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Board 99: Utilizing the Solar District Cup Competition as a Case Study for a Renewable Energy Capstone to Enhance Students' Learning Experience

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Utilizing the Solar District Cup Competition as a Case Study for a Renewable Energy Capstone to Enhance Students' Learning Experience

A team of faculty and students at Illinois State University participated in the U.S. Department of Energy (USDOE) Solar District Cup Competition as part of their renewable energy capstone requirements. USDOE provided the North Carolina State University campus as a competition site. North Carolina State University is exploring commercial-scale solar photovoltaic (PV) interconnection investment to advance its sustainability goals, enhance student well-being, and reduce future energy expenses. The competition team evaluated the case study site to identify the optimum solar system configuration on campus. The case study university's energy supplier recognizes that solar PV interconnection supports the expansion of its customer base. While the case study university's campus currently houses a few buildings with small educational solar PV systems, most of these installations must be updated. The competition team employed various solar performance simulation tools, such as Aurora Solar, Open Distribution System Simulator, REopt, and System Advisor Model (SAM), to analyze system sizes and energy consumption data. Through comprehensive techno-economic analyses, the competition project team proposed fourteen solar PV systems with varying production capacities. In aggregate, photovoltaic interconnection is anticipated to reduce the local utility company's demand by approximately 10%. This case study equipped the strategic plan for the university with the solutions required to realize its aspiration of expanding its photovoltaic portfolio. The work performed by the competition team at Illinois State University placed second in their district in 2023. This was the third year of Illinois State University's participation in the competition, and they intend to encourage at least one student group to participate in the competition in the future. This paper aims to document the unique opportunity for students to leverage the national competition as their renewable energy capstone, detail the learning outcomes, and promote the exchange of ideas among educators in related fields.

1. Introduction

Higher educational institutions are vital in reducing energy consumption and carbon footprint, promoting energy efficiency, and fostering environmentally sustainable communities [1]. A team of faculty and students at Illinois State University participated in the U.S. Department of Energy Solar District Cup Competition. The competition district featured a case study using the North Carolina State University campus, where the university is exploring commercial-scale solar photovoltaic (PV) interconnection investment to advance sustainability goals, enhance student well-being, and reduce future energy expenses. Employing various solar performance simulation tools, the competition team analyzed system sizes and load data to devise a strategic plan, equipping the case study university with solutions needed to expand its sustainable energy system portfolio. In 2023, the competition team at Illinois State University placed second in their district. This made the university's third consecutive year of participation in the competition. They aim to encourage at least one capstone student group to participate in future editions.

Participation in the Solar District Cup competition offers students unique experiences distinct from the typical capstone project. This paper describes the project results and discusses how this competition opportunity enhances student learning. It documents the unique opportunity for students to utilize the national competition as their renewable energy capstone, facilitating the exchange of ideas among educators in related fields.

2. Solar District Cup and Renewable Energy Capstone

Illinois State University's Sustainable and Renewable Energy program mandates senior-level capstone courses for its major students. These capstone projects are intended to provide students with a synthesizing experience, allowing students to integrate knowledge and skills acquired throughout their major coursework. Students explore technical, social, and policy barriers to adopting new energy sources and develop and defend their positions on these contentious issues. As part of the course, students undertake a semester-long project demonstrating their mastery of the renewable energy curriculum. Learning objectives include identifying and defending positions on environmental, social, and technical issues related to renewable energy systems, developing a business case or energy forecast for a commercial energy project, conducting research on a topic, and presenting their findings.

Every year, the U.S. Department of Energy's Solar District Cup challenges multidisciplinary student teams to design and model optimized distributed energy systems for campuses or urban districts [2]. These systems may incorporate solar, storage, and other technologies across mixed-use districts, served by a standard electrical distribution feeder. The competition engages students in engineering, urban planning, finance, and related disciplines to rethink how districts generate, manage, and utilize energy. Its objective is to design, model, and present the most innovative and cost-effective systems possible. Teams compete in divisions around specific districts, with designs evaluated based on offsetting annual energy and financial savings through techno-economic analysis [2].

While Illinois State University students have participated in this competition since 2021, it was adopted in lieu of the capstone requirement beginning in 2023. This decision was made to align the scope of work, project timeline, and team size with capstone project requirements. Despite being a valuable tool for inspiring students, teaching industry-relevant skills, engaging with the professional marketplace, and preparing students for leadership roles in distributed solar energy, further evaluation was necessary to ensure alignment with capstone requirements.

