Agrivoltaics Citizen Science: A Model for Collaboration between Engineers and K-12 Schools

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***Abstract*—This paper reports on a project that brings together photovoltaics engineers with 4th-12th-grade teachers and students to test agrivoltaics applications using citizen science. A summer research experience for teachers (RET) program engaged teachers in building and programming a novel agrivoltaic school garden monitoring device facilitated by photovoltaics engineering researchers. The teachers and their students will design and install school gardens for their own community purposes and collect data on garden conditions with and without solar panels covering the crops. A set of curriculum materials are outlined to support implementation across multiple contexts.**

Keywords—agrivoltaics, K-12 education, citizen science

I. Introduction

In the summer of 2020, nine STEM (science, technology, engineering and math) teachers participated in a five-week Research Experience for Teachers (RET) program focused on agrivoltiacs citizen science, working with faculty and students associated with the QESST Solar Energy Engineering Research Center. Teachers interacted with a broad range of engineering and education faculty and graduate students at ASU and from around the country. RET participants were each mailed two boxes of materials, one for curriculum, the other for agrivoltaics research. Their challenge was two-fold:

- Conduct solar energy research with the nation's top solar energy scientists.
- Design innovative STEM curricula to take back to their classrooms

The RET teachers worked with engineering faculty and graduate students on research in *agrivoltaics* - a new area of engineering that couples agriculture with photovoltaics to increase food production and generate renewable energy. Each teacher built, programmed, and tested a novel device that collects data about environmental conditions in school gardens: temperature, humidity, and soil moisture (Figure 1). Working with the entire lab team, they co-designed a photovoltaic (PV) mobile racking system that could be used in a school garden context.

Teachers developed curricular activities to engage their students in agrivoltaics, working with ASU faculty members in engineering and education. Research suggests that STEM learning is fostered when students see authentic purpose for their work, when they engage in real work with real consequences [1].

Once Covid-19 restrictions are lifted, teachers will lead their students in making two contributions through their agrivoltaic school gardens:

- *Contribute to the science of engineering through citizen science.* Using the data acquisition device built by their teacher, students will collect and analyze data to compare conditions in their school garden with and without solar panels. This data will be shared across schools and with the entire lab team.
- *Contribute to their community through energy engineering.* Students must decide how to design their agrivoltiacs garden to help their community. Each teacher will support their students as they develop community purposes for their gardens, make decisions about what crops to grow, and use the engineering design process to improve the garden and make a positive impact in their community. These community engineering activities may occur in the classroom or after school, depending on what each teacher decides in conjunction with campus leadership.

Finally, each teacher developed their own community energy engineering curriculum specific to their students, who range from 4th through 12th grade. QESST faculty and staff will continue to support each teacher in implementing their curriculum, partnering with collaborators in energy-related industry, policy, and research sectors. The goal is to foster STEM learning while inspiring youth to enlist energy science and engineering as tools for navigating opportunities and challenges in their communities. Faculty and staff will continue

Figure 1. Agrivoltaic School Garden Monitoring Device

to support each teacher in implementing their curriculum, partnering with collaborators in energy-related industry, policy, and research sectors.

II. AgriVoltaics Background

As researchers and engineers grapple with the future of photovoltaics, reducing land commitment becomes an increasing concern. Deciding where to place solar panels must consider optimizing energy production for people while avoiding environmental degradation. Agrivoltaics could be a win-win for agriculture and energy production, particularly in regards to land use near population centers.

Scholars investigating agrivoltaic systems are interested in increasing land productivity through the symbiosis between growing food crops (or raising animals) and producing renewable energy. Specifically, PV panels erected to create dappled lighting effects can reduce the damaging effects of direct sunlight on some food crops by reducing photosynthetic active radiation and increasing humidity while decreasing irrigation water requirements. Simultaneously, plants being watered under solar arrays can decrease the temperature of the solar cells. This is important because typical silicon solar cells lose efficiency at temperatures above 25 degrees Celsius due to rapid decreases in voltage and thus, decreases in output power. For instance, at 45 degrees Celsius a panel rated for 200 watts will only output 180 watts. Typical strategies of installing ground-mounted PV systems with gravel groundcover can create a heat island effect. Co-locating agricultural food production and PV infrastructure energy production can reduce such feedback loops [2].

Researchers are exploring the effects of agriPV on different kinds of crops around the world [e.g., 3]. The Sonoran Desert region of the U.S., the region in which our team operates, is a promising geographic location for agriPV due to its high yearly temperatures, high solar irradiance, and fast population growth [e.g., 4]. One recent study monitored light levels, air temperature, and relative humidity of conditions beneath PV panels installed over three representative dryland crops: chiltepin pepper, jalapeño, and cherry tomato. Compared to control crops, the agriPV systems reduced direct sunlight exposure, leading to cooler day temperatures and warmer night temperatures and therefore, greater moisture retention by the crops. Moreover, production was three times higher for the chiltepin crops and two times greater for the cherry tomatoes in the agriPV condition; water-use efficiency was 157% greater for the jalapeño, and 65% greater for the cherry tomato. Finally, the ground-mounted PV panels over the crops were approximately 9 degrees Celsius cooler during the day compared to panel arrays with gravel groundcover [2].

