140 min	Link	DONE						
Lesson 2 - Conceptual System Design 60 min	Link		DONE				DONE	
Lesson 3 - Impact Analysis 30 min	Link			DONE	DONE			DONE
Lesson 4 - Solar Project Finance 30 min	Link	DONE				DONE		
Lesson 5 - Development Plan 20 min	Link	DONE					DONE	
Heatspring - Module 2								
Aurora Solar Demo 90 min	Link	DONE	DONE				DONE	
Financial Analysis Spreadsheet 60 min	Link	DONE					DONE	
S.A.M. Training 70 min	Link			DONE				
Agrivoltaics 30 min	Link		DONE			DONE		
Impact Analysis & OpenDSS 75 min	Link			DONE				DONE
Good Solar Proposal 60 min	Link	DONE						
Optional								
2020-1 Progress Deliverable 60 min	Link	DONE	DONE			DONE	DONE	DONE

Legend

	General/Rules
A	Engineering (Design)
B	Engineering (Analysis)
	Finance
	Project Management

*OpenDSS is not required Watch until Open DSS

Figure 4. Matrix of Responsibility.

Being a virtual team, we hosted weekly team meetings where we started with updates from our personal lives, updates on our section of the project's progress, and discussion for moving forward with the project. For example, Olivia and Gustavo accepted being experts in Aurora Solar for the PV systems' design. During one of the first meetings, they showed us the basics of the software and their initial design, which allowed the team to become informed of the methodology performed, and we voted on which geographical locations for our system(s). They updated us on their progress in the following weeks and asked the team about the design's validation in terms of our project's overall goal. Everyone on the team understood each portion of the project while being an expert in their topic and a partial expert in a secondary topic seen by the color-coded legend.

Olivia and Gustavo were in charge of the Aurora Solar software and the design of the systems on the medical campus. Stephen focused on the development plan and the agrivoltaics design. Hein was responsible for the distribution impact and the SAM simulation. Nelson developed the distribution impact and finance. The roles division took into account the strengths of each member, promoting optimal performance through the competition.

The competition team branched from the Green Roof Team, a group of students at SIU Carbondale and other universities, to design small-scale wind and solar technologies for SIU Carbondale's Green Roof with the aspiration of inspiring students to think more about sustainability and pursue their passions with projects. In addition, we utilized our industry sponsors throughout the organization, such as Kyle Smith from Supplied Energy and Clayton Hanks of C.H. Electrical, solar vendors, and contractors. They primarily validated and offered suggestions for Aurora Solar's conceptual design, especially keeping in compliance with national standards and regulations. Additionally, a professor close to Nelson at SIU Carbondale suggested our participation in the competition for an experiential learning experience.

Figure 5. Green Roof Team members are pictured with their designed and installed wind turbine.

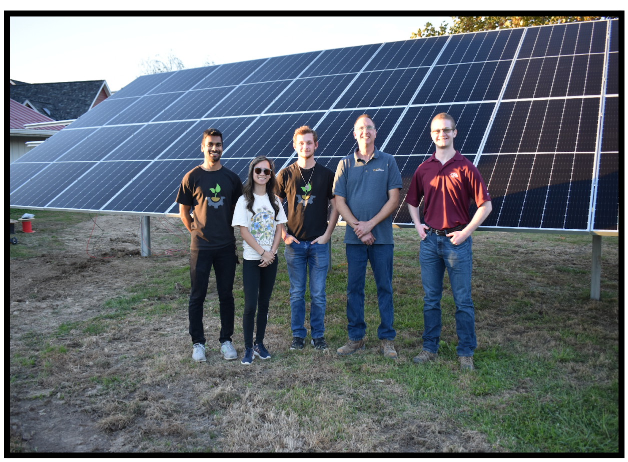


Figure 6. Green Roof Team members with Clayton Hanks working on a PV system installation.

Project Overview

Conceptual Design

The Green Roof Solar team at Southern Illinois University established a systematic way of designing a photovoltaic system to be placed at The Ohio State University Medical Campus for the Solar District Cup Competition. Among many resources, Aurora Solar was utilized to design and simulate the photovoltaic system on select buildings within The OSU Medical Campus. As a result, the SIU Green Roof Team decided upon a photovoltaic system design for three buildings, a parking lot ground mount system, and the agrivoltaic area.

