Feasibility and Potential Benefits of APV on Small and Urban Farms in Southeast Michigan

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Clients: University of Michigan Campus Farm; Cadillac Urban Gardens; D-Town Farm; MSU-Detroit Partnership for Food, Learning and Innovation; We the People Opportunity Farm

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A project submitted in partial fulfillment of the requirements for the degree of Master of Science in Environment and Sustainability at the University of Michigan
April 2022

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Abstract

The practice of placing solar panels above working farmland, also known as agrivoltaics or APV, is relatively new around the world and is still in its early stages in the United States. In particular, little work has been done to understand how this technology can support the work of small-scale and urban farms. For this project, we worked with five small and urban farms in southeast Michigan, each with unique site characteristics and organizational purposes. Our research objective was to explore APV as a mechanism for supporting the overarching goals of our partner organizations, and to understand what benefits it might offer to small and urban farms through a feasibility study. The methods used to assess APV feasibility included: a review of APV, food justice, and relevant policy documents and literature; client interviews and site visits; site suitability mapping with ArcGIS; estimated energy demand assessments; hand calculations for system sizing; and associated payback period calculations. This information was compiled into design briefs which included both APV and traditional PV system options, to adequately respond to our partner sites' stated goals and needs. Of the five farms we partnered with, only the two university farms showed serious interest in installing on-site APV. A combination of factors contributed to this difference, including the university farms having higher funding and more interest in the demonstration of APV technology.

1. Introduction

1.1. Purpose and Project Summary

The practice of growing crops under solar panels, also known as agrivoltaics or APV, is relatively new around the world and is still in its early stages in the United States. However, several factors are contributing to its growth: universities producing more research on APV, competition for land between renewable energy production and agriculture, and farmer interest in diversifying income streams. This project aims to explore APV on small-scale and urban farms and what, if any, benefits it may offer farmers and surrounding communities. Our research is initiated by the University of Michigan Campus Farm's desire to pursue APV, both for research purposes and to offset its carbon emissions. We also aim to produce broader research and benefits by including several urban farms in Wayne and Washtenaw counties. We worked with five farms on this project: Cadillac Urban Gardens (CUGM), the Michigan State University (MSU) Detroit Partnership for Food, Learning, and Innovation (DPFLI), D-Town Farm, the University of Michigan Campus Farm, and We the People Opportunity Farm (WTPOF).

After conducting several interviews with farm managers from these five farms, we created design briefs which detailed APV and other solar panel systems for the organizations' consideration. These design briefs are specialized to the expressed goals and needs of each site. While our work centered around farms within southeast Michigan, these briefs can offer examples of how APV may be used on small-scale and urban farms more generally. To broaden the applicability of our research, we created a roadmap for farms to use when considering APV.

Finally, this paper includes information on the energy policy landscape in Michigan and the U.S. for those wishing to influence policy as it relates to APV.

1.2. Food and Energy Sovereignty

The current national and global food landscapes stage intersecting crises. Ever-expanding agricultural land use drives habitat loss and fragmentation, which are in turn primary causes of wildlife loss and species extinction around the globe (Crooks et al., 2017). Conventional farming techniques also cause land degradation and soil loss at an outstanding rate (Bhadwal et al., n.d.). At the same time, racist and classist land use policies such as redlining have created systemic divestment in urban communities of color. This results in high incidences of "food apartheid"—a term that, according to Penniman, "makes clear that we have a *human-created* system of segregation that relegates certain groups to food opulence and prevents others from accessing life-giving nourishment" (Digital Scholarship Lab; Essig et al., 2020; Penniman, 2018; Reese, 2019). Energy insecurity—defined by the International Energy Agency (IEA) as "the uninterrupted availability of energy sources at an affordable price"—is another such manifestation of these histories of racially-driven divestment and disenfranchisement (IEA, 2019; Sovacool & Dworkin, 2014). These challenges intersect for those dealing with them; for instance, it is harder to keep food fresh if one's power is unreliable.

The ongoing COVID-19 pandemic has further exacerbated food and energy insecurity, particularly in communities of color, through national lockdowns, mass layoffs, and supply chain backlogs (Bethel, 2021; Hake et al., 2021; Reese, 2021; Robinson-Jacobs, 2021). These challenges have re-centered conversations around community sovereignty and self-determination as necessary mechanisms to build greater resiliency in the face of extreme challenges, from pandemics to anthropogenic climate change (Bethel, 2021; Thigpen, 2021).

As part of this conversation, Black farmer historian and sociologist Dr. Monica White has developed a theoretical framework for understanding how communities "actively build alternatives to existing political and economic relationships…[to support] knowledge, skills, community and economic independence" (White, 2018). She refers to this framework as Collective Agency and Community Resilience or CACR, which is exemplified by the work of Fannie Lou Hamer's Freedom Farm, Booker T. Washington and Tuskegee University, and the Detroit Black Community Food Security Network (DBCFSN) in their creation of transformative food systems. D-Town Farm is affiliated with DBCFSN and CACR is integral to the organizational missions of both organizations. Similar goals can be found in the mission statements of We the People Opportunity Farm, Cadillac Urban Gardens and the Detroit Partnership for Food, Learning and Innovation, all of which are partner sites in this research. An in-depth analysis of these sites' missions and priorities is discussed in section 1.5 of this report.

In understanding the intersections of food and energy sovereignty, one burgeoning question regards the extent to which urban farms could serve as sites of electricity production in addition to their current roles in community-building and knowledge-sharing spaces. Independent, on-site energy could serve as a means of increasing energy sovereignty for urban farms. Photovoltaic solar panel technology makes this possibility increasingly attainable. For instance, although not an urban farm *per se*, Casa Pueblo in Puerto Rico provides an incredible example of community resistance to disaster via on-site energy creation (Massol-González et al., 2008).

Our research specifically investigates how APV may fit on small and urban farms, how it might promote food and energy sovereignty, and whether the APV strategy could serve urban farms seeking both energy and food production. APV could offer a way for urban farms to efficiently produce energy on-site even with limited space, allowing greater agency in deciding where an organization's energy comes from. We hope to answer the question of whether and how this APV strategy might support Detroit-area small-scale and urban farms' energy needs while aligning with the organizational priorities and values of each farm.

Our research also adds to the growing conversation around land use and siting renewable energy to meet decarbonization goals. Land-use constraints will likely become more apparent in both urban and rural arenas over the next decades, as clean energy goals will result in significant increases in the amount of wind and solar energy installations. Locating renewable energy within cities reduces the need for expensive transmission lines, improves the rate at which clean energy is delivered to consumers, and could boost community resilience in times of power outages when paired with battery storage; however, the critical role urban farms currently play should not be threatened by outside impositions to mitigate climate harms for which members of urban farm organizations, and their surrounding communities, are not responsible. (Shaver, 2019). Therefore, the primary intention of this project is to evaluate how APV may provide a useful tool for small and urban farms themselves, particularly our five partner sites. Nonetheless, subsequent sections of this paper explore how APV can be a useful tool for decarbonization in some contexts.

1.3. Agrivoltaics

The practice of agrivoltaics, also known as agriphotovoltaics or APV, was first proposed in 1981 by Adolf Goetzberger and Armin Zastrow (1982). Their seminal work proposes that "solar-energy conversion [need not preclude] any other use of the land area involved." That is to say that plant growth and solar energy production need not be in competition on a given plot of land. This concept has wide implications, including that large-scale solar panel arrays could be inclusive of natural plant growth. This could allow solar arrays to co-exist with agriculture, promoting a "land-sharing" approach as described in conservation biology (Kremen, 2015). The APV strategy goes further; it specifically places agriculture with solar energy production on the same plot of land.

As described by Goetzberger and Zastrow, a maximization of combined plant and solar generation is achieved when photovoltaic panels are spaced over an agricultural field at a footprint ratio of ⅓ PV to ⅔ agriculture. The panels are angled southward at an angle equivalent to the northern latitude of the APV installation so that they are most productive in the winter and let much of the sun's energy through to the crops during the growing season. Not surprisingly, some crops, specifically those that can handle or prefer some shade, are more suitable for this simultaneous production with photovoltaic energy.

Three decades after the strategy was proposed, the advent of the *Agrivoltaics Conference* in 2020 marked a coming-of-age for the APV innovation, underlined by significant growth of the conference in the following year (Agrivoltaics Conference, 2020). Presenters at the 2021 Agrivoltaics Conference proposed broad possibilities for the stacked land use strategy, exemplified by the claim that installing "PV on 1% of the world's agricultural land covers [the] entire global energy demand" (Fell, 2021). Across a variety of applications, the conference presenters signaled their hopes for APV to accomplish more with less: In Australia, Nassar has employed a method used to measure the efficiency of this stacked land use that yields 134% energy and crop yield compared to the same amount of land split halfway between agriculture and a solar field (Nassar, 2021). In Germany, Pataczek et al. have highlighted potential synergies between APV and certain shade-tolerant fruits and vegetables like lettuce and berries (Pataczek, 2021). It has also been suggested that the entire energy needs of many metropolitan areas could theoretically be met solely with APV in the surrounding area (Majumdar & Pasqualetti, 2021). The two Agrivoltaics Conferences have also been a proving ground for APV innovations beyond the simple original design.

Researchers in countries around the globe have shown exciting potential for the employment of APV systems in the pursuit of:

1. renewable energy production that is overall less expensive, and has a smaller carbon footprint, than solar fields alone (Kral, 2021; Nassar, 2021)
2. strategic shading and water retention to facilitate plant growth, especially in hot and dry conditions (Feistel et al., 2021)
3. the introduction of habitat elements for livestock (Heins et al., 2021)

Our study attempts to contextualize these benefits within the urban and small-scale farming context, particularly within Southeast Michigan. In addition, we aim to explore how APV on urban farms might further the goals of relieving food insecurity, promoting community food sovereignty, energy sovereignty, and self-determination. Interviews with farm managers help elucidate how these goals might be made more achievable with APV.

1.4. Energy Policy

Policies governing energy production at the state and local level can significantly impact the ability of farmers to pursue APV. In particular, zoning and permitting ordinances, net metering laws, and funding opportunities for renewable energy projects impact the feasibility of APV projects, particularly for small and urban farms. The following three subsections will detail the policies we researched in designing briefs for our partner organizations, and how they may affect the feasibility of APV on these sites.

1.4.1. Zoning and Permitting Ordinances

In Michigan, cities and townships have the authority to regulate solar development according to their own ordinances and review processes, meaning APV projects may be more easily pursued in some municipalities than others. For example, the city of Detroit currently lacks a specific solar zoning ordinance, which can cause confusion for those hoping to add solar to their properties. Currently, most small-scale solar within Detroit is regulated as an "accessory structure" and subject to zoning district rules. An accessory structure is defined as being subordinate to the main structure or use of the property in area, extent, and purpose, and which "contributes to the comfort, convenience, or necessity of the occupants, business or industry" (City of Detroit, 2021). Solar projects can also be considered "principal use" if they are located on a property in which the main purpose is generating energy. A principal use solar energy system would be considered a "solar generation station" if it is a ground-mounted array which exceeds one acre in size and produces energy for use primarily outside of the property. While the Detroit municipal code explicitly allows for solar generation stations as a conditional use (meaning city review is required) in Parks and Recreation (PR) and Planned Development (PD) districts, solar systems are not clearly identified in any other capacity, such as rooftop solar or other small-scale arrays.

Although the Detroit municipal code does not ban solar, lack of official guidance on PV installations can hinder development. According to the National Renewable Energy Laboratory, when cities don't have official language on solar, this can leave PV owners vulnerable to neighbors who may oppose solar installations (Day, 2017). They may even attempt to sue the city for allowing something that's not officially allowed in the municipal code. In addition, having solar ordinances in place would better position the city to institute regulations, incentives, or funding programs for solar.

A 2019 Solar Policy Deployment Guide which was prepared for the city of Detroit identified the lack of an expressed solar zoning ordinance in the city's municipal code and outlined ways in which the city could better promote solar (Great Lakes Environmental Law Center et al., 2019). One of the report's policy recommendations was for Detroit to identify a goal for collective solar capacity within the city. In fact, the city has since identified a goal within its Sustainability Action Agenda to double the amount of solar installations within the city by 2024, although specific actions toward meeting this goal have yet to be identified (City of Detroit, Office of Sustainability, 2019).

While having more guidance on solar within a municipal code can make the process clearer for developers and homeowners alike, overly restrictive policies can severely limit solar development. For example, in Ann Arbor Township, where the University of Michigan Campus Farm is located, the municipal code contains several restrictions on solar development, particularly on farmland. The township differentiates between small- and large-scale solar energy systems (SES), with different regulations for each category. Large-scale SES are those which have a solar-collecting surface greater than eight square feet. These projects cannot reside on prime farmland, must be setback at least 50 feet from the property lines, and cannot use cement footings (Ann Arbor Township, 2020). The Campus Farm is designated as part of a research university and is not subject to Ann Arbor Township's regulations. However, these regulations strictly limit APV development in the township overall. Cement footings provide needed support for some large-scale APV system designs, such as those designed to allow a tractor to drive underneath the panels. Ultimately, each solar system installed within Ann Arbor Township must go through a review process and it remains unclear what sorts of APV installations the township may approve. While these ordinances should succeed in preserving farmland within the community, they could be updated with more amenable rules for dual-use installations such as APV, which promote both energy and agricultural production.

1.4.2. Net Metering

Net metering laws also affect the feasibility of pursuing APV projects, as they determine how much money an organization can get back for excess energy produced by a solar energy system. When solar panels are connected to the grid, energy which is not consumed on-site is sent back to the general system, to supply energy elsewhere. When this happens, the owner of the solar panels receives a credit for this excess energy. In 2019, the Michigan Public Service Commission approved investor-owned utility DTE's change to their net metering program. Before, customers would receive a credit that was calculated at the full retail rate. However, after 2019, the net metering program changed such that customers only receive a credit for the excess energy they put back onto the grid, minus transmission charges (DTE, n.d.). This means that it now takes longer to pay back the upfront costs of installing a solar system, as net metering revenues for customers are lower.

1.4.3. Funding Programs

The existence of funding programs for renewable energy projects like APV can also affect the likelihood that such projects will be implemented by small and urban farms. All of our partner sites are nonprofits, and their tax-exempt status means that they cannot make use of tax incentives. One of the most important policies around solar energy at the federal level is the investment tax credit (ITC), which provides a credit worth 26% of the up-front cost of a project (SEIA, 2022). While this credit provides valuable assistance to for-profit farms pursuing solar, as well as homeowners installing rooftop solar, nonprofits are unable to reap the benefits.

However, Michigan offers a couple of funding programs for renewable energy projects, including the AgriEnergy and Sustainable Farming Program and Michigan Saves loans. The AgriEnergy and Sustainable Farming Program offered by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) provides funding for farms and small businesses to invest in energy efficiency and renewable energy projects. The program has $100,000 in funding to distribute, with a maximum of $15,000 for eligible projects. Project funding is limited to 50% of the total project cost (Department of Environment, Great Lakes, and Energy, 2022). Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR (Michigan Saves, 2022).These state funding programs could prove useful for small and urban farms considering APV, although they still require organizations to make up a significant portion of the funds themselves. It remains to be seen whether these programs provide enough assistance for APV to be a worthwhile investment for small organizations.

1.5. Partner Sites

To explore the feasibility of APV on southeast Michigan urban farms, we partnered with five unique farms to imagine what the implementation of APV systems on those sites could look like. These evaluations were shaped through interviews and months-long conversations with farm managers and directors, in addition to at least one site visit per farm.

The five partner farms in this study have unique and complex goals, communities, external partnerships, scales, political involvement, and land-based memories and relationships. Utilizing the CACR framework and with respect to farmer and organizational self-determination, we approached each design with respect for an array of nuances.

1.5.1. Cadillac Urban Gardens

Cadillac Urban Gardens on Merritt (CUGM), in Mexicantown of Southwest Detroit, is a 1-acre raised bed community garden and nonprofit. Their production focus is to provide free, culturally-relevant food to the surrounding, predominantly Latinx community. CUGM's greater mission is to support food access and food education while also place-making for youth mentorship and community-building (Perales, 2021). Their space is meant to bring the community together to promote food sovereignty, neighborhood beautification, and inter-generational learning (Southwest Detroit Environmental Vision, 2022).

Currently, the site doesn't have a grid connection and lacks power to meet electricity needs. As such, APV and PV systems can support organizational outcomes by providing on-site energy generation for internet access, device charging, events, etc. The structure of an APV installation could serve as a rain collection system to water crops while also providing shade for both plants and people, reducing heat stress, food waste, and decreasing evaporation on hot days.

1.5.2. MSU-Detroit Partnership for Food, Learning and Innovation

The MSU-Detroit Partnership for Food, Learning and Innovation (DPFLI) is a 3.3-acre urban agriculture center located in Redford Township just outside of Detroit (Edwards, 2021). It is a Michigan State University extension site for urban agriculture and forestry research and community engagement programming. On-site activities include demonstration and educational programming, serving both MSU and surrounding communities. The site's stated mission is to improve the quality of life for the people they serve. They do this by acting as a model for farm sites and communities, demonstrating how they can be designed for sustainability and food sovereignty.

APV and PV systems can play a crucial role by providing on-site demonstration of how solar energy can contribute to these goals. The site aims to support a diverse array of technology and skills to help people be connected with each other and environmentally-aware. As such, an APV installation may be one of several future energy infrastructures. Just as all the site's food goes to the local community, energy generated with APV can also be used by community members on-site. MSU researchers and educators can utilize an installation to support collaborative learning and research opportunities.

1.5.3. D-Town Farm

D-Town Farm, part of the Detroit Black Community Food Security Network (DBCFSN), is a 7-acre farm in Rouge Park of West Detroit that follows organic practices. In addition to several acres of diverse vegetable production, the site has a demonstration pop-up kitchen, a stage and event space, several hoop houses, a storage shed and a solar energy station. DBCFSN's mission is to "address food insecurity in Detroit's Black community and to organize members of that community to play a more active leadership role in the local food security movement" (DBCFSN, 2019). As of summer 2022, DBCFSN will replace "food security" in their title and organizational language with "food sovereignty."

D-Town Farm has access to energy via a solar array on their shipping container energy station and storage unit. They have stated that energy generation is less of a problem than energy distribution and that any APV or PV designs must be integrated into their larger energy generation infrastructure. Additionally, D-Town Farm has an existing partnership with Ryter Cooperative Industries to install and maintain their solar energy system. This partnership will likely provide support for implementation of any designs this research provides.

1.5.4. University of Michigan Campus Farm

The University of Michigan Campus Farm at Matthaei Botanical Gardens is an 11-acre property with four hoop houses, a field office and an adjacent greenhouse. In total, 3.5 acres are used for diversified vegetable production following agroecological and organic farming practices. Their mission is to operate as a "student-driven multi-stakeholder living learning lab for sustainable food systems work built around principles of food grown by students for students; on-farm carbon-neutrality; and diversity, equity, inclusion, and justice; in a learning community that fosters student leadership development and high-impact teaching, research, and learning opportunities" (The UM Campus Farm, 2022).

The Campus Farm's primary question for this study is whether APV can offset their current carbon footprint, providing energy for all on-site operations, including the use of the adjacent greenhouse. In addition to supporting on-farm carbon-neutrality, the Campus Farm seeks to determine how APV can be used for educational and demonstration purposes.

1.5.5. We the People Opportunity Farm

We the People Opportunity Farm (WTPOF) is a half-acre urban farm located on a section of land owned by a Protestant church in Ypsilanti, Michigan. WTPOF aims to break the cycle of incarceration by providing food free of charge to the local community and employing formerly incarcerated individuals through an internship program. Their stated values include “radical inclusion, intentional collaboration, courageous disruption, rooting in justice, and commitment to growth” (We the People Opportunity Farm, 2022).

WTPOF currently does not have access to energy on-site so APV could introduce a wide range of new possibilities. Internet access and charging stations could serve farm interns and the local community. Cold storage could enhance food accessibility for the community and improve access to farmers markets. On-site energy could also provide lighting in the newly built shed or across the farm site for working after dark.

2. Problem Statement

Upon considering the potential APV has to enhance food and energy sovereignty within communities, we set out to understand what kinds of benefits APV could offer our partners and how it could facilitate their organizational missions. These design briefs are meant to be used by partners to implement solar how they best see fit. They not only include information for partners on how to integrate solar energy production within their agricultural operations, but also how to use APV and PV to meet other goals such as building community and fostering educational spaces.

Our first motivation was to explore APV system options at each individual site through research and iterative design. Each partner has a variety of goals, challenges, needs, and constraints that are unique to their organization and community, and that directly impact the role APV can play. They each required customized research and designs to center the served community instead of the APV technology itself.

Our second motivation was to remove barriers to APV and PV implementation by providing information on costs, maintenance and funding sources. If a partner decides to move forward with an APV or PV installation in the future, the design briefs include enough information, resources, and inspiration to reduce planning and administrative burdens. Our designs and research serve as a beginning point for the partners to advance their unique APV-related energy and food sovereignty goals.

3. Methods

3.1. APV Literature Review

We conducted a review of the published materials on APV via two primary methods: a search of published literature via search engines like Google Scholar, and an extensive investigation of the materials published from the 2020 and 2021 Agrivoltaics Conference (AgriVoltaics2021 Conference & Exhibition). To find materials through the search engines, we used phrases such as “APV,” “agrophotovoltaic,” “agri-photovoltaic,” or “agrivoltaic,” with one or more of the phrases “urban farms,” “small farms,” “southeast Michigan,” “land use,” “stacked land use strategy,” “dual land use strategy,” or words like “urban,” “feasibility,” “benefits,” “costs,” or “yield.” Some searches did not include a variation of “APV,” for instance, we also used a search term for “stacked land use strategy.”

The conference materials were accessed with paid subscriptions through the online portal for the Agrivoltaics Conference. Each presenter at the conference had a paper, an abstract, a virtual poster board, and/or a video presentation associated with their work available to view. Relevant materials were investigated.

3.2. Social Frameworks Literature Review

Given that all of our partner sites’ work is grounded in social justice (DBCFSN, 2019; D. Perales, personal communication, November 4, 2021; Stuever, 2017; The Campus Farm, 2022; We the People Opportunity Farm, 2022), a literature review on food justice, particularly in the context of racial justice, served to broaden the researchers' understanding of urban farming histories and current contexts. Particular attention was paid to literature on urban farms in Southeast Michigan, especially the Detroit area. The work of Drs. Monica White and Ashanté Reese, scholars on Black farming and urban food justice, were used as cornerstone references from which further publications were identified in citations and bibliographies (Garth & Reese, 2020; Reese, 2021; White, 2018).

Academic literature was also identified through searches in Google Scholar using combinations of these search terms: “food justice,” “racial justice,” “Black,” “African American,” “food sovereignty,” “urban,” “food system,” “urban farm,” “energy justice,” “energy sovereignty,” “Detroit,” and “Michigan.” These terms were also used in a general Google search to identify news articles and blogs on the same topics. We intentionally included these non-peer-reviewed articles in recognition that much of the work of urban farms occurs outside of academic and research institutions. While some references to solar and renewable energy were identified, these search terms and contexts yielded no mention of APV.

3.3. Policy Research

Policy research for the design briefs focused on areas of energy policy which directly affect our partners' ability to install solar systems. We focused on practical considerations such as zoning and permitting ordinances within the municipalities where the farms are located, how much money partners could receive through net metering, and any funding programs which might be available. To provide easily digestible zoning and permitting information, we looked up the municipal codes in Ann Arbor Township, Detroit, and Ypsilanti Township, the three places where partner sites are located. All of these municipal codes are readily available online for free public access. The digital municipal codes also allow users to search for keywords. We searched keywords such as "solar," "APV," "agriculture," and "farms" to see if the municipalities had any specific ordinances related to solar energy systems or urban farming. We also looked for sections on accessory structures and use, as many of the municipalities regulated solar energy systems under these terms. Some municipalities regulate solar energy systems differently in different zones. To find out which zone each farm was in, we looked at municipal maps of zoning districts which were available on each municipality's website. We then found the corresponding ordinance within each municipal code for a particular zoning district.

To research net metering laws in Michigan and within DTE's jurisdiction, we performed standard internet searches using keywords such as "net metering laws in Michigan," and read articles and government documents on the current policies. This included reading Michigan Public Service Commission documents on net metering and the rate at which customers are credited for excess energy.

To research funding opportunities, we performed standard internet searches using keywords like "funding for solar in Michigan" or "funding for solar in Detroit." These searches resulted in articles, reports, and government program websites which provided valuable information on the types of funding sources which are available.

3.4. Client Interviews and Feedback Meetings

To better understand the priorities and goals of each client organization, we conducted initial interviews and subsequent follow-up meetings throughout the research period. Conversations followed a standardized interview guide; we asked the same questions of each client organization, with time for open dialogue at the end of each session. Initial interviews included questions about organizations' missions, priorities, and general operations. Subsequent follow-up meetings incorporated questions on proposed design suitability, accessibility, and formatting. These subsequent interviews served as feedback mechanisms to ensure that partner organizations' stated priorities and needs were forefronted throughout the design process.

3.5. Site Visits

We visited each partner farm site either once or twice during the 2021 growing season. In each visit, we were introduced to some key members of the farm organization, and spoke with a farm manager or director about the farm site in an informal interview. Primary subjects of these talks included the size, activity, shading, crop choices, water profiles, and missions of the sites, as well as interest in the addition of electricity production, APV, and potential uses of newly generated electricity.

At three of the five sites, D-Town Farm, Cadillac Urban Gardens, and DPFLI, we also volunteered with the farm sites' operations on two separate occasions. These experiences helped us gain understanding of the farm sites and their operations, and, as outsiders to these organizations, helped build rapport between us and members of the farm sites.

3.6. Technical Research and Design Methods

3.6.1. System Design Approaches

The following section outlines the methods used to compile a set of potential system designs that can benefit each farm while considering the unique and nuanced circumstances of each organization. This type of investigation is known as a feasibility study. The information gathered and used to perform this feasibility study contributes to each site's design brief. These are multi-page documents which detail the feasibility of each design, and include information and resources to remove potential barriers to implementation. The goal of each design brief is to provide a navigable starting point for the partner farms if they ever consider implementing APV or PV, and include approximate sizing and general technical considerations. If a partner decides to proceed with a specific design, professional contractors and engineers will need to be consulted to appropriately design and accurately size each component of the system.

The design process provided the framework for our team to begin creating the design briefs. We followed the design process outlined by Grondzik and Kwok in *Mechanical and Electrical Equipment for Buildings*, in which the first step of the design process is to establish design intent, which is defined as the statements that outline an "expected high level outcome of the design process" and orient the direction of the project (Grondzik and Kwok, 2015). To establish the design intent for each farm, we took information from aforementioned interviews and farm sites' public websites to create a list of goals and priorities of each organization. These goals were verified with organization representatives and function as the design intents for each farm. We then established design criteria, which are defined as the benchmarks or measures that determine the success or failure in meeting design intent. However, since this is a theoretical feasibility study with very little explicit technical or performance goals relating to the systems themselves, we mainly used design considerations to guide the direction of the designs. These considerations were based on comments and requests from farm representatives to guide the direction of the feasibility study. The only specific design criteria beyond these considerations are to comply with the applicable local building codes and zoning regulations, which are addressed on an individual basis at each location.

3.6.2. Determining Energy Demands of Each Farm

Each farm has different functions, different forms of energy use, and different goals that influence the electrical design of APV and PV solutions as well as the energy generation potential. In order to assess the electrical demands of each partner farm, we inquired about energy usage in each introductory interview, including current electricity usage, whether the current access is adequate for farm functions, and whether they need more electricity to achieve their goals. By understanding how each site uses energy currently and how they hope to use energy in the future, we can ensure our APV and PV designs are compatible with each farm's respective visions. Flexibility in these designs is necessary to ensure the system will continue to serve each community as they evolve.

For the Campus Farm, DPFLI, and WTPOF we estimated PV system sizes, costs, payback periods, and associated carbon emissions reductions. For the Campus Farm and DPFLI, the purpose of these calculations was to determine how big of a PV system was needed to offset carbon emissions. Calculations for WTPOF were intended to size a PV system to power a CoolBot cooler for food storage.

3.7. GIS Analysis

In order to design the suitability maps for each site, we used Light Detection and Ranging (LiDAR). The LiDAR data was taken from the USGS elevation source database. We used ArcGIS Pro to create the suitability models for each site. The Digital Surface Models (DSM) we generated from the LIDAR datasets for each site took into account the features (trees, buildings, vegetation, and man-made structures) above the bare surface.

The area solar radiation tool in ArcGIS was used to estimate the solar potential for the total area of each site for the entirety of the current year. We utilized geoprocessing tools which are part of the ArcGIS Spatial Analyst extension. We used the ArcGIS ModelBuilder tool which is a geoprocessing workflow represented as a diagram that strings together a sequence of tools using the output as one tool and the input as another tool. We applied two primary spatial analysis geoprocessing tools which were Area Solar Radiation and Slope.

We derived suitability maps using the model builder tool. The model builder based the suitable locations for each site based on slope and area solar radiation. If the solar radiation was less than 800 kWh/m^2, then the area was classified as not a suitable location for PV or APV. We used slope analysis to categorize areas where the slopes were too steep for PV installation. Slope surfaces that were greater than 32° were considered too steep for our PV suitability analysis.

4. Data

4.1. Design Intent, Criteria, and Considerations

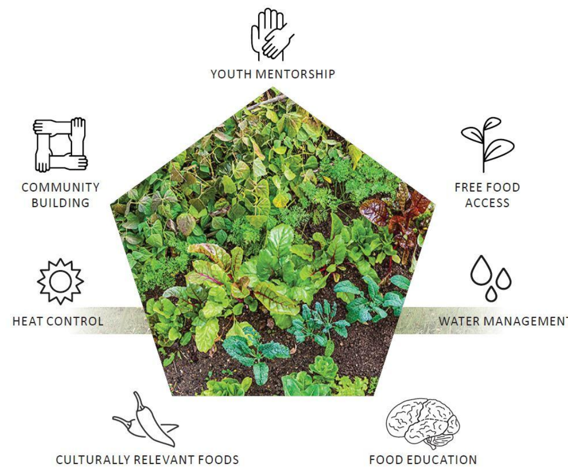
We established the design intent of each partner site to align with their organizational goals. The intent, criteria, and considerations used to perform the feasibility studies and produce informational design briefs are described here.

4.1.1 Cadillac Urban Gardens

Design Intent

Cadillac Urban Gardens (CUGM), in Mexicantown of Southwest Detroit, is a 1-acre raised bed community garden. Their production focus is to provide free, culturally-relevant food to the surrounding, predominantly Latinx community. CUGM's greater mission is to support food access and food education while also place-making for youth mentorship and community-building. This mission established the following design goals:

- Youth mentorship
- Community building
- Food access free of charge
- Food education
- Growing culturally relevant foods



Design Criteria

CUGM is not connected to the power grid, so all designs must be stand-alone systems. In Detroit, solar systems are regulated according to the district in which they reside. CUGM is located in a B4 General Business District, in which a "power or heating plant with fuel storage on site" is regulated as a conditional use, meaning city review is required (City of Detroit, 2022). The code does not list requirements for accessory structures within this business district, but does specify that "all other uses" on such parcels of land can be at most 35 feet in height.

Design Considerations

The garden currently lacks power to meet electricity needs because they do not have a grid connection on-site. If electricity is required, they consensually obtain it from the building across the street through the use of an extension cord, which experiences damage from vehicles. Any on-site energy production would increase electricity access and convenience.

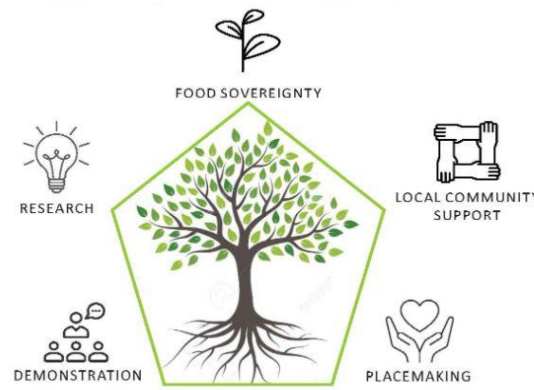
Due to their location on a paved asphalt lot, the site also experiences heat stress. This creates issues for food storage and makes harvested food vulnerable to accelerated spoilage. They currently have a water catchment system installed across the lot, but the garden representative reports this system as being ineffective or difficult to use. Proposed designs should therefore provide solutions for reducing heat stress and enhancing water management, such as shading or electric water pumps.

4.1.2. MSU-Detroit Partnership for Food, Learning and Innovation

Design Intent

DPFLI's stated mission is to improve the quality of life for the people they serve. They do this by acting as a model for farm sites and communities, demonstrating how they can be designed for sustainability and food sovereignty. The site's farm goals are as follows:

- Placemaking
- Demonstration
- Food Sovereignty
- Research
- Local Community Support



Design Criteria

DPFLI is currently connected to the power grid and already receives electricity for a building on-site. The farm is located in an R1 Single-Family Residential District, in which accessory structures are allowed up to a height of 15 feet. In addition, they cannot be closer than 10 feet to buildings (City of Detroit, 2022).

Design Considerations

The site aims to support a diverse array of technology and skills to help people become more environmentally aware and demonstrate the possibilities of energy sovereignty in urban areas. To serve these goals of demonstration, education, and community support, APV designs may be preferred over PV designs.

DPFLI could achieve carbon neutrality by sizing a PV system large enough to power the grid-tied building, and additional energy generation could support a cooler and water pump. Designs can be scaled as needed to accommodate desired or future energy demands.

4.1.3. D-Town Farm

Design Intent

As a member of the Detroit Black Community Food Security Network (DBCFSN), D-Town Farm aims to become a place where community members can gather, learn about, and celebrate locally grown food. D-Town is Detroit's

largest urban farm, practicing sustainable cultivation of 40 different crops in an effort to promote food sovereignty, particularly among Detroit's Black community. The list of goals is as follows:

- Food sovereignty via increased sustainable food production
- Energy sovereignty via on-site energy production versus traditional power grid energy dependence
- Community building via hosting more community events on the farm

Design Criteria

D-Town Farm is not connected to the grid, so all designs must be stand-alone systems. In Detroit, solar systems are regulated according to the district which they reside in. D-Town is located in a Parks and Recreation (PR) District, which means that "conditional use" of solar is allowed (City of Detroit, 2022). Under "conditional use" designation, the city must review the PV system before providing building permits.

Design Considerations

The site of D-Town Farm floods in various areas due to its positioning on a 100-year floodplain. This is an important consideration for all designs, as the flooding potential affects the bearing capacity of the soil and therefore mounting solutions. This would suggest that concrete poured footings might be preferable for non-mobile designs.