To accommodate student participation in the competition, capstone faculty mentors worked with a group of students in the prior semester for the initial round of proposal submissions. This was facilitated through a course, a prerequisite to the capstone course, to recruit students promptly. In 2023, the competition was officially adopted to fulfill capstone requirements, with five students recruited to complete the project. The competition team achieved second place in their district. The subsequent section will document the completed project and discuss the findings.

3. 2023 Solar District Cup Project

Project Planning

The North Carolina State University (NCSU) site was selected as a competition project to address its high energy demand. As Duke Energy's largest consumer, NCSU's energy demand challenges regional land development due to limited capacity. To address this issue, the Illinois State University's competition team focused on three categories: Conceptual Design, Distribution Impact, and Development better to serve the needs of the case study site.

The Centennial Campus of North Carolina State University offers numerous feasible areas for roof-mounted photovoltaic solar panel installation, making it an ideal candidate for renewable energy production [3]. Adjacent to Lake Raleigh and Lake Raleigh Woods, potential sites for solar panel installation include parking lots and energy-intensive buildings. The team analyzed circuitry and load data to identify capacity limits and selected potential solar sites based on techno-economic viability. Various solar system designs were modeled to optimize benefits.

Distribution impact was also considered, with the team exploring incorporating battery energy systems (BESS) to reduce peak load demand. BESS can be charged during off-peak hours and discharged during high-demand periods, decreasing reliance on the electrical grid. Design software like Helioscope and SAM aided in site assessment, system design, and performance optimization. Helioscope calculated shading and orientation coefficients to maximize energy yield, while SAM simulated and produced performance data for each site.

The Distribution Impact Analysis involved verifying site suitability through aerial imagery and selecting appropriate equipment based on manufacturer data and compatibility with preexisting circuitry. Battery integration improves reactive power during peak hours, further reducing grid demand. Development phase considerations include establishing PV installation requirements to ensure compliance with permitting, zoning regulations, and NCSU's master plan. Community engagement focused on educating and building relationships to promote understanding of renewable energy benefits on campus.

The competition team achieved objectives by developing diversified solutions, combining building-tied roof-mount designs with larger-scale ground-mounts, carport, and floatovoltaic designs. Initial investigations revealed challenges in designing site-specific systems capable of offsetting more than roughly 10% of a building's total energy consumption due to varying population densities and per-capita energy demand across buildings.

Design Approach

The competition team's approach involved investigating interconnection limitations initially to prevent potential issues with oversized systems in the future. Site assessment ensured that all locations met necessary criteria, including ease of access for installation, adequate space for solar panels, proximity to consumer/interconnection points, and minimal disruption to campus activities. System design commenced after identifying optimal locations for roof mount, ground mount, and carport designs. Aurora Solar provided accurate height measurements of surrounding obstructions, processed production data, and then transferred to the HelioScope solar PV design tool. SAM and REopt were subsequently utilized to optimize economic viability. The team used various design tools to develop efficient solar energy solutions while meeting project site requirements.

Several variables influenced building designs to ensure optimal financial performance, with a critical consideration being avoiding circuitry overload on campus. Crucial metrics included shading, solar access, offset percentages, and available area. HelioScope facilitated the simulation of preliminary designs, with its module shading cutoff function verifying proper modular placement for maximum output. Aurora Solar's LIDAR feature enhanced structure designs, revealing many viable system candidates in the northern portion of Centennial Campus near the substation. Further south, two sizable ground mounts were proposed near Hunt Library and Wolf Ridge Apartments, a sizable floatovoltaic design on Raleigh Lake, and an extensive carport system in the Research District.

Equipment Selections

The team meticulously evaluated various commercial-sized solar panel modules to identify the optimal option for the site. They ultimately selected 400W panels for ground mount, carport, and floatovoltaic designs while recommending 420W panels for all roof mount installations. These modules are highly compatible with efficient-output DC optimizers, with three 1201W DC optimizers in series with the 400W panels and two 860W DC optimizers with the 420W panels.

DC optimizers utilize advanced technology for maximum power point tracking at the panel level, ensuring optimal energy output from each solar panel. SolarEdge optimizers also provide module-level monitoring capabilities, enabling early detection of potential issues and offering valuable maintenance data. The team evaluated several SolarEdge inverter technologies, ranging from 17.3 kW for smaller systems to 120 kW for more oversized carport and ground mount systems. This provides flexibility in selecting optimal interconnection points and final system sizing.