The primary step in designing a photovoltaic system for OSU was to determine which buildings within the challenge area better fit for solar installation. The deciding factors were:

- The availability of solar resources (irradiance).
- Building consumption.
- Building size.
- Accessibility.
- Presence of nearby obstructions that may provide shading.

The primary area considered was the Medical Campus at OSU, encompassing roughly 226,312.88 square meters of land and commercial buildings. It is assumed that the taller buildings in the area may have a higher irradiance. The first set of considered buildings were the ones for which the consumption data was provided. The second set of buildings considered were the surrounding ones that appear to have a large, flat surface area to provide plenty of room for the modules, minimal shade and obstructions, and facing a direction in which it will maximize the benefits of being aligned with the sun's path. An estimated 11 buildings were initially considered eligible for implementing an initial grid-tied solar system for The Ohio State University Medical Campus.

The consumption data and size were primarily used to filter through the options to narrow down the building selection. The choice was based on which building consumed the most energy to maximize the energy offset for the district use case. Other factors were the structure of the roof, the available solar resources, and the provided consumption data.

The system and design approach and final solution for the conceptual design involved multiple trial and error designs in deciding on the primary locations to implement the solar PV systems on The OSU Campus. The conclusion resulted in the decision that Dodd Hall, McCampbell Hall, Newton Hall, and the 9th Avenue West Parking Garage were locations that seemed reasonable (Figure 7). The Green Roof Team also designed a solar PV system for the agrivoltaic location. Each system was designed to the best of the team's ability using NEC codes, guidance from alumni and professionals, and our research on system designs. For the final proposal, extensive research was conducted to include a battery storage option for the designed PV systems.

Dodd Hall was selected due to its roof structure, the high consumption data, and the location where it can receive a higher irradiance. McCampbell Hall was selected as a result of the high consumption data, as well as the access to solar resources. Newton Hall was selected due to the consumption data being provided and the potential to expand the system onto the neighboring buildings. The location is relatively small, but the use of a solar PV system will still have the opportunity to offset that energy and surrounding buildings, if necessary. The 9th Avenue West Parking garage was selected due to a relatively high irradiance factor as well. The parking garage also presents the possibility of incorporating electric vehicle chargers to utilize the energy stored in the PV system.

The agrivoltaic location for the secondary challenge of the competition was designed to consider livestock dwelling in and around the site. The decision to keep the system limited to the east side of the lot is also based on the assumption that the PV system will interconnect to the distribution lines running along Carmack rock. There is room for expansion to the west of the current design, but the team decided that it would not be economically efficient to install PV there at this time.

For each PV system, excluding the agrivoltaic site, microinverters were chosen for efficiency and based on a recommendation from a professional, which our research supported their advice. The microinverter will allow the design to reduce single-point failure, increase efficiency, and longer lifespan.

The battery storage option was a challenge for the team to design, but with much research, it was decided that the Enphase IQ 10 battery was the best selection for our designs. For sizing the battery storage option, The Green Roof Team observed the critical loads of each building to determine the size of battery storage necessary or fitting for each system that was designed. A total of 52 batteries were determined to be sufficient for the three PV system designs. The batteries are sized to be capable of 4 days of backup storage. Each section of batteries can connect through the building, as discussed in the Battery Storage Strategy section. Additional Battery Storage details are covered in section 2B of the deliverable.