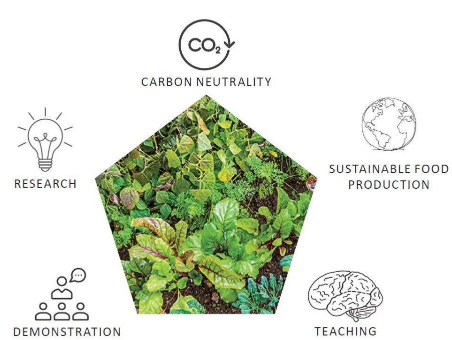
Since D-Town wants to host more community events, designs that can provide an adequate amount of power for essential functions such as sound systems, charging equipment, and cooking appliances were considered.

4.1.4. University of Michigan Campus Farm

Design Intent

Although carbon neutrality is the predominant reason for the university to consider APV, there are other goals the farm is working towards to which APV or PV could contribute. The complete list of farm goals used to establish intent were determined to be the following:

- Achieve carbon neutrality
- Produce food using sustainable methods
- Foster research within the university system
- Foster a teaching environment for students, staff, faculty, and visitors
- Provide demonstrations of agriculturally-related methods and technologies



Design Criteria

Ann Arbor Township has strict rules for PV systems, such as prohibiting concrete footings, requiring large setback distances, prioritizing aesthetic considerations, and prohibiting PV systems on prime farmland (Ann Arbor Township, 2020). These ordinances would have severely limited the type of PV system which the Campus Farm could install. However, according to the university's Facilities & Operations code, the University of Michigan is only subject to Michigan state laws and regulations and not local building and zoning ordinances (Facilities & Operations, University of Michigan, 2022). Any PV system which the Campus Farm decides to pursue will be subject to internal university review.

All designs must be sized at a minimum capacity to offset the farm's total carbon emissions. This includes all equivalent emissions associated with direct electricity usage, natural gas heating, and equipment fuel consumption. Our calculations indicate that a minimum 63 kW system will offset these emissions. According to engineering concepts and the National Electric Code (NFPA, 2020), electrical systems must be oversized to account for generation losses, inverter losses, efficiencies, derating factors, and more, and the system designs should be sized accordingly at the discretion of the engineer. After incorporating these estimated adjustments and adding capacity for additional electric tools, the final Direct Current (DC) system size should be approximately 97 kW.

Design Considerations

The following considerations were developed by the team through conversations with farm representatives:

- Viewshed of the farm landscape must be maintained in an aesthetically pleasing way
- All designs must be low maintenance and easily accessible

Additional design criteria determined by the team on site visits include:

- Strategic placement of all electrical systems or components to prevent excess energy or voltage loss

<u>4.1.5. We the People Opportunity Farm</u>

Design Intent

The farm supports and invests in their formerly incarcerated interns to break the cycle of incarceration within Washtenaw Country and works to create "a sustainable farming system that could support a workforce of formerly incarcerated men and women" (We the People Opportunity Farm, n.d.). Based on this mission, our team outlined the following goals and design intent of the farm:

- Maintenance of the internship program for returning citizens, including the provision of amenities for interns and alumni
- Continued support for program alumni
- Community building
- Increase representation within the food industry
- Expand operations and intern program capacity

WTPOF hopes to expand its operations as a mechanism to further support their mission. This vision of expansion could include employing eight to 10 interns at once, expanding growing area to 3/4 or one acre total, as well as becoming a vendor at the Ann Arbor Kerrytown Farmers Market. In addition to this, the farm also hopes to build a stronger relationship with the community, perhaps by hosting educational field trips for local school children. Lastly, continued support of interns and program alumni is a crucial focus of WTPOF.

Design Criteria

All designs must comply with local building codes and zoning regulations. PV systems in Ypsilanti Township are regulated as accessory buildings, which are regulated according to the district in which they reside (Ypsilanti Charter Township, 2021). WTPOF is located in an RM-2 Multiple-Family Residential district. In such districts, PV systems cannot exceed 14 feet in height and must be setback from the street by at least 10 feet. In addition, they cannot be closer than five feet to a rear or side yard line, nor closer than 10 feet to the main building. Finally, PV systems cannot take up more than 25% of a yard.

Design Considerations

Through conversations with farm representatives, our team outlined additional criteria to further develop these designs in the pursuit of the farm's mission: Mobility of structures is preferred over permanent structures; the property on which the farm is located is not owned by the organization itself, which introduces a level of uncertainty regarding flexibility. Mobile solutions would ensure flexibility of system location and function. Minimizing food waste and the ability to transport food are goals desired by the farm. Both of these considerations suggest the need for food-cooling solutions.

Designs should lend themselves to community connection and place-making to support the social environment at the farm, and to promote relationship-building among farmers, visitors, and volunteers. Additionally, designs should support farmers and their work, and enhance the overall function of the organization.

4.2. Sizing Systems

APV and PV technology is constantly evolving and improving, therefore any specific system recommendations made in the design briefs might not be applicable at a future time of installation. To minimize the disconnect between current and future technology, policies, and cost, the system sizes in the briefs are intended to serve as general guidelines for estimating system demand. Final capacities of all designs will ultimately be determined by an engineer, contractor, or other subject matter expert at the time of system design and installation.

After determining the energy needs of each site, we were able to approximately size each system design to meet a selection of those demands. System sizes were estimated for two or three energy demand scenarios for each site. An upper range of potential capacity supports all electric loads the organization expressed interest for and more. A lower range capacity supports a minimal amount of electric loads that still enhance organizational goals, but at a fraction of the cost of the upper range. For some sites that had significant differences in upper and lower range estimates, a middle range was also calculated. All electric loads used to calculate capacity requirements were taken from various online resources and product specification sheets.[1]

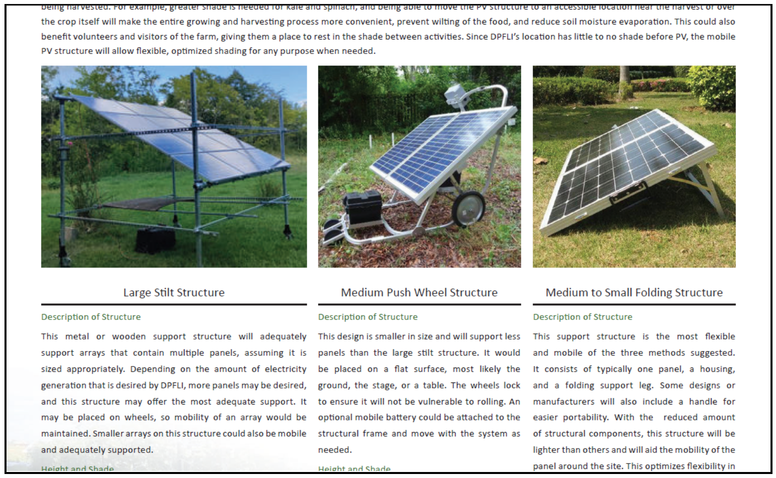
The designed capacities account for total electricity demand determined by the design; available sun hours in Southeast Michigan; potential losses from weather variations, dust and snow buildup, and other typical system losses; efficiency values of typical inverters; standard derating factors according to the National Renewable Energy Laboratory; and general guidelines per the National Electric Code (NFPA, 2020; National Renewable Energy Laboratory - Solar Resource Maps and Data, 2018). The equation used for system capacity estimation is

$$DC\ System\ Size\ (kW) = \frac{\Sigma(Demand\ kWh)}{0.7 \times 0.96 \times 0.84 \times (4\ h)}$$

where *0.7* accounts for system losses, *0.96* accounts for inverter efficiency, *0.84* incorporates standard NREL derating factors, and *4 h* indicates how many full-sun hours Southeast Michigan experiences in an average day. Battery storage sizing was briefly addressed for sites that either expressed interest or had goals that would uniquely benefit from energy storage. For complete sizing data and assumptions, see Appendix 4.

The recommended scale of each system capacity varies depending on the goal of the energy production and the mounting methods. For example, one of D-Town Farm's designs is a PV-shaded stage installation, which contributes to their goals of energy sovereignty and community-building by allowing them to host more community festivals that require electricity for musical performances. This design would require a large wooden mounting structure and poured concrete footings. Since the scale of the design is permanent and large, it can support a substantial array of panels and therefore substantial energy production. The recommended system size for this design is equally large in scale to accommodate the electrical demand from audio and visual equipment. Conversely, the small, portable panel with a collapsible frame is more suited for charging electronic devices or power tools only, and the system size is equally small to accommodate this.

[1] Electrical loads were determined from the following sources: Unbound Solar, Rain Harvest, EEFOW, LG, Koldfront, CoolBot, Rain Harvest Systems, The Home Depot, My Natural Pond, InnoGear, Aracky, Black+Decker, Rayolon, Shure, Rockville.


being harvested. For example, greater shade is needed for kale and spinach, and being able to move the PV structure to an accessible location near the harvest or over the crop itself will make the entire growing and harvesting process more convenient, prevent wilting of the food, and reduce soil moisture evaporation. This could also benefit volunteers and visitors of the farm, giving them a place to rest in the shade between activities. Since DPFLI's location has little to no shade before PV, the mobile PV structure will allow flexible, optimized shading for any purpose when needed.

Large Stilt Structure

Description of Structure

This metal or wooden support structure will adequately support arrays that contain multiple panels, assuming it is sized appropriately. Depending on the amount of electricity generation that is desired by DPFLI, more panels may be desired, and this structure may offer the most adequate support. It may be placed on wheels, so mobility of an array would be maintained. Smaller arrays on this structure could also be mobile and adequately supported.

Height and Shade

Medium Push Wheel Structure

Description of Structure

This design is smaller in size and will support less panels than the large stilt structure. It would be placed on a flat surface, most likely the ground, the stage, or a table. The wheels lock to ensure it will not be vulnerable to rolling. An optional mobile battery could be attached to the structural frame and move with the system as needed.

Height and Shade

Medium to Small Folding Structure

Description of Structure

This support structure is the most flexible and mobile of the three methods suggested. It consists of typically one panel, a housing, and a folding support leg. Some designs or manufacturers will also include a handle for easier portability. With the reduced amount of structural components, this structure will be lighter than others and will aid the mobility of the panel around the site. This optimizes flexibility in

Figure 1. Example of Relative Scales of APV and PV Designs Within the Briefs. The recommended size of the PV system for each design was proportional to the relative scale of the supporting structure, as demonstrated by the various mobile PV options.

4.3. Carbon Accounting and Payback Periods

Although we calculated PV system sizes that could power a range of tools for each site, a few of our partner sites also expressed the desire for APV or PV systems that would be large enough to meet specific goals, such as offsetting their carbon emissions. For example, both the Campus Farm and DPFLI were interested in carbon offsets, and WTPOF specifically asked for a cost comparison between a PV system with a battery and a new grid connection. The following subsections detail the calculations we made for each of these three partner sites, which include carbon accounting, system sizing, and payback periods.

4.3.1. University of Michigan Campus Farm

To calculate the Campus Farm's total carbon emissions, we assumed that the Campus Farm accounted for 4.5% of both the electricity and natural gas consumption from the Matthaei Botanical Gardens and Nichols Arboretum. This percentage was provided to us by a representative of Campus Farm. We used University of Michigan Office of Campus Sustainability data to calculate this number; data from 2019 was used to avoid differences due to the COVID-19 pandemic (Office of Campus Sustainability, 2022).

The Campus Farm consumes energy from electricity, natural gas, diesel, and gasoline. These sources of energy provide lighting, heating, and the ability to use vehicles on the farm. We calculated the carbon emissions from the farm's consumption of each thermal fuel source (natural gas, diesel, and gasoline) and converted this number into the equivalent annual electricity generation in kilowatt-hours given DTE's fuel mix carbon intensity as of 2021 (DTE Energy, n.d.). To estimate the system size which would offset all of the farm's energy consumption, we divided the total equivalent annual electricity generation in kilowatt-hours by 365 days, divided that number by Michigan's sun hours—which we assumed to be four—and multiplied the result by an efficiency factor of 1.15. This calculation takes into account the average daily amount of sunlight in the region as well as standard efficiency losses.

Assuming a PV system cost of $2.50 per watt, we calculated the upfront cost of the system. Next, we calculated how long it would take for the Campus Farm to make back the upfront cost, given annual electricity bill savings and net metering revenues. First, we estimated the Campus Farm's average monthly electricity bill, using all of the charges included on standard commercial DTE electricity bills, including the capacity, service, and distribution charges, along with other charges. To calculate annual savings, we assumed that on-site electricity consumption would be completely offset by the APV system, and monthly electricity bills would be zero. We also assumed that the remainder of the solar energy produced by the system would go back onto the grid, resulting in net metering revenues. Considering the upfront cost for the project in year one, we calculated how many years it would take for electricity bill savings plus net metering revenues to exceed this cost. Finally, we calculated the carbon emissions reductions associated with installing the APV system by multiplying DTE's carbon intensity by the Campus Farm's total energy consumption and adding this amount to the cumulative total each year until the project was paid off.

4.3.2. MSU-Detroit Partnership for Food, Learning and Innovation

We followed a similar process for DPFLI to size a PV system to offset their carbon emission from a building on-site. For these calculations, we used the partner's actual electricity bills from 2021. We used the average consumption over 12 months to estimate the system size which would offset emissions. We did not take into account other fuel sources which may be used on the farm. Assuming a PV system cost of $2.50 per watt, we calculated the upfront cost of the system. We assumed all electricity would be used on-site, and that the partner would not receive any net metering revenue. We then calculated how long it would take the partner to make back the upfront cost, assuming that monthly energy bills were zero. Finally, we followed the same method as with the Campus Farm to calculate the cumulative carbon emissions reductions associated with installing the PV system.

4.3.3. We the People Opportunity Farm

WTPOF specifically requested calculations for the upfront cost of a PV system large enough to power a CoolBot walk-in cooler, along with a cost comparison for a PV system with a battery versus getting a grid connection for conventional energy. First, we estimated how large of a PV system the farm would need to power a CoolBot cooler. We assumed the farm would cool a shed sized at four feet long, five feet wide, and six feet tall and kept at 38 degrees Fahrenheit (CoolBot, 2022). We used the CoolBot website calculator to estimate how large of a system the farm would need for this size shed. Assuming a solar PV system cost of $2.50 per watt, we calculated the upfront cost of the system.

Because WTPOF is not currently connected to the grid, the farm could install a solar PV system with battery storage, apply for a grid connection and hook a solar PV system up to the grid, or apply for a grid connection and purchase energy through DTE. To estimate the costs of each option, we calculated hypothetical annual energy bill costs if the farm bought energy from DTE to power a CoolBot system. We compared these costs to that of a PV system with battery storage and to that of a PV system with a grid connection. Next, we calculated how long it would take WTPOF to make back these upfront costs assuming that monthly energy bills were zero. Finally, we followed the same method as in the previous two cases to calculate the cumulative carbon emissions reductions associated with installing the PV system.

4.4. GIS Maps

For our GIS site deliverables, we created suitability maps of each APV and PV design included in each partner's brief. They were developed using ArcGIS software and are color coded for clarity and enhanced visualization of PV design locations (see Appendix 2).

The purpose of the suitability map is to visually represent areas where PV is possible. We used Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey (USGS) to create a digital surface model (DSM). The DSM for this site was used to identify the surface features such as canopy coverage, building features, and steep hill faces. The ArcGIS ModelBuilder tool was used to conduct this APV and PV feasibility analysis. See Figure 2 below of the ModelBuilder analysis used to derive APV and PV feasibility of each site.

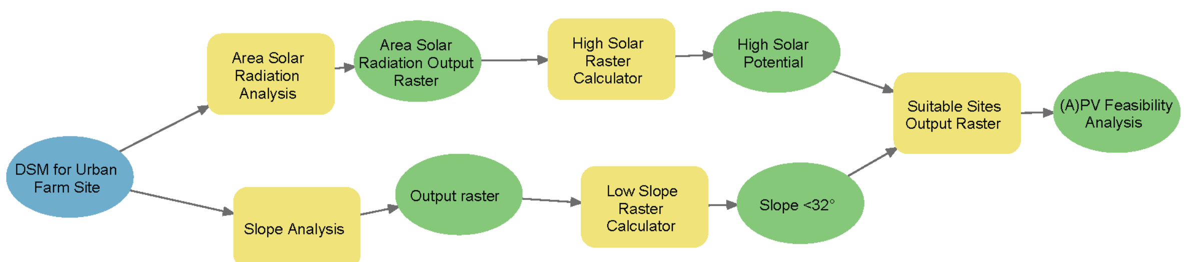


Figure 2. Model Builder Diagram Built for Each APV and PV Feasibility Analysis. For each site, Lidar data was converted to a DSM raster dataset. The geoprocessing tools were used to create an Area Solar Radiation Analysis and Slope Analysis raster output.

These suitability maps use area solar radiation and slope analysis to determine the potentially ideal spaces for PV installation. The suitable APV and PV areas are represented using yellow shading, and the light green areas are not recommended due to high tree canopy coverage (See Appendix 2).

The Area Solar Radiation analysis calculates radiation based on a sophisticated model that takes into account the position of the sun throughout the year and at different times of day, obstacles that may block sunlight such as nearby trees or buildings, and the slope and orientation of the surface. The output raster is reported in WH/m^2 which was then converted to kWH/m^2 A slope layer was also derived from the DSM to find areas where the slope was less than 32 degrees.

Areas shaded in yellow were determined to be suitable to install PV primarily based on two geospatial analyses: solar radiation and slope. For land to be considered suitable for PV installation, or ‘PV possible,’ the slope surface raster was required to be less than 32° and the area solar radiation was required to be greater than 800 kWh/m^2. We used these values consistently throughout each site; this decision was based on the ArcGIS official guide on Solar Potential (Khanna, 2021). The areas shaded in light green were identified as areas where PV is not recommended, generally because they lie underneath tree coverage.

In Table 1 below, we provide a breakdown of the total areas where PV is possible based on the suitability analysis conducted for each site. The total area for each site is reported in square meters because the raster analysis was reported in the same units.

Farm Site Name	**Total area where PV is possible (%)**	**Total area where PV is not recommended (%)**	**Total Area** (m^2)
Cadillac Urban Gardens	98.3	1.7	4046.9
D-Town	65.3	35.7	28328.0
DPFLI	91.0	9.0	13354.6
U-M Campus Farm	96.1	3.9	14164.0
We the People Opportunity Farm	89.1	10.9	2023.4

Table 1. Breakdown of the GIS (A)PV suitability analysis based on the total area for each site.

5. Results

5.1. Technical Feasibility

<u>5.1.1. Design Brief Content</u>

The data of the feasibility studies were compiled to create individualized documents, referred to as design briefs. The goal of each brief is to provide a navigable starting point for partners if they ever consider implementing APV or PV on their site in the future. While the briefs are not official or technical plans for specific systems, they are schematic and informational documents that highlight and visualize the possibilities of certain designs and solutions, and can be used as reference material when consulting a PV contractor or engineer.

Each design brief contains the same general page progression: an overview page, including a description of the partner's organization; a summary of their goals; the establishment of design intent and considerations and a high level overview of electrical generation potential and cost; a suitability map, which layers a map of the partner's site with a color-coded, high level, GIS map detailing ideal locations for various design solutions; a series of design pages dedicated to descriptions, benefits, and images about specific design solutions; and a PV resource page that includes funding resources, cost estimations, and operations and maintenance information. The design briefs are provided in Appendix 1 and a short summary of the content of each brief's designs are detailed below.

<u>5.1.2. Cadillac Urban Garden</u>

System Size Calculations

Three approximate system sizes were calculated for Cadillac Urban Garden (CUGM) to accommodate a selection of electrical needs. We estimate the largest PV system size to be 12 kW, which can power multiple lamps, several tools, several electronic devices, WiFi, one water harvesting pump, and one efficient air conditioning unit for food cooling in a shed per day. A middle range system with the same loads per day minus the air conditioning unit would be about 1.5 kW. The smallest system is 1.1 kW, which can power one tool, a few lamps, several phones, WiFi, and one water harvesting pump per day. See Appendix 4 for sizing details.

Resulting Designs

Design Name	Requirements	Benefits & Design Intent Alignment	Benefits	Constraints
Shed-mounted PV	Shed structure of adequate support	Youth mentorship, free food access, water management, heat control	Non-accessible to public, potential for power generation	Funding for shed-top installation
Bed-mounted APV	Wooden support structures attached to beds	Youth mentorship, free food access, heat control, culturally relevant foods, food education	Water retention and shading of crops, affordable structure	Might interrupt access to bed from various angles
Wash/Pack PV	Supportive pergola structure	Free food access, heat control, water management	Flexible space programming, accessible tool charging, wash area	Funding for larger structure
Shaded Seating (A)PV	Supportive pergola structure	Youth mentorship, community building, free food access, heat control, water management	Flexible space programming, accessible tool and device charging, shaded seating	Funding for larger structure
Mobile Solutions	Mobile support system	Youth education, heat control, free food access, food education	Mobility and flexibility of location	Storage of some portable systems for safety and theft prevention

Table 2. APV and PV Design Solutions for Cadillac Urban Garden.

Table 2 provides a high-level overview of the designs compiled for CUGM. The most common constraint across all designs is the price of associated costs, particularly involving structural support systems. Many of the designs assist CUGM with heat control and water management, particularly if the system size accommodates a water pump.

Cost of System Sizes

Since CUGM did not express interest in a particular system size, we calculated a basic estimation of PV system costs for each DC system size we suggested. For the 12 kW, 1.5 kW, and 1.1 kW systems, we estimate PV system costs of $30,000, $3,750, and $2,750, respectively, which is priced at $2.50 per watt. Capacities less than those suggested will cost less.

Costs of Electrical Loads

The cost of the equipment used to calculate approximate system size is not included in the cost of the PV system itself. Electric equipment that requires purchase will be an indirect cost of an APV or PV installation if the organization decides to transition away from gas equipment. For the 12 kW, 1.5 kW, and 1.1 kW systems, we estimate additional electrical load costs of $1,542, $1,033, and $613, respectively. These cost estimates assume the organization does not own electric equipment currently. However, if the organization does own electric equipment, this cost will either be reduced or negligible. See Appendix 4 for electrical load estimation details.

5.1.3 MSU-Detroit Partnership for Food, Learning and Innovation

System Size Calculations

Two approximate system sizes were calculated for DPLFI. We estimated the largest PV system size to be 2.73 kW, which can support powering a corded push mower, multiple lamps, several tools, WiFi, and several electronic devices per day, as well as offset the building's carbon emissions. The smaller system is 1.66 kW, and can power the same loads per day minus a corded push mower.

Resulting Designs

Design Name	Requirements	Benefits & Design Intent Alignment	Benefits	Constraints
Rooftop PV	Building	Demonstration, community support	Carbon neutrality, easily added to existing structure	Non-APV design
Gazebo PV	Gazebo structure	Placemaking, demonstration, community support	Carbon neutrality, easily added to existing structure	Minimal PV panel capacity
Parking Lot (A)PV	Parking lot support structure	Demonstration, community support	Carbon neutrality, easily added to existing parking lot	Non-APV centric design unless intentionally added
Classic APV	Large, in-ground, stilt support structure	Demonstration, research	Carbon neutrality, water retention, customizable research opportunities	Permanent structures cannot move with crop rotations
Small Bed APV	Small support structure	Demonstration, research	Carbon neutrality, water retention, customizable research opportunities	Permanent structures cannot move with crop rotations, creating excess shading
Bramble APV	Large, in-ground structure	Demonstration, research	Carbon neutrality, increasing bramble yield	Permanent structures cannot move with crop rotations
Solar & Hydroponic Combination	Electric water pump and hydroponic system or combined kit	Demonstration, research, food sovereignty	Carbon neutrality, demonstration of innovative farming techniques	Panel might not be attached to hydroponic component meaning less demonstration potential
Mobile Solutions	Mobile support system	Demonstration, research	Mobility and flexibility of location	Cannot support large PV capacities

Table 3. APV and PV Design Solutions for DPFLI.

As seen in Table 3, many designs accommodated demonstration and research goals. DPFLI was interested in a variety of PV applications, which allowed us to consider traditional PV designs, typical APV designs, and more innovative designs such as bramble and hydroponic applications. The most common constraint was related to the limitation of permanent structures, which cannot be moved with crop rotations every year.

Costs of Electrical Loads

If the organization does not own electric equipment but wants to use PV electricity for power, electric equipment must be purchased, making it an indirect cost of an APV or PV installation. For the 2.73 kW and 1.66 kW systems, we estimate additional electrical load costs of $1,227 and $927, respectively. These cost estimates assume the organization does not own electric equipment currently. However, if the organization does own electric equipment, this cost will either be reduced or negligible.

5.1.4. D-Town Farm

System Size Calculations

Two approximate system sizes were calculated for D-Town Farm to accommodate a selection of electrical needs. We estimated the larger PV system size to be 16.3 kW, and can support powering a few lamps; several tools including three weed whackers, a power drill, a chainsaw, and a corded electric push mower; several electronic devices; an electric cooktop; two microphones; one speaker; one sound mixer; and an electric pond pump. The smaller system was estimated to be 7.7 kW, and can power the same loads minus the electric pond pump, the corded push mower, and some capacity for electronic devices.

Resulting Designs

Design Name	Requirements	Benefits & Design Intent Alignment	Benefits	Constraints
Community Station PV	Pergola or shaded bench structure	Community building, energy sovereignty	Space to gather and connect, space for charging devices or for a portable cooktop	PV on a bench might not be conducive to tool charging or all PV applications
Stage PV	Permanent stage structure	Community building, energy sovereignty	Space for A/V equipment and festival activities	Funding for a larger PV array
Shipping Container PV	Replacement or updates of current system	Energy sovereignty, food sovereignty	Existing infrastructure ensures streamlined installation, space for charging equipment, securable space for safety and theft prevention	Does not contribute to community building
Small Bed APV	Small, on-ground infrastructure	Energy sovereignty, food sovereignty	Innovative solution for increasing crop yield for certain plants	Permanent structures cannot move with crop rotations, too much shade
Classic APV	In-ground, pole type, permanent mounting structure	Energy sovereignty, food sovereignty	Innovative solution for increasing crop yield for certain plants	Permanent structures cannot move with crop rotations, too much shade
Fence (A)PV	Existing or new fence	Energy sovereignty, food sovereignty	Makes use of space aside from crops to produce energy	Might not support large PV capacities
Mobile Solutions	Mobile support system	Community building, energy sovereignty, food sovereignty	Mobility and flexibility of location	Storage of some portable systems for safety and theft prevention

Table 4. APV and PV Design Solutions for D-Town Farm.

D-Town expressed greater interest in designs that contribute to community-building and support audio and visual equipment for festivals. All designs contribute to goals of energy sovereignty. The traditional APV solutions might provide too much shade to crops since D-Town's location already receives a fair amount of shading from trees. These structures might also limit D-Town in where they can plant certain crops due to the permanence of the mounting methods.

Cost of System Sizes

Considering D-Town did not express interest in a particular system size, we calculated a basic estimation of PV system costs for each DC system size we suggested. For the 16.3 kW and 10.1 kW systems, we estimate PV system costs of $40,750 and $25,250, respectively, priced at $2.50 per watt. Capacities less than the ones suggested will cost less.

Costs of Electrical Loads

The estimated additional costs of the 16.3 kW and 10.1 kW systems are $2,648 and $1,761, respectively. This assumes the farm currently does not own electric equipment that can be charged with the PV systems. If the farm does own electric equipment, these costs will be reduced.

5.1.5. University of Michigan Campus Farm

System Size Calculations

Campus Farm aspires to offset their carbon emissions through APV and PV systems, therefore both DC system sizes include the demand for their carbon offset. The larger size of 97.3 kW includes some additional capacity to charge multiple tools, a water harvesting pump, and a couple lamps for a seating area. The smaller size of 96.2 kW supports only one of these additional tools. Since the difference in system sizes is less than 1 kW, we recommend that the university invest in the larger system size for the most effective use.

Resulting Designs

Design Name	Requirements	Benefits & Design Intent Alignment	Benefits	Constraints
Baseline APV	Permanent, in-ground, polt or stilt support structure	Sustainable food production, carbon neutrality, research, demonstration, teaching	Innovative, dual-land use solution for educational purposes, tall enough for people to pass under	Not suitable for crops that need constant or full sun, requires poured foundations in crop field
Tractor Friendly APV	Permanent, in-ground, polt or stilt support structure	Sustainable food production, carbon neutrality, research, demonstration, teaching	Innovative, dual-land use solution for educational purposes, tall enough for tractors to pass under	Not suitable for crops that need constant or full sun, requires poured foundations in crop field
Combine Harvester APV	Permanent, in-ground, polt or stilt support structure	Sustainable food production, carbon neutrality, research, demonstration, teaching	Innovative, dual-land use solution for educational purposes, tall enough for combine harvester to pass under	Not suitable for crops that need constant or full sun, requires poured foundations in crop field
Fence (A)PV	Existing or new rigid fence	Sustainable food production, carbon neutrality, research, demonstration, teaching	Makes area near fence an energy productive area	Might not support large PV capacities
Greenhouse APV	Existing or new greenhouse	Sustainable food production, carbon neutrality, research, demonstration, teaching	Can support large PV capacities for maximum energy production depending on greenhouse size	Not contributing to educational goals, not as innovative in design
Ground APV	Ground-level mounting infrastructure	Sustainable food production, carbon neutrality, research, demonstration, teaching	Contributes towards all farm goals without large or expensive infrastructure	Might provide too much shade for most crops, no room for people or equipment to pass under
Parking (A)PV	Parking lot canopy for PV support	Sustainable food production, carbon neutrality, demonstration	Makes the parking lot an energy productive area	Does not contribute to research goals

Table 5. APV and PV Design Solutions for UM Campus Farm.

All designs support the farm's educational and research goals and can be tailored to any capacity size. The Campus Farm did not express concern for funding, so funding of systems is not considered a constraint. Fence PV in particular might not benefit the Campus Farm's goals as effectively, particularly since they might not have a suitable fence for PV installation.

Costs of Electrical Loads

The 97 kW system will not have many additional load costs. Since the system serves the purpose of carbon neutrality and accounts for the use of fuel-powered equipment, electrical equipment is not necessarily required. However, if the farm chooses to purchase additional electric equipment that can be supported by this capacity, the estimated cost would be approximately $700.

5.1.6. We the People Opportunity Farm

System Size Calculations

We estimated a total of three system sizes for WTPOF. The largest size of 12 kW supports the powering of multiple electronic devices, power tools, and lamps per day, and WiFi, as well as a CoolBot-operated, efficient air conditioning unit for food storage. This capacity assumes maximum use of the air conditioning unit in a larger cooler space with no insulation, and is also a majority of the demand for this capacity. The middle range of 1.6 kW supports these same loads per day minus the air conditioning unit. This estimation was included to show how much the system size and cost could be reduced either without the CoolBot-operated unit, with R-25 insulation throughout the cooled space, or the unit running very minimally in only the summer. Realistically, inclusion of the air conditioning unit could cause the system capacity to vary significantly, and require anywhere from a 1.6 kW to 12 kW system size. The smallest system size of 0.4 kW could support two power tools, a few lamps, and several electronic devices per day plus WiFi. A 0.4 kW system could require one 400 watt panel.

Resulting Designs

Design Name	Requirements	Benefits & Design Intent Alignment	Benefits	Constraints
Small Bed APV	On-ground mounting infrastructure	Expansion of operations	Energy production paired with food production	Not suitable for crops that need constant or full sun, permanent structures cannot move with crop rotations, funding for infrastructure
Large Bed APV	Permanent, in-ground mounting infrastructure	Expansion of operations	Energy production paired with food production, raised off ground for people to work under	Not suitable for crops that need constant or full sun, requires poured foundations in crop field, permanent structures cannot move with crop rotations, funding for infrastructure
Shed PV	Shed with adequate support for PV system	Expansion of operations, increased food industry representation	Energy production available on unused shed roof, secured area for safety and theft prevention, can pair with food cooling	Funding for suitable shed structure
Shaded Seating (A)PV	Pergola or bench structure	Expansion of operations, internship program support, continued support for program alumni	Provides space for farmers and volunteers to relax, can be paired with WiFi and device charging	Funding for pergola or bench structure and PV installation
Fence (A)PV	New or existing rigid fence	Expansion of operations, internship program support, continued support for program alumni	Can power food storage or tool and device charging	Might not be suitable for existing fences, funding for new fence
Mobile Solutions	Mobile mounting structure	Expansion of operations, internship program support, continued support for program alumni	Flexibility of location and use of power	Cannot support large PV capacities

Table 6. APV and PV Design Solutions for WTPOF.

WTPOF prefers mobile solutions, thus in-ground designs are less desired and produce constraints that might not be worth the benefits. However, WTPOF also expressed interest in cold-storage solutions, which might make larger system capacities more desirable, requiring more funding and larger support structures. Since the DC system size can vary significantly with a cooling unit, a more accurate system size would need to be determined by a contractor or engineer.

Costs of Electrical Loads

It should be noted that a CoolBot sensor, attached to a separate air conditioning unit, has multiple requirements for the system to work effectively and with the most efficient energy use. It requires a compatible air conditioning unit as well as R25 insulation installed in the walls and roof of the cooled space. The larger the cooled volume, the more energy the system will expend to cool the space, particularly in the summer. Installing R25 insulation will reduce the energy use, but will also require additional installation and costs.

The DC system capacities of 12 kW, 1.6 kW, and 0.4 kW will be $2,040, $1,156, and $986, respectively. This assumes WTPOF currently does not own electrical equipment. This equipment will require purchase. The systems that include a CoolBot will require purchase of R25 insulation and the CoolBot sensor as well.

5.2. System Sizing and Cost

For the Campus Farm, DPFLI, and WTPOF, we calculated the cost of PV systems to offset carbon emissions and provide energy for specific needs. These three farms had specific energy requirements, which allowed for precise system sizing and cost estimates.

We calculated that the Campus Farm would require 62.35 kW minimum generation from a PV system to offset their carbon emissions from electricity and other fuel sources. We estimated that the cost of this system would be approximately $155,875 and that it would take at least 21 years to make back the costs through energy savings and net metering revenues. While this payback period is somewhat long, this is because the APV system was sized to offset the emissions of *both* the electricity and natural gas consumption of the farm, which most solar projects do not aim to do. Still, the Campus Farm would receive about $275 in net metering revenue each month for excess power generated. The cumulative carbon emissions reductions associated with installing this PV system would be about 2,398,718 pounds of carbon dioxide over 21 years.

Second, we calculated that DPFLI would require 1.6 kW minimum generation from a PV system to offset their electricity consumption from the single building on-site. We estimated that the upfront cost of a PV system of this size would be approximately $4,013 and that it would take eight years to make back the costs through energy savings. The cumulative carbon emissions reductions associated with installing this PV system would be about 34,889 pounds of carbon dioxide over eight years.