The team proposes installing 576 EG4-LL batteries in multiple buildings around campus, each paired in a rack with six batteries. These batteries are designed for 7,000 x 10-90% charge cycles and feature internal fuses, overload protection, and thermal protection. Each series of six batteries is wired in series to match one AIMS 30kW Pure sine power inverter charger (model PICOGLF30KW300V240VS), which is programmable to accept a wide range of DC input voltage and convert it to 120- or 240-volt AC. The battery and inverter meet UL certification requirements for ease of use and integration. The AIMS inverter is designed to respond instantaneously to power outages and can be configured with a timer to cease production during peak hours.

Implementing battery energy storage systems is recommended to reduce peak demand from the energy supplier, Duke Energy. As North Carolina State University is Duke's largest energy consumer, reducing demand benefits both the university and the supplier. The overall circuit's efficiency, known as the power factor, improves by utilizing energy stored on-site, especially when charged during off-peak hours. This efficiency improvement not only benefits the university but also enhances the efficiency of its solar system. The synergistic effect of batteries proves valuable, allowing NCSU to marginally improve PV hosting capacity by reducing stress on interconnection points during peak energy usage hours [4].

Project Results

The most extensive ground-mount design is on the south end of the campus near the Hunt Library, as shown in Figure 1. This ground-mount system has 1,328 modules with 531 kW DC in size. It is projected to produce just under 827,000 kWh, with a specific yield of 1,560 kWh/kWp. The second largest ground-mount design, the Wolf Ridge Apartments, consists of 322 modules, is 129 kW DC in size, and produces 195,000 kWh annually with a specific yield of 1,530 kWh/kWp. The Wolf Ridge Apartments ground-mount design feeds into Grove Hall and Lake View Hall. Together, these ground-mount systems account for 1,650 modules, 660 kW in size, and produce around one million kWh of clean energy annually. The last ground mount system, Partners 3, is smaller, only totaling 80.6 kW DC. It has a specific yield of 1,532 kWh/kWp and a total first-year annual production of 123 MWh.

Figure 1. Hunt Library Ground Mount

Research Parking Lot resides on the West campus and is the second largest carport design with 880 modules, as shown in Figure 2; it is 352 kW in size and would produce 471,100 kWh annually with a specific yield of 1,343 kWh/kWp. The team plans this system to feed 1/3 of the generated energy to Research 1 building and the other 2/3 to the grid. Partners III Parking Deck resides on the north end of the campus and is the larger of the three carports. Partners III Parking Deck has 1,008 modules, is 441.6 kW in size, produces 637.5 kWh annually, and has a specific yield of 1,445 kWh/kWp. This system is critical because it is the most significant offset for the Partners III building. The third and final carport design is the Oval Parking Deck, which resides next to the Engineering I building in the center of the campus. The Oval Parking Deck design is made of 551 modules, is 220.4 kW in size, produces 316,900 kWh annually with a specific yield of 1,448 kWh/kWp, and feeds directly into the grid. The carport designs consist of 2,439 total modules, are 975.6 kW in size, and would produce 1.36 million kWh of clean energy annually.

Figure 2. Partners III carport

The team implemented seven designs for the roof mount designs in the proposal. As shown in Figure 3, the Engineering II building consists of 795 modules (334 kW), produces 493,100 kWh annually, and offsets 13% of its annual consumption. The Engineering I building installation comprises 465 modules (196 kW), produces 284,700 kWh annually, and offsets 5% of its annual consumption. The Engineering III building installation comprises 400 modules (168 kW), produces 230,700 kWh annually, and offsets 6% of its annual consumption. Partner's II installation comprises 135 modules (57 kW), produces 80,240 kWh annually, and offsets 3% of its annual consumption. The installation of bio-manufacturing buildings consists of 164 modules (69 kW), produces 98,280 kWh annually, and offsets 4% of its annual consumption. The Partner's III installation is made of 105 modules (44 kW) in size, produces 68,870 kWh annually, and offsets 1.61% of its annual consumption. Lastly, the Toxicology installation consists of 60 modules (25 kW), produces 32,270 kWh annually, and offsets 1% of its annual consumption. Ultimately, those roof mount designs consist of 2,124 modules (892 kW) and would produce 1.28 million kWh annually.