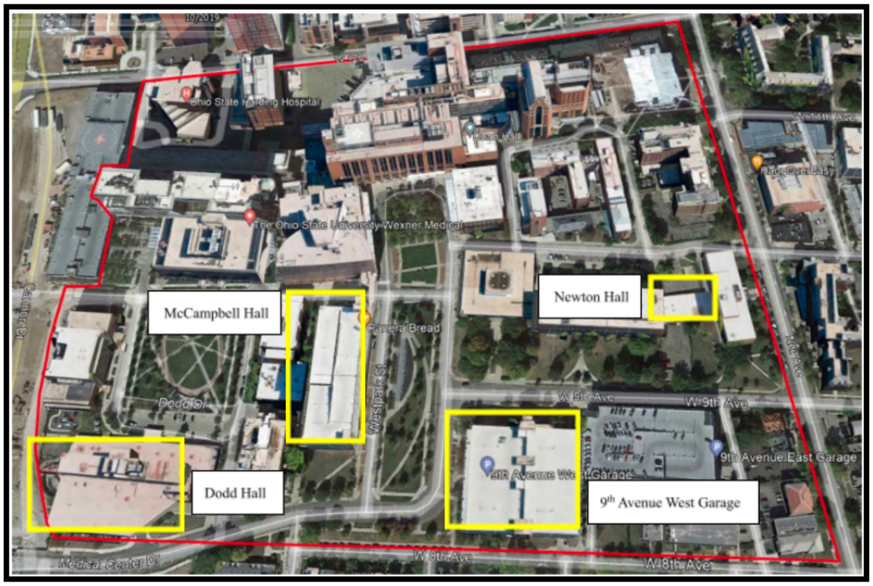


Figure 7. Building Selection at the OSU Medical Campus.

Figure 8 shows the simulation results for each of the systems designed. Dodd Hall, Figure 8a) has 832 panels in a 272.1 kW system producing 317MWh annually and promoting an offset of 10%. McCampbell Hall, Figure 8b), would receive a 191 kW system of 584 panels producing 224MWh annually with an offset of 17%. Newton Hall system, Figure 8c), was designed for 67.4kW with 155 panels producing 71MWh annually with a 6% offset. The 9th Avenue West Garage system, Figure 8d), was designed as a 497kW system with 1520 panels producing 541MWh annually. The system will be connected to the grid. Finally, the agrivoltaic system data seen in Figure 8e) refers to a 2MW system producing 2,334MWh annually and it has 5040 panels.