Finally, we calculated that WTPOF would require approximately 2 to 12 kW minimum generation from a PV system to provide energy for a CoolBot food storage cooler, depending on the volume of the cooler, the rate of heat gain, and the wattage of the digital air conditioning unit. Since WTPOF is not grid-connected at this time, the farm would either need to invest in battery storage or grid interconnection to keep the cooler chilled at all times. Our estimates suggest that the cost of a PV system with battery storage would be between $4,795 and $6,395, depending on the cost of a battery. We estimated that the cost of a PV system with a grid connection would be between $5,195 and $6,295, depending on the cost of interconnection. The payback period for either installing a PV system with a battery or a power grid connection would be between eight and nine years. The cumulative carbon emissions reductions associated with installing this PV system would be about 50,382 pounds of carbon dioxide over nine years.

It should be noted that these estimated system sizes are not the final sizes, but rather the minimum generation required to offset each farm's carbon emissions footprint. Since the systems at these sites are grid-connected, they must be designed according to the NEC and other applicable codes, which typically require upsizing electrical systems for safety reasons and overcurrent damage prevention. Since Campus Farm is only offsetting emissions and not sizing for direct electricity use, these codes may or may not apply. The engineer will ultimately determine what system sizes are appropriate for each farm's intent and electricity use based on these regulations and standards.

5.3. Results Conclusion

After months-long interactions with five partner sites, farm sites' interest in APV follows a distinct trend: the two partner sites associated with universities (The Campus Farm and DPFLI) are much more interested in implementing the APV strategy on their sites in the near future than are the three partner sites not associated with universities (D-Town Farm, Cadillac Urban Garden, and WTPOF). Some of the many possible factors to explain this trend include: differing missions and goals, funding, size and stability, shading, and overall quality of the five sites. Of the five partner sites, the two university-associated sites tend to include education and demonstration in their goals, have great funding, have larger and more secure access to land, have less shading, and have a higher overall land quality than the three sites not associated with universities. In particular, greater access to funding and an interest in research contributed to these farms' willingness to explore APV, despite the costs. However, all five partner sites have shown significant interest in generating more electricity on-site; the three farms not associated with universities are likely to pursue the addition of traditional PV systems before they pursue APV.

Focusing on PV rather than APV at this time is a sensible choice for many of the farms we worked with for this project, as they are limited in space, do not need more shade, or both. Because there is typically an associated agricultural yield loss with the implementation of APV over crops which do not need more shade, installing APV would create more tradeoffs than rewards for many of these farms. The one exception to this trend may be Cadillac Urban

Gardens: there are locations on that farm site which receive an abundance of sun and often become overly dry. One possibility is to strategically place APV within the site to provide some favorable shade and increase soil moisture.

Our partner sites have named a variety of goals that electricity production could help them achieve. These range from quickly and highly attainable goals like the introduction of PV charging stations that, with proper funding, could be achieved almost immediately, to broad ambitious goals involving significant and deep direct benefits to the local community like microgridding or on-site amenities that would require long-term planning and, in some cases, changes to local policies. None of these outcomes are unrealistic or out-of-reach. The attainment of any of these myriad organizational goals would further our partners' value-driven aspirations.

6. Discussion and Impact

6.1. Introduction

Although three of the five urban farms we partnered with were not as interested in APV as traditional PV energy systems, this application of solar panels can offer synergies for other types of sites. In many cases, a relatively small amount of power produced on-site could positively impact the ability of urban farms to serve their communities, whether via the ability for workers and visitors to charge their devices, an increased ease for the organizations to run their operations or keep produce fresh, or a variety of other goals. This is especially true in cases where there is currently no electricity on-site. In general, PV is often a more intuitive solution than APV when sites do not include overly sunny agricultural spots, or when they feature plenty of non-agricultural land which can be devoted to energy production. The roadmap in the next subsection can help urban farm managers, directors, or workers decide whether APV is a sensible choice for their farms.

Considering that successful APV implementation on urban farms is highly dependent on local circumstances and organizational goals, we also consider other potential opportunities for APV development. In the following subsections, we consider the interplay between APV and local governments, companies, and universities, including how the goals of some Southeast Michigan municipalities might interact with APV on small or urban farms. Finally, this section also provides background on state-level energy policies in Michigan which affect APV development.

6.2. Roadmap on the Decision to Implement APV

The following roadmap is intended for urban farm managers, directors, or workers considering whether to implement APV on their site. For instance, urban farms which are legally and financially able to install APV, and which would like to dedicate space to shade-tolerant crops will be led to the conclusion in the lower right of the roadmap, indicating that APV is a good choice for their farm. One factor that was not included in the roadmap is land tenure. Urban farms that do not have a long-term guarantee to stay on the land should consider avoiding installing permanent structures, and may consider mobile APV options instead.

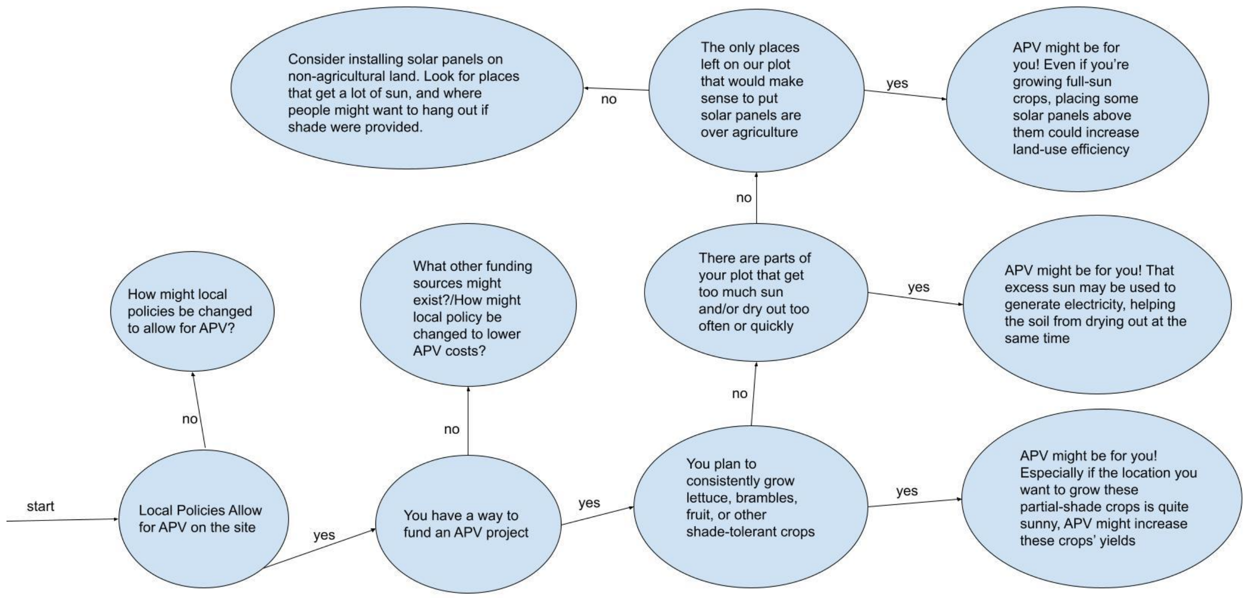


Figure 3. Decision-Making Roadmap for Urban Farmers Considering APV.

6.3. Synthesis: Who Should Initiate Urban APV Projects?

Our work with our partners suggests that the uptake of APV in urban settings may be better pursued by municipal governments, companies, or universities that have a direct interest in bringing more clean energy onto the grid. The primary goals of the independent urban farms which we worked with for this project were centered around producing local food and building community. While these partners were generally interested in lowering their carbon footprint, producing solar energy for the sake of decarbonization and exploring ways of doing so tended not to be a main priority. In fact, the energy consumption of all of the urban farms we worked with, excluding the Campus Farm, was relatively low to begin with.

While APV in urban settings can have many benefits—such as providing a form of clean, distributed energy to the grid while also making efficient use of space—governments, companies, and universities may be better equipped to take on or fund APV projects in urban spaces than pre-existing urban farms. For example, a municipal government working to lower carbon emissions, expand green spaces, and promote local food may have a greater incentive to explore APV. Companies may want to offset their carbon emissions or improve the working environment for their employees by taking on APV projects. Solar panels could be co-located with a rooftop garden on a corporate building rooftop or elsewhere on-site. Universities may have an interest in researching the benefits of APV and may be more willing to initiate costly projects. In addition, municipal governments, companies, and universities are often more likely to have the funding to pursue small-scale APV projects than existing urban farms, many of which are non-profits and don't have as much access to private capital and donations.

Another option would be for governments or other organizations to fund APV on urban farms. This could be accomplished through incentives, bulk purchasing programs, or power purchase agreements. Such programs could help small farms save money on energy bills while bringing more renewable energy online. Existing urban farms are a critical part of their communities and promoting the work which they are already doing is key. Thus we suggest that one of the most powerful ways governments, companies, and universities can further their own decarbonization goals is to directly fund the installation and maintenance of PV or APV on existing urban farm sites. In this way, the farm organizations' crucial goals can be advanced at the same time as the goal of decarbonization is pursued. It is imperative in such cases that the urban farms enter into arrangements with full understanding, and always retain every possible degree of autonomy in the arrangement, so that they are not reduced to a means to an end.

Two Michigan state programs already exist which provide funding for renewable energy improvements on farms: the Michigan Saves loan program and the AgriEnergy and Sustainable Farming program, which are discussed in section 1.4 of this paper. Municipalities can also pursue bulk purchasing programs, in which they partner with a local solar company to secure a discounted rate for landowners who use the company. APV adoption could be facilitated when both small farms and homeowners are allowed to participate in bulk solar purchasing programs. Universities, organizations, or companies could also enter into a power purchase agreement with urban farms, in which they agree to buy the energy produced on the farm for a certain number of years. In this type of arrangement, urban farm owners receive payment for the energy they produce through APV. If farms are able to grow a similar amount of food with solar panels on-site, a power purchase agreement could offer a beneficial extra revenue stream. With any of these potential solutions, it is crucial that both parties mutually benefit.

6.4. Municipal Climate Action Plans and APV

To further explore how city governments might use APV as a means for lowering local carbon emissions, this section will detail climate action plans in Ann Arbor and Detroit. In researching these plans, we have found several areas in which APV could act to efficiently facilitate implementation of multiple policy goals at once. While municipally owned APV sites may offer different types of benefits than APV installed by individual urban farms, it could be another way in which APV might find success at the small and urban scale.

Both Ann Arbor and Detroit have ambitious roadmaps for decarbonizing their cities: Ann Arbor aims to transition to 100% renewable energy by 2027 and Detroit aims to reduce municipal emissions 75% by 2034 (City of Ann Arbor, 2020; City of Detroit, Office of Sustainability, 2019). Meeting these goals on these timescales will be difficult if both cities continue to receive a large portion of their energy from DTE, which has pledged to achieve net-zero carbon emissions by 2050—a far less ambitious goal (DTE Energy, 2022). Procuring renewable energy from a variety of sources, including distributed generation, will likely be crucial for cities across Michigan to succeed in implementing their climate action plans. Incorporating APV within urban farms and gardens could be one strategy by which cities could meet their decarbonization goals. Over the next ten years, cities like Ann Arbor and Detroit plan to confront a myriad of issues, from transitioning to clean energy to promoting community resilience. This section details how APV can be used to meet several goals at once within these two cities' climate action plans, and identifies specific recommendations for policymakers to implement.

6.4.1. Ann Arbor

The city of Ann Arbor has identified several goals to achieve by 2030 as part of its Carbon Neutrality Plan, including having an electrical grid powered by 100% renewable energy, reducing miles traveled by car, and enhancing community resilience (City of Ann Arbor, 2020). APV could be an innovative solution in helping achieve these goals. For example, as part of Ann Arbor's plan to power the electrical grid with renewable energy, the city aims to support on-site renewable energy generation with battery storage. The city estimates that achieving this goal will cost a total of $605,000 from 2020 to 2030 and address 3.7% of the city's carbon emissions. The plan notes that Ann Arbor could achieve this goal by establishing a bulk purchasing program allowing residents, businesses, or organizations to purchase solar panels at a discounted rate. The city's vision is to bring 78 MW of additional solar online which could be generated on building rooftops, parcels of land, and carports. APV would also present an efficient way of generating more renewable energy on-site. In addition, it may offer a way to get more people involved, and to advertise the bulk purchasing program. City residents could interact more closely with an APV community garden or pollinator-friendly solar array, which could help spread awareness of the city's carbon neutrality efforts.

Ann Arbor also identified a strategy of investing in resilience hubs within its Carbon Neutrality Plan. These hubs are meant to support residents and provide resources before, during, and after natural hazard events. As a climate mitigation and adaptation measure, these hubs are also meant to reduce greenhouse gas emissions. APV community gardens or small urban farms equipped with battery storage can achieve all of these goals. For example, an APV urban farm could be centrally located within a neighborhood and power a small building or shed so that residents could access charging ports, heating, cooling, or lighting during an emergency. Food could be grown underneath or nearby the solar panels to provide a source of discounted or free food to the neighborhood throughout the growing season. Creating APV community gardens or small urban farms within neighborhoods would also help the city achieve its goal of developing mixed-use neighborhoods in which residents can walk or bike to places rather than taking a car. If more neighborhoods had access to local produce (which could be purchased or provided for free) at APV sites, residents would be able to reduce the miles they drive for groceries. At the same time, growing and distributing food locally would help the city meet its goal of supporting plant-rich diets. Table 7 below identifies these goals from the AnnArbor Carbon Neutrality Plan and corresponding recommendations for using APV to meet these goals.

Existing Climate Action Plan Goal	Corresponding Recommendations
Support on-site renewable energy generation with battery storage (bulk buys)	Advertise or incentivize APV as part of this solution, particularly in schools, churches, or parks where there is open green space
Develop mixed-use neighborhoods	Advertise or incentivize APV community gardens/urban farms within neighborhoods to provide local produce
Invest in resilience hubs	Use electricity generated through an on-site APV system and provide free or discounted produce from the farm/garden throughout the growing season
Support a plant rich diet	See above recommendations

Table 7. Ann Arbor Climate Action Plan Goals and APV Recommendations.

In addition to the city of Ann Arbor's Carbon Neutrality Plan, in the fall of 2021, the city announced plans to create a sustainable energy utility (SEU) which would supplement DTE's power by offering residents renewable distributed energy options (City of Ann Arbor, 2021). Although Michigan state law limits distributed generation and community solar, an SEU would offer an alternative path to providing another source of energy for city residents (Department of Environment, Great Lakes, and Energy, 2022). Because an SEU would be considered a municipal utility, Ann Arbor could install microgrids and community solar within neighborhoods under its jurisdiction, according to the city's SEU report. While the report does not mention the possibility of using APV to supply electricity, community gardens or urban farms with solar panels—as outlined in the recommendations above—could complement the city's plans to form an SEU. Under this scenario, APV installations would not need to be tied into the main electrical grid operated by DTE; instead, they could power a microgrid providing electricity to nearby homes or businesses.

6.4.2. Detroit

The city of Detroit identified four key outcomes which it aims to meet through its Sustainability Action Agenda: healthy, thriving people; affordable, quality homes; clean, connected neighborhoods; and an equitable, green city (City of Detroit, Office of Sustainability, 2019). To reach these outcomes, the city identified several actionable goals to accomplish over the next decade, which are outlined in Table 8 below. Many of these goals can be met at once with APV, meaning city funding could be used efficiently while promoting synergies across projects. For example, APV can explicitly address the city's goal of redeveloping vacant lots into safe community spaces, while also adding more renewable energy to the grid and enhancing resilience. The city could incentivize redevelopment of vacant lots into urban farms or gardens by offering payments for creating urban gardens, with an adder for APV. For example, urban farms could receive an extra payment on top of the base rate for installing APV, as this would help the city meet its decarbonization goals. In addition, the city could set up municipally owned resilience hubs with APV (as in the Ann Arbor example), which could remain off the grid and be paired with batteries to provide needed power during outages, directly within communities.

At the same time, APV projects could help the city meet its goal of increasing access to healthy food, green spaces, and recreational opportunities within the city. For example, a community garden with APV could provide free produce to the surrounding neighborhood while also serving as a green space for recreation. Essentially, APV offers city sustainability staff a way to address many of the goals laid out in the Detroit Sustainability Action Agenda at once. Policies and programs which incentivize APV within the city—on urban farms, community gardens, and vacant lots—should be considered as part of the implementation process. The table below highlights some of the goals included in the agenda and corresponding policy suggestions for action.

Existing Climate Action Plan Goal	Corresponding Recommendations
Transform vacant lots and structures into safe, productive, sustainable spaces	Create a government fund to assist non-profit urban farms with investing in APV
Double the amount of energy generated by solar installations in the city by 2024	Provide a financial incentive to invest in APV, such as a bulk purchasing program
Increase access to healthy food, green spaces, and recreation opportunities	Offer incentives for transforming vacant lots into urban gardens, with an adder for APV
Reduce the total cost of housing, including utilities	Set up a sustainable energy utility (SEU) to supplement DTE power and provide additional distributed energy options through APV installations
Enhance infrastructure and operations to improve resilience to climate impacts	Invest in APV microgrids and storage, to provide energy during outages

Table 8. Detroit Climate Action Plan Goals and APV Recommendations.

6.4.3. Municipal APV: Summary

While this section has highlighted some ways in which local governments may take on APV projects to meet municipal goals, more work is needed to understand how such projects would be implemented. Community input will be crucial in understanding how these kinds of projects may be perceived and what kinds of impacts they may have on surrounding neighborhoods. Ensuring that APV stations offer win-win solutions for local governments and nearby residents will be key in achieving success. In particular, resilience hubs powered by APV can provide the benefits of decarbonization, local food access, and community space. Solutions which further promote the spirit of APV, by providing a host of benefits in one physical space, will likely be the most successful.

6.5. Energy Policy in Michigan

Widespread adoption and success of APV on the small and urban scale will largely depend on state-level energy policies. Thus far, farmers, developers, and researchers have largely focused on APV on more expansive rural farms, where farmers may be more willing to use a section of their land for energy production. However, as this paper has shown, APV can also offer benefits at the small scale.

Currently, energy policies in Michigan are not as favorable to distributed energy resources (DERs)—energy that is produced for use on-site—as they are to utility-scale energy generation. For example, in Michigan, distributed generation is capped at 1% of the local utility's average peak load over the past five years, limiting the use of grid-connected small solar energy installations (Michigan Public Service Commission, 2021). In 2020, Consumers Energy voluntarily agreed to expand their cap to 2% of their peak load after temporarily pausing all rooftop solar and other small-scale energy projects because the 1% cap for distributed generation had been reached (Balaskovitz, 2020). As of fall 2021, the MPSC reported that DTE had reached 65% capacity for Category 1 projects, which are those under 20 kW (Michigan Public Service Commission, 2021). In the long term, maintaining distributed generation caps will limit solar development, including innovative solutions like urban APV. We recommend that the MPSC should require utilities to lift or greatly expand their caps on distributed generation to allow the state to be a part of the growth and development in distributed energy resources (DER's) that is now underway.

Indeed, the relatively small amount of distributed solar energy within Michigan compared to other states should be one reason for the distributed generation caps to be lifted. According to a Distributed Energy Resources (DER) Outlook report published by research firm Wood Mackenzie, 175 GW of DER's are projected to be developed in the US from 2022 through 2026, more than twice the 78 GW which were installed from 2017 to 2021 (Hertz-Shagel, 2022). This is a significant amount of power—for reference, there are 198 GW of energy in the entire Midwest Independent System Operator (MISO) grid (MISO, 2020). While DER's are not as cost-effective as centralized energy systems, they play an important role in bringing more renewable energy online, close to where it will be used. When connected to microgrids or battery storage, they can also improve resiliency.

While legislation to lift the cap on distributed generation has been defeated in the past, another bill was introduced in 2021 which would attempt to change the law once more. HB 4236 has support from Democrat and Republican representatives, and may be more timely now that major utilities are coming up against their distributed generation caps (Perkins, 2021). While utilities have been outspoken in their opposition to the bill, it may still find favor with people on all sides of the political spectrum, as it would offer customers more freedom in deciding how to get their energy.

In addition, policies limiting distributed generation affect the great majority of people within the state of Michigan who receive power from the grid. This is because Michigan has a partially regulated energy market, in which private utilities are guaranteed at least 90% of customers within their jurisdiction. Because only 10% of customers are allowed to choose their energy provider, alternative suppliers are scarce. Michigan also lacks the regulatory framework for community solar, meaning consumers do not have the option to purchase a solar array which provides energy for multiple households—unless the local utility owns and operates it (Department of Environment, Great Lakes, and Energy, 2022). Power generated on urban farms through APV could be a unique source of energy for a community solar project, if the regulatory framework in Michigan were more amenable. While working on this project, a couple of our partners asked if it was possible to share the energy they would be producing on-site with an APV system with their neighbors. Amending state law to allow for community solar would open the door for possibilities like this.

Two clean energy bills are currently under review in the Michigan House Energy Committee, HB 4715 and HB 4716, which would allow community solar. Both Democrat and Republican representatives support these bills, which proponents say would allow consumers to save money (Via, 2021). In fact, according to a 2021 poll conducted by the Michigan Community Solar Alliance, 76% of respondents would be supportive of community solar in the state and 40% would be interested in subscribing to a project (Resch, 2021). If these bills are passed, they would provide the legal framework for sharing power produced on an urban farm or garden with the surrounding community.

7. Future Research Recommendations

7.1. Urban Agriculture Recommendations

While this project focused on how APV and PV systems could be integrated within particular small-scale and urban farms in southeast Michigan, it also revealed the need for more research on the feasibility of small-scale APV more broadly. Due to a general scarcity of peer-reviewed research on urban farming, current applications of APV must be assessed on a case-by-case basis, as this study has done. Further research could be conducted to better understand urban farming practices, challenges, benefits, and overall outcomes. In tandem, more research into the technical details of APV systems that support the unique contexts of urban agriculture would be useful. Based on our conversations with our partners, we suggest further research on water capture and flood mitigation, portability and mobility considerations that interact with crop rotations or changing farm sites, and microgrid or other off-grid applications to meet community-building and sovereignty goals. Research on these topics would help to address some of the primary barriers to APV adoption which came up in designing briefs for our partners.

Furthermore, we recommend research and organizing around mechanisms to support urban livestock, as livestock grazing holds high potential for use of marginal urban farmlands and APV applications. Sheep and goats could make use of the land beneath a solar installation for grazing, as well as offering a "mowing" service to reduce labor requirements. In the City of Detroit, an amended urban livestock ordinance has been in the works since 2014, yet little progress has been made (Mondry, 2019). Likewise, increased financial incentives to plant pollinator habitats could support another non-vegetable crop option that provides direct benefit to food production and farming outcomes. These types of plants have demonstrated ability to support pollination in APV systems and provide further options for farmers to utilize APV in non-vegetable cropping systems (Graham et al., 2021).

7.2. Land Use Recommendations

Light availability and secure, long-term land access are two of the greatest challenges to urban farming operations (Gregory et al., 2016; Griffin, 2019). These barriers were further confirmed in interviews with farm managers from partner sites. This presents challenges to APV implementation as such systems are dependent on high light availability and, from the urban farming timescale, long-term investments in both funding and land. So long as APV mechanisms constrain food production by way of requiring tradeoffs in available land and light, we expect continued challenges to APV implementation in small-scale, urban spaces.

These issues could be addressed by increasing access to desirable farmland within city limits. Light availability could be increased by supporting urban agriculture on prime farmland with desirable conditions (i.e. reduced shading), rather than it being relegated to marginal and heavily developed land. Long-term land access could be supported by increased land ownership, whether by individuals, communities or land trusts. With an increase in available land and sunlight through greater and more secure open space for urban farming, APV barriers may be lowered for urban farmers. Consequently, we recommend policies which would facilitate urban farming land tenure, particularly for farmers of color.

Community land trusts are one way to support this. For example, NeighborSpace is "the only nonprofit urban land trust [in Chicago]…that preserves and sustains gardens on behalf of dedicated community groups" (NeighborSpace, 2022). They support resources from property ownership and insurance to water access and technical training to communities that actively cultivate land and demonstrate a local need for open space. NeighborSpace purchases land from private individuals and the City Parks District to hold specifically for community-led urban agriculture initiatives. Similar organizations across the country, like the Detroit Black Farmer Land Fund, the Boston Food Forest Coalition and the Sogorea Te' Land Trust in California offer various models for enhancing land tenure on prime urban farmland, supporting an increased potential for APV applications (Black Farmer Land Fund, 2022; Boston Food Forest Coalition, 2022; Sogorea Te' Land Trust, 2022).

7.3. APV Technology Recommendations

More research and development around APV technological innovations could help to reduce the negative impacts of APV-caused shading. In particular, transparent panels and sun-tracking panels could help to reduce shading impact. Researchers at Colorado State University conducted an experiment in 2019 and 2020 which showed that transparent panels may allow for more crop growth (Hickey et al., 2019-2020). The Campus Farm or DPFLI could replicate this experiment to see if results are similar in a different climate. With further research and innovation, shading may become less of a barrier to APV implementation in the future.

7.4. Funding Recommendations

Considering the high cost of installing APV, we recommend that greater funding be made available to urban farmers of color and urban farming non-profit organizations. This could be done through targeted federal, state, and local grants to support food and energy security projects in communities of color. Funding could also be made available through a redistribution of resources from universities and research institutions, by way of research and capacity-building projects, grants, and volunteer and internship opportunities such as the University of Michigan's Semester in Detroit and Urban Agriculture Internship. With greater resource availability to meet food production needs, urban farmers may be better equipped to invest in on-site energy projects such as APV.

7.5. Energy Policy Recommendations

This paper has explored several ways in which state and local policies could incentivize and support APV development. In particular, more research is needed on the benefits of urban or small-scale APV as public works projects managed and paid for by local governments. Urban APV has the potential to offer a key source of distributed clean energy to supplement traditional grid power. Further analysis of the benefits of producing renewable energy within city limits, closer to where it will be used, is needed. Co-benefits of APV, such as improved access to healthy, local food and common green space may be more difficult to quantify, although more research into how these may be realized within city spaces is also needed.

In addition, more research on the potential for APV to offer supplemental revenue streams to small and urban farms is needed. APV can allow farmers to keep land in agricultural production while also leasing out land for solar energy production. This paper has discussed the potential benefits of power purchase agreements between universities, businesses, or local governments and urban farms. However, more research into the feasibility of such arrangements on small plots of land is needed. In addition, more work is needed to gauge interest among small and urban farmers, as well as how communication channels between urban farms and those looking to purchase energy might be built.

8. Conclusion

This research explored how agrivoltaic systems could be used on small-scale and urban farms to support food and energy production and farm organizations' missions. Through a review of relevant literature, farmer interviews, site visits, geospatial modeling, systems designs, and cost calculations, we developed five "design briefs" as applied feasibility studies. Upon analysis of the design recommendations contained within these briefs, we identified several central conclusions:

1. APV can serve education and demonstration goals of research institution-affiliated farms such as the University of Michigan Campus Farm and the MSU-Detroit Partnership for Food, Learning and Innovation.
2. Standard PV designs were preferred over APV installations by urban farms such as D-Town Farm, Cadillac Urban Gardens, and We the People Opportunity Farm.
3. Barriers to APV implementation on urban farms include: secure land tenure, lack of APV synergies, costs, need for structural permanence, and light availability.
4. Major opportunities to support APV installations include: desire for technical demonstration, and the need for increased crop shading.

While most of the urban farms that participated in this study were not interested in pursuing APV, it is a novel application of solar energy generation that other farms may choose to pursue. This preference depends largely on the types of benefits and synergies APV can provide to farms on an individual, case-by-case basis. Urban farms which need energy on-site, and which have no other viable non-agricultural land for PV installation may find great benefit in the addition of APV. Farms which desire increased shade for livestock or crops may also find APV useful. In addition, APV pairs naturally with farms which serve as education and demonstration sites. Finally, leasing out land for solar energy production can also serve as a valuable income stream for small farms; APV allows farmers to access this extra income while maintaining agricultural production.

Many urban farms exist as food and culture refugia in urban landscapes pockmarked by poverty, land insecurity, food insecurity, and other flavors of institutional marginalization. The creation of on-site "free" energy has and will continue to bolster urban farms' ability to increase energy and food sovereignty and self-determination; the APV innovation widens the window of opportunity and possibility, but it will not upend the societal conditions which make urban farms necessary. Instead, APV on urban farms should be seen as one tool that, in certain contexts, synergistically promotes multiple important goals at once.

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Appendix 1. Design Briefs

April 2022 Date Issued

04 Design Revision

APV/PV Design Brief

Schematic Design Iterations

Designed and compiled by the Urban Farm APV Master's Project Team at the University of Michigan School for Environment and Sustainability

Team Members: Brian Geiringer, Karlene Robich, Julian Tabron, Jess Tang, Rebecca Turley

DESIGN OVERVIEW

Cadillac Urban Garden

Cadillac Urban Gardens (CUGM), in Mexicantown of south Detroit, is a 1-acre raised bed community garden. Their production focus is to provide free, culturally-relevant food to the surrounding, predominantly Latinx community. CUGM's greater mission is to support food access and food education while also place-making for youth mentorship and community-building.

Currently, the site doesn't have a grid connection and lacks power to meet electricity needs. They also experience heat stress, which interferes with their operations. (A)PV can support these organizational outcomes by providing on-site energy generation for Internet access, device charging, events, etc., reducing heat stress, and enhancing water management strategies.

Established Garden Goals

CUGM has stated the following in interviews with a garden representative as their organizational goals;

- Youth mentorship
- Community building
- Food access free of charge
- Food education
- Growing culturally relevant foods

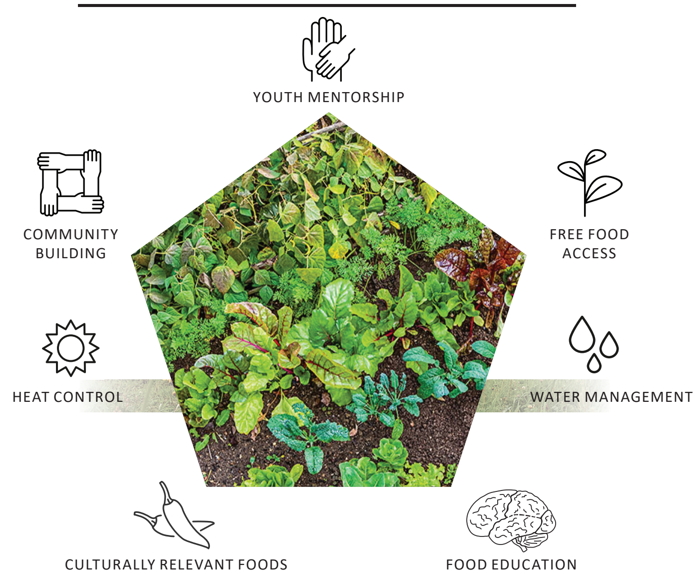
These goals are used as design intent for all solutions developed during the design process. APV and PV have the potential to support many of these goals, as well as relieve potential stressors the garden experiences.

Additional Considerations

Additional criteria and considerations will be necessary to develop solutions that effectively align with CUGM's goals. The following considerations were identified by the team through conversations with farm representatives:

- CUGM works solely with raised beds since they are located on a parking lot. For this reason, permanent structures are not ideal, and all designs must account for this structural limitation by featuring mobility and flexibility. If the layout or location of the garden evolves, mobile solutions will integrate more seamlessly than permanent structures.
- Crops, harvested food, and people are currently vulnerable to heat stress. Solutions should consider the integration of an electric water pump or other water catchment and retention strategies to minimize heat stress and heat damage on the site.
- There are often children playing on-site, therefore mounting should be highly secure with safety in mind.
- Special attention should be paid to Detroit zoning and PV regulation policy.

Visualizing Garden Goals



ELECTRICITY GENERATION POTENTIAL

1.1 - 12 kW

Electricity generation potential depending on the energy demand of the desired loads.

UPFRONT COSTS

$2,750 - $30,000

Average total cost of a system with a capacity of 1.1 kilowatts - 12 kilowatts.

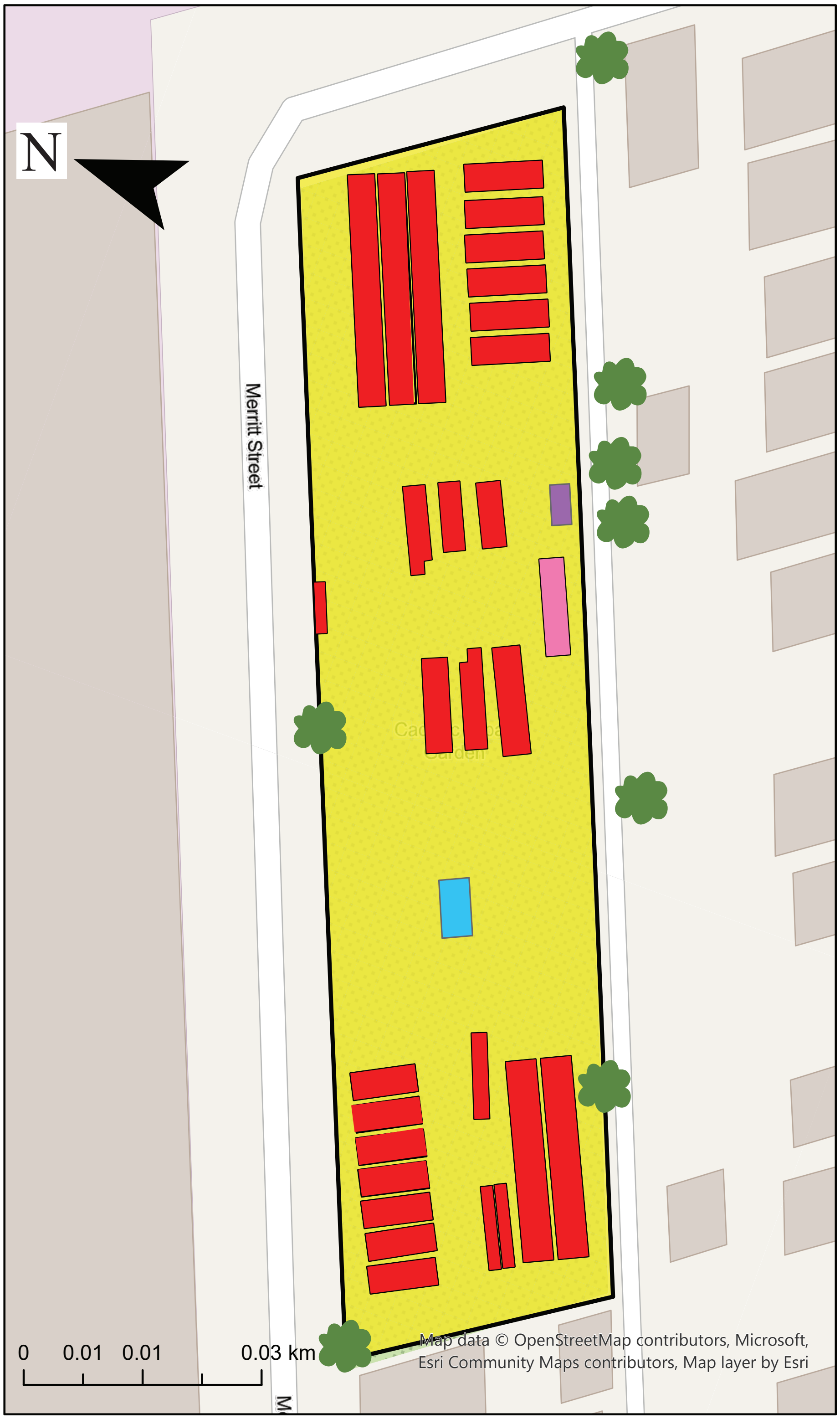
SUITABILITY MAP

Developed Using ESRI's ArcGIS Pro Software

This page contains a map of the site that shows suitable or possible areas of each (A)PV design included in the brief. It is color coded for clarity, and was developed using GIS software and the ArcGIS ModelBuilder tool. A small key in the corner of each subsequent design page will indicate that specific design's most suitable locations, taken from this map.