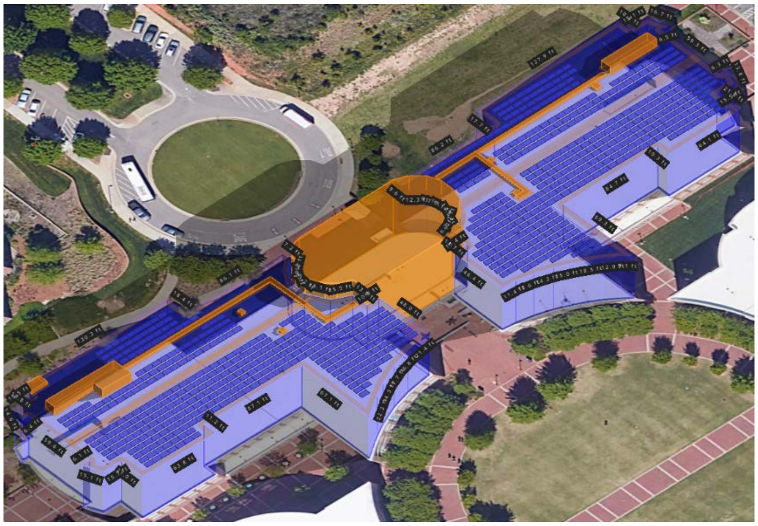

Figure 3. Roof Mounted System on top of Engineering II

The floatovoltaic design was proposed to be installed on Lake Raleigh at the southern end of the campus, as shown in Figure 4. This system comprises 5,230 modules (2,196 kW) and would produce 3,146,000 kWh annually. The floatovoltaic design feeds into the grid to offset the substation load. For community outreach, the team proposed to have a part of this system feed into the North Shore apartments to provide EV charging.

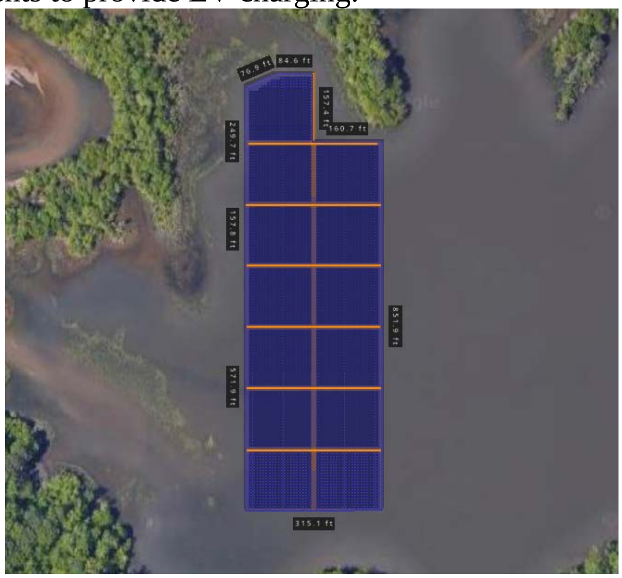

Figure 4. Floatovoltaic System on Lake Raleigh

The battery design involves distributing pairs of 576 x EG4-LLv2 48V x 100Ah Lithium-Ion Phosphate batteries alongside 96 x AIMS model PICOGLF30KW300V240VS Pure Sine Wave Power Inverter Chargers. A mobile battery rack provided by EG4 comes free with the purchase of six (6) batteries; wiring each of the 48V batteries in series produces DC voltage that can be handled by one power inverter. The inverters are programmable for varying DC input and AC connection voltages, including 120V or 240V 2- or 3-phase for industrial appliances, which is likely the case in Engineering II. For every six batteries, there is one inverter. The inverter wires to the wall and batteries and internally responds to power outages.

To satisfy NCSU/SDC's initial requirement, the design team proposed the following amounts of batteries per building as seen in Table 1; 108 to Engineering II offsetting 25% of 172kW peak demand for two (2) hours; 66 to Research I offsetting 25% of 110kW peak demand for two (2) hours; 228 to the Toxicology offsetting 40% of 114kW peak demand for three (3) hours; 108 to Partners III offsetting 30% of 143kW peak demand for two (2) hours; and 66 to National Weather Service/Research III offsetting 25% of 100kW peak demand for three (3) hours. Each building is paired with one (1) AIMS PICOGLF30KW300V240VS inverter every six (6) batteries. The benefit of installing batteries is multifold: while it offsets the peak load by the given thresholds each day, improving grid resiliency reduces the power demand from Duke Energy and enhances the efficiency of power delivery. We place the system to function entirely behind the meter to avoid power flow redundancy, ensuring that kVA demand from the grid is reduced. From the beginning, the focus of the proposed design has been to keep an eye on the limited capacity of the distribution network to the substation. Although every line and transformer on the grid is designed to operate at a specific voltage with a wiggle room of +-5%, the team would ensure the battery and PV systems would not incur any problems.