III. AgriVoltaics Research Experience for Teachers

Our interdisciplinary team is interested in furthering applied research in agrivoltaics, and also in how such research can benefit communities. Thus, the QESST team sought both to educate teachers and to learn from teachers.

The purpose of this applied research is to collect data to determine the impact of the environmental conditions on plant growth at different locations and the effect of a photovoltaic array. There are ways to get the data, including nearby weather stations and climate predictions for our location. We take measurements to determine the conditions at our location (sometimes called the micro-climate) with a data acquisition system. Our goal is to collect data to determine the impact of the environmental conditions on plants' growth at different locations and the effect of a photovoltaic array.

The agrivoltaic school garden monitoring device consists of an ESP32 microcontroller and a few sensors. The ESP32 contains Bluetooth, WiFi, and voltage measurement in addition to the primary microcontroller. To make the ESP32 interact with the sensors and the WiFi network, we wrote the code to program it. The ESP32 has specific connections, called pins, to connect to the sensors, and we use specific code to talk to each sensor. Steps for the programming and wiring needed to complete our device include to following:

(a) install the programming environment: install the Arduino IDE, test the installation, prepare to test the ESP32

(b) assemble and test the components on the PCB: wires, resistor for DHT22, terminal blocks, ESP32 board

(c) attach the sensors: DHT22 sensor and cable, soil monitor, solar sensor cell

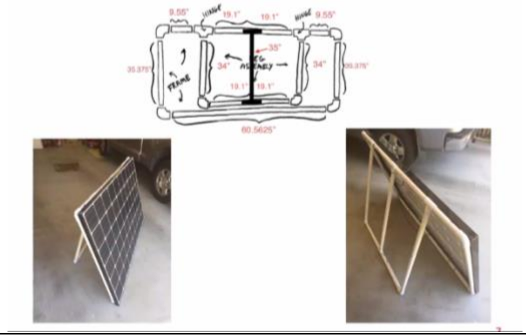
(d) write the programs: We use the C/C++ language the Arduino IDE to write code to tell the ESP32 how and when to take measurements and what to do with the data.

(e) troubleshoot and test the system; work with campus and district leaders to determine data collection protocols

The finished systems are able to measure and send data to a web dashboard. A full set of instructions for building and programming our system are available at https://github.com/pvedu/agripv

In addition to designing the monitoring device, it was necessary to design a mobile racking system for our 300-watt donated panels that can be used on school campuses (Figure 2). Students on each campus decide on uses for the energy generated (e.g., irrigation pump, lighting, charging laptops, mixers for food prep).

Figure 2. Mobile PV Racking System



IV. AgriVoltaics Curriculum

Working across multiple organizations, we organized a diverse curriculum development team comprised of K-12 teachers, high school students, education masters degree students, and engineering graduate students. Working in multiple configurations, the team has developed agrivoltiacs curriculum over the past two years, iteratively testing them with middle grade teachers and students. The curriculum is organized into six sets of lessons as follows:

1) Introduction to AgriPV
2) Exploring Solar Energy for AgriPV Applications
3) AgriPV family and community ethnography
   a) energy ethnography
   b) agriculture ethnography
4) Community Garden
   a) researching crops for social & geographic location
   b) square foot garden planner
5) Engineering your AgriPV Garden
   a) designing a PV racking System
   b) designing a solar-powered irrigation system
   c) collaborating & consulting with community members
6) Contributing to AgriPV research through citizen science

The agrivoltaics lessons are designed to integrate learning across disciplines and are aligned with the Next Generation Science Standards and with Arizona state standards in science and social studies. Lessons and collected data will be made freely available on the QESST website.

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References

[1] M. E. Jordan, S. Zuiker, W. Wakefield, and M. DeLaRosa. "Real Work with Real Consequences: Enlisting Community Energy Engineering as an Approach to Envisioning Engineering in Context," *Journal of Pre-College Engineering Education Research (J-PEER)*, in press.

[2] G.A. Barron-Gafford, M.A. Pavao-Zuckerman; R.L. Minor, et al. "Agrivoltaics provide mutual benefits across the food-energy-water nextus in drylands," *Nat. Sustain, vol. 2*., pp. 848-855, 2019. https://doi.org/10.1038/s41893-019-0364-5

[3] A. Weselek, A Bauerle, S. Sikeli, I Lewandowski, and P. Högy. "Effects on Crop Development, Yields and Chemical Composition of Celeriac (*Apium graveolens* L. *var. rapaceum*) Cultivated Underneath an Agrivoltaic System," *Agronomy*, vol. 11(4), pp. 733-745, 2021. https://doi.org/10.3390/agronomy11040733

[4] D. Majumdar, and M.J. Pasqualetti. "Dual use of agricultural land: Introducing 'agrivoltaics' in Phoenix Metropolitan Statistical Area, USA," *Landscape and Urban Planning, Vol 170*, pp. 150-168, 2018. ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2017.10.011.