The suitable (A)PV areas are represented using yellow shading ("PV Possible"), and the light green areas are not recommended due to high tree canopy coverage.

Suitability for (A)PV installation was determined by analyzing area solar radiation and slope analysis. A digital surface model (DSM) was created using Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey, which identified open areas and other site features, such as canopy coverage, buildings, structures, and steep hill faces. For an area to be considered suitable for PV installation, the slope surface must be less than 32° in angle (not located on a sharp hill or the side of a building) and the area solar radiation must be greater than 800 kWh/m² (the minimum recommended radiation required for PV panels to be effective).



Site Features
- Site Boundary
- Raised Beds
- Tree Coverage

(A)PV Type
- Shaded Seating (A)PV
- Bed-Mounted APV
- *Wash/Pack PV
- Shed PV

Feasibility
- PV Possible

*Mobile Wash and Pack can be moved to any place on site.

Shed-Mounted PV

This design involves adding PV to a shed or similar structure.

MOUNTING & STRUCTURE

It could be added on the sloped roof of a shed assuming there is enough structural support. If additional structural support is needed, support poles can be added to reinforce the system weight. This design does not necessarily add shading, but could potentially save CUGM money on support structure costs.

MULTIFUNCTIONALITY

The system can work as a source of power for food-cooling and tool-charging. It offers a space to charge equipment overnight in a secure area.

ENERGY GENERATION & USAGE

The equipment associated with the PV system could be located inside the shed, making it non-accessible to the public and children. The electricity produced can be used to cool the shed or structure, making it a suitable environment for storing food after it has been harvested. Power tools and devices can also be charged in or near the shed.

GARDEN GOALS ADDRESSED

Free Food Access From Reduced Heat Stress

If the panels are used to cool the shed to create an environment suitable for storing food, the garden will be able to reduce food waste due to heat stress. This will increase overall food access.

Youth Mentorship

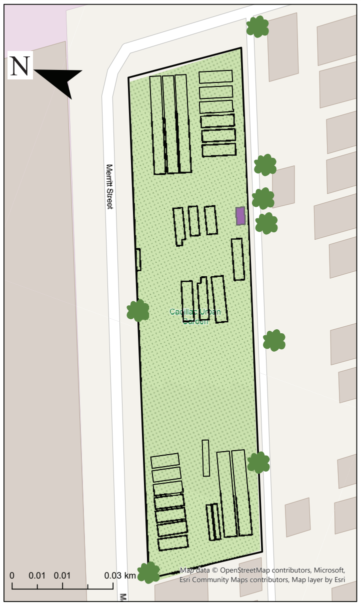
This design could allow for youth mentorship through sustainable energy production education. Youth could learn more about how to integrate clean and renewable energy into garden operations, and how this integration can benefit food production overall.

Water Management

Water catchment equipment could be integrated with the panels and collected in a basin in or near the shed. The electricity generated by the panels could be used for a small water pump, making it easy to collect and manage water on the site.

OPTIONAL MODIFICATIONS

A porch light or other similar outdoor light can be attached to the Shed PV system to provide lighting at night.



Source: https://tinyurl.com/ShedPV

Source: https://tinyurl.com/RooftopOrShedPV

SYSTEM SIZING INFORMATION

12 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump + Efficient AC Unit

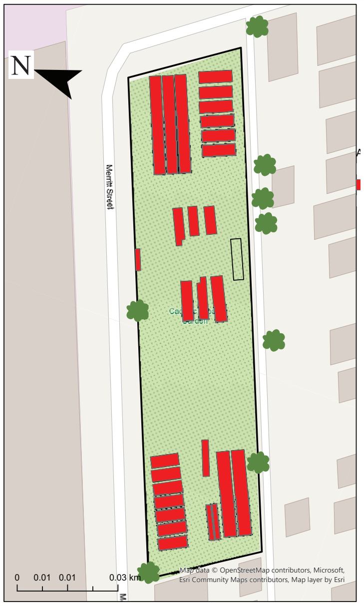
Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump **= 1.4 kW System**

1.1 kW System = Power Drill + Picnic Table Lamps + Mobile Lamp + 1 Laptop + 5 Phones + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Bed-Mounted APV

This design would consist of a panel mounted



MOUNTING & STRUCTURE

Smaller-scale PV panels could be installed on top of raised beds to partially cover crops below, offering more shade and improved water retention. Since this design would be highly accessible to all those able to work in a raised bed, this design is not childproof; safety caging would be required on sensitive or dangerous components to prevent damage or harm. The exact types and methods will be recommended by the contractor or system manufacturer. While this design can be minimal in scale and relatively mobile when attached to a raised bed, it might require strategic spacing of beds to ensure access to the crops are maintained from at least one direction.

ENERGY GENERATION & USAGE

The energy could be routed to the shed or to the seating area to provide electricity for tool and device charging.

GARDEN GOALS ADDRESSED

Reduced Heat Stress

Small PV panels installed over beds could provide much needed shade to crops below, potentially increasing crop production by increasing water retention, reducing soil moisture evaporation, and creating a more moderate temperature for plants. Panels could be spread out to allow for more sun, or positioned close together for more shade, allowing a certain amount of flexibility.

Small PV panels may also be mobile, as they won't need large supports, and can be moved throughout the space as needed.

Free Food Access

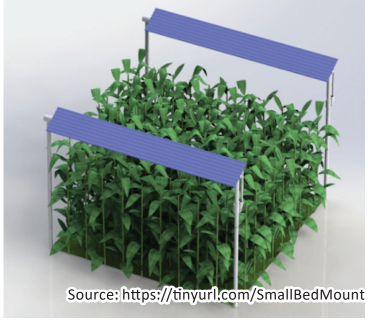
With increased crop yield due to reduced heat damage, the garden will produce more food to distribute to the local community. This supports food access and sovereignty.

Culturally Relevant Foods

The increased water retention or shade offered by APV can create a more suitable environment for certain types of foods. One of these crops is cilantro, which prefers shade. Peppers have also been known to prefer water retention in full sun. Having more access to these types of foods for a longer period of time through the year would enable the community to access more culturally relevant foods.

Food Education and Youth Mentorship

Since this design is easier to see than shed-mounted or shaded seating designs, it can also contribute to food education opportunities. The community can be taught about how the panels reduce heat stress, increase food access, and help the garden to grow culturally relevant foods that the community can enjoy.



Source: https://tinyurl.com/SmallBedMount

Source: Pinterest

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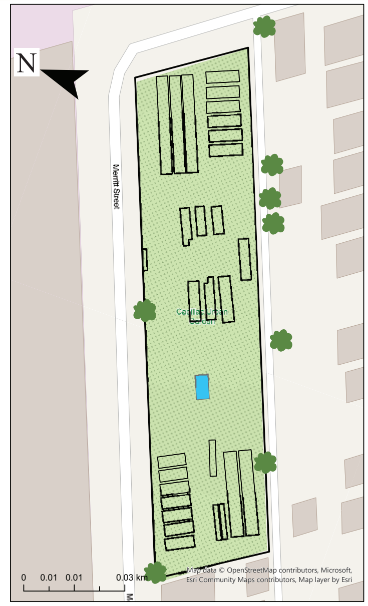
Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump = 1.4 kW System

1.1 kW System = Power Drill + Picnic Table Lamps + Mobile Lamp + 1 Laptop + 5 Phones + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Wash/Pack PV

Adding a PV structure to a wash/pack area would provide shade and cooling to the site as well as a space for visitors and volunteers to gather and take a break from the heat.



Wash/Pack PV can be located anywhere were PV is Possible on the paved ground.

GARDEN GOALS ADDRESSED

Free Food Access and Reduced Heat Stress

PV panels could be raised with a supporting structure, such as a wooden frame or gazebo, to act as a shade structure. This would create an ideal spot for washing and packing produce, while keeping vegetables relatively cool until they can be distributed to community members. Minimizing heat damage to food will enhance the impact of the garden on the surrounding community and increase food access.

This shade structure would be producing energy to use on site, offering an efficient dual-use solution to the farm's needs. This electricity can power coolers for food or fans for volunteers. It can also be used to charge power tools.

Water Management

Water catchment equipment could be integrated to collect rain water in a basin near the structure. The electricity generated by the panels could be used for a small water pump, making it easier to collect and manage water on the site.

MOUNTING & STRUCTURE

A solar array can be mounted atop supporting poles to act as a shade structure, or be installed on top of a wooden frame or gazebo-like structure. It may or may not include seating or a space to charge laptops and phones.

ENERGY GENERATION & USAGE

Electricity generated from the array can power electrical receptacles underneath, providing a source of energy to charge power tools or other equipment. Any design that combines electrical equipment and water usage must be appropriately designed and maintained to prevent electrical injury or damage related to water exposure and ground faults. PV contractors will know the safest installation methods to make this design possible, including weather-proof enclosures and GFCI (ground fault current interrupter) rated receptacles.

Source: https://www.thesolarnerd.com/blog/solar-gazebo-pergola/

SYSTEM SIZING INFORMATION

12 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump + Efficient AC Unit

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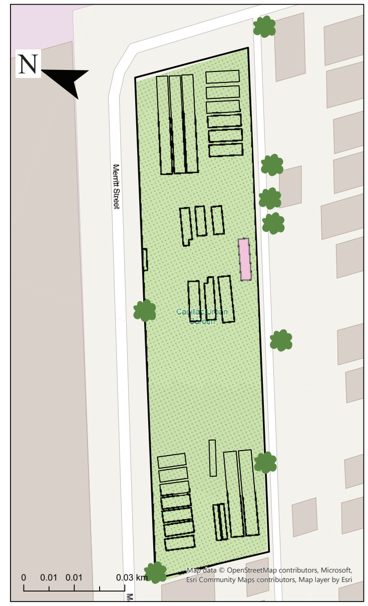
1.1 kW System = Power Drill + Picnic Table Lamps + Mobile Lamp + 1 Laptop + 5 Phones + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Shaded Seating (A)PV

A PV-shaded seating area would provide shade and cooling to the site, a space for visitors and volunteers to gather and cool off from the heat, and an innovative solution for integrating energy production within the garden.



Shaded Seating PV can be located anywhere were PV is Possible on the paved ground.

MOUNTING & STRUCTURE

A solar array can be mounted atop supporting poles to act as a shade structure, or be installed on top of a gazebo. Tables, seating, or a crop storage area could be positioned below the structure as well for people to relax and take breaks from working in the sun.

MULTIFUNCTIONALITY

The system can provide a place of relaxation and connection, a food-cooling space, and tool-charging power source. A pollinator habitat could also be added to promote biodiversity.

ENERGY GENERATION & USAGE

Electricity generated from the array can power electrical receptacles underneath, providing a source of energy to charge laptops and phones, or to power a WiFi router to avoid spending excess money on mobile hot-spots.

GARDEN GOALS ADDRESSED

Youth Mentorship and Community Building

This type of system could be used to promote a sense of community and place at Cadillac, inviting people to sit and spend time on site. In addition, having covered areas could allow Cadillac to hold more community events in the summer and fall, such as concerts, talks, lessons, or demonstrations. At the same time, energy generated by the solar panels could provide electricity for charging phones, laptops, or gardening equipment.

Free Food Access and Reduced Heat Stress

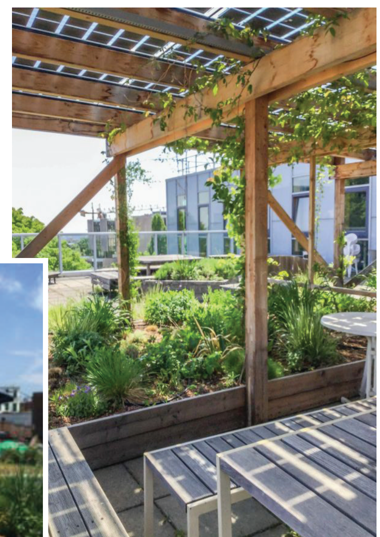
A shaded area under PV can also provide a suitable environment for shade loving crops such as leafy greens and herbs like lettuce and cilantro, making this design multi-functional. It can increase food access by lowering food waste due to heat stress.

Optional Upgrade - Shaded Stage PV

This upgrade would maintain the same attributes and benefits, but would be larger in scale to accommodate more panels, generate more electricity, add battery storage, and provide more energy and space for events that might require more demanding equipment, such as amplifiers and microphones for concerts or festivals. This could contribute to CUGM's goal of Food Education, Youth Mentorship, and Community Building.

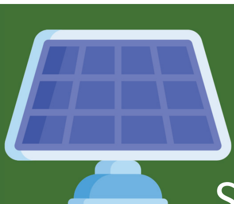
Source: https://livingroofs.org/gallery-home/solar-intensive-green-roof/

Source: https://tinyurl.com/PergolaPV



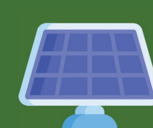
Source: https://livingroofs.org/gallery-home/solar-intensive-green-roof/

SYSTEM SIZING INFORMATION



12 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump + Efficient AC Unit

Power Drill + Chain Saw + Portable Charging and Lighting Device + Shed Lamp + Picnic Table Lamps + Mobile Lamp + Standing Flood Lamp + 2 Laptops + 7 Phones + WiFi Router and Modem + Water Harvesting Pump = 1.4 kW System



1.1 kW System = Power Drill + Picnic Table Lamps + Mobile Lamp + 1 Laptop + 5 Phones + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Mobile Mounting Methods

Making a design mobile, such as the Wash/Pack design or the Shaded Seating design, allows for greater flexibility and versatility for both designs.

BENEFITS OF MOBILITY

Mobile mounting allows CUGM to move the PV structure wherever it is needed during the day depending on the angles of the sun, the time of year, and what food is being washed and packed. For example, greater shade is needed for kale and spinach, and being able to move the PV structure to an accessible location near the harvest or over the crop itself will make the entire growing and harvesting process more convenient, prevent wilting of the food, and reduce soil moisture evaporation. This could also benefit volunteers and visitors to the farm, giving them a place to rest in the shade between activities. Since CUGM's location has little to no shade, the mobile PV structure will allow flexible, optimized shading for any purpose when needed.

Large Stilt Structure (Steel or Wood)

Description of Structure

This support structure will adequately support arrays that contain multiple panels, assuming it is sized appropriately. Depending on the amount of electricity generation that is desired by CUGM, more panels may be desired, and this structure may offer the most adequate support. It is placed on wheels, so mobility of an array would be maintained. Smaller arrays on this structure would also be mobile and adequately supported.

Height and Shade

This design also allows for the most height between the ground and the panels. This could be desirable if CUGM plans on placing a table or multiple raised beds beneath the structure and plenty of space is desired underneath, such as for shaded seating, wash/pack areas, and other gathering spaces.

Safety

This design, however, might not be as safe as other mobile solutions. Due to the nature of the structure, it may allow children to climb the structure. To ensure safety with this design, measures should be taken that prevent climbing and toppling at the recommendation of a contractor.

Medium Push Wheel Structure

Description of Structure

This design is smaller in size and will support less panels than the large stilt structure. It would be placed on a flat surface, most likely the ground, the stage, or a table. The wheels lock to ensure it will not be vulnerable to rolling. An optional mobile battery could be attached to the structural frame and move with the system as needed.

Height and Shade

This structure might not be as tall as the stilt design and therefore might not necessarily cover multiple raised beds. However, it could be designed in a taller fashion to allow for a larger cast shadow. By designing it this way, it can be placed strategically over certain crops or certain harvested bundles to selectively shade as needed. Mobility allows for this location and shading flexibility throughout the day.

Safety

This design is much safer than the stilt structure and would not require extra protective measures.

Medium to Small Folding Structure

Description of Structure

This support structure is the most flexible and mobile of the three methods suggested. It consists of typically one panel, a housing, and a folding support leg. Some designs or manufacturers will also include a handle for easier portability. With the reduced amount of structural components, this structure will be lighter than others and will aid the mobility of the panel around the site. This optimizes flexibility in where CUGM wants to provide shade. However, this design supports a less panels. If CUGM decides they do not require large amount of energy, this mounting option might be most suitable for mobile methods.

Height and Shade

The leg can be designed or ordered in specific lengths/heights to create the ideal shadow length. The longer the leg, the taller the panel will sit, and the larger the shadow. This will allow more square footage of crops to be shaded when needed. If the panel remains in one location, it would be suitable for shade-loving crops such as cilantro or lettuce. However, since this method is highly flexible, it can be placed over any crop for any amount of time as deemed appropriate.

Safety

This design is also the safest, as it can be folded and stored when not in use.


Source: Facebook

PV Information and Resources

Policy, Cost, Research Opportunities

Policy Considerations

Zoning and Permitting

In Detroit, solar systems are regulated according to the district which they reside in. CUGM is located in a B4 General Business District, in which a “power or heating plant with fuel storage on site” is regulated as a conditional use, meaning city review is required. The municipal code does not list requirements for accessory structures within this business district, but does specify that “all other uses” on such parcels of land can be at most 35 feet in height.

Net Metering

If CUGM decides to connect to the grid, excess energy would be credited at market rate, minus distribution charges. This could offer a small revenue stream to help offset upfront costs.

Cost Breakdown

The cost of a PV system will be approximately $2.50 per watt of the DC system size.

The cost of the equipment used to calculate approximate system size is not included in the cost of the PV system itself. Electric equipment that requires purchase will be an indirect cost of an APV or PV installation if the organization decides to transition away from gas equipment. For the 12 kW, 1.5 kW, and 1.1 kW systems, we estimate additional electrical load costs of $1,542, $1,033, and $613, respectively.

If CUGM would like a different system size, the following chart can be used to estimate the energy demand and cost, and from there a contractor or engineer can appropriately size the system.

Electrical Load	Cost per Unit	Estimated Wattage (W)
Battery-Op Power Drill (1")	$200	1000
Battery-Op Power Chain Saw (12")	$200	1100
Portable Solar Charging and Lighting System	$70	15
1 Shed Lamp	$50	10
2 Picnic Table Lamps	$50	26
Mobile Battery-Op Lamp	$37	10
Standing Battery-Op Lamp	$100	70
Wifi Router & Modem (Service Not Included)	$150	14
Window AC Unit (12,000 BTU, Efficient)	$600	100
Electric Water Harvesting Pump	$100	84
Phone (charging for 1 hour)	N/A	8
Laptop (charging for 1 hour)	N/A	100

Community Benefits and Support

Benefits and support provided to the community include, but are not limited to:

1. Electricity Sharing with Community
2. Internet Access for Community (if WiFi is added to the site)
3. Educational Opportunities about Innovative and Sustainable Farming

Community Learning Days

(A)PV Installation Days have the potential to be educational, particularly if students or volunteers participate in the installation. (A)PV designs that could be suitable for group installation will have either smaller support structures or have the option to be modular in set up, making them ideal for community participation without professional oversight. The manufacturer or contractor would give specific guidance and instruction as needed to maintain safety and proper installation. This can also save a significant amount of money for the cost of the system.

Funding Resources

Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR.

The AgriEnergy and Sustainable Farming Program offered by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) provides funding for farms and small businesses to invest in energy efficiency and renewable energy projects. The program has $100,000 to distribute, with a maximum of $15,000 for eligible projects. Project funding is limited to 50% of the total project cost.

Operation and Maintenance

It’s important to note that PV manufacturers have specific recommendations for their products to maximize the lifetime of your system. They will also have specific information on how often system components need to be maintained, which can vary by manufacturer, system size, and more. The manufacturer’s guidance should be the main resource for operation, maintenance, and cleaning instruction.

Cleaning

To keep your system clean and effective, clean it with warm water and soap as needed. You can use a hose to water down the panels, or you can use a soft cloth or sponge to prevent scratches. Wiring and other electronic components do not require cleaning and should not be washed in order to prevent ground fault interruption damage and maintain safety.

Maintenance

PV systems require maintenance throughout their lifetime. The frequency depends on the manufacturer of the system components, but expect maintenance to be required every 3-6 years. Costs may include labor or replacement for damaged components.

Warranty

Depending on the manufacturer, PV panel warranty timelines can be measured by a pre-determined number of years after purchase or based on the panels’ generation output. Pre-determined year warranties typically cover more costs for a shorter amount of time, whereas output warranties will last throughout the panel’s lifetime but cover a smaller proportion of costs as panel output efficiency decreases.

March 2022 Date Issued
04 Design Revision

DPFLI

APV/PV Design Brief

Schematic Design Iterations

Designed and compiled by the Urban Farm APV Master's Project Team at the University of Michigan School for Environment and Sustainability

Team Members: Brian Geiringer, Karlene Robich, Julian Tabron, Jess Tang, Rebecca Turley

DESIGN OVERVIEW

Michigan State University's Detroit Partnership for Food, Learning, and Innovation (DPFLI)

DPFLI is a 3.3-acre urban agriculture center. On-site activities include demonstration and educational programming, serving both the MSU and surrounding communities. The site's stated mission is to improve the quality of life for the people they serve. They do this by acting as a model for farm sites and communities, demonstrating how they can be designed for sustainability and food sovereignty.

(A)PV can play a crucial role by providing on-site demonstration of how solar energy can contribute to food sovereignty and sustainability goals. Just as all the site's food goes to the local community, energy generated with APV can also be used by community members on-site. MSU researchers and educators can utilize an installation to support collaborative learning and research opportunities.

Establishing Farm Goals

DPFLI's core farm goals as stated in interviews are as follows:

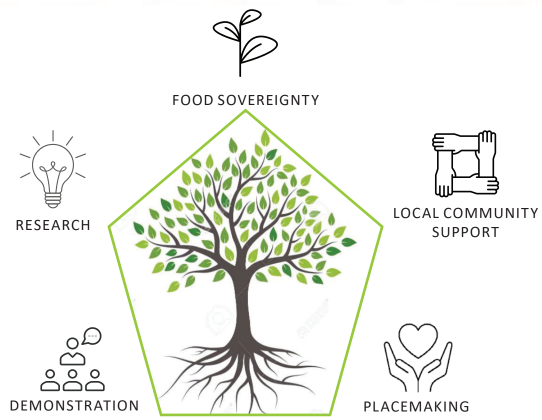
- Placemaking
- Demonstration

These core goals serve and support three additional mechanisms:

- Food Sovereignty
- Research
- Local Community Support

These farm goals and mechanisms were established as design intent for all designs within the brief. Additionally, an APV installation may be one of several future energy infrastructures to support research and demonstration goals.

Visualizing Farm Goals



Design Considerations

While the farm goals establish the design intent for each APV or PV solution, there are additional criteria and considerations identified by the team through interviews with farm representatives that guide the direction of the design process. Some of the main considerations are as follows:

- The site aims to support a diverse array of technology and skills to help people connect with each other and become environmentally-aware. To serve goals of demonstration and education, an APV design may be preferred over PV designs.
- The one building on-site is currently powered by electricity from the grid, and an APV installation could help the site achieve carbon neutrality. Additional energy generation could support a cooler and water pump.
- There are bramble patches and a large parking lot that were explicitly identified as potential locations for APV and PV, respectively.

CARBON OFFSETTING		MINIMUM UPFRONT COSTS	ENERGY BILL SAVINGS
110 lb CO_2e	1.6 kW	$ 4,013	$ 541
The total amount of carbon dioxide equivalent emissions DPFLI seeks to offset per year.	The **minimum** generation required to offset DPFLI's carbon footprint.*	The average total cost of a 1.6 kilowatt capacity system.*	The estimated total energy bill savings per year when all electricity is offset by (A)PV, based on 2021 utility bills.

* Calculated from carbon offset metrics only, not final DC system size or system cost.

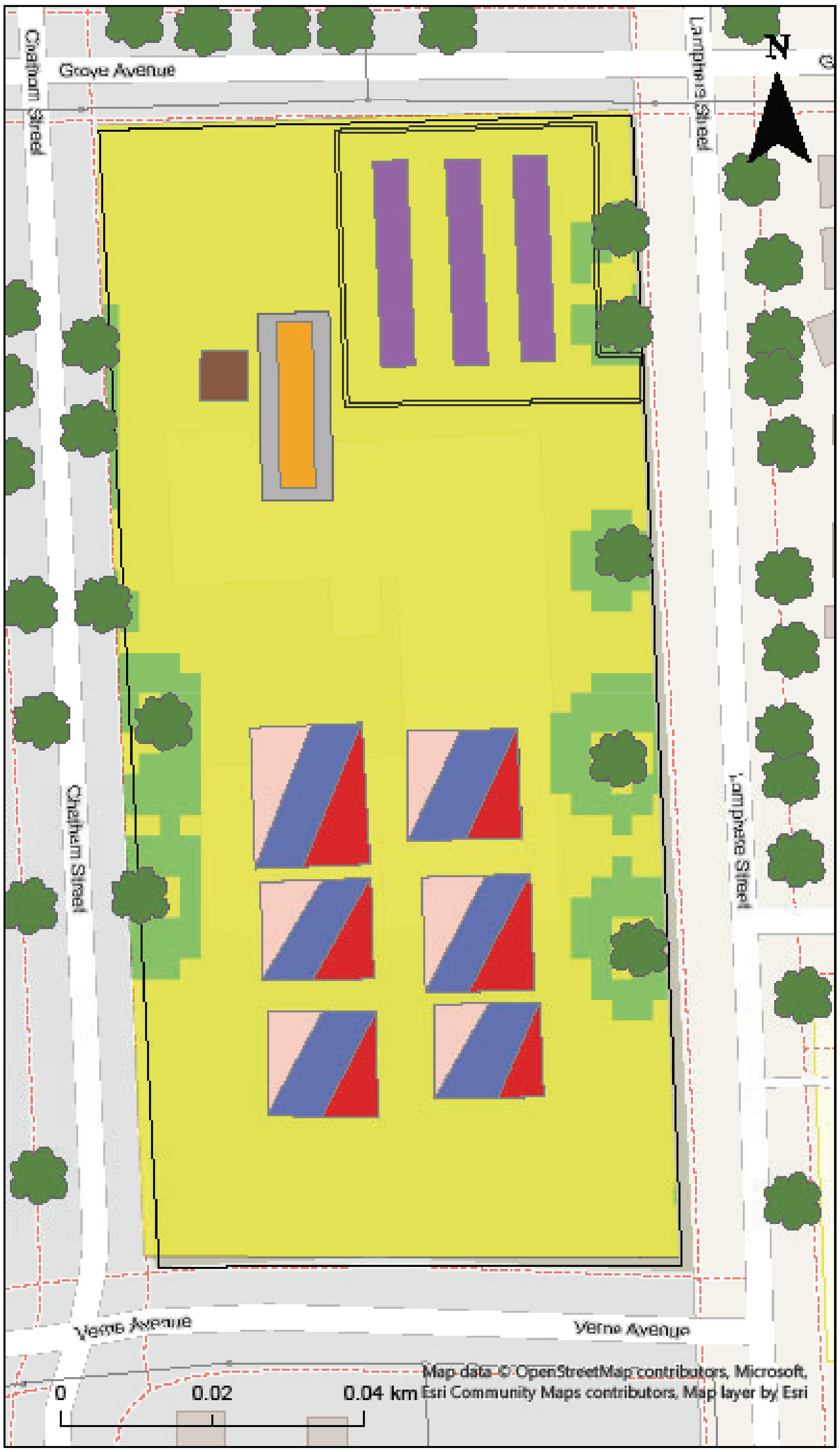
SUITABILITY MAP

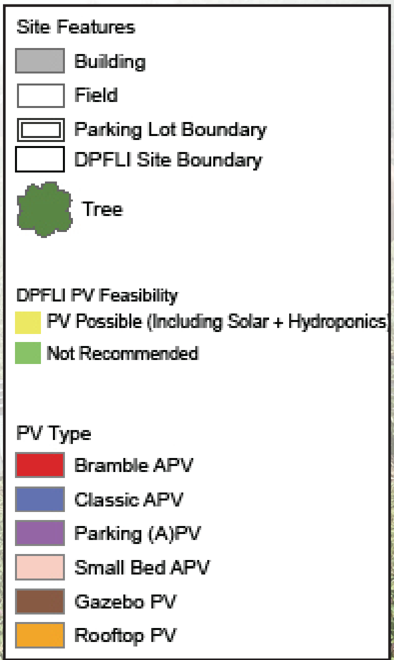
Developed Using ESRI's ArcGIS Pro Software

This page contains a map of the site that shows suitable or possible areas of each (A)PV design included in the brief. It is color coded for clarity, and was developed using GIS software and the ArcGIS ModelBuilder tool. A small key in the corner of each subsequent design page will indicate that specific design's most suitable locations, taken from this map.

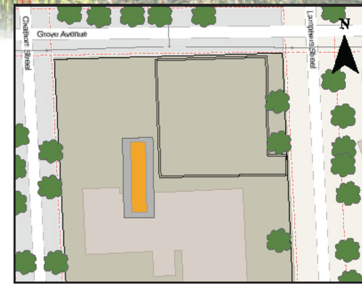
The suitable (A)PV areas are represented using yellow shading ("PV Possible"), and the light green areas are not recommended due to high tree canopy coverage.

Suitability for (A)PV installation was determined by analyzing area solar radiation and slope analysis. A digital surface model (DSM) was created using Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey, which identified open areas and other site features, such as canopy coverage, buildings, structures, and steep hill faces. For an area to be considered suitable for PV installation, the slope surface must be less than 32° in angle (not located on a sharp hill or the side of a building) and the area solar radiation must be greater than 800 kWh/m² (the minimum recommended radiation required for PV panels to be effective).





Rooftop PV



Adding rooftop PV is an intuitive option since DPFLI has an existing structure on site. This design easily has the potential to offset DPFLI's carbon emissions and electricity usage with energy generation to support additional electric loads.

Source: https://tinyurl.com/RooftopOrShedPV

MOUNTING & STRUCTURE

Installing this design on DPFLI's existing building takes advantage of currently empty space. Utilizing an existing building or shed for PV potentially minimizes costs associated with in-ground or pergola-type supporting structures. The structure needs to have adequate support to hold the weight of the PV system.

ENERGY GENERATION & USAGE

Electricity generated can be used to make the building operations carbon neutral by offsetting all grid consumption. Depending on the system size, spare energy can be generated to support additional electric loads, leaving room for expansion.

OPTIONAL MODIFICATIONS

A battery storage component can store energy for times when electricity is not actively produced by the panels, such as nighttime, or if the system is generating more electricity than you need in that moment.

FARM GOALS ADDRESSED

Demonstration

Panels located directly on the building minimize the total footprint of the PV system and won't compete for space with anything else on the farm. If DPFLI anticipates significant energy needs, installing rooftop PV along with another form of PV on site would allow for maximum energy generation, making this option extremely flexible and customizable. This system can also lend itself to demonstration, since all system components can be viewed within the building. An interactive building management system with LED display can show the instantaneous generation information of the panels, as well as track previous generation and how that translates to carbon offsets and offset grid usage.

Community Support

Generated energy can be used to support community members as DPFLI desires. Battery storage would allow for energy usage even when energy is not actively generated, meaning the form of community support through shared electricity is flexible.

SYSTEM SIZING INFORMATION

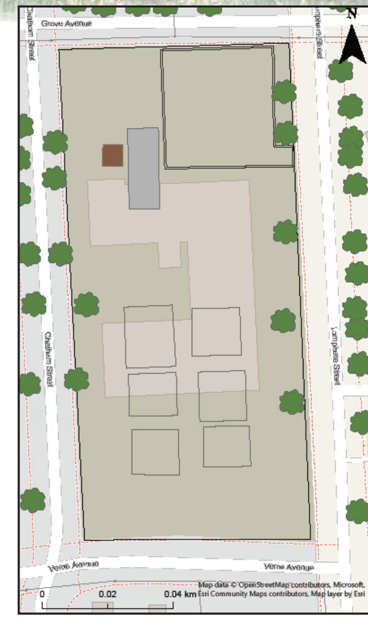
2.73 kW System = Building Electricity Offset + Corded Push Mower + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem + Water Harvesting Pump

1.66 kW System = Building Electricity Offset + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem

All icons from FlatIcon.com

Gazebo PV

Using PV panels to provide shade for community members and events is an innovative way of integrating energy production within the farm.




Source: https://tinyurl.com/PergolaPV


Source: https://livingroofs.org/gallery-home/solar-intensive-green-roof/


Source: https://tinyurl.com/DeckShadedPV


Source:https://tinyurl.com/DeckShadedPVn

MOUNTING & STRUCTURE

A solar array can be mounted atop a gazebo structure, permitted the structure can support the total weight of the panels. See the images on this page for various mounting methods for reference.

ENERGY GENERATION & USAGE

A number of electrical receptacles can be used to charge electronic devices within the seating area. Depending on the size of the system, it might also be able to charge power tools.

OPTIONAL MODIFICATIONS

A battery storage component can store energy for times when electricity is not actively produced by the panels, such as nighttime, or if the system is generating more electricity than you need in that moment.

MULTIFUNCTIONALITY

The shaded space underneath could be suitable location for shade-tolerant vining plants, such as wild edible grapes or coral honeysuckle for pollinators.

FARM GOALS ADDRESSED

Placemaking

This type of solar system could be used to promote a sense of community and place at DPFLI, inviting people to sit and spend time on site.

Demonstration

A gazebo provides a covered space for people to gather during gazebo PV demonstrations. Energy generated by the solar panels could provide electricity for equipment for such events, including microphones, amps, laptops, phone charging stations, or any other desired equipment. The system might be designed in a way to support visual learning of PV systems with exposed, weatherproof, secured components.

Community Support

Covered areas could allow DPFLI to hold more community events, such as talks, lessons, or demonstrations. Energy generated by the solar panels could provide electricity for charging laptops or phones. This electricity can be shared with the community as desired by DPFLI.