Building	Desired Peak offset (%)	Desired Peak Offset Duration (Hours)	Number of Batteries	Occupied Area (ft2)	System Weight (lbs)
Weather Service	25%	3	66	267	267
Partners III	30%	2	108	456	456
Toxicology	40%	4	228	920	921
Research I	25%	2	66	267	267
Engineering	25%	2	108	456	436
TOTALS	N/A	2-4	576	2,366	2,366

Table 1. Building battery profile

Project Conclusion

The proposed plan encompasses fourteen designs, including three ground-mounts, three carports, seven rooftops, and one standalone photovoltaic system. These designs are projected to produce 7.11 GWh of energy annually in the first year. While the designs offset a maximum of 10% of the campus' annual consumption, they do not adversely impact the distribution system, except for the standalone floatovoltaic system. Since PV production accounts for approximately 10% of the annual energy demand, concerns regarding overloading or overvoltage are not anticipated. The hosting capacity of the distribution network, at 33,448 kVA, suggests no risk of overloading the system if the energy production remains under 15 MWh. The proposed systems are also strategically located near transformers, minimizing constraint risks, transmission line requirements, and upgrade costs.

The addition of batteries is expected to provide further annual savings and enhance system resilience. The systems were meticulously designed using Helioscope, Aurora Solar, and REopt to analyze available data. Considering the significant civic vitality of the location, battery storage systems were integrated into several PV systems and the Research III/National Weather Service station. Using EG4 batteries ensures a product with warranty coverage and a long service life of approximately 19 years under daily use. Coupled with AIMS inverters, these systems are well-suited for the buildings. Furthermore, features such as ease of programming, UL certification, RS-485 communication ports, internal fault and thermal durability, and high-volume production justify implementing this system on NCSU's campus. The project’s overall annual grid consumption before and after the proposed PV system implementation is shown in Figure 5.

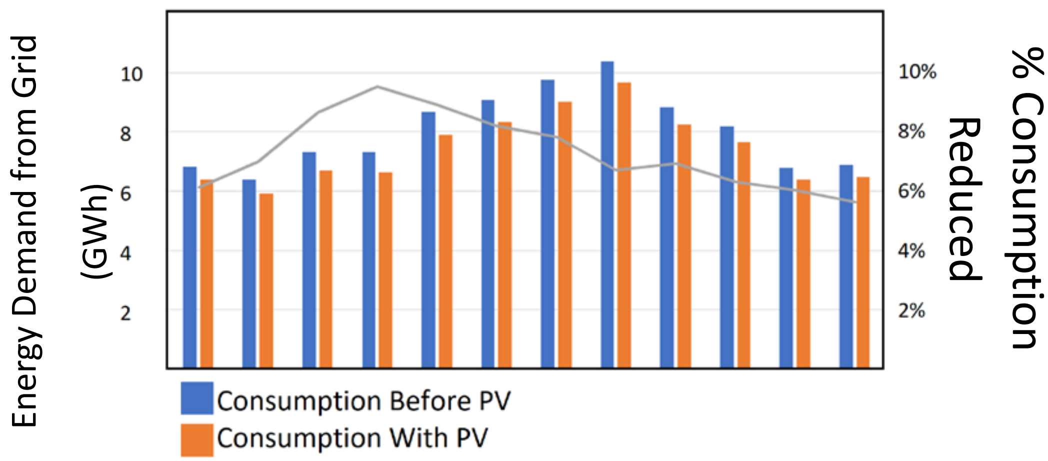

Figure 5. Annual grid consumption before and after the proposed PV system implementation

Finally, according to the Renewable Energy World [5], "more than 60 percent of incoming college students want to attend an environmentally responsible university," which would mean that the team's proposed implementation of solar photovoltaics would increase the student satisfaction and possibly retention rate of NCSU.

4. Learning Outcomes and Insights

The Department of Energy's Solar District Cup competition provided the Illinois State University capstone students firsthand experience in distributed solar energy design. The student competition team developed innovative solutions to real-world, district-scale challenges and engaged with industry professionals and mentors at the national labs. Overall, students felt their project paved the way for exploring more opportunities in the related industry and achieving more than they would have typically done in the capstone class.