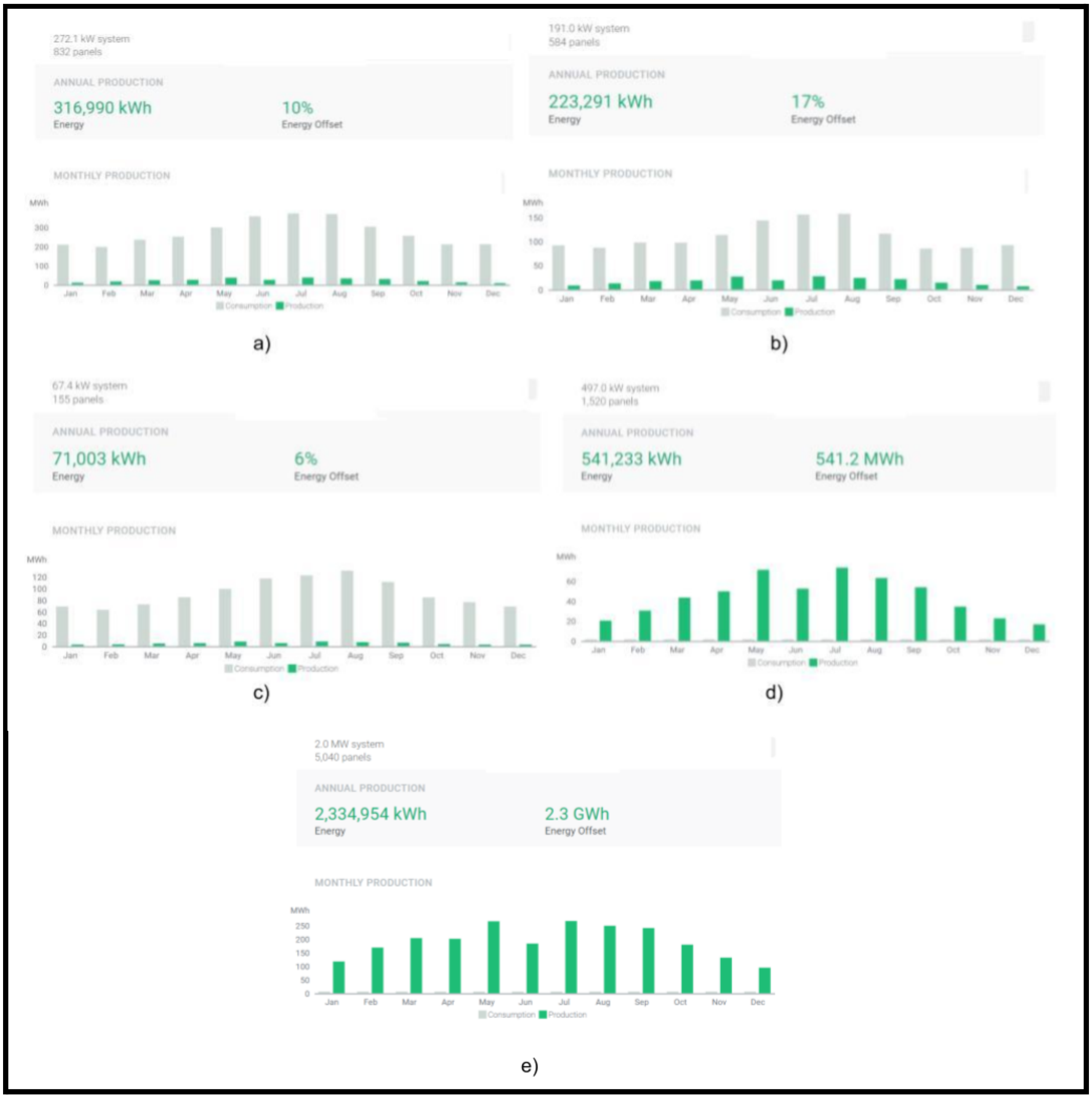


Figure 8. Simulation results for the buildings selected from OSU Medical Campus. a) Dodd Hall. b) McCampbell hall. c) Newton Hall. d) 9th Avenue West Garage. e) Agrivoltaics.

Distribution Impact Analysis

Solar design is an iterative process by meeting compliance with standards, regulations, cost, and engineering analysis. Several factors limit the size of a PV system from being interconnected with the grid from an engineering perspective. The use of heatmaps visualizing the PV Host Capacity is discussed later in this summary and further discussed in the deliverable.

The significant contributors to the distribution system impact include the PV system size, Point of Connection (PoC), and voltage and thermal constraints. A PV system has a specific voltage that dictates the amount of energy generated and the system's voltage. The Point of Connection involves the distance of the feeder from the transformers and substation. Longer distances correlate to lower host capacity available. Then, several factors to consider regarding the voltage and thermal limits originate from the choice of equipment, their specific ratings, and meteorological conditions such as temperature, radiation, wind speed, humidity, etc. Overall, these constraints can be minimized by various engineering choices.

Utilizing modern technology from smart inverters and energy storage are two solutions towards improving the PV Host Capacity or the total PV power that can be accommodated on a given feeder for interconnection. Smart inverters include control systems for improved and dynamic regulation of the voltage and thermal responses. Additionally, there are settings for different priorities where reactive and active power can be utilized to extend the production time of a system. Another solution, energy storage allows for three specific uses: (a) storing energy as a backup for when there is an outage, in our system, we planned for four days of autonomy; however, (b) using the stored energy for peak shaving allows us to a portion of the energy towards reducing high demand by users, but the energy storage will not drop below 50% which can be available for two full days of autonomy of critical loads in the designed rooftop PV systems; and lastly (c) exported stored energy to the grid for financial revenue; however, we do not see this option feasible for OSU due to the size of their critical loads in comparison to energy being generated daily.

PV Host Capacity (PVHC) is the total PV power that can be accommodated on a given feeder without adverse impacts. The provided heatmaps visualize the feeders in the Columbus area, specifically for the Agrivoltaic and 9th Avenue Parking Garage PV systems since these designs will be connected directly to the feeder without energy storage in comparison to the rooftop PV systems (Dodd Hall, McCampbell Hall, and Newton Hall) which are ideally connected to the main distribution panel in their respective buildings with energy storage included. The heat maps show the Max PV Capacity with the units KVA, where we can use the following equation for translating to KV: S(kVA) = P(kW) / PF. The apparent power S in kilovolt-amps (kVA) is equal to the real power P in kilowatts (kW), divided by the power factor PF.