SYSTEM SIZING INFORMATION

2.73 kW System

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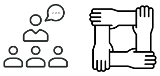
Building Electricity Offset + Corded Push Mower + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem + Water Harvesting Pump

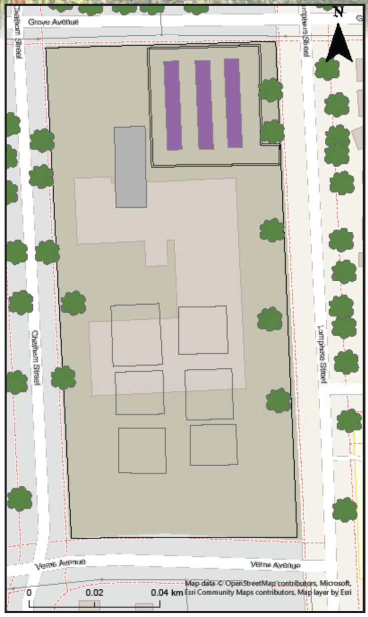
All icons from FlatIcon.com

Parking Lot (A)PV



Adding solar panels above the parking lot is another stacked land-use option. Since the parking lot does not produce food, installing a PV system would serve multiple functions that do not compete with the existing food production of DPFLI.

Source: MSU Website, Lansing PV Installation



Source: https://www.thesolarnerd.com/blog/solar-gazebo-pergola/

MOUNTING & STRUCTURE

An in-ground, permanent canopy structure can provide shade from the sun to keep vehicles cool. A larger structure can also accommodate a large generation capacity.

MULTIFUNCTIONALITY

This design can supplement any other PV design, including Bramble APV. A previously non-food producing area can be utilized for vine or shade loving crop production in raised beds. This would increase the overall food production of the farm and re-envision the function of the parking lot.

ENERGY GENERATION & USAGE

Energy can be routed to the building to offset electricity usage on site. Electric vehicle chargers could be added in the future if desired by DPFLI.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design, likely located in the building. A rain water harvesting system could also be added, which would require rain gutters, cisterns, and optional water pumps.

FARM GOALS ADDRESSED

Demonstration

Installing a solar array above the existing parking lot at DPFLI will add shade and cooling to the space and cars below while providing a significant amount of energy to the farm, making the parking lot useful to the organization beyond providing parking alone. Much like rooftop solar, this type of efficient, stacked land use design can also be paired with other types of PV within the farm if more energy is needed. If desired, the installation of an electric vehicle charging station can contribute to PV demonstration goals.

The additional shading produced by the structure could allow the growth of vine or bush-like crops, such as brambles or other fruit, making this design a demonstration for APV as well as stacked land use for energy production and volunteer/visitor parking.

Community Support

Aside from using the energy for the building located on site, energy can be shared with the community as desired. Adding crops to the supporting structure can increase food production, meaning the farm can grow more food for the surrounding community and nurture the biodiversity of the neighborhood.

SYSTEM SIZING INFORMATION

2.73 kW System

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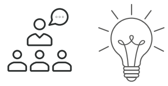
Building Electricity Offset + Corded Push Mower + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Classic APV



Installing a classic APV system, in which solar panels are positioned over crops, offers DPFLI the opportunity to experiment with co-locating energy and food production. For crops that need slightly more shade or protection from high summer temperatures, APV is a great option to maximize crop yield.

Source: https://tinyurl.com/ClassicAPV

Source: https://tinyurl.com/SinglePoleAPV

Source: https://tinyurl.com/MediumFlowerAPV

Source: https://tinyurl.com/FlowerAPV

MOUNTING & STRUCTURE

This design would consist of a large, permanent, in-ground mounting system, such as poles and racks, with or without poured concrete foundations. Depending on weight, racks can also be gravity driven, eliminating the need for concrete entirely. Depending on the height and layout, it could be tall enough for animals, people, and small mowers to pass under and not inhibit farm work. See the larger image for the classic, generic structure scale.

MULTIFUNCTIONALITY

Crops would continue to receive rain water impact as normal, but this design does offer the benefit of improved water retention.

ENERGY GENERATION & USAGE

Energy can be routed to the building to offset electricity usage on site. Tools could also be easily charged next to the system.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design, likely located in the building. If large structures are not desired, smaller, "flower-like" PV panels can be installed. See the smaller images on this page for variations in mounting methods. Smaller support structures will result in lesser costs.

FARM GOALS ADDRESSED

Demonstration & Research

Positioning classic tilted solar panels above crops would allow DPFLI to increase clean energy production for use on site while maintaining food production. This type of APV design can be maximized for efficient energy production as panels can be tilted to optimize the amount of solar energy captured. In addition, this design offers flexibility in the amount of shading it provides, as panels can be positioned together in an array or spread out to allow for more sunlight to reach crops below.

This design offers unique research and demonstration opportunities. DPFLI could replicate experiments from other parts of the U.S. and the world, providing valuable research on how APV performs in the southeastern Michigan climate.

While this is a conventional APV design, there is room for experimentation. For example, DPFLI could install a variety of different types of panels, including semi-transparent and opaque panels, to understand how different materials affect crop and energy production. It's also possible to install panels in which the tilt can be manually adjusted. This allows for experimentation in the amount of shading provided to crops below as well the potential for protection against hail and snow.

SYSTEM SIZING INFORMATION

2.73 kW System

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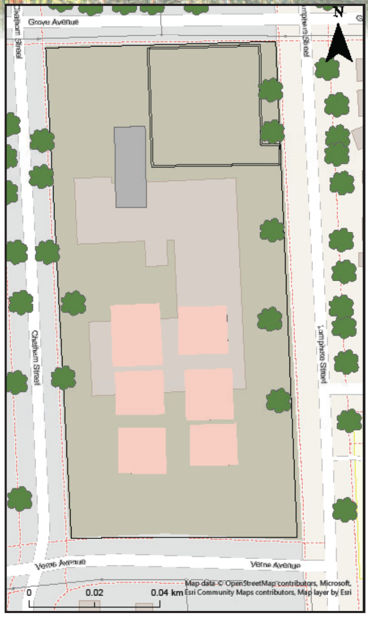
Building Electricity Offset + Corded Push Mower + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting

+ Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Small Bed APV

Much like Classic APV, this design offers DPFLI the ability to stack land use for energy production and food production. This design is just as flexible as classic APV, but with less need for larger, more expensive support structures.



Source: https://www.pv-magazine-india.com/2019/09/30/jodhpur-agrivoltaic-pilot-project-replicated/

Source: https://tinyurl.com/TinyFlowerAPV

Source: https://tinyurl.com/GroundRackAPV

MULTIFUNCTIONALITY

This design offers the benefit of improved water retention and reduced impact from rain on tender sprouts and transplants.

ENERGY GENERATION & USAGE

Energy can be routed to the building to offset electricity usage on site.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design, likely located in the building.

MOUNTING & STRUCTURE

This design mounting is similar to classic APV, but has one key difference; while the classic APV structure is raised off the ground, this design is mostly on the ground. It might require gravity driven support poles or distributed mounting racks, as seen in the images on this page. With less support poles driven into the ground and less need for poured foundations, costs will be reduced. However, this support method requires suitable soil bearing capacities. Poured foundations might be necessary if there is a risk of flooding. The panels can be placed strategically over beds or next to walkways as desired.

FARM GOALS ADDRESSED

Demonstration & Research

Positioning tilted solar panels above and between crops would allow DPFLI to increase clean energy production for use on site while maintaining food production. This type of APV design can be maximized for efficient energy production as panels can be tilted to optimize the amount of solar energy captured. In addition, this design offers flexibility in the amount of shading it provides, as panels can be positioned together in an array or spread out to allow for more sunlight to reach crops below.

Much like the classic APV design, small bed APV offers its own unique experimentation, research, and demonstration opportunities.

SYSTEM SIZING INFORMATION

2.73 kW System

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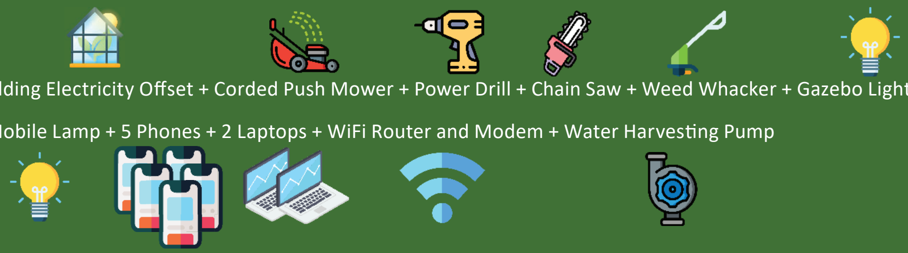
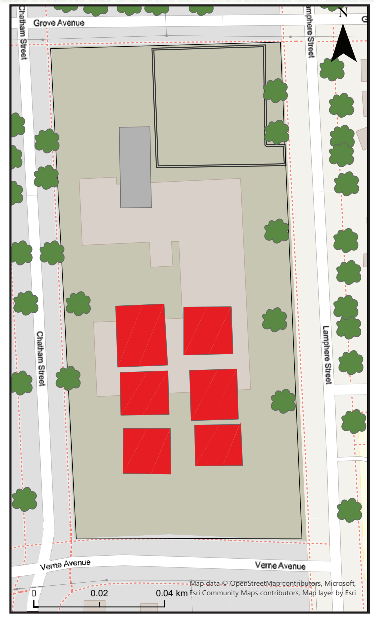


Building Electricity Offset + Corded Push Mower + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem + Water Harvesting Pump

All icons from FlatIcon.com

Bramble APV

PV panels add a flexible amount of shading to provide a suitable environment for brambles or other shade-loving or vining crops. Brambles and other vining foods can be grown under most types of (A)PV installations, meaning this design could be compatible with other system designs as well as a stand-alone design.



Source: https://www.pv-magazine.com/magazine-archive/raspberry-pv-protects-the-crop-and-avoids-waste/

Source: https://tinyurl.com/FruitUnderAPV

MULTIFUNCTIONALITY

The key benefit of this design is the shade provided for vining or shade loving crops. It could be used in tandem with other APV or PV designs, meaning multiple crops can be grown below at once. It can also be combined with a hydroponic system.

ENERGY GENERATION & USAGE

Energy can be routed to the building to offset electricity usage on site. Energy storage can be easily paired with this design, likely located in the building.

MOUNTING & STRUCTURE

While Small Bed APV is short and close to the ground, Bramble APV would be taller with crops growing vertically. The plants can be supported by either the support structure for the panels, or with an additional structure placed strategically and securely underneath. It would most likely require in-ground support poles to support vertical weight.

FARM GOALS ADDRESSED

Demonstration & Research

This design increases clean energy production for use on site while maintaining food production. This type of APV design can be maximized for efficient energy production as panels can be tilted to optimize the amount of solar energy captured. In addition, this design offers flexibility in the amount of shading it provides, as panels can be positioned together in an array or spread out to allow for more sunlight to reach crops below.

Panels can be semi-transparent or opaque, allowing DPFLI to customize how much shading the crops receive. Adjustable tilt panels, whether controlled manually or through an automated system, can also adjust sun exposure to the crops below. This design can support research on how various PV materials and arrangements can affect crop and energy production as a result of variable shading. There is also the potential of this system to provide limited protection from hail and snow.

SYSTEM SIZING INFORMATION

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1.66 kW System =

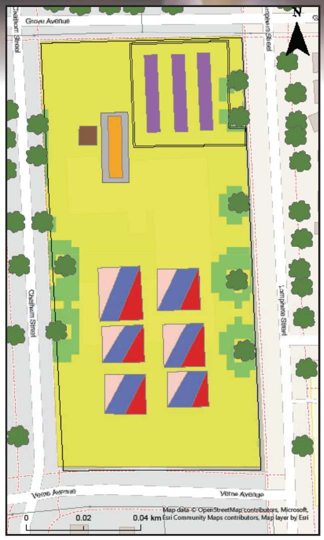
Building Electricity Offset + Power Drill + Chain Saw + Weed Whacker + Gazebo Lighting + Mobile Lamp + 5 Phones + 2 Laptops + WiFi Router and Modem

All icons from FlatIcon.com

Solar + Hydroponic Combination

This design can be a stand-alone design as well as an extension of any other designs within the brief or beyond. By layering a small solar system with a hydroponic system, DPFLI can power an innovative and educational growing system with clean energy. This system can be indoors or outdoors depending on the ideal conditions of the plants in the system. It can be hooked up to a stand-alone water supply and can be refilled when needed, or it can be connected to the building's water supply.

This design can be placed wherever PV is possible, which would be any yellow location on the map to the right.



Source:https://tinyurl.com/MinnesotaCommunitySolarGarden

Demonstration, Research, and Food Sovereignty Benefits

This system has the potential to contribute to sustainable education, research, and demonstration. It shows how clean energy from the sun can be used to power what is known as a "living system" that reuses nutrients, heat, and energy with minimal input. Hydroponic agriculture is also a method of farming without the use of soil, making it a non-conventional, affordable, and empowering demonstration of agriculture, potentially enhancing food sovereignty. With such a integrative and innovative application, this can be useful to the education or experiential learning of many people from diverse backgrounds, including horticultural students, engineering students, volunteers at the farm, community members, and everyone in-between. It can also demonstrate concepts of thermodynamics (heat transfer) and fluid dynamics.

How it Works with Solar

Much like a typical hydroponic system, this one would function in much the same way; a feed of nutrient-rich water from the top of the system to the bottom provides nourishment to plants, whose root systems are located strategically within the water stream. However, typical hydroponic systems require energy use for the use of a water pump or LED lighting. By adding a PV panel, all aspects of the system will be powered by the sun's energy.

DPFLI currently owns a vertical, hydroponic agriculture system. Adding PV panels to the roof of the building on the site, or a small one near the ground outside the building, can provide energy to power a water pump, pH and humidity sensors, grow lights, or any other desired components. Prefabricated hydroponic towers with integrated PV, such as the system shown to the left, are commercially available.

https://tinyurl.com/SolarPoweredHydroponics

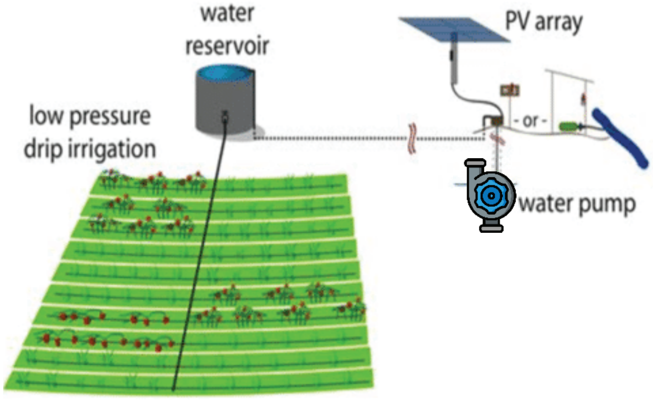
Other Water-Related Applications of PV

Irrigation from Rainwater Harvesting

Hydroponics is not the only water-related integration of solar energy from (A)PV on a farm. If a hydroponic tower is not desired or available, an alternative use is to power a water pump for other uses on-site. For example, a water pump can power an irrigation system, as seen in the diagram below. By using water collected from precipitation, DPFLI reduces water use within the building, keeping overall energy demand and carbon footprint low.

Reduced Overall Water Use

Water cisterns can provide water for both crop irrigation and building water use simultaneously. The larger the energy generation from the PV panels, the more functions those panels can facilitate. Battery storage extends the usefulness of this energy, allowing the pumps to function beyond sun hours.



Source: https://tinyurl.com/SolarIrrigationDiagram

Mobile Mounting Methods

Making a design mobile, such as the Shaded Seating design, allows for greater flexibility and versatility.

BENEFITS OF MOBILITY

Mobile mounting allows DPFLI to move the PV structure wherever it is needed during the day depending on the angles of the sun, the time of year, and what food is being harvested. For example, greater shade is needed for kale and spinach, and being able to move the PV structure to an accessible location near the harvest or over the crop itself will make the entire growing and harvesting process more convenient, prevent wilting of the food, and reduce soil moisture evaporation. This could also benefit volunteers and visitors of the farm, giving them a place to rest in the shade between activities. Since DPFLI's location has little to no shade before PV, the mobile PV structure will allow flexible, optimized shading for any purpose when needed.

Large Stilt Structure (Steel or Wood)

Description of Structure

This metal or wooden support structure will adequately support arrays that contain multiple panels, assuming it is sized appropriately. Depending on the amount of electricity generation that is desired by DPFLI, more panels may be desired, and this structure may offer the most adequate support. It may be placed on wheels, so mobility of an array would be maintained. Smaller arrays on this structure could also be mobile and adequately supported.

Height and Shade

This design also allows for the most height between the ground and the panels. This could be desirable if DPFLI plans on placing a table or multiple beds beneath the structure, such as shaded seating, wash/pack areas, or other gathering spaces.

Safety

This design, however, might not be as safe as other mobile solutions. Due to the nature of the structure, it may allow children to climb the structure. To ensure safety with this design, measures should be taken that prevent climbing and toppling.

Medium Push Wheel Structure

Description of Structure

This design is smaller in size and will support less panels than the large stilt structure. It would be placed on a flat surface, most likely the ground, the stage, or a table. The wheels lock to ensure it will not be vulnerable to rolling. An optional mobile battery could be attached to the structural frame and move with the system as needed.

Height and Shade

This structure might not be as tall as the stilt design and therefore might not necessarily cover multiple raised beds. However, it could be designed in a taller fashion to allow for a larger cast shadow. By designing it this way, it can be placed strategically over certain crops or certain harvested bundles to selectively shade as needed. Mobility allows for this location and shading flexibility throughout the day.

Safety

This design is much safer than the stilt structure and would not require extra protective measures.

Medium to Small Folding Structure

Description of Structure

This support structure is the most flexible and mobile of the three methods suggested. It consists of typically one panel, a housing, and a folding support leg. Some designs or manufacturers will also include a handle for easier portability. With the reduced amount of structural components, this structure will be lighter than others and will aid the mobility of the panel around the site. This optimizes flexibility in where DPFLI wants to provide shade. However, this design supports a lesser number of panels. If DPFLI decides they do not require large amount of energy, this mounting option might be most suitable for mobile methods.

Height and Shade

The leg can be designed or ordered in specific lengths/heights to create the ideal shadow length. The longer the leg, the taller the panel will sit, and the larger the shadow. This will allow more square footage of crops to be shaded when needed. If the panel remains in one location, it would be suitable for shade loving crops such as kale or lettuce. However, since this method is highly flexible, it can be placed over any crop for any amount of time as deemed appropriate.

Safety

This design is also the safest, as it can be folded and stored when not in use.

Source: https://www.smithsonianmag.com/innovation/solar-power-and-honey-bees-180964743/

PV Information and Resources

POLICY, COST, RESEARCH OPPORTUNITIES

Policy Considerations

Zoning and Permitting

DPFLI is located in an R1 Single-Family Residential District, in which accessory structures are allowed up to a height of 15 feet. In addition, they cannot be closer than 10 feet to buildings.

Net Metering

Excess energy sent back to the grid would be credited at market rate, minus distribution charges. This could offer a small revenue stream to help offset upfront costs.

Payback Period & Cost

Carbon Offsetting Results

To offset carbon emissions from electricity consumption in the building on site, DPFLI would need a system sized for a minimum generation of **1.6 kW** at an upfront cost of **$4,013** or more. We assumed that all energy produced by the PV system would be used on site. Using energy bills from 2021, we estimated that the payback period for this PV system would be about **eight years**. This means that around year eight, a PV system would begin to pay for itself through energy bill savings.

Pricing Assumptions

For this cost estimate, we assumed a price per watt of $2.50 for a PV system, including labor. However, costs for installing PV systems can vary widely, depending on the manufacturer, local labor costs, and the type and size of PV system being installed. It's important to consult with a contractor to fully understand local costs. It is also standard practice for contractors to size a PV system larger than a site's energy needs, to account for efficiency losses.

Research Opportunities

DPFLI can offer research opportunities related to APV or PV systems to students and faculty. Future research topics include, but are not limited to:

1. EFFECTS OF APV ON SURFACE TEMPERATURE OF CROPS
2. SOIL MOISTURE LEVELS OF CROPS UNDER APV
3. EVAPOTRANSPORTATION UNDER APV SYSTEMS
4. SOIL CARBON LEVELS UNDER APV
5. APV EFFECTS ON INSECT BIODIVERSITY AND/OR BEHAVIOR
6. APV EFFECTS ON POLLINATORS
7. MICRO-CLIMATES RELATED TO APV SYSTEMS
8. YIELD IMPACTS OF CROPS GROWN UNDER APV
9. STACKED LAND USE RESEARCH RELATED TO APV AND CROP YIELD
10. HYDROPONICS RESEARCH

Community Learning

(A)PV Installation and Learning Days

(A)PV installations of any kind have the potential to be educational, particularly if students or volunteers participate in the installation. (A)PV designs that could be suitable for group installation include Solar and Hydroponic designs and Small Bed designs. These types have either small support structures or have the option to be modular in set up, making them ideal for community participation without professional oversight. The manufacturer or contractor would give specific guidance and instruction as needed to maintain safety and proper installation.

Funding Resources

Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR.

The AgriEnergy and Sustainable Farming Program offered by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) provides funding for farms and small businesses to invest in energy efficiency and renewable energy projects. The program has $100,000 to distribute, with a maximum of $15,000 for eligible projects. Project funding is limited to 50% of the total project cost.

Operation & Maintenance

It's important to note that PV manufacturers have specific recommendations for their products to maximize the lifetime of your system. They will also have specific information on how often system components need to be maintained, which can vary by manufacturer, system size, and more. The manufacturer's guidance should be the main resource for operation, maintenance, and cleaning instruction.

Cleaning

To keep your system clean and effective, clean it with warm water and soap as needed. You can use a hose to water down the panels, or you can use a soft cloth or sponge to prevent scratches. Wiring and other electronic components do not require cleaning and should not be washed in order to prevent ground fault interruption damage and maintain safety.

Maintenance

PV systems require maintenance throughout their lifetime. The frequency depends on the manufacturer of the system components, but expect maintenance to be required every 3-6 years. Costs may include labor or replacement for damaged components.

Warranty

Depending on the manufacturer, PV panel warranty timelines can be measured by a pre-determined number of years after purchase or based on the panels' generation output. Pre-determined year warranties typically cover more costs for a shorter amount of time, whereas output warranties will last throughout the panel's lifetime but cover a smaller proportion of costs as panel output efficiency decreases.

D-TOWN FARMS
APV/PV Design Brief

April 2022 Date Issued
04 Design Revision

Schematic Design Iterations

Designed and Compiled by the Urban Farm APV Master's Project Team at the University of Michigan School for Environment and Sustainability

Team Members: Brian Geiringer, Karlene Robich, Julian Tabron, Jess Tang, Rebecca Turley

Source: https://towardfreedom.org/story/black-food-spaces-seed-sovereignty/

DESIGN OVERVIEW

D-Town Farm's Commitment to Community

As a member of the Detroit Black Community Food Security Network (DBCFSN), D-Town Farm is a space where community members can gather, learn about, and celebrate locally-grown food. D-Town is Detroit's largest urban farm, practicing sustainable cultivation of 40 different crops in an effort to promote food sovereignty and security, particularly among Detroit's Black community.

Energy is a crucial aspect of the farm's operations, as the organization envisions expanding its crop production and hosting more community events in the future. With D-Town's commitment to sustainability, solar energy produced on site to power the farm and its operations is a key long-term goal of the organization. Incorporating on-site production of solar energy will help D-Town meet its goals of promoting food security, sovereignty, and sustainability.

A variety of different types of solar PV systems could be developed on the farm to meet particular needs. Some of the organization's most significant energy needs are charging power tools on site, powering fans for more hoop houses to increase production, and providing energy for speakers, microphones, and recording equipment to be used during community events. This design brief will detail various potential (A)PV solutions to assist the farm in achieving and maintaining their overarching goals, which are as follows:

- Perpetuate food sovereignty by sustainably increasing growing season and food production
- Perpetuate energy sovereignty by streamlining operations with on-site power
- Enhance community connections by hosting more community events on the farm

These goals provide design intent and act as a foundation for the development of all included designs.

Visualizing Farm Goals

Additional Considerations

Through conversations with the farm, our team outlined some additional considerations to develop designs in the pursuit of the farm's mission:

- Designs should consider flooding risks, as D-Town is located in a 100-year floodplain.
- Designs should lend themselves to community building and self-determination.
- Designs should support farmers and their work, and enhance the overall function of the organization.
- Stand-alone systems are preferred to maintain energy and food sovereignty outside of the grid.

POTENTIAL SYSTEM CAPACITY

10.1 kW - 16.3 kW

A measure of electricity generation potential, depending on what the power is used for.

UPFRONT COSTS

$ 25,250 - $40,750

The average total cost of a 10.1 kW - 16.3 kW system. A smaller system can be selected which will reduce system cost.

Source: https://goodlifedetroit.com/wp-content/uploads/2019/09/ZechariahReggaeDancing.jpeg

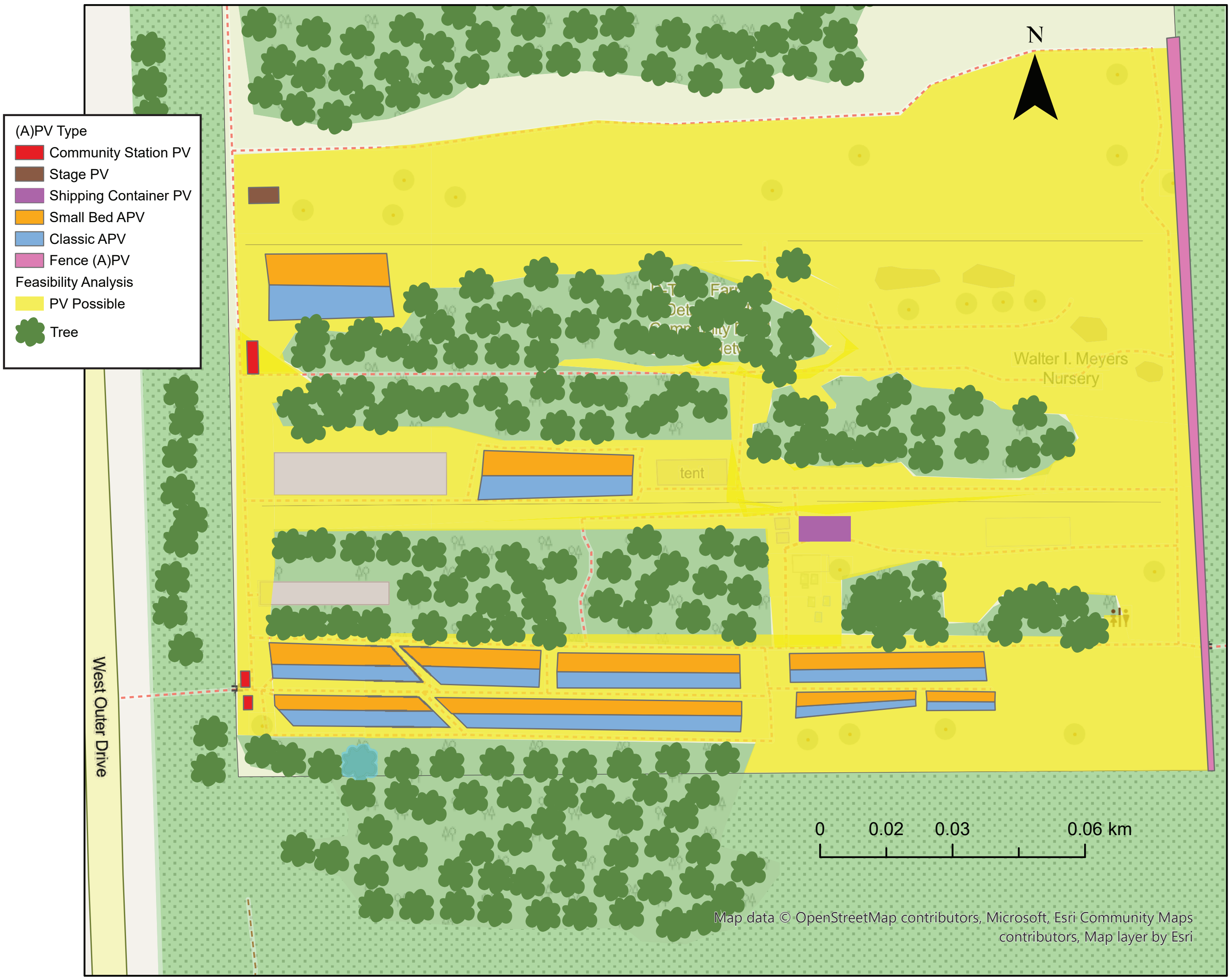
SUITABILITY MAP

Developed Using Esri's ArcGIS Pro Software

This page contains a map of the site that shows suitable or possible areas of each (A)PV design included in the brief. It is color coded for clarity, and was developed using GIS software and the ArcGIS ModelBuilder tool. A small key in the corner of each subsequent design page will indicate that specific design's most suitable locations, taken from this map.

The suitable (A)PV areas are represented using yellow shading ("PV Possible"), and the light green areas are not recommended due to high tree canopy coverage.

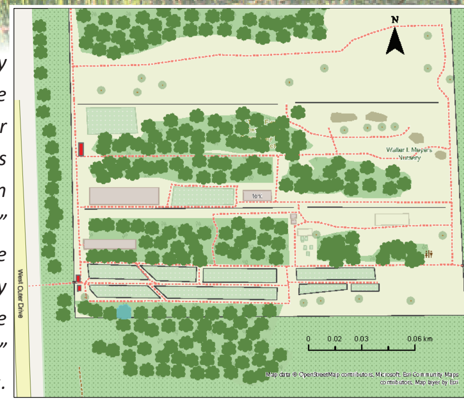
Suitability for (A)PV installation was determined by analyzing area solar radiation and slope analysis. A digital surface model (DSM) was created using Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey, which identified open areas and other site features, such as canopy coverage, buildings, structures, and steep hill faces. For an area to be considered suitable for PV installation, the slope surface must be less than 32° in angle (not located on a sharp hill or the side of a building) and the area solar radiation must be greater than 800 kWh/m² (the minimum recommended radiation required for PV panels to be effective).



Community Station PV

Using solar panels to provide shade for community members and events is an innovative way of integrating energy production within the farm.

Community Station PV can be located wherever D-Town desires as long as it is in a "PV Possible" location. See full Suitability map for more "PV Possible" locations.



MOUNTING & STRUCTURE

A solar array can be mounted atop supporting poles to act as a shade structure, or be installed on top of a gazebo structure. Depending on the structure design, concrete footings may or may not be required. Tables and seating could be positioned below the structure. There are also a selection of prefabricated Solar PV benches available for purchase commercially.

There is potential for this design to be mobile with the incorporation of wheels at the base.

Source https://tinyurl.com/UMSolarBench

ENERGY GENERATION & USAGE

A number of electrical receptacles can be used to charge electronic devices. It can be located near the entrance where volunteers gather for breaks, or in the festival area of the farm to be used for cooking demonstrations.

Source: https://tinyurl.com/PergolaPV

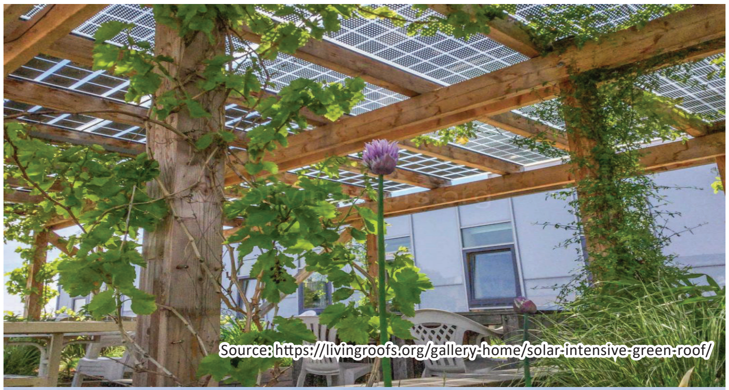
Source: https://newenergyworks.com/the-solar-canopy

FARM GOALS ADDRESSED

Community Building and Energy Sovereignty

This type of solar system could be used to promote a sense of community and place at D-Town Farm, inviting people to sit and spend time on site. In addition, having covered areas could allow D-Town to hold more community events in the summer and fall, such as concerts, talks, lessons, or demonstrations.

Energy generated by the solar panels could provide electricity for equipment such as microphones, amps, laptops, or phone charging stations. Producing this energy for events on-site would promote both D-Town's values of self-determination and community building.



Source: https://livingroofs.org/gallery-home/solar-intensive-green-roof/

Source: https://livingroofs.org/gallery-home/solar-intensive-green-roof/

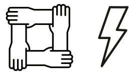
SYSTEM SIZING INFORMATION

16.3 kW System = Power Drill + Chain Saw + 3 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop + 8 Phones + Portable Cook-top + 2 Microphones + Speaker + Sound Mixer + Corded Push Mower + Pond Pump

Power Drill + Chain Saw + 2 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop or 12 Phones + Portable Cook-top + Microphone + Speaker + Sound Mixer = 10.1 kW System

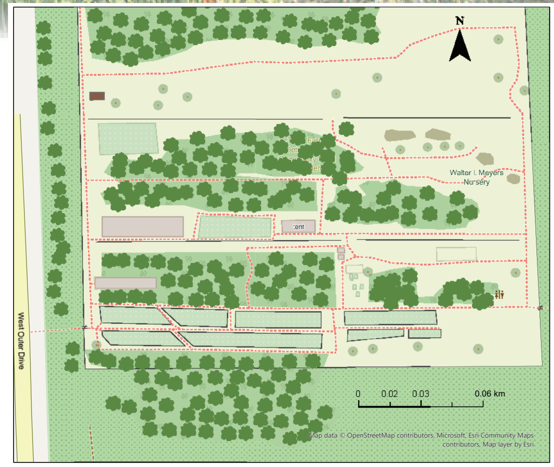
All icons from FlatIcon.com

Stage PV



A PV array installed above a stage can serve as a multipurpose focal point for community events, rest, and connection.

Stage PV can be located where D-Town desires to put a stage as long as it is in a "PV Possible" location. See full Suitability map for more "PV Possible" locations.



MOUNTING & STRUCTURE

This design would be larger in scale than most other designs to accommodate a large capacity of energy generation. It is permanent and requires poured concrete footings, a wooden canopy structure, and mounting racks.

The space underneath a stage canopy can be used as a weather shade for the stage and can protect various electronics, including power tools and audio/visual equipment.

MULTIFUNCTIONALITY

Since the stage would be covered, it can become a multipurpose space, a community gathering space, a farmer and volunteer rest space, and a charging station. This versatility lends itself to cost-effectiveness and will ultimately be determined by how D-Town's community chooses to use the space.

ENERGY GENERATION & USAGE

Energy can be used directly on the site for tools, devices, water pumps, and more. The most accessible use of a Stage PV system would be to power audio/visual equipment for performances and festivals, as well as a portable cook-top for cooking demonstrations.

The large energy generation capacity coupled with battery storage is a useful solution for community events that require electronic equipment use over a certain number of hours, even when the sun might not be shining.