Although there were many benefits to having students participate in the competition, several limitations exist. Students on the competition team are expected to start the project sooner as the competition begins before the capstone project in the spring semester. Recruiting students is another hurdle due to the timeline and willingness to participate, given the workload required by the competition. Students may also need to determine their availability in the spring semester, as this is typically their last semester before graduation. We recruited the student competition teams in 2021, 2022, and 2023. Although a few students were interested in this opportunity, most had schedule conflicts in 2024. Another uncertainty is that the finalists are selected at the beginning of the spring semester. Capstone students who may be willing to participate in the competition may not be chosen as finalists, and these students need to be assigned to different projects to fulfill the capstone requirements. Finally, the competition cannot be offered to all students in the capstone course. If the demand is too high, some students may be unable to join the competition team.

Utilizing the student competition in lieu of the capstone requirements has its pros and cons. The case study site and preliminary data are provided for the competition project, whereas other capstone students must select their project site and acquire the necessary data. For the competition project, this makes logistical sense as multiple competitors work on the same site, and the scope of the competition project is typically broader than what's required for the capstone project. Additionally, the competition project is not recommended for students who might already have selected the project site for the senior capstone project. Another benefit of the competition project is access to experts and mentors. Although capstone students have a faculty mentor for their project, students may need additional subject matter experts to complete the capstone project. Finding experts on the selected topic can be challenging for the students. The following quote is directly from one of the student competition team members.

"Reflecting on the event, the biggest benefit I realize by participating in the program is that my work impacts those beyond homework, assignments, and projects. Working in the SDC competition for our capstone project adds an elevated challenge for me beyond data analysis and paper writing. This environment is one where I may engage with individuals in a new sense: alongside classmates, academics at ISU, and professionals in the industry nationwide. Short of visiting the project site location, I recalled knowledge from previous extracurricular projects and prospecting and oratorical skills from over the years and added these skills and insights to the table. The SDC is there to give students a slew of real and ongoing challenges faced in renewables. The full scope of everybody's work was best realized after we would share skills and work as a team to support each other in preparation for our presentation and interview and to compress the innumerable hours behind the scenes into something that both makes sense to the judging panel and project development teams."

Overall, the students who participated in the competition project expressed that they gained more practical experience by participating in the Solar District Cup competition. However, they noted that it required significant dedication and time commitment. To better assist the capstone students in the future, the competition opportunity will be encouraged for interested students. In addition, several sites and data will be selected for students who prefer to work on a pre-selected site. This will not impact the project's timeline while providing non-competition students with a similar experience working on a capstone project, even if they decide not to pursue the competition as their capstone project.

5. Conclusion

A team of faculty and students at Illinois State University participated in the U.S. Department of Energy Solar District Cup Competition in lieu of their renewable energy capstone requirements. The competition district featured a case study of one university's campus on the East Coast. The case study university pursued commercial-scale solar photovoltaic (PV) interconnection investment to advance its sustainability goals, enhance student well-being, and reduce future energy expenses. The Solar District Cup challenges the competition team to elevate the case study site to a new standard. The university's energy supplier recognizes that solar PV interconnection supports the expansion of its customer base. While the case study university's campus currently houses a few buildings with small educational solar PV systems, most of these installations must be updated. The competition team employed various solar performance simulation tools, such as Aurora Solar, Open Distribution System Simulator, REopt, and System Advisor Model (SAM), to analyze system sizes and load data. The team identified fourteen solar PV systems with varying production capacities through comprehensive techno-economic analyses. In aggregate, photovoltaic interconnection is anticipated to reduce the local utility company's electrical demand by approximately 10%. With a focus on improving the quality of life, students can charge electric vehicles and enjoy outdoor recreational enhancements, such as solar-powered standalone accessory units. This strategic plan equips the case study university with the solutions required to realize its aspiration of expanding its photovoltaic portfolio. The competition team at Illinois State University placed second in their competition district in 2023. This marked the third year Illinois State University's participation in the competition, and they intend to encourage at least one student group to participate in the competition in the future. The competition team students who participated in the project said they gained more practical experience. However, they noted that it required dedication and time commitment. To better assist the capstone students in the future, several sites and data will be provided for students who would like an experience similar to the competition project. The capstone requirements would be modified if they chose this option as their capstone project. This will not impact the capstone project timeline while providing a competition-like experience.

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