The Agrivoltaic system is designed at the Waterman Agriculture and Natural Resources Laboratory Complex indicated by the red box. The land use and site selection is further discussed in the Development Plan regarding the installation feasibility. For interconnecting the system, lines will be made to Carmack Road based on the provided heatmap seen below, 3,600-3,900 KVA. Based on our designed system for the site seen in the Conceptual Design, the system size is 2,000 KW, or 2 MW, with the power factor assumed to be 0.95, which results in a 2106 KVA. As a result, our system does not violate the PV Capacity and is approximately 58.9% of the max capacity.

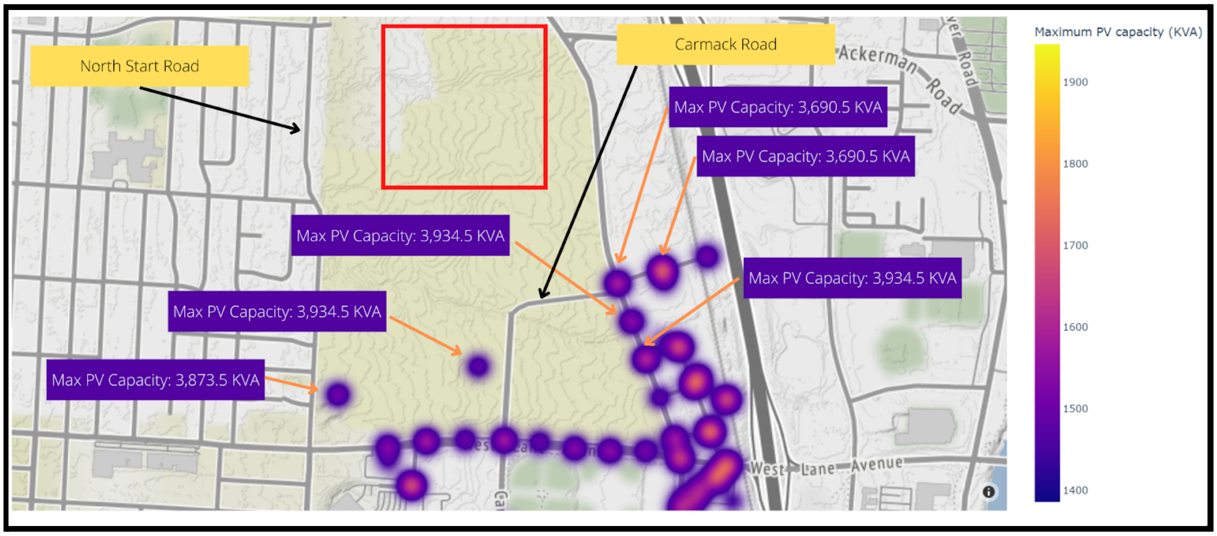


Figure 9. Waterman Agriculture and Natural Resources Laboratory Complex, Columbus, OH.

The second and only other non-building interconnection site is the 9th Avenue West Garage where there is a feeder available on each corner of the site. The feeders range from 3477 to 3934.5 KVA. The system size is 497KW with the power factor assumed to be 0.95; which results in a 523.6 KVA. As a result, our system does not violate the PV Capacity and is approximately 15% of the max capacity.

Figure 10. 9th Avenue West Garage, West 9th Avenue, Columbus, OH.

Finance Analysis

There are three pillars of sustainability: environmental, social, and economic. The prevalent goal of installing distributed resources (DR) also known as renewable/clean energy is environmentally reducing the emissions of carbon dioxide and greenhouse gasses. However, one pillar that coincides with project management is the cost of a project. The government has set incentives for renewable energy customers to receive these financial incentives and tax credits to encourage the installation of more renewable energy technologies. For the proposed system, a spreadsheet outlining and detailing the various aspects of calculating the price and payback is shown with formulas and the type of value (user-defined, calculated, constant).