Source: https://tinyurl.com/PergolaPV

FARM GOALS ADDRESSED

Energy Sovereignty, Community Building

Much like the Community Station PV design, this type of solar system could be used to promote a sense of community and place at D-Town Farm by inviting people to sit and spend time on site. Having covered areas could allow D-Town to hold more community events in the summer and fall, such as concerts, talks, lessons, or demonstrations. Energy generated by the solar panels could provide electricity for equipment such as microphones, amps, laptops, or phone charging stations. Battery storage would allow D-Town to use this energy whenever desired, including evening hours. Producing this energy on-site to be used for events would promote both D-Town's values of energy sovereignty and community building.

Source: https://www.thesolarnerd.com/blog/solar-gazebo-pergola/

Source: https://i.pinimg.com/originals/82/66/74/826674e6bba6ee21836501b9783ce775.png

SYSTEM SIZING INFORMATION

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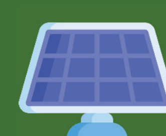
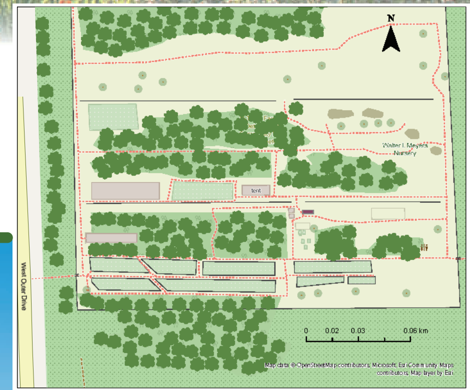
Power Drill + Chain Saw + 2 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop or 12 Phones + Portable Cook-top + Microphone + Speaker + Sound Mixer = 10.1 kW System



All icons from FlatIcon.com

Shipping Container PV

Updating or replacing D-Town Farm's existing PV system atop a shipping container and potentially expanding this system would allow the farm to continue generating solar energy on site. This PV design has already been designed, installed, tested, and it integrates well within the farm's operations.



Source: https://www.modeldmedia.com/features/Detroit-solar-energy-121817.aspx

MOUNTING & STRUCTURE

Additional infrastructure may be needed to maintain or improve this system, including general maintenance, potential connection upgrades, or potential capacity upgrades. Expanding the capacity may also require another shipping container.

ENERGY GENERATION & USAGE

This system does not impact food production, although it does provide a needed source of energy. Tools can be charged here and stored securely inside the shipping container. If energy is used to cool food inside the container, it could also be a place for employees and volunteers to cool off during hot summer months.

FARM GOALS ADDRESSED

Energy & Food Sovereignty, Community Building

Stand-alone systems that are not grid-tied allow continued energy sovereignty on the site. It also allows more direct energy for on-site operations. If D-Town routes electricity towards the festival or community area, it can also contribute to community building by powering audio/visual equipment or a portable cook-top.

OPTIONAL MODIFICATIONS

A secured battery storage component can store energy for times when electricity is not actively produced by the panels, such as nighttime, or if the system is generating more electricity than you need in that moment.

SYSTEM SIZING INFORMATION

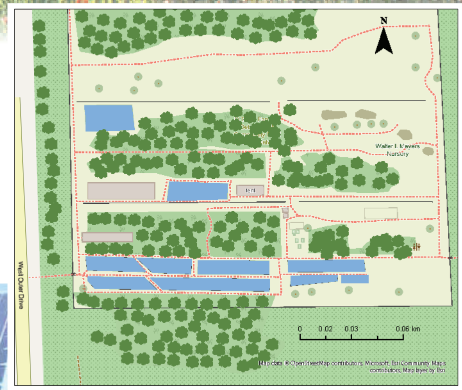
16.3 kW System = Power Drill + Chain Saw + 3 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop + 8 Phones + Portable Cook-top + 2 Microphones + Speaker + Sound Mixer + Corded Push Mower + Pond Pump

Power Drill + Chain Saw + 2 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop or 12 Phones + Portable Cook-top + Microphone + Speaker + Sound Mixer = 10.1 kW System

All icons from FlatIcon.com

Classic APV

Installing a classic APV system, in which solar panels are positioned over crops, offers D-Town the opportunity to co-locate energy and food production. For crops that need slightly more shade or protection from high summer temperatures, APV is a great option to maximize crop yield.



Source: https://tinyurl.com/ClassicAPV

Source: https://tinyurl.com/SinglePoleAPV

MOUNTING & STRUCTURE

It would consist of a large, permanent, in-ground mounting system, such as poles and racks with poured concrete foundations. Racks can also be gravity driven, eliminating the need for concrete entirely. The PV system would be positioned strategically over crops and stand at a moderate height. It could be tall enough for animals and people to pass under, but not necessarily tall enough for certain equipment.

MULTIFUNCTIONALITY

Crops would continue to receive rain water impact as normal, but this design does offer the benefit of improved water retention.

ENERGY GENERATION & USAGE

Energy can be used directly on the site for tools, devices, water pumps, and more. Tools could also be easily charged next to the system.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design, likely located in the building. If large structures are not desired, smaller, "flower-like" PV panels can be installed. See the smaller images on this page for variations in mounting methods. Smaller support structures will result in lesser costs.

FARM GOALS ADDRESSED

Food & Energy Sovereignty

This design provides increased food production for shade-loving crops or more pollinator habitats, which will further enhance food productivity. There is also the benefit of increased water retention in the soil.

Stand-alone systems that are not grid-tied allow continued energy sovereignty on the site. It also allows more direct energy for on-site operations.

Source https://tinyurl.com/MediumFlowerAPV

Source: https://tinyurl.com/FlowerAPV

SYSTEM SIZING INFORMATION

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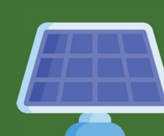
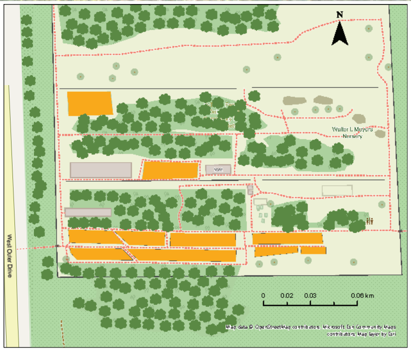


All icons from FlatIcon.com

Small Bed APV

This APV design lays low to the ground. It provides the benefits of APV without expensive support structures.



MULTIFUNCTIONALITY

Some potential uses for APV include growing shade-tolerant herbs like cilantro or root vegetables, and providing shade over a pollinator habitat. Both of these benefits can support food productivity.

ENERGY GENERATION & USAGE

Energy can be routed to the side of the bed or somewhere else to provide power for device and tool charging.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

MOUNTING & STRUCTURE

APV mounted on ground-level racks can provide shading by being placed over crops and can be spaced as desired. This can be set up across the entire bed, or it can be located along the edges of beds to not block the sun on the crops. There is flexibility in the location of the structures, how tall they are, how opaque they are, and what can be placed under it. Higher mounting would likely result in greater variability of shading, while greater transparency would let more light through to limit the direct sun trade-offs of an opaque panel above crops. At this scale, the panels can be relocated easily

This system can be large as depicted, or can be scaled down to one or two rows.

FARM GOALS ADDRESSED

Food & Energy Sovereignty

This design provides increased food production for shade-loving crops or more pollinator habitats, which will further enhance food productivity. There is also the benefit of increased water retention in the soil.

Stand-alone systems that are not grid-tied allow continued energy sovereignty on the site. It also allows more direct energy for on-site operations.

SYSTEM SIZING INFORMATION

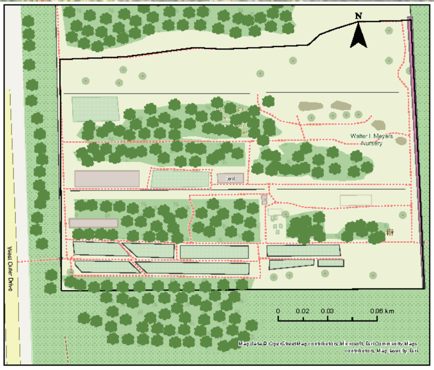
16.3 kW System = Power Drill + Chain Saw + 3 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop + 8 Phones + Portable Cook-top + 2 Microphones + Speaker + Sound Mixer + Corded Push Mower + Pond Pump

Power Drill + Chain Saw + 2 Weed Whackers + Portable Charging and Lighting Device + Picnic Table Lamps + 1 Laptop or 12 Phones + Portable Cook-top + Microphone + Speaker + Sound Mixer = 10.1 kW System

All icons from FlatIcon.com

Fence (A)PV

By utilizing existing or new fencing structure for energy generation, D-Town has the potential to make more efficient use of their space. This design may also be one of the easiest to get approved by the city.



FARM GOALS ADDRESSED

Food & Energy Sovereignty, Community Building

Stand-alone systems that are not grid-tied allow continued energy sovereignty on the site. It also allows the use of direct energy for on-site operations. This can contribute to community building goals as well if it is used to power a portable cook-top for cooking demonstrations, or as a power source for audio/visual equipment.

MULTIFUNCTIONALITY

The space underneath the PV might be a suitable environment for brambles and vine crops to grow, or for pollinator habitats to enhance biodiversity. This design wouldn't interfere with crop production, which would maintain current operations as it currently is. It would provide additional energy without taking up any more physical space on the site.


Source: https://tinyurl.com/PVFenceDIYForum


Source: https://tinyurl.com/FullPVFence

MOUNTING & STRUCTURE

This design depends on an existing wooden or steel fence that is sturdy and stable enough to support a small PV system. If no such fence exists, one can be built to accommodate PV panels of certain dimensions. Alternatively, the panels themselves can act as a fence.

Vertical panels might not produce as much energy as tilted panels, but there are certain innovations that could maximize energy generation. Bi-facial panels can capture light from both sides and would allow the fence to generate electricity from multiple angles. Panels can also be placed on a rotating axis, and the tilt can be adjusted manually or automatically to adjust the amount of energy and shade generation.


Source: https://tinyurl.com/SmallestFencePV

ENERGY GENERATION & USAGE

Electricity generated from Fence PV can power laptops, phones, tools, lamps, a WiFi router, or a battery to use for any desired application.

MODIFICATIONS & CONSIDERATIONS

If vines grow over the panels, regular pruning may be needed.

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

The other components of a PV system could be mounted on the fence or located near the fence to minimize the length of conduit running from the panels.


Source: https://youtu.be/7t4hGBWLtxM

SYSTEM SIZING POTENTIALS

10.1 kW System = 25 400W-panels or 100 100W-panels

5 kW System = 13 400W-panels or 50 100W-panels

2.5 kW System = 7 400W-panels or 25 100W-panels

1 kW System = 3 400W-panels or 10 100W-panels

Mobile Mounting Methods

Making a design mobile, such as the Community Station PV design, allows for greater flexibility and versatility.

BENEFITS OF MOBILITY

Mobile mounting allows D-Town to move the PV structure wherever it is needed during the day depending on the angles of the sun, the time of year, and what food is being harvested.Mobile PV panels can provide more shade for crops which need it, and can be moved to correspond with crop rotations each year. The extra shade can also contribute to improving soil moisture. In addition, mobile PV panels can be used to provide shade for storing harvested crops, reducing wilting and spoilage. This could also benefit volunteers and visitors of the farm, giving them a place to rest in the shade between activities.

Large Stilt Structure (Steel or Wood)

Description of Structure

This support structure will adequately support arrays that contain multiple panels, assuming it is sized appropriately. Depending on the amount of electricity generation that is desired by D-Town, more panels may be desired, and this structure may offer the most adequate support. It is placed on wheels, so mobility of an array would be maintained. Smaller arrays on this structure would also be mobile and adequately supported.

Height and Shade

This design also allows for the most height between the ground and the panels. This could be desirable if D-Town plans on placing a table or multiple beds beneath the structure, such as shaded seating, wash/pack areas, or other gathering spaces.

Safety

This design, however, might not be as safe as other mobile solutions. Due to the nature of the structure, it may allow children to climb the structure. To ensure safety with this design, measures should be taken that prevent climbing and toppling at the recommendation of a contractor.

Medium Push Wheel Structure

Description of Structure

This design is smaller in size and will support less panels than the large stilt structure. It would be placed on a flat surface, most likely the ground, the stage, or a table. The wheels lock to ensure it will not be vulnerable to rolling. An optional mobile battery could be attached to the structural frame and move with the system as needed.

Height and Shade

This structure might not be as tall as the stilt design and therefore might not necessarily cover multiple raised beds. However, it could be designed in a taller fashion to allow for a larger cast shadow. By designing it this way, it can be placed strategically over certain crops or certain harvested bundles to selectively shade as needed. Mobility allows for this location and shading flexibility throughout the day.

Safety

This design is much safer than the stilt structure and would not require extra protective measures.

Medium to Small Folding Structure

Description of Structure

This support structure is the most flexible and mobile of the three methods suggested. It consists of typically one panel, a housing, and a folding support leg. Some designs or manufacturers will also include a handle for easier portability. With the reduced amount of structural components, this structure will be lighter than others and will aid the mobility of the panel around the site. This optimizes flexibility in where D-Town wants to provide shade. However, this design supports a less panels. If D-Town decides they do not require a large amount of energy, this mounting option might be most suitable for mobile methods.

Height and Shade

The leg can be designed or ordered in specific lengths/heights to create the ideal shadow length. The longer the leg, the taller the panel will sit, and the larger the shadow. This will allow more square footage of crops to be shaded when needed. If the panel remains in one location, it would be suitable for shade-loving crops such as spinach or lettuce. However, since this method is highly flexible, it can be placed over any crop for any amount of time as deemed appropriate.

Safety

This design is also the safest, as it can be folded and stored when not in use.

Source: https://www.smithsonianmag.com/innovation/solar-power-and-honey-bees-180964743/

PV Information and Resources

Policy, Cost, Research Opportunities

Policy Considerations

Zoning and Permitting

In Detroit, solar systems are regulated according to the district which they reside in. D-Town is located in a Parks and Recreation (PR) District, which means that "conditional use" of solar is allowed. Under "conditional use" designation, the city must review the PV system before providing building permits.

Net Metering

If D-Town decides to connect to the grid, excess energy would be credited at market rate, minus distribution charges. This could offer a small revenue stream to help offset upfront costs.

Cost Breakdown

The cost of a PV system will be approximately $2.50 per watt of the DC system size.

The cost of the electrical equipment used to calculate approximate system size is not included in the cost of the PV system itself. Electric equipment that requires purchase will be an indirect cost of an APV or PV installation if D-Town decides to transition away from gas equipment. The 16.3 kW system and 10.1 kW system would require an additional $2,648 and $1,761 for electrical equipment purchase, respectively.

If D-Town would like a different system size, the following chart can be used to estimate the energy demand and cost, and from there a contractor or engineer can appropriately size the system.

Electrical Load	Cost per Unit	Estimated Wattage (W)
Corded Electric Push Mower	$300	1600
Battery-Op Power Drill (1")	$200	1000
Battery-Op Power Chain Saw (12")	$200	1100
Week Whacker 1	$150	500
Portable Solar Charging and Lighting System	$70	15
2 Picnic Table Lamps	$50	26
Mobile Battery-Op Lamp	$37	10
Phone	N/A	8
Laptop	N/A	100
Electric Cook-top	$50	1500
Microphone	$130	0.3
Speaker	$290	1400
Sound Mixer	$100	700
Electric Pond Pump	$270	306

Organization & Community Benefits

Benefits and support provided to the community include electricity sharing, educational opportunities about sustainable farming, enhanced community connection, and strengthening the existing relationship between Ryter Industries and DBCFSN.

Community Learning Days

(A)PV installations of any kind have the potential to be educational, particularly if students or volunteers participate in the installation. (A)PV designs that could be suitable for group installation include Fence PV, Community Station PV, and Small bed APV. These types have either small support structures or have the option to be modular in set up, making them ideal for community participation without professional oversight. The manufacturer or contractor would give specific guidance and instruction as needed to maintain safety and proper installation.

Funding Resources

Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR.

The AgriEnergy and Sustainable Farming Program offered by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) provides funding for farms and small businesses to invest in energy efficiency and renewable energy projects. The program has $100,000 to distribute, with a maximum of $15,000 for eligible projects. Project funding is limited to 50% of the total project cost.

Operation & Maintenance

It's important to note that PV manufacturers have specific recommendations for their products to maximize the lifetime of your system. They will also have specific information on how often system components need to be maintained, which can vary by manufacturer, system size, and more. The manufacturer's guidance should be the main resource for operation, maintenance, and cleaning instruction.

Cleaning

To keep your system clean and effective, clean it with warm water and soap as needed. You can use a hose to water down the panels, or you can use a soft cloth or sponge to prevent scratches. Wiring and other electronic components do not require cleaning and should not be washed in order to prevent ground fault interruption damage and maintain safety.

Maintenance

PV systems require maintenance throughout their lifetime. The frequency depends on the manufacturer of the system components, but expect maintenance to be required every 3-6 years. Costs may include labor or replacement for damaged components.

Warranty

Depending on the manufacturer, PV panel warranty timelines can be measured by a pre-determined number of years after purchase or based on the panels' generation output. Pre-determined year warranties typically cover more costs for a shorter amount of time, whereas output warranties will last throughout the panel's lifetime but cover a smaller proportion of costs as panel output efficiency decreases.

April 2022 Date Issued
04 Design Revision

UNIVERSITY OF MICHIGAN CAMPUS FARMS APV/PV Design Brief

Schematic Design Iterations

Designed and Compiled by the Urban Farm APV Master's Project Team at the University of Michigan School for Environment and Sustainability

Team Members: Brian Geiringer, Karlene Robich, Julian Tabron, Jess Tang, Rebecca Turley

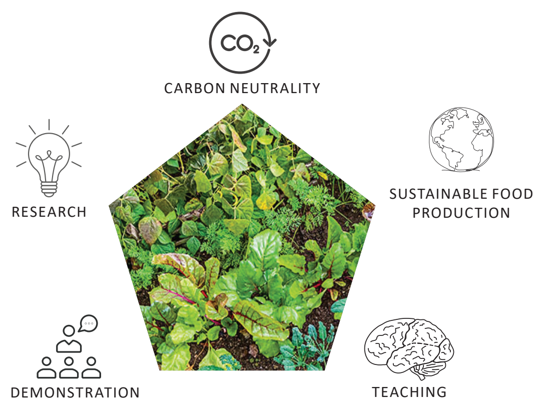
DESIGN OVERVIEW

Commitment to Carbon Neutrality

University of Michigan created a carbon neutrality plan in 2021 that promises to reach carbon neutrality for scope 1 emissions by 2040. In response to this plan, the Campus Farm set a goal of offsetting all the carbon emissions generated on-site by 2026. The Campus Farm aims to install a 100 kW agrivoltaics (APV) system that will offset its current emissions from electricity, natural gas, and diesel consumption.

In addition to generating renewable energy for use on site, an APV system can also provide additional benefits to the farm, such as demonstration and research opportunities and extra shade where needed. It could help increase crop yields, as well as provide an educational experience for students and visitors of the farm and gardens.

Visualizing Farm Goals



Working Towards Greater Goals

Although carbon neutrality is the predominant reason for considering APV, there are other goals the farm is working towards that APV could contribute to;

- Renewable energy and stacked land use education
- Sustainable food production
- Increasing awareness and understanding of technology's potential roles in agriculture through demonstration

APV has the potential to play a role in all of these goals, therefore the goals are used as design criteria for APV designs. By investigating APV potential and recommending possible implementation solutions, we aim to remove barriers from future implementation should the university move forward with an installation.

Additional Considerations

The following additional considerations were developed by the team through conversations with farm representatives;

- View-shed of the farm landscape must be maintained in an aesthetic way.
- All designs must be low maintenance and easily accessible.
- Any electrical systems or components must be strategically placed to prevent excess energy and voltage loss.

EMISSIONS OFFSET GOAL

1,841,744 lb CO2e

The total amount of carbon dioxide equivalent the farm seeks to offset, including electricity and natural gas emission sources.

ELECTRICITY GENERATION MINIMUM

97 kW

The calculated system capacity required to offset the Campus Farm's carbon footprint.

UPFRONT SYSTEM COSTS

$ 155,875

The average total upfront cost of a 63 kilowatt capacity system.*

COST PAYBACK PERIOD

21 years

The number of years it will take for the farm to earn back all investment costs of a 63 kilowatt system.*

* 63 kW required to offset carbon emissions. Accounting for losses and efficiencies, final DC system capacity would be 97 kW. Cost is calculated for carbon offset only, not entire system.

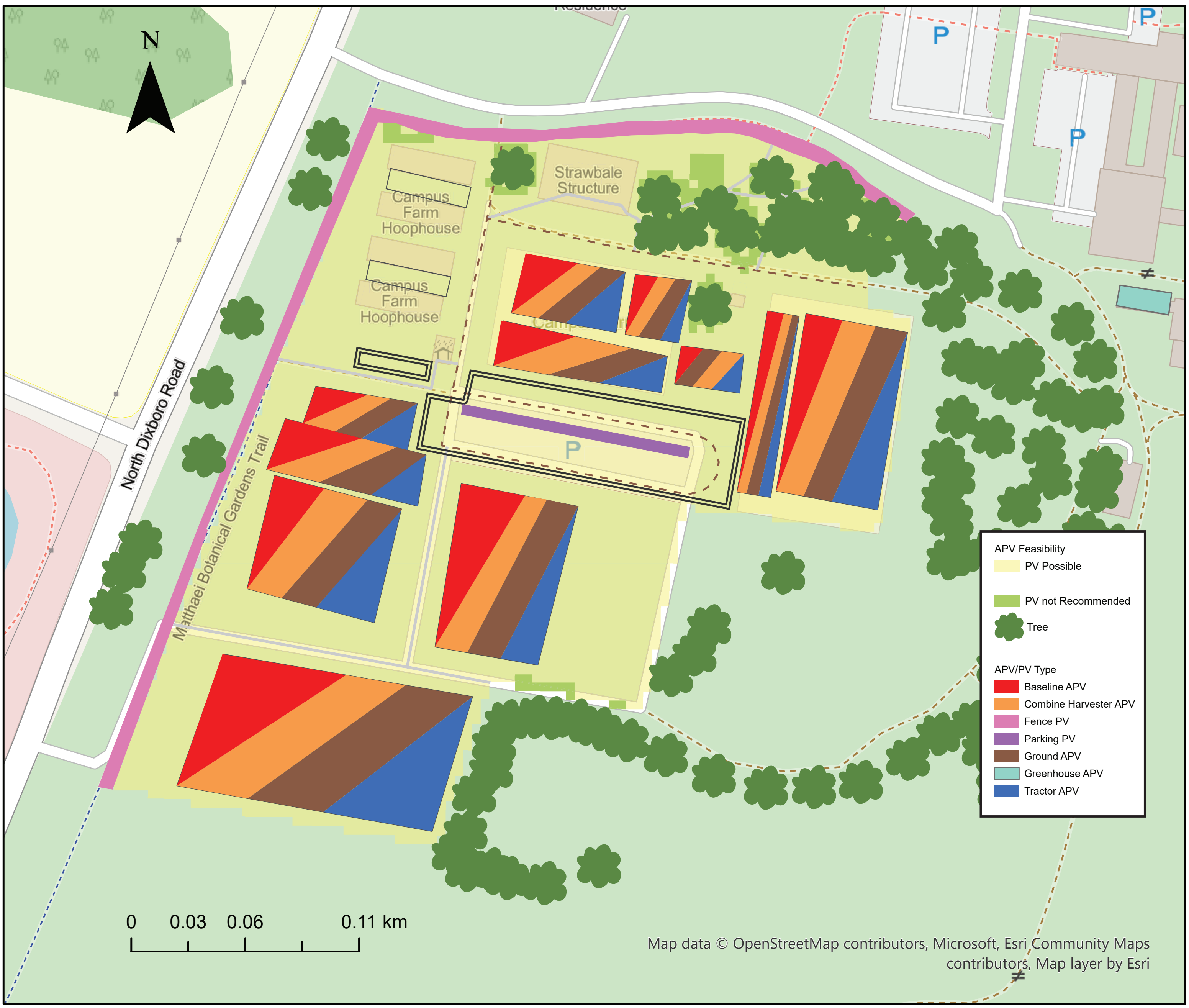
SUITABILITY MAP

Developed Using ESRI's ArcGIS Pro Software

This page contains a map of the site that shows suitable or possible areas of each (A)PV design included in the brief. It is color coded for clarity, and was developed using GIS software and the ArcGIS ModelBuilder tool. A small key in the corner of each subsequent design page will indicate that specific design's most suitable locations, taken from this map.

The suitable (A)PV areas are represented using transparent yellow shading ("PV Possible"), and the light green areas are not recommended due to high tree canopy coverage.

Suitability for (A)PV installation was determined by analyzing area solar radiation and slope analysis. A digital surface model (DSM) was created using Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey, which identified open areas and other site features, such as canopy coverage, buildings, structures, and steep hill faces. For an area to be considered suitable for PV installation, the slope surface must be less than 32° in angle (not located on a sharp hill or the side of a building) and the area solar radiation must be greater than 800 kWh/m² (the minimum recommended radiation required for PV panels to be effective).



Baseline APV

This design will be used as a reference for the most common APV solution at farms of similar sizes to Campus Farm.


Source: https://tinyurl.com/ClassicAPV


Source: https://tinyurl.com/LargePoleAPV


Source:https://tinyurl.com/CSUResearchesAPV


Source: https://tinyurl.com/NPRonAPV

MOUNTING & STRUCTURE

It would consist of a large, permanent, in-ground mounting system, likely with poles and racks, with or without poured concrete foundations. Depending on weight of the PV system, racks can also be gravity driven, eliminating the need for concrete entirely. They can be spaced at any desired width, as seen in the images on this page.

MULTIFUNCTIONALITY

Tall APV allows the farm to benefit from stacked land use and offset the farm's carbon emissions while providing the unique advantages of shading and continued food production. Pollinator habitats can also be placed near the panels.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions.

OPTIONAL MODIFICATIONS

The height of this design is customizable. Depending on the desired height and layout, it could be tall enough for animals, people, and small mowers to pass under and not inhibit farm work. The Tractor-Friendly APV and Combine Harvester-APV designs on other pages show this design in various heights to allow various equipment to pass through.

FARM GOALS ADDRESSED

Sustainable Food Production and Carbon Neutrality

This type of APV design can be maximized for efficient energy production as panels can be tilted to optimize the amount of solar energy captured. In addition, this design offers flexibility in the amount of shading it provides, as panels can be positioned together in an array or spread out to allow for more sunlight to reach crops below.

Research, Demonstration, and Teaching

Because this type of APV design is one of the most common, it offers unique research and demonstration opportunities. UM Campus Farm could replicate experiments from other parts of the U.S. and the world, providing valuable research on how APV performs in the southeastern Michigan climate.

There is room for experimentation in this design. For example, the Campus Farm could install a variety of different types of panels, including semi-transparent and opaque panels, to understand how different materials affect crop and energy production.

It's also possible to install panels in which the tilt can be manually adjusted. This allows for experimentation in the amount of shading provided to crops below as well the potential for protection against hail and snow.

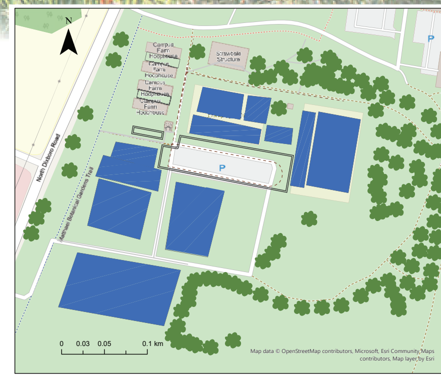
SYSTEM SIZING INFORMATION

97.3 kW System = Carbon Emission Offset + Power Drill + Chain Saw + Weed Whacker + Picnic Table Lighting + Water Harvesting Pump

All icons from FlatIcon.com

Tractor-Friendly APV

This design is a taller version of Baseline APV.



Source: https://tinyurl.com/TractorAPV

Source: https://tinyurl.com/PouredFootingAPV

Source: https://tinyurl.com/Tractor-BetweenAPV

MOUNTING & STRUCTURE

Due to the Campus Farm's use of tractors and larger equipment, this design is raised for a minimum of 12 - 15 feet clearance depending on the height of Campus Farm's tractor, so that it can move beneath the array without disruption. The panels can also be on motorized adjusters to tilt the panels as tractors pass through and gain more clearance space.

Taller structures weigh more and require more structural support. The system would consist of large PV panels mounted on tall, permanent structures on a poured foundation for ensured stability. The number of support poles can vary depending on the total weight of the system, as well as the chosen diameter of the support poles. This is important to consider in order to maintain maximum access and minimize disturbance to the crops underneath.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions.

OPTIONAL CONSIDERATIONS

Larger arrays built to allow for freedom of movement with tractors and other equipment also require larger mounting systems. This means tractor-friendly designs are typically more expensive. This design would likely necessitate concrete foundations, which offer less flexibility and may be more difficult to get approved. This larger design would also be more visible from the road, another consideration in receiving university approval.

FARM GOALS ADDRESSED

Carbon Neutrality

Larger arrays would also likely be larger in generation capacity to make the system cost-effective, meaning more solar energy produced to contribute to the farm's carbon neutrality.

Research, Demonstration, and Teaching

A tractor-friendly APV system would allow the Campus Farm to provide valuable research opportunities on large-scale APV systems and farming machinery, developing probable applications for Midwestern farming contexts.

Sustainable Food Production

Taller APV system designs create less of a micro-climate for crops below, as more sunlight is able to penetrate around the panels and through to the ground. This design allows for more flexibility in farming practices, as modern farm equipment such as tractors, mowers, or combine harvesters could be operated underneath the panels—a key benefit for larger farms.

MULTIFUNCTIONALITY

Tall APV allows the farm to benefit from stacked land use and offset the farm's carbon emissions while providing the unique advantages of shading and continued food production. Pollinator habitats can also be placed near the panels.

SYSTEM SIZING INFORMATION

97.3 kW System =

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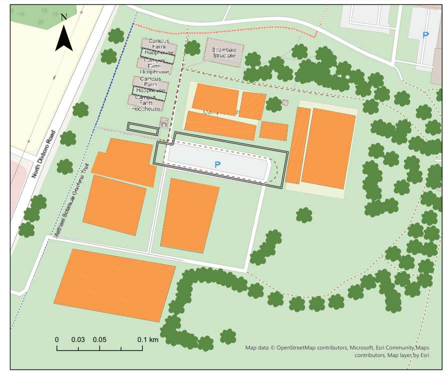
All icons from FlatIcon.com

Combine Harvester-Friendly APV

This is the tallest version of Baseline APV, which is tall enough for combine harvesters to pass under. This equipment might be another essential piece of equipment that assists UM Campus Farm in their work.



©Fraunhofer ISE

Source: https://ensia.com/features/solar-farms/

Source: https://tinyurl.com/GrainAPV

MOUNTING & STRUCTURE

This system would consist of large PV panels mounted on tall, permanent structures on a poured foundation for ensured stability. The number of support poles can vary depending on the design of the support system. With larger systems, larger support poles are required, which can minimize the number of poles installed in productive crop area. An example of poured concrete mounting variations can be seen in the images on this page.

This design can also be spaced at any desired layout, much like Baseline and Tractor-Friendly APV.

MULTIFUNCTIONALITY

Tall APV allows the farm to benefit from stacked land use and offset the farm's carbon emissions while providing the unique advantages of shading and continued food production. Pollinator habitats can also be placed near the panels.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions.

OPTIONAL CONSIDERATIONS

Larger arrays built to allow for freedom of movement with tractors and other equipment also require larger mounting systems. This means tractor-friendly designs are typically more expensive. This design would likely necessitate concrete foundations, which offer less flexibility and may be more difficult to get approved. This larger design would also be more visible from the road, another consideration in receiving university approval.

FARM GOALS ADDRESSED

Carbon Neutrality

PV panels can be tilted to optimize the amount of solar energy captured. Larger arrays would also likely be larger in generation capacity to make the system cost-effective, meaning more solar energy produced to contribute to the farm's carbon neutrality.

Research, Demonstration, and Teaching

Much like Tractor Friendly APV, this design allows the Campus Farm to provide valuable research opportunities to develop potential applications for Midwestern farming contexts

Sustainable Food Production

Taller APV system designs create less of a micro-climate for crops below, as more sunlight is able to penetrate through to the ground. This design allows for more flexibility in farming practices, as modern farm equipment such as tractors, mowers, or combine harvesters could be operated underneath the panels—a key benefit for larger farms.

Source: https://tinyurl.com/PouredFootingAPV

SYSTEM SIZING INFORMATION

97.3 kW System =

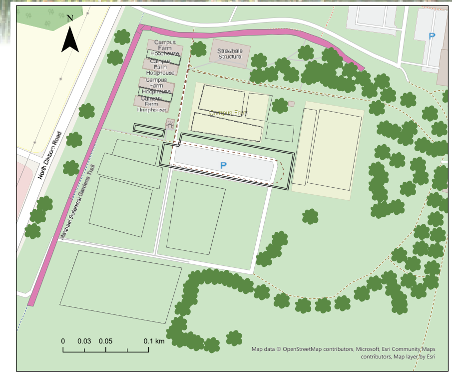
Carbon Emission Offset + Power Drill + Chain Saw + Weed Whacker + Picnic Table Lighting + Water Harvesting Pump

All icons from FlatIcon.com

Fence (A)PV

By utilizing existing fencing structures for energy generation, UM Campus Farms has the potential to make more efficient use of their space.

Source: https://tinyurl.com/PVFenceDIYForum



The map shows existing fencing that might be suitable, but locations will need verification. Fences can be built or used in any other PV Possible area.

EXISTING FENCE

UM Campus Farm might have an existing fence that would be suitable for attaching one or multiple panels. Utilizing an existing structure would save on labor and structural support costs. Wire fencing is not suitable because it is too weak. Wooden or steel fences are more ideal because they are more rigid and tend to support more weight. Fences with poured foundations or gravity driven wooden posts are preferred to ensure the system will not sink or damage the fence over time.

Some examples of various ways panels could be mounted on a fence are pictured on this page. The other components of a PV or APV system could be mounted on the fence or located near the fence to minimize the length of conduit running from the panels. These panels could include manual or automatic rotational capabilities to adjust the amount of shade and energy generated at various times of day.

NEW FENCE

If a suitable fence does not already exist, UM Campus Farm could install a new one. This can consist of a basic solid or mesh fence, or the fence itself could be composed of PV panels. Examples of these configurations are seen on this page. A new fence would add to the overall cost, but could produce a significant amount of energy if the panel is placed in a suitable area.

Alternatively, the panels themselves can act as a fence. See Images for reference.

OPTIONAL CONSIDERATIONS

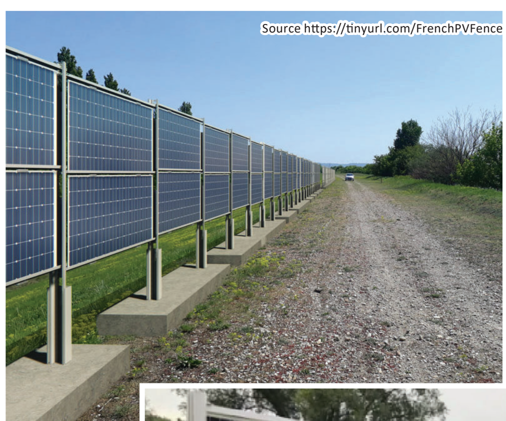
The space underneath the PV might be a suitable environment for brambles or vine crops to grow, as well as pollinator habitats.

Vertical panels might not produce as much energy as tilted panels, but there are certain innovations that could maximize energy generation. Bi-facial panels can capture light from both sides and would allow the fence to generate electricity from multiple angles. Panels can also be placed on a rotating axis, and the tilt can be adjusted manually or automatically to adjust the amount of energy and shade generation. However, It is not recommended to use bi-facial panels if your organization is trying to maximize energy capture. However, bi-facial panels may be preferable if is flexibility is valued above energy capture, as panels can be mounted on a rotating axis to be adjusted throughout the day and year. Consult with a PV contractor who can help you calculate potential generation of bi-facial panels before deciding.

Source: https://tinyurl.com/PollinatorHabitatAPV

Source: https://tinyurl.com/SmallestFencePV

Source: https://youtu.be/7t4hGBWLtxM

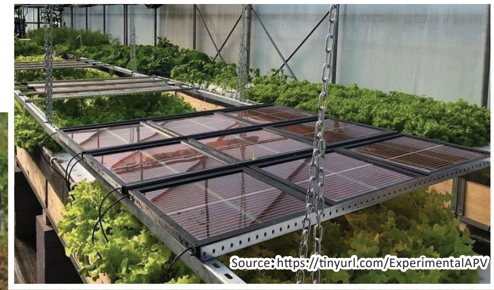


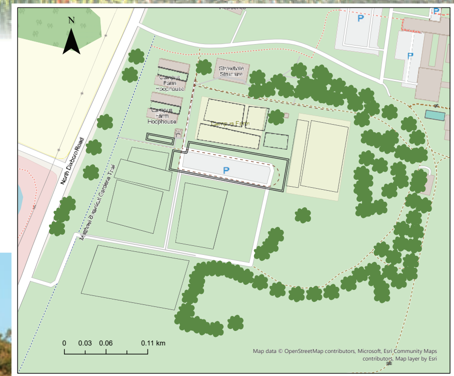
Source https://tinyurl.com/FrenchPVFence

Source: https://tinyurl.com/FullPVFence

Greenhouse APV

Installing solar panels on greenhouses would allow the Campus Farm to experiment with dual solar and food production year-round, an important consideration in Michigan's climate.





MOUNTING & STRUCTURE

The system would be mounted directly on the existing greenhouse. The structural integrity of the current greenhouse on the site would need to be assessed by a contractor or engineer before installation.

MULTIFUNCTIONALITY

Tall APV allows the farm to benefit from stacked land use and offset the farm's carbon emissions while providing the unique advantages of shading and continued food production.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions. It could also act as an important supplement to traditional APV models.

OPTIONAL CONSIDERATIONS

PV cells could be transparent to allow light to travel through to the crops more easily than if they were completely opaque.

Greenhouse APV may also be easier to get approved by the university than freestanding systems and would allow the Campus Farm to begin pursuing a form of APV right away

APV can also be placed in the greenhouse, as see in the top image on the page. This presents research opportunities.

FARM GOALS ADDRESSED

Carbon Neutrality

Adding solar panels to a greenhouse in addition to other parts of the farm would allow the Campus Farm to more easily meet its goal of reaching carbon neutrality, as this maximizes space for energy production.

Research, Demonstration, and Teaching

Installing solar panels on a greenhouse and in fields would provide diverse research opportunities for the Campus Farm. Multiple research projects could be conducted at once, and comparisons of different types of APV in Michigan's climate could be made. Research on greenhouse APV may also be more widely applicable to farms in the Midwest.

Sustainable Food Production

It is possible to install semi-transparent solar panels to the roof of a greenhouse, which allow for more sunlight to reach plants. Research has shown that semi-transparent panels can keep greenhouses warmer in winter and cooler in summer, aiding in year-round crop growth. Alternatively, opaque solar panels can be installed, limiting coverage to 25% to avoid significant effects on crop yield.

SYSTEM SIZING INFORMATION

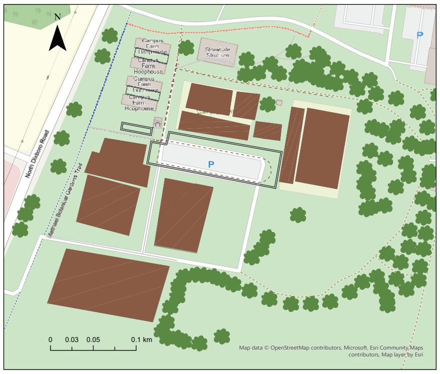
97.3 kW System =

Carbon Emission Offset + Power Drill + Chain Saw + Weed Whacker + Picnic Table Lighting + Water Harvesting Pump

All icons from FlatIcon.com

Ground APV

This design is like Baseline APV, but instead of raised or pole mounting to make the system taller, it is low to the ground, typically supported with racks laid directly on the ground surface. Much like taller APV designs, this design offers UM Campus Farm the ability to stack land use for energy production and food production.



FARM GOALS ADDRESSED

Sustainable Food Production and Carbon Neutrality

This type of APV design can be maximized for efficient energy production as panels can be tilted to optimize the amount of solar energy captured. In addition, this design offers flexibility in the amount of shading it provides, as panels can be positioned together in an array or spread out to allow for more sunlight to reach crops below.

Research, Demonstration, and Teaching

Because this type of APV design is relatively common, it offers unique research and demonstration opportunities. UM Campus Farm could replicate experiments from other parts of the U.S. and the world, providing valuable research on how APV performs in the southeastern Michigan climate.

MOUNTING & STRUCTURE

This design is mounted directly on the ground, and just as flexible and customizable without the need for larger, more expensive support structures such as poles. Suitable soil bearing capacity may be required. Panels can be placed at whatever spacing and layout is desired.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions. It could also act as an important supplement to other APV models.

MULTIFUNCTIONALITY

This design offers the benefit of improved water retention and increased shade for crops that prefer less direct or little sunlight.

OPTIONAL CONSIDERATIONS

PV cells could be transparent to allow light to travel through to the crops more easily than if they were completely opaque, expanding the options of what crops can be planted underneath.

SYSTEM SIZING INFORMATION

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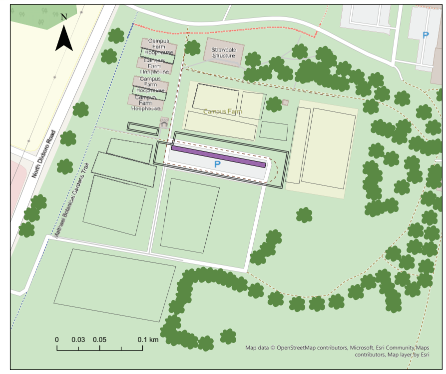
All icons from FlatIcon.com

Parking (A)PV



Adding solar panels above the parking lot transforms the function of currently non-productive areas. This would increase the overall food production of the farm and re-envision the function of the parking lot.

MOUNTING & STRUCTURE

A structural canopy would be added over parking space. With the addition of a shaded area utilizing structural supports, an area that previously did not produce food can be utilized for vine or bramble crop production.

MULTIFUNCTIONALITY

Since the parking lot does not currently produce food, installing a parking lot PV system would serve multiple functions that do not compete with the food production of UM Campus Farms; It can provide shade from the sun to keep vehicles cool as well as increase clean energy production and carbon neutrality.

ENERGY GENERATION & USAGE

The energy generated from these panels can be routed to the Farm's main electrical supply to offset the current electricity use and carbon emissions. Electric vehicle chargers could be added in the future if desired. This design can supplement any other PV design as well.

FARM GOALS ADDRESSED

Carbon Neutrality

Installing a solar array above the existing parking lot at UM Campus Farm will add shade and cooling to the space and cars below while providing a significant amount of energy to the farm. Like rooftop solar, this kind of efficient, stacked land use design can also be paired with another type of PV within the farm if more energy is needed.

Demonstration

If desired, the installation of this design and/or an electric vehicle charging station can contribute to (A)PV demonstration goals.

Sustainable Food Production

The additional shading and structure provided by this design could allow the growth of vine or climbing crops, such as beans, cucumbers, brambles, wild grapes, or other fruit, making this design a demonstration for APV as well as stacked land use for food and energy production. This would increase the food production of the farm as well as make the parking lot space useful to the organization beyond providing parking. It could also provide food and habitat for pollinators and increase biodiversity.

SYSTEM SIZING INFORMATION

97.3 kW System = Carbon Emission Offset + Power Drill + Chain Saw + Weed Whacker + Picnic Table Lighting + Water Harvesting Pump

All icons from FlatIcon.com

Source: https://www.smithsonianmag.com/innovation/solar-power-and-honey-bees-180964743/

PV Information and Resources

Policy, Cost, Research Opportunities

Policy Considerations

Zoning and Permitting

Although Ann Arbor Township has strict rules regarding solar energy systems, according to the university's Facilities & Operations code, the University of Michigan is only subject to Michigan state laws and regulations and not local building and zoning ordinances (Facilities & Operations, University of Michigan, 2022). Any PV system which the Campus Farm decides to pursue will be subject to internal university review.

Net Metering

Excess energy sent back to the grid would be credited at market rate, minus distribution charges. This could offer a small revenue stream to help offset upfront costs.

Payback Period & Cost

To offset all on-site carbon emissions, the Campus Farm would need a minimum generation of 63 kW, which would cost about $155,875. We assumed that the equivalent of the farm's current electricity consumption would be used on site, while the rest of the power generated by this PV system would be sent back onto the grid. The Campus Farm would receive net metering revenue for this excess energy at market rate, minus distribution charges. The payback period for this PV system would be **21 years**, considering electricity bill savings and net metering revenues.

For this cost estimate, we assumed a price per watt of $2.50 for a PV system, including labor. However, costs for installing PV systems can vary widely, depending on the manufacturer, local labor costs, and the type and size of PV system being installed. It's important to consult with a contractor to fully understand local costs. It is also standard practice for contractors to size a PV system larger than a site's energy needs, to account for efficiency losses.

To calculate the PV system size which the Campus Farm would need to offset all on-site carbon emissions, we calculated the associated annual carbon emissions from natural gas consumption for heating, tractor diesel, and gasoline for the Gator vehicle. We then converted the total carbon emissions from these various thermal energy sources into an equivalent kilowatt-hour amount. To obtain this rough estimate, we divided the total carbon emissions by the carbon intensity of DTE's fuel mix in 2021. Next, we added this amount to the farm's annual electricity consumption. Finally, we calculated the PV system size which the farm would need to offset all of its energy consumption, taking into account Michigan's solar rating and standard efficiency losses.

Research Opportunities

As a research university, the University of Michigan can offer research opportunities to students and faculty related to any APV or PV systems on Campus Farms. Future research topics can include, but are not limited to;

1. EFFECTS OF APV ON SURFACE TEMPERATURE OF CROPS
2. SOIL MOISTURE LEVELS OF CROPS UNDER APV
3. EVAPOTRANSPORTATION UNDER APV SYSTEMS
4. SOIL CARBON LEVELS UNDER APV
5. APV EFFECTS ON INSECT BIODIVERSITY AND/OR BEHAVIOR
6. APV EFFECTS ON POLLINATORS
7. MICRO-CLIMATES RELATED TO APV SYSTEMS
8. YIELD IMPACTS OF CROPS GROWN UNDER APV
9. STACKED LAND USE RESEARCH RELATED TO APV AND CROP YIELD

Funding Resources

Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR.

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To keep your system clean and effective, clean it with warm water and soap as needed. You can use a hose to water down the panels, or you can use a soft cloth or sponge to prevent scratches. Wiring and other electronic components do not require cleaning and should not be washed in order to prevent ground fault interruption damage and maintain safety.

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Source: Facebook

April 2022 Date Issued
04 Design Revision

WE THE PEOPLE OPPORTUNITY FARM
APV/PV Design Brief

Schematic Design Iterations

Designed and Compiled by the Urban Farm APV Master's Project Team at the University of Michigan School for Environment and Sustainability

Team Members: Brian Geiringer, Karlene Robich, Julian Tabron, Jess Tang, Rebecca Turley

DESIGN OVERVIEW

We the People Opportunity Farm (WTPOF)

WTPOF in Ypsilanti Township was founded by Melvin Parson in December 2018 with the vision to "create a sustainable farming system that could support a workforce of formerly incarcerated men and women". The organic farm offers paid internship programs for those returning home from incarceration and continue to support them through their continued education and employment journeys. The food produced is distributed at no cost to the surrounding community. The farm employed five interns in 2020 and three in 2021. Everything the farm does is to support and invest in their formerly incarcerated employees as farmers and as people.*

Based on this mission, our team outlined the following goals of the farm that we intend to uphold through our designs. They are in no particular order:

- Break the cycle of incarceration within Washtenaw County
- Provide amenities and continued support for employees
- Increase representation within the food industry

As a mechanism to support their mission, WTPOF hopes to expand its operations. This vision of expansion could include employing 8 to 10 interns at once, expanding growing area to 3/4 or 1 acre total, as well as becoming a vendor at the Ann Arbor Kerrytown Farmers Market. In addition to this, the farm also hopes to build a stronger relationship with the community, perhaps by hosting educational field trips for local school children. Lastly, continued support and development of all interns and program alumni remains a crucial focus.

Expansion of any organization typically requires more available resources. APV and PV solutions can provide energy and newfound capabilities to help support WTPOF's mission.

*(wtpof.org)

Visualizing Farm Goals

Additional Considerations

Through conversations with the farm, our team outlined some additional criteria to further develop these designs in the pursuit of the farm's mission:

- Mobility of structures is preferred over permanent structures
- Minimizing food waste is desired, as well as the ability to transport food
- Designs should lend themselves to community connection and place-making
- Designs should support farmers and their work, and enhance the overall function of the organization

ELECTRICITY GENERATION POTENTIAL

2 - 12 kW

A measure of potential energy generation depending on how much power the loads require.

A CoolBot running minimally with R25 insulation could require 2 kW, while standard functioning without insulation could require up to 12 kW.

UPFRONT SYSTEM COSTS

$ 4,795 - $ 6,395

The estimated cost of a 2 kW PV system with battery storage.

SUITABILITY MAP

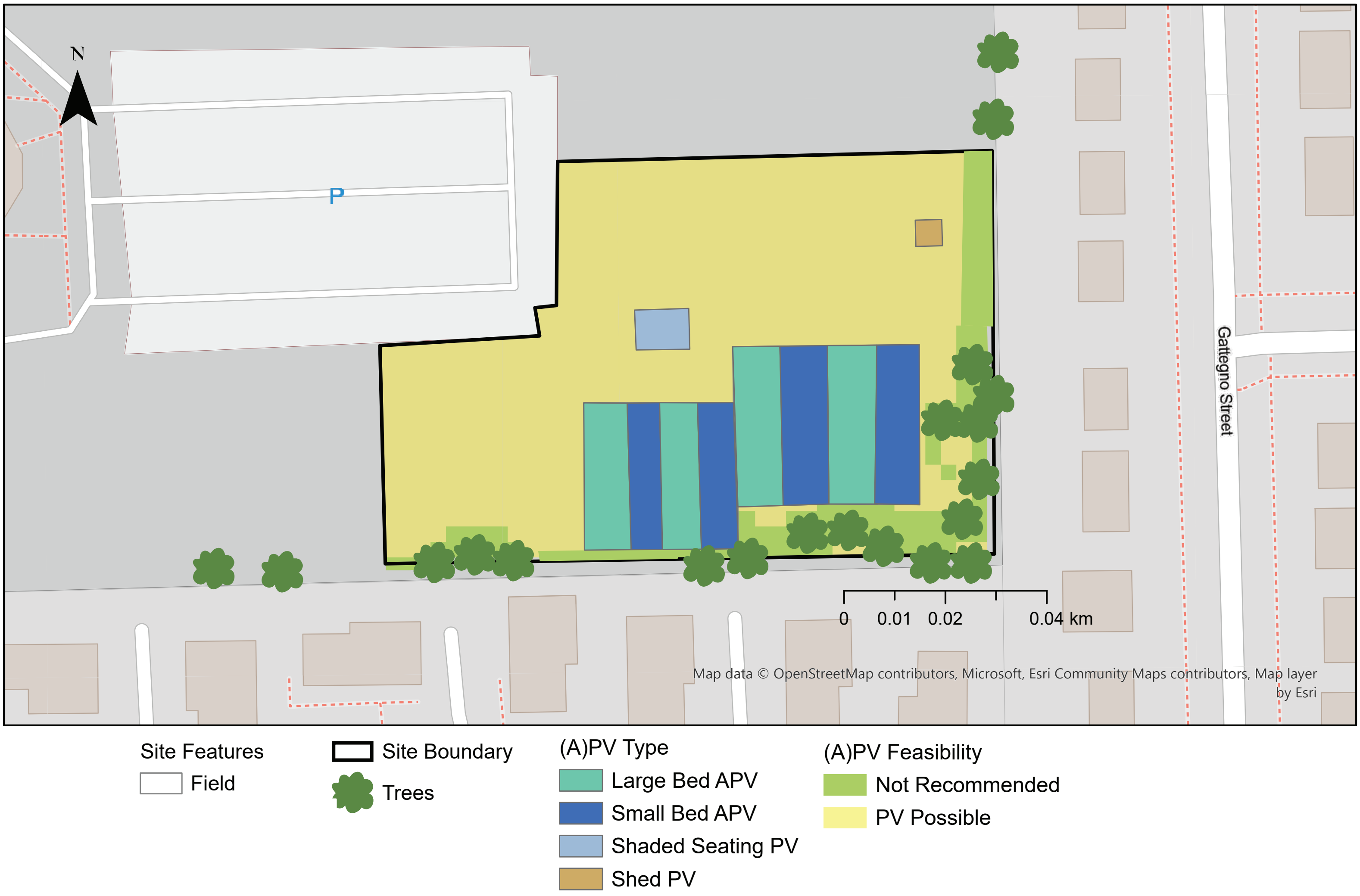
Source: Facebook

Developed Using ESRI's ArcGIS Pro Software

This page contains a map of the site that shows suitable or possible areas of each (A)PV design included in the brief. It is color coded for clarity, and was developed using GIS software and the ArcGIS ModelBuilder tool. A small key in the corner of each subsequent design page will indicate that specific design's most suitable locations, taken from this map.

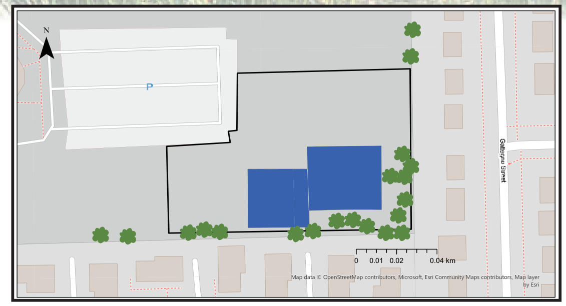
The suitable (A)PV areas are represented using yellow shading ("PV Possible"), and the light green areas are not recommended due to high tree canopy coverage.

Suitability for (A)PV installation was determined by analyzing area solar radiation and slope analysis. A digital surface model (DSM) was created using Light Detection and Ranging (LiDAR) data sourced from the US Geological Survey, which identified open areas and other site features, such as canopy coverage, buildings, structures, and steep hill faces. For an area to be considered suitable for PV installation, the slope surface must be less than 32° in angle (not located on a sharp hill or the side of a building) and the area solar radiation must be greater than 800 kWh/m² (the minimum recommended radiation required for PV panels to be effective).



Small Bed APV

This APV design lays low to the ground. It provides the benefits of APV without expensive support structures.



MULTIFUNCTIONALITY

Some potential uses for APV include growing shade-tolerant herbs like cilantro or root vegetables and providing shade over a pollinator habitat. Both of these benefits can support food productivity.

ENERGY GENERATION & USAGE

Energy can be routed to the shed or seating area to provide power for device and tool charging, or it can be used for cold food storage.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

MOUNTING & STRUCTURE

APV mounted on ground-level racks can provide shading by being placed over crops and can be spaced as desired. This can be set up across the entire bed, or it can be located along the edges of beds to not block the sun on the crops. There is flexibility in the location of the structures, how tall they are, how opaque they are, and what can be placed under it. Higher mounting would likely result in greater variability of shading, while greater transparency would limit the direct sun trade-offs of an opaque panel above crops.

See the images on this page to see a variety of ground-mount APV application. This system can be large as depicted, or can be scaled down to one or two rows.

FARM GOALS ADDRESSED

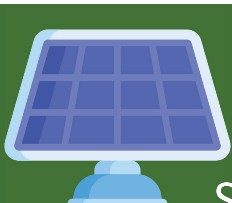
Expansion of Operations & Increased Representation

This design can enhance food productivity and energy access on the site. Additional energy can provide food cooling, which can expand the amount of harvested food and reduce food spoilage. This also allows food to stay cool while transporting it to a farmer's market.

Intern and Alumni Support

The additional energy generated by the system could provide energy access for interns, alumni, and volunteers, allowing them to maintain a work-life balance and look for employment Online after their program ends.

SYSTEM SIZING INFORMATION

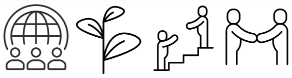


12 kW System = Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem + Efficient AC Unit with CoolBot Sensor

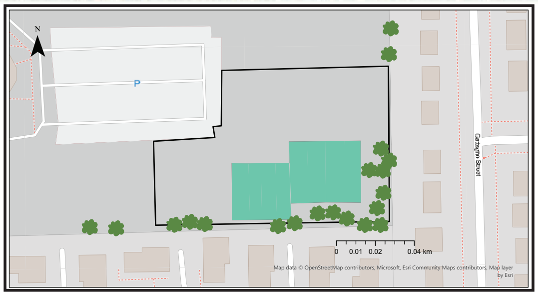
Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem = 1.5 kW System

0.4 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + 1 Laptop + 3 Phones + WiFi Router and Modem

All icons from FlatIcon.com

Large Bed APV 

This design depicts crop APV at a large scale. This structure would be taller than ground-mounted APV, making more space for people and equipment to pass under.



MULTIFUNCTIONALITY

Much like Small Bed APV, it can provide a habitat for pollinators and enhance food productivity, but this design provides more space for farmers to work underneath.

ENERGY GENERATION & USAGE

Energy can be routed to the shed or seating area to provide power for device and tool charging, or it can be used for cold food storage.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

MOUNTING & STRUCTURE

This is a permanent solution, which may require either concrete footings or gravity driven poles depending on the weight of the system. Panels could be installed in any number, spacing, and location as desired. The more panels installed, the more shade provided to the crops, and the more energy produced. There is flexibility in the location of the structures, how tall they are, how opaque the panels are, and what can be placed under it.

See the images on this page to see a variety of typical APV mounting and applications. This system can be large as depicted, or can be scaled down to one or two poles.


Source: https://tinyurl.com/ClassicAPV


Source: https://tinyurl.com/NPRonAPV


Source:https://tinyurl.com/CSUResearchesAPV


Source: https://tinyurl.com/LargePoleAPV

FARM GOALS ADDRESSED

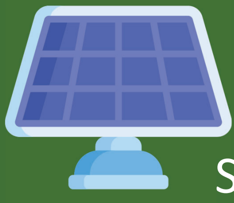
Expansion of Operations & Increased Representation

This design can enhance food productivity and energy access on the site. Additional energy can provide food cooling, which can expand the amount of harvested food and reduce food spoilage. This also allows food to stay cool while transporting it to a farmer's market.

Intern and Alumni Support

The additional energy generated by the system could provide energy access for interns, alumni, and volunteers, allowing them to maintain a work-life balance and look for employment Online after their program ends.

SYSTEM SIZING INFORMATION



12 kW System = Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem + Efficient AC Unit with CoolBot Sensor

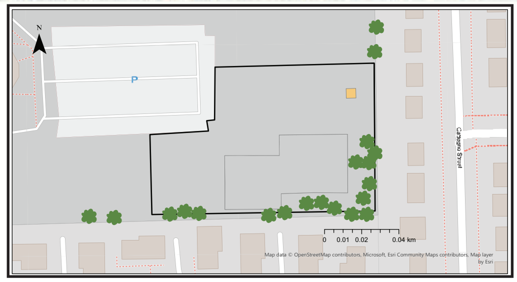
Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem = 1.5 kW System

0.4 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + 1 Laptop + 3 Phones + WiFi Router and Modem

All icons from FlatIcon.com

Shed PV

This design is a standard PV array mounted on the roof of a shed or similar structure.



ENERGY GENERATION & USAGE

Energy can provide power for device and tool charging, or it can be used for cold food storage within the shed to minimize heat damage to harvested food.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery. This design would be the most compatible with a CoolBot, which requires an R25-insulated room to function properly.

MOUNTING & STRUCTURE

This design requires a shed to be mounted on. All components of the system could be located within the shed, providing more safety and convenience than if the system was entirely on the ground. This design, however, would be limited to only the shed's roof, and would not be a mobile solution. If WTPOF ever decides to move locations, the panels would need to be disassembled, transported, and reinstalled at the new site, which is an additional cost to consider.


Source: https://tinyurl.com/ShedPV

FARM GOALS ADDRESSED

Expansion of Operations & Increased Representation

The addition of PV can provide WTPOF with electricity to use for charging tools, electronic devices, or to power lights to work later into the day if needed. Cold storage would help extend the shelf life of harvested crops, enabling interns to harvest over the course of a week and bring greater quantities to farmer's markets.

Intern and Alumni Support

The additional energy generated by the system could provide energy access for interns, alumni, and volunteers, allowing them to maintain a work-life balance and look for employment Online after their program ends.


Source: https://tinyurl.com/RooftopOrShedPV


Source: https://www.energysage.com/project/6433/solar-pv-garden-shed/

SYSTEM SIZING INFORMATION

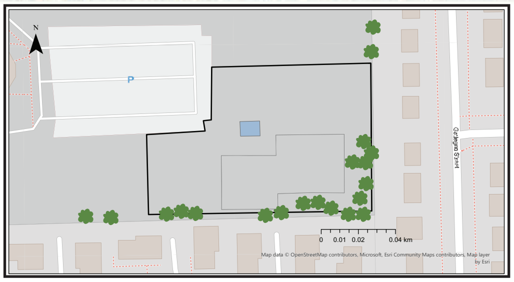
12 kW System = Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem + Efficient AC Unit with CoolBot Sensor

Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem **= 1.5 kW System**

0.4 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + 1 Laptop + 3 Phones + WiFi Router and Modem

All icons from FlatIcon.com

Shaded Seating (A)PV



A PV-shaded seating area would provide shade and cooling to the site, a space for employees and volunteers to gather and take a break from the heat, and an innovative solution for integrating energy production within the farm.

MOUNTING & STRUCTURE

A solar array can be mounted atop supporting poles to act as a shade structure, or be installed on top of a gazebo or similar wooden, canopy structure.

MULTIFUNCTIONALITY

Tables, seating, or a crop storage area could be positioned below the structure as well for people to relax and take breaks from working in the sun.

ENERGY GENERATION & USAGE

Electricity generated from the array can power electrical receptacles underneath, providing a source of energy to charge laptops and phones, or to power a WiFi router.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

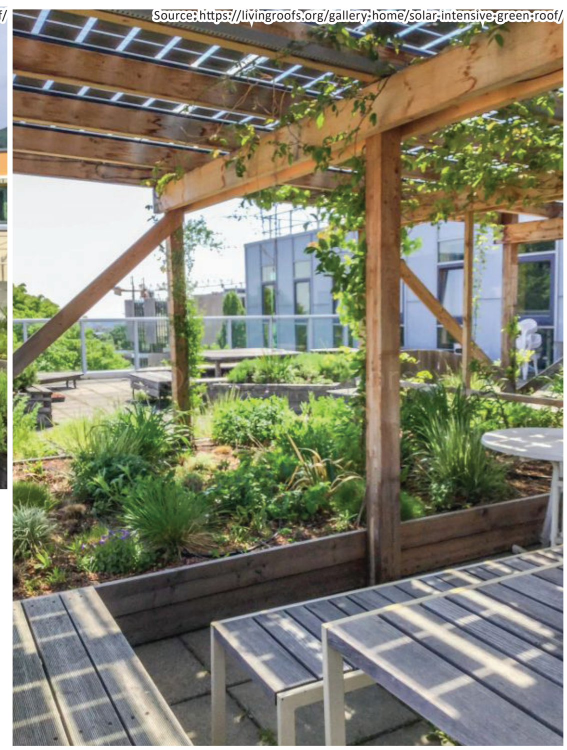
FARM GOALS ADDRESSED

Intern and Alumni Support, Community Building

A space to relax could benefit all interns, alumni, and visitors as a place to father and connect. The additional energy generated by the system could provide energy access for interns, alumni, and volunteers, allowing them to maintain a work-life balance and look for employment Online after their program ends.

Expansion of Operations & Increased Representation

The addition of PV can provide WTPOF with electricity to use for charging tools, electronic devices, or to power lights to work later into the day if needed. Cold storage would help extend the shelf life of harvested crops, enabling interns to harvest over the course of a week and bring greater quantities to farmer's markets.



SYSTEM SIZING INFORMATION

Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem = 1.5 kW System

0.4 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + 1 Laptop + 3 Phones + WiFi Router and Modem

All icons from FlatIcon.com

Fence (A)PV

By utilizing existing or new fencing structure for energy generation, WTPOF has the potential to make more efficient use of their space. This design may also be one of the easiest to get approved by the city.

This design must be placed on a fence that is at least 5 feet from the property line and 10 feet away from the Church or other buildings.

MULTIFUNCTIONALITY

The space underneath the PV might be a suitable environment for brambles and vine crops to grow. This design wouldn't interfere with crop production, which would maintain current operations as it currently is. It would provide additional energy without taking up any more physical space on the site.

ENERGY GENERATION & USAGE

Electricity generated from Fence PV can power laptops, phones, tools, lamps, a WiFi router, or a battery to use for any desired application.

MOUNTING & STRUCTURE

This design depends on an existing wooden or steel fence that is sturdy and stable enough to support a small PV system. If no such fence exists, one can be built to accommodate PV panels of certain dimensions. Alternatively, the panels themselves can act as a fence.

OPTIONAL MODIFICATIONS

Energy storage can be easily paired with this design depending on the capacity and cost of a battery.

FARM GOALS ADDRESSED

Intern and Alumni Support

The additional energy generated by the system could provide energy access for interns, alumni, and volunteers, allowing them to maintain a work-life balance and look for employment Online for after their program ends.

Expansion of Operations & Increased Representation

The addition of PV can provide WTPOF with electricity to use for charging tools, electronic devices, or to power lights to work later into the day if needed. Battery stored energy could provide power for cold storage to extend harvest shelf life, enabling interns to harvest over the course of a week and bring greater quantities to farmer's markets.

SYSTEM SIZING INFORMATION

Corded Push Mower + Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + Standing Flood Lamp + 1 Laptop + 3 Phones + WiFi Router and Modem = 1.5 kW System

0.4 kW System = Power Drill + Chain Saw + Portable Charging and Lighting Device + 1 Shed Lamp + Picnic Table Lamps + 1 Laptop + 3 Phones + WiFi Router and Modem

All icons from FlatIcon.com

Mobile Mounting Methods

A mobile PV structure will allow flexible, optimized shading for any purpose when needed. Mobile PV panels can provide more shade for crops which need it, and can be moved to correspond with crop rotations each year. The extra shade can also contribute to improving soil moisture. In addition, mobile PV panels can be used to provide shade for storing harvested crops, reducing wilting and spoilage. The taller structure specifically could benefit volunteers and employees of the farm, giving them a place to rest in the shade between activities. When paired with battery storage, the energy can be stored and used at a later time, such as charging equipment at night, or keeping food cool when preparing to take it to the farmer's market.

BENEFITS OF MOBILITY

Source: https://cuttingedgepower.com/products/power-boss

Large Stilt Structure (Steel or Wood)

Description of Structure

This support structure will adequately support arrays that contain multiple panels, assuming it is sized appropriately. Depending on the amount of electricity generation that is desired by WTPOF, more panels may be desired, and this structure may offer the most adequate support. It is placed on wheels, so mobility of an array would be maintained. Smaller arrays on this structure would also be mobile and adequately supported.

Height and Shade

This design also allows for the most height between the ground and the panels. This could be desirable if WTPOF plans on placing another structure beneath the panels, such as shaded seating, wash/pack areas, or other gathering spaces. The taller the structure is, the larger the shadow is that it casts, and therefore more total food area will experience shade. This also means the shaded food will be shaded for less time overall as the sun moves through the sky. This could be preferable for plants that require sunlight, but would benefit from short exposure to shade.

Safety

This design, however, might not be as safe as other mobile solutions. Due to the nature of the structure, it may allow children to climb the structure. To ensure safety with this design, measures should be taken that prevent climbing and toppling at the recommendation of the contractor.

Source: https://www.popularmechanics.com/science/energy/a8925/appropriate-tech-comes-to-appalachia-15450859/

Medium Push Wheel Structure

Description of Structure

This design is smaller in size and will support less panels than the large stilt structure. It would be placed on a flat surface, most likely the ground, the parking lot, or on a table. The thick wheels lock to ensure it will not be vulnerable to rolling. To prevent the panels from sinking into the soil, the wheels can be sized with a thick tread and the housing would have a built-in stand that distributes the weight of the system.

Height and Shade

This structure is not as tall as the stilt design and therefore might not necessarily cover multiple beds. However, it could be designed in a taller fashion to allow for a larger cast shadow. By designing it this way, it can be placed strategically over certain crops or certain harvested bundles to selectively shade as needed. Large wheels allow for the structure to move to any place at any time, meaning any crop can be shaded for any amount of time WTPOF desires. This makes the Medium Push Wheel structure the most versatile.

Safety

This design is much safer than the stilt structure and would not require extra protective measures. An optional mobile battery could be attached to the structural frame and move with the system as needed.

Source: https://www.indiamart.com/proddetail/portable-solar-panel-19719397873.html

Medium to Small Folding Structure

Description of Structure

This support structure is the most flexible and mobile of the three methods suggested. It consists of typically one panel, a housing, and a folding support leg. Some designs or manufacturers will also include a handle for easier portability. With the reduced amount of structural components, this structure will be lighter than others and will aid the mobility of the panel around the site. This optimizes flexibility in where WTPOF wants to provide shade. However, this design supports a less panels. If WTPOF decides they do not require a large amount of energy, this mounting option might be most suitable for mobile methods.