The primary settings used were dependent on the PV system inputs. The size of the system (Watts) and the total cost per wattage. There are several other factors and values important for the calculation. In addition to the spreadsheet, the NREL System Advisor Model (SAM) was utilized for conducting financial analysis on the proposed system.

Table 2. System Size and Total Install Cost.

Site	System Size (kW)	Total Install Cost
Agrivoltaic	2,000	$3,716,390
9th Avenue Garage	497	$1,403,618
Dodd Hall	272.1	$5,021,617
McCampbell Hall	191	$4,787,845
Newton Hall	67.4	$5,372,275

Development Plan

The development plan was based on the following assumptions:

- Each design was planned with the assumption that the transformer in the area would be able to take the increased load from the designed PV system.
- For the agrivoltaic design, we have assumed that no utility lines are running under the design area. If this design were to be fully implemented, we would need to contact the Public Utilities Commission of Ohio to have the area marked.
- We assumed that each area uses a high leg voltage of 480V.

Afterward, the different systems that could be installed were noted: roof-mounted, canopy, and ground-mounted solar PV systems. Also, the minimum load for the area's substation was noted. Finally, the agrivoltaic system considered the potential for grass growth and livestock interaction, such as sheep, to graze underneath the system.

Beyond the regular District Use Case Master Plan, we also looked at Ohio State University's Climate Action Plan. They outline multiple ways to lower our emissions and reduce the university's overall carbon footprint. Another important consideration was that solar energy is the most feasible setup for the university to move toward carbon neutrality due to it matching the daytime energy use better than wind energy.

Next, the necessary permits were analyzed along with applicable codes. Essential permits were: City of Columbus Contractor's License, City of Columbus Electrical Contractor's License, and Building permits for construction in a University-College Research-Park District (commercial and mixed-use building permit). As for applicable codes, it is essential to cite: Residential Code of Ohio Chapter 3, sections 324 (Solar Energy Systems) and 301 (Design Criteria), and Chapter 34 (Electrical); Columbus City code Chapters 3374 (University-College Research-Park District) and 4125 (Construction Standards and Materials); International Building Code; and National Electrical Code. Article 690 and all relevant articles it references.

With all the variables analyzed and the design ready, the development plan was finalized. Figure 11 presents a timeline that outlines all necessary actions for a successful installation.

Figure 11. Timeline for the project development plan.

Conclusion

How might we promote clean energy education and inspire university students to pursue their passions in sustainability?

Every Green Roof Team member bought into our vision, the question above. We aspire to be the model for inspiring others to become empowered. We successfully installed a wind turbine from the engineering design to working with facilities for installation approval and a construction plan, and joining the Solar District Cup challenged us to think more significantly and how our proposal impacts a larger audience. Each team member conducted their research and built a strong foundation of knowledge through the NREL organizer's webinars, then reached out to our solar-related sponsors for additional help with applying the newly learned technical knowledge from the conceptual design and development plan. We are confident and proud of the designs we proposed because of the experience we enjoyed during the process.

There are many choices involved and many variations available for the project. We thoroughly analyzed and dissected our project to comply with various standards, including the NEC, NFPA, and IEE, and within the PV Host Capacity (PVHC) through the provided heatmaps. In consideration of the client, The Ohio State University, we considered details for the agrivoltaic, rooftop, and garage PV system and storage. The Agrivoltaic considered the land use from the animals on-site and how they interact with the system. The rooftop system included storage considering grid outages, so we designed for a total of four-day autonomy, which allows the batteries to use a portion for peak shaving while maintaining two days of autonomy at any given time. Then, the garage site included the use of EV chargers on the ground level to encourage the future of electrification as more electric vehicles, especially in the Columbus area, are more prevalent. OSU is a premier university, and increasing its renewable energy generation enhances the campus and overall environmental sustainability by taking ownership of a portion of its energy generation on-site and less reliance on external utilities.

We believe in shaping a more sustainable world, and this competition allows us to gain experiences we will carry as we either complete our degree or enter the workforce.