Height and Shade

The leg can be designed or ordered in specific lengths/heights to create the ideal shadow length. The longer the leg, the taller the panel will sit, and the larger the shadow. This will allow more square footage of crops to be shaded when needed. Since this method is highly flexible, it can be placed over any crop for any amount of time as deemed appropriate.

Safety

This design is the safest, as it can be folded and stored when not in use.

PV Information and Resources

Policy, Cost, Internship Expansion Opportunities

Source: https://www.smithsonianmag.com/innovation/solar-power-and-honey-bees-180964743/

Policy Considerations

Zoning and Permitting

PV systems in Ypsilanti Township are regulated as accessory buildings, which are regulated according to the district which they reside in. WTPOF is located in an RM-2 Multiple-Family Residential district. In such districts, PV systems cannot exceed 14 feet in height and must be setback from the street by at least 10 feet. In addition, they cannot be closer than five feet to a rear or side yard line, nor closer than 10 feet to the main building. Finally, PV systems cannot take up more than 25% of a yard.

Net Metering

If WTPOF decides to connect to the grid, excess energy would be credited at market rate, minus distribution charges. This could offer a small revenue stream to help offset upfront costs.

Payback Period & Costs

WTPOF has a few options when considering adding electricity on site: installing a PV system and battery, installing a PV system and investing in a grid connection, or simply investing in a grid connection to receive conventional energy. We estimated the cost of installing a 1.75 kw PV system, which would provide enough energy to power a 4’x5’x6’ shed with a CoolBot cooler.

Our estimates suggest that the cost of a PV system with battery storage would be between $4,795 and $6,395, depending on the cost of a battery. We estimated that the cost of a PV system with a grid connection would be between $5,195 and $6,295, depending on the cost of interconnection. For this cost estimate, we assumed a price per watt of $2.50 for a PV system, including labor. However, these costs can vary widely.

Costs for battery storage and grid connections can vary widely, so it’s important to consult with a contractor to fully understand local costs. We assumed that the cost of a battery would be between $400 and $2,000 and that the cost of interconnection would be $37 per foot, or $800 to $1,900 to the nearest transmission line, along with a $50 application fee for DTE to begin interconnection.

The payback period for either installing a PV system with a battery or a grid tie would be between eight and nine years. This means that around year eight or nine, a PV system would begin to pay for itself through energy bill savings.

Internship Program Benefits & Support

The addition of APV or PV and partnership with a PV contractor could provide multiple opportunities to interns, such as:

1. Expansion of internship program opportunities

2. Training in PV system installation and maintenance to enhance future employment opportunities

Funding Resources

Michigan Saves offers financing programs for solar systems, water efficiency, and energy efficiency improvements. The program provides funding for projects with minimum financing amounts of $5,000 and interest rates starting at 6.99% APR.

The AgriEnergy and Sustainable Farming Program offered by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) provides funding for farms and small businesses to invest in energy efficiency and renewable energy projects. The program has $100,000 to distribute, with a maximum of $15,000 for eligible projects. Project funding is limited to 50% of the total project cost.

Operation & Maintenance

It’s important to note that PV manufacturers have specific recommendations for their products to maximize the lifetime of your system. They will also have specific information on how often system components need to be maintained, which can vary by manufacturer, system size, and more. The manufacturer’s guidance should be the main resource for operation, maintenance, and cleaning instruction.

Cleaning

To keep your system clean and effective, clean it with warm water and soap as needed. You can use a hose to water down the panels, or you can use a soft cloth or sponge to prevent scratches. Wiring and other electronic components do not require cleaning and should not be washed in order to prevent ground fault interruption damage and maintain safety.

Maintenance

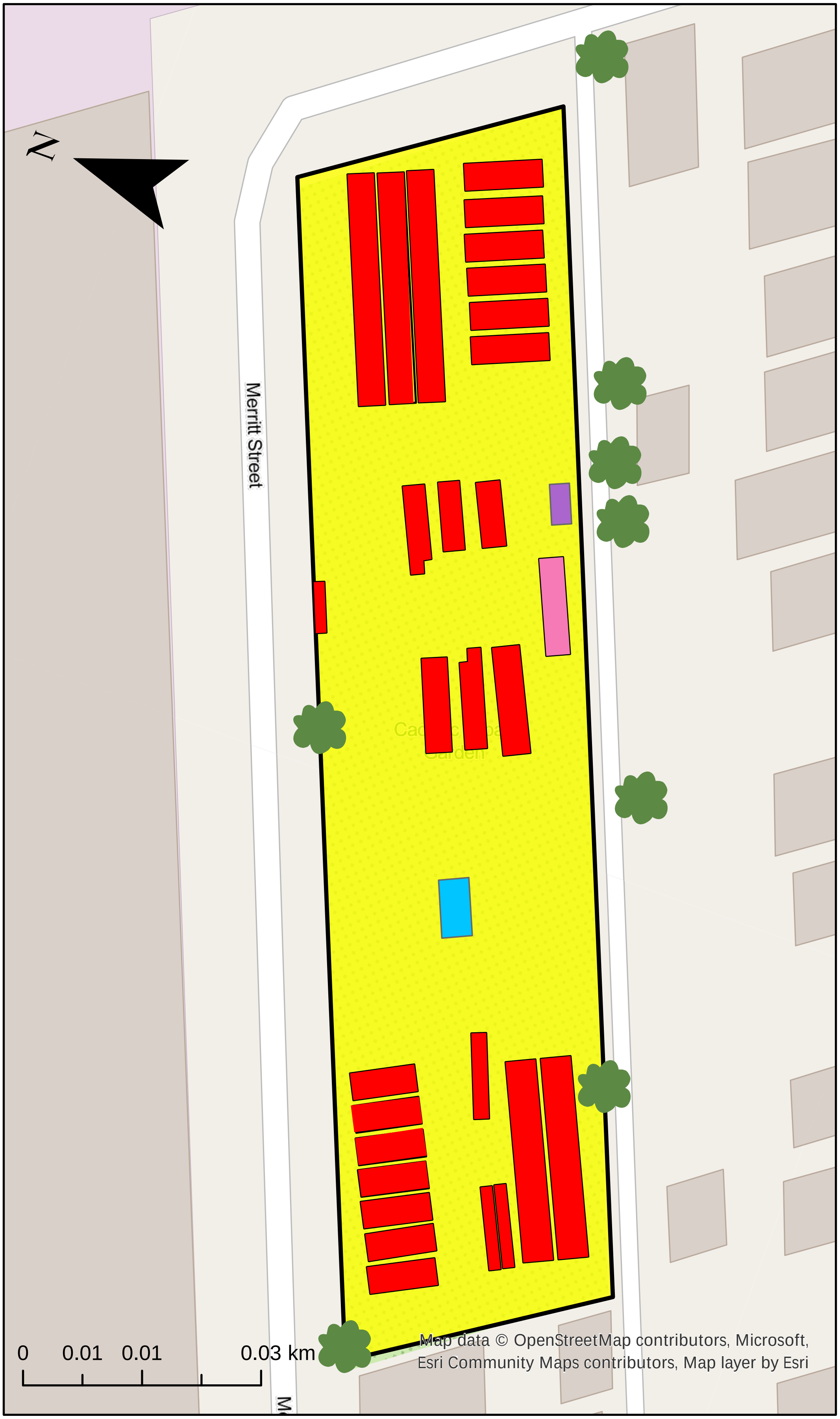
PV systems require maintenance throughout their lifetime. The frequency depends on the manufacturer of the system components, but expect maintenance to be required every 3-6 years. Costs may include labor or replacement for damaged components.

Warranty

Depending on the manufacturer, PV panel warranty timelines can be measured by a pre-determined number of years after purchase or based on the panels’ generation output. Pre-determined year warranties typically cover more costs for a shorter amount of time, whereas output warranties will last throughout the panel’s lifetime but cover a smaller proportion of costs as panel output efficiency decreases.

Appendix 2. Suitability Maps

Cadillac Urban Gardens Suitability Map



Site Features

Site Boundary

Raised Beds

Tree Coverage

(A)PV Type

Shaded Seating (A)PV

Bed-Mounted APV

*Wash/Pack PV

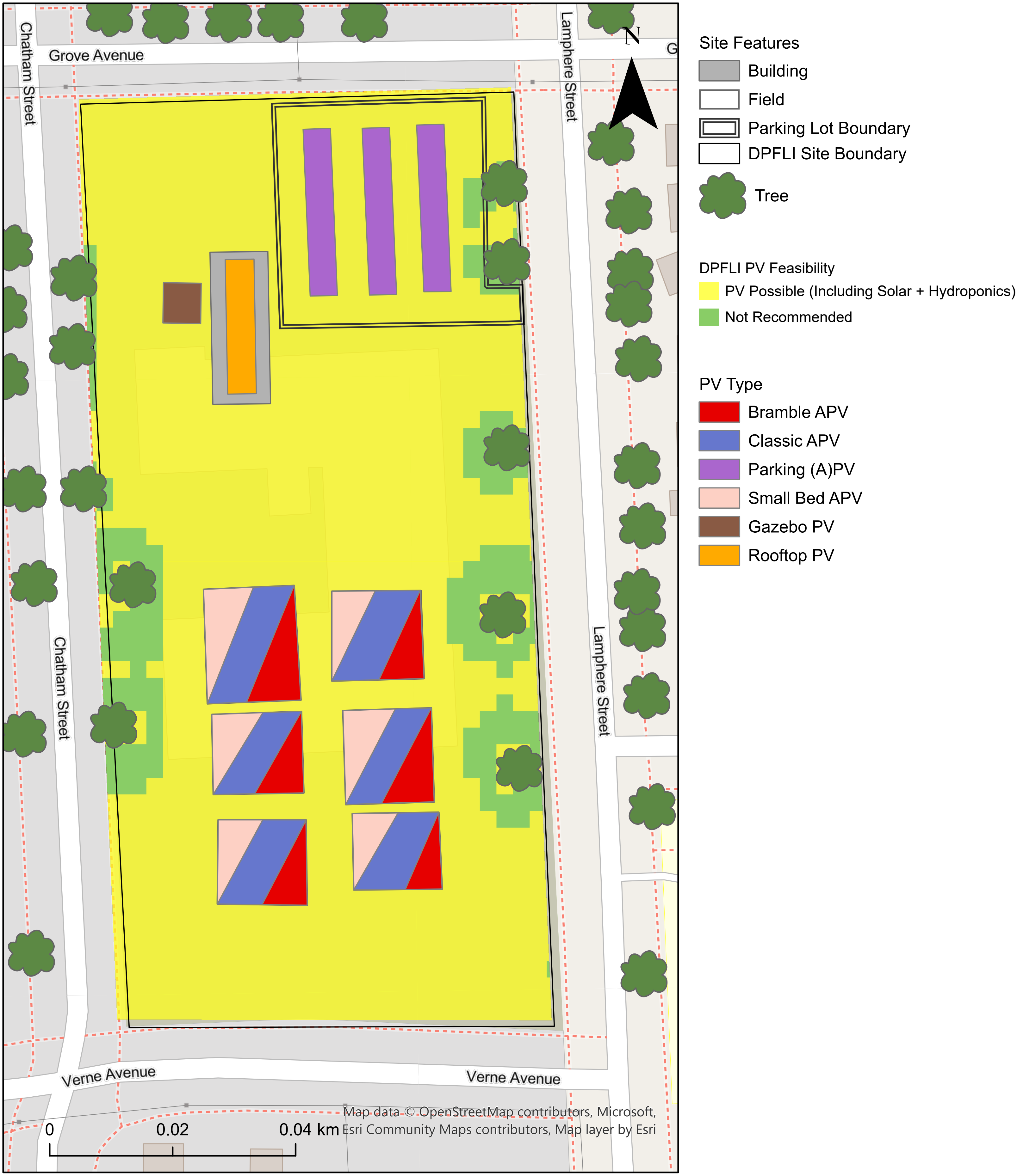
Shed PV

Feasibility

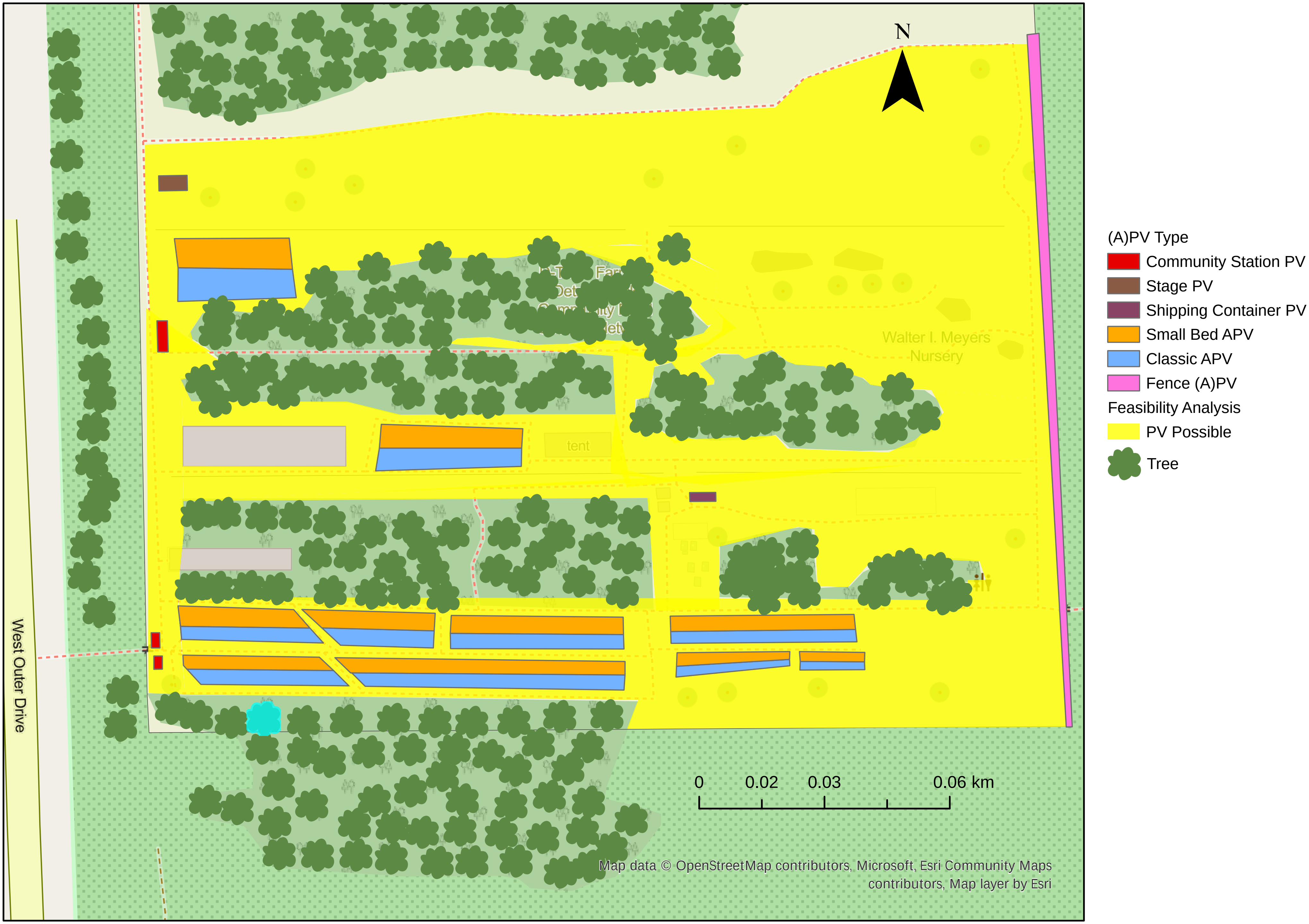
PV Possible

*Mobile Wash and Pack can be moved to any place on site.

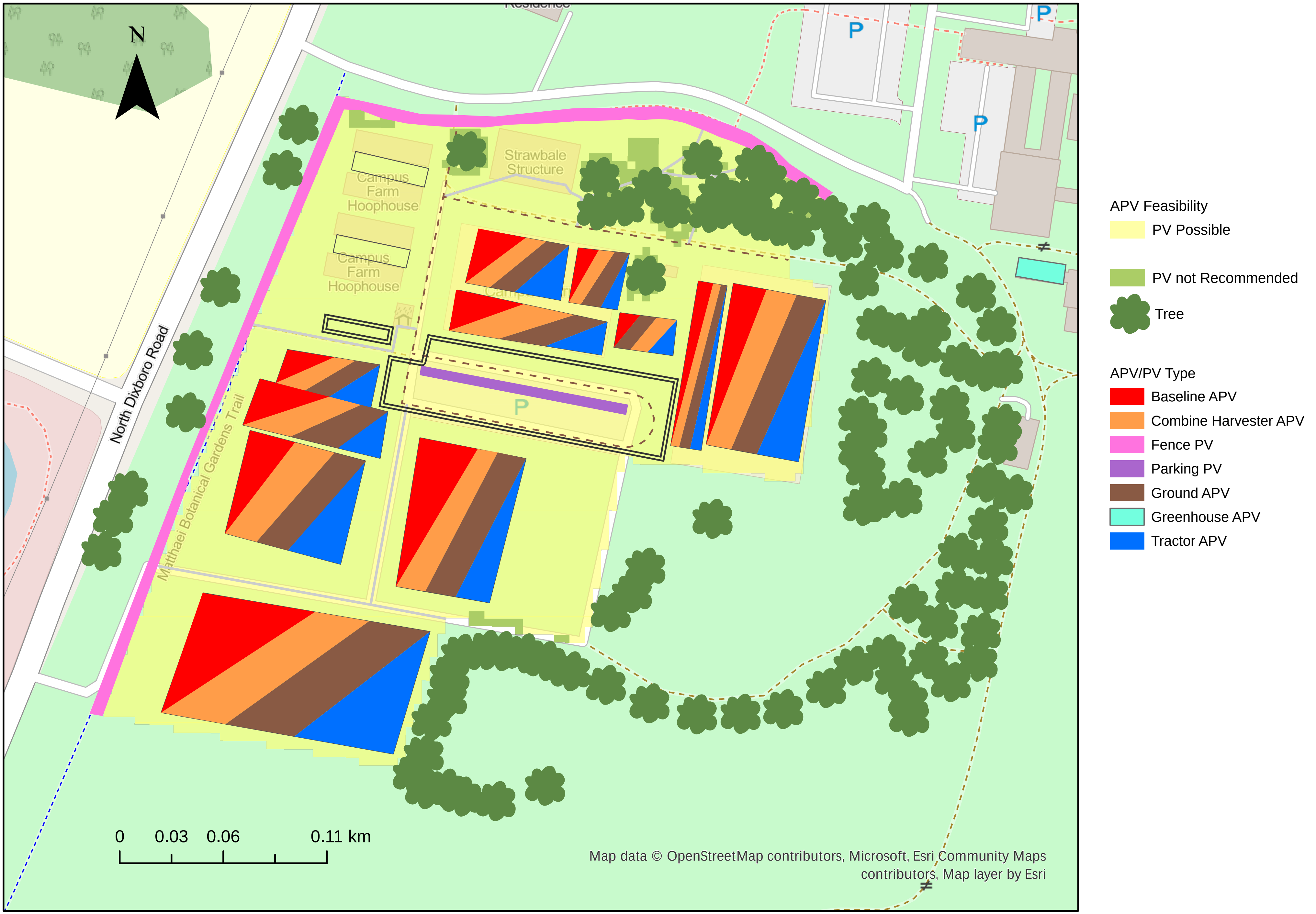
DPFLI Suitability Map



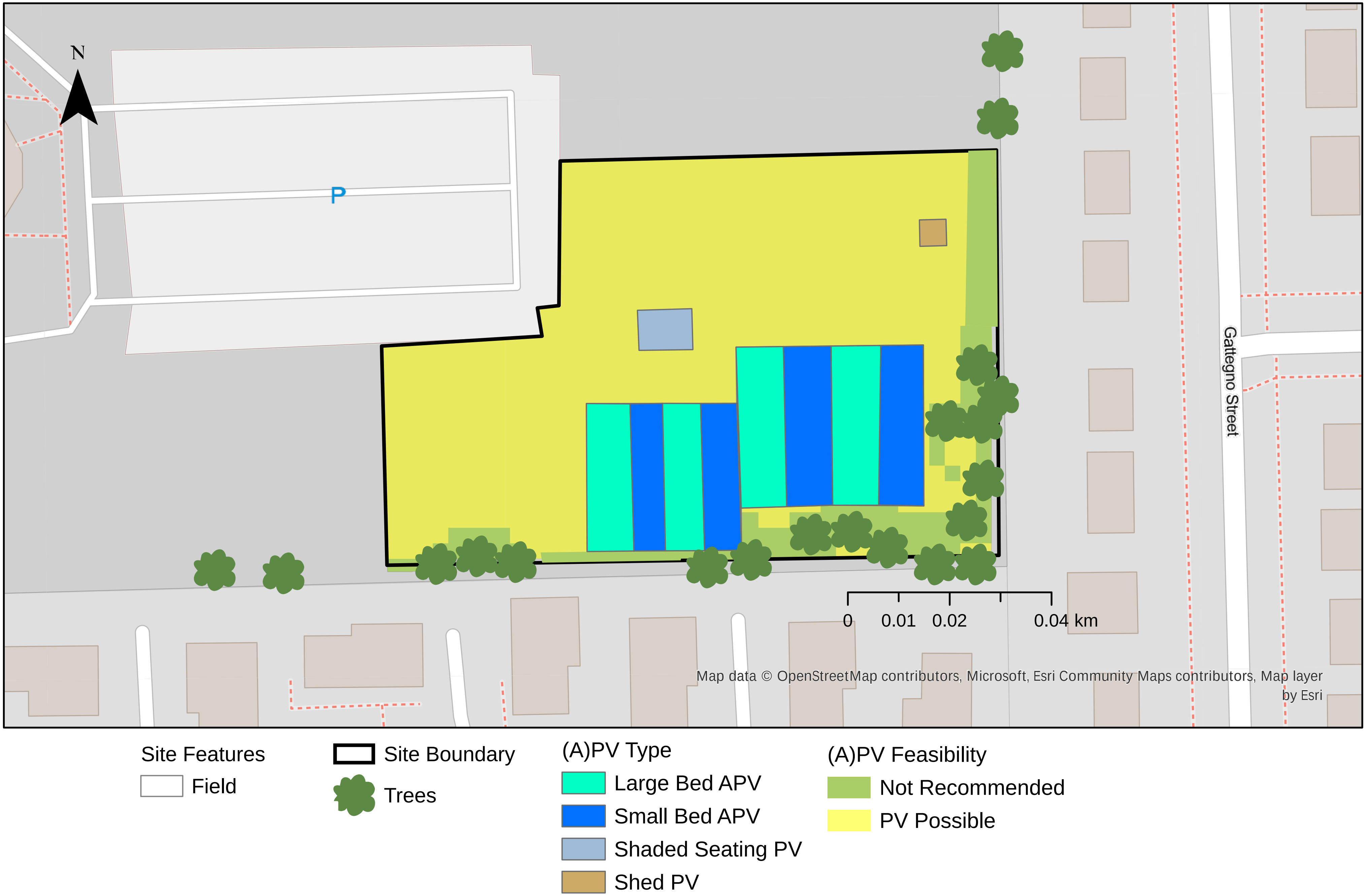
D-Town Farm (DBCFSN) Suitability Map



Campus Farm Suitability Map



We The People Opportunity Farm Suitability Map



Appendix 3: Energy Policy Background

Introduction

While this project focused specifically on the feasibility of APV development on small and urban farms in Southeast Michigan, policies and programs at the federal level and across different states also play an important role in APV adoption. This section will detail the existing energy policies in place at the federal and state level which affect APV development in the US. By aggregating this information, this section serves as a resource for developing new policies which facilitate APV adoption, as states can draw from examples in place elsewhere. Policymakers should be interested in APV as it has the potential to help promote multiple goals at once, including generating renewable energy, promoting local and healthy food, and boosting community resilience.

Federal Policies

One of the most important policies around solar energy at the federal level is the investment tax credit (ITC). The ITC provides businesses and individuals installing solar with a tax credit worth a sizable percentage of the up-front cost of the project. Since its inception in 2006, the federal ITC has helped the solar industry accelerate, with growth averaging 50% each year (SEIA, 2022). At present, in 2022, the ITC is worth 26% of the cost of a project, meaning solar developers pay 26% less in federal taxes. While this program has helped the cost of most solar projects to go down, non-profit organizations are unable to reap the benefits of this policy, as they are tax-exempt. Direct funding for APV projects would help to facilitate APV development on both large commercial farms and small non-profit farms.

Towards this front, two federal programs were recently launched to study APV, in the Department of Energy (DOE) and the Department of Agriculture (USDA). In 2020, through the Solar Energy Technologies Office, the DOE offered $130 million in funding for 55 to 80 solar research projects. Eligible research included solar and agriculture projects which would "enable farmers, ranchers, and other agricultural enterprises to gain value from solar technologies while keeping land available for agricultural purposes" (Office of Energy Efficiency & Sustainability, U.S. Department of Energy, n.d.). The four selected projects in Montana, Tennessee, Illinois, and Massahcusetts will explore new system designs, co-location models, and the ecological and performance impacts of dual-use systems. In 2021, the USDA announced $150 million in funding through the National Institute of Food and Agriculture for projects focused on sustainable agricultural intensification, climate adaptation, and innovation (Sustainable Agricultural Systems, U.S. Department of Agriculture et al., 2021). Through this program, the University of Illinois Urbana-Champaign was awarded $10 million to research APV, along with subawards for the University of Arizona, Colorado State University, Auburn University, the University of Illinois Chicago, and the National Renewable Energy Laboratory (Institute for Sustainability, Energy, and the Environment, University of Illinois Urbana-Champaign, 2021). Both of these federal programs should provide valuable research on potential yields, costs, and tradeoffs of APV in the coming years, and help facilitate its adoption.

Another federal program which aids in renewable energy development on farms is the Rural Energy for America program. Under this program, farmers and rural small businesses can apply for grants and loans to install renewable energy systems or invest in energy efficiency improvements (USDA, 2022). The program offers renewable energy grants for up to $500,000 or a minimum of $2,500. Grants are available for up to 25% of project costs while loans are available for up to 75% of total eligible project costs. Established in 2008, REAP has allowed farmers to make efficiency improvements on their properties and lower their energy bills with solar, while bringing more renewable energy online.

State Policies

Ten states have some form of APV policy in place: Massachusetts, Michigan, Minnesota, Illinois, Missouri, Virginia, Maryland, South Carolina, New York, and Vermont. All of these states except Massachusetts have voluntary pollinator-friendly solar designations which farms can apply for. This designation is not required; it simply offers another certification which farms can attain, much like being certified organic. Massachusetts is the only state which currently offers a monetary incentive for solar arrays to be co-located with agriculture, by offering a payment per kilowatt hour which developers receive through the state's Solar Massachusetts Renewable Target (SMART) regulations.

The next section will explore policies and progress on APV in four states: Massachusetts, Colorado, California, and Michigan. These states represent the diverse state of APV policies in place across the country along with a range of natural environments and farming economies. While some progress has been made to integrate APV within energy and agricultural policy frameworks, there is further opportunity for states to guide solar development and incentivize dual land uses.

<u>Massachusetts</u>

Massachusetts currently leads the way in developing policies which incentivize APV, after including a carve-out for dual-use agriculture and solar production within the state's Solar Massachusetts Renewable Target (SMART) program. The SMART program incentivizes certain types of solar development within the state, and developers who participate in the program must comply with rules around land use and size. By offering owners of eligible solar projects a base compensation rate per kilowatt-hour of energy produced and including “adders” for certain types of solar projects, the SMART program effectively pushes developers to comply or forgo valuable incentives. For example, "agricultural solar tariff generation units," in which solar panels are placed above farmland that remains in productive use receive six cents per kilowatt-hour in addition to the base compensation rate under the program (Massachusetts Department of Energy Resources, n.d.). This makes APV an attractive option for developers and farmers alike. By including adders for solar projects which make efficient use of space, whether stacked above farmland or a parking lot, Massachusetts created the conditions to make innovative solutions such as APV more cost-effective.

Indeed, there are several examples of APV within Massachusetts, and the solar industry has adapted to provide dual-use and agrivoltaic solar projects. For example, BlueWave Solar, headquartered in Boston, is one of the state's leading "dual-use developers," describing solar projects meant to promote pollinators, grazing, agrivoltaics, and conservation on their website (BlueWave Solar, 2022). In 2020, BlueWave partnered with another Massachusetts company focused on APV—Solar Agricultural Services—to install 14 acres of dual-use solar on a farm in Grafton (Gellerman, 2020). Cranberry bogs in the state have also proven to be an innovative spot for APV: in response to growing competition from cranberry farmers in Wisconsin and Quebec and lower prices for their crop, owners of cranberry farms in Massachusetts have increasingly sought to install APV over their bogs to remain financially afloat (Shemkus, 2021). Because cranberries are grown in submerged bogs, landowners are unable to sell the land for some other use. APV allows them to continue farming the bogs while simultaneously producing solar energy. A nine-megawatt cranberry bog APV project is underway in Carver, Massachusetts, and other projects have been proposed in the towns of Rochester, Wareham, and Plymouth. These examples speak to the early successes of the SMART program in Massachusetts and the potential which similar programs could have if enacted in other states.

Colorado

Several APV demonstration sites are underway in Colorado which are providing valuable research. Colorado State University has been collecting data from a field with solar panels installed over crops since 2019, in partnership with local renewable energy company Sandbox Solar. Colorado State was also recently chosen to be one of the universities to participate in the USDA grant program for APV research. In addition, Jack's Solar Garden in Boulder County hosts the Colorado Agrivoltaic Learning Center, which engages the public through farm tours. Jacks' Solar Garden has enough solar to power 300 homes in a year, with 3,200 solar panels or 1.2 megawatts (Jack's Solar Garden, 2022). In addition to these projects, in 2021 the Colorado state legislature included APV in a funding package for programs meant to increase the efficiency of agriculture within the state. The legislation stipulates that at least $150,000 of the $3 million in funding must go to "research, guidance, technical assistance, feasibility studies, and projects related to agrivoltaics" (Stimulus Funding Department Of Agriculture Efficiency Programs, 2021). With both federal and state funding going to APV research, Colorado will be an important state to watch over the next several years for progress and innovations around APV.

California

Although California has not yet enacted policies which incentivize APV in particular, farmers in the state are increasingly considering solar as a means of supplementing their incomes. In contrast to Massachusetts, this market development is not in response to falling crop prices, but decreasing water availability. Ongoing drought, the expansion of water-intensive farms, and new groundwater management policies are all straining the state's resources and forcing farmers in California's agricultural Central Valley to let portions of their land go fallow which otherwise would have remained in production (Roth, 2019). Covering part of their land with solar offers a way for farmers to make up for lost income, although in general, farms in the state are not yet experimenting with dual agriculture and solar production on the same portion of land.

Many of the types of crops grown in the Central Valley require ample sunlight and may not be the most ideal to mix with APV, given the extra shade the solar panels would introduce. However, mixing livestock and solar production in the same space could prove to be a more natural fit in California. Grazing animals like sheep eliminate the need for expensive landscaping around solar panels, and the panels can provide welcome shade. These cost savings can be incredibly attractive to developers, as using livestock to graze and maintain the land around a solar farm can cost 30% less than conventional landscape maintenance, according to the American Solar Grazing Association (Freehill-Maye, 2020). For example, the Sacramento Municipal Utility District uses a herd of sheep to graze the 523 acres at Rancho Seco II, a 160 MW solar array which came online in 2020 (SMUD, 2022). Similarly, in San Luis Obispo County, sheep graze the land around the 550 MW Topaz Solar Farms array which was completed in 2015 (Tierney, n.d.). In dry environments, sheep pose less of a fire risk than mowers, which can create sparks, and prevent damage from kicked-up rocks. Both Rancho Seco and Topaz Solar Farms also contain native species of plants and flowers which support pollinators. While developments towards integrating solar energy and food production in California have thus far not been driven by policy changes but environmental conditions on the ground, policies which incentivize co-locating grazing animals and solar arrays could help this practice become standard.

<u>Michigan</u>

In Michigan, the Farmland and Open Space Preservation Act is a key program which governs how farmland in the state is used. While farmers opt in to the program, enrollment is attractive as landowners can receive tax credits for compliance. The purpose of the program is to preserve farmland in the state and protect land from development, maintaining Michigan's agricultural economy and heritage. Only farms which are 40 acres or more in size are eligible to enroll, meaning the program is concentrated in rural areas of the state. Before 2019, farmers who agreed to lease their land to solar developers had to give up membership in the program and pay back up to seven years of tax credits with 6% interest (Barrett, 2019). However, Governor Gretchen Whitmer's administration changed this policy to allow farmers to keep their membership even if they add solar (Michigan Department of Agriculture and Rural Development, 2021). While the new program does not explicitly account for the possibility of dual agricultural and solar land use, it does open the door for farmers to explore this option.

Under the new policy, landowners enter into two separate agreements: one for the portion of land housing solar panels and one for any remaining agricultural land. Farmers won't have to pay back their credits if they remain within the program throughout the lifetime of the solar system, and if they ensure the land remains in proper shape for agricultural use once the solar panels are decommissioned. This means that landowners now have the option to keep their tax credits while installing solar—whether an APV or other system—on one portion of their property. Additionally, the new policy requires farms which add solar to meet pollinator habitat requirements, in an effort to prevent additional energy infrastructure from harming ecosystem services (Morehouse, 2019). While these changes to the Farmland and Open Space Preservation Act will serve as a first step in integrating solar and agricultural production in Michigan, further policies should be enacted which incentivize dual land uses. These policies could be modeled off of Massachusetts' SMART program. The purpose of the Farmland and Open Space Preservation Act is to protect farmland from development, yet the new changes to the law will result in some farmland being taken out of production. The state should take these policies a step further by offering incentives for APV, which would recognize both the need for producing more renewable energy and maintaining Michigan's status as a key agricultural producer.

Conclusion

Recent policy developments and programs at the federal and state level show progress on APV adoption in the US, although much more work is still to be done. APV could be an important solution as renewable energy development continues over the next decades, making land use an increasingly salient issue. Policies which incentivize developers and farmers to pursue efficient, dual land uses like APV will help to promote both agricultural and energy production.

Appendix 4. Sizing Calculations

Cadillac Urban Garden

UPPER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.150	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	1	0.015		$70
1 Shed Lamp	10	0.01	Intermittent	2	0.02		$50
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Mobile Battery-Op Lamp	10	0.01	Instantaneous	3	0.03		$37
Standing Battery-Op Lamp	70	0.07	Continuous or Instantaneous	3	0.21		$100
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Phone 4	8	0.008	Instantaneous	1	0.008		--
Phone 5	8	0.008	Instantaneous	1	0.008		--
Phone 6	8	0.008	Instantaneous	1	0.008		--
Phone 7	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Laptop 2	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Window AC Unit (12,000 BTU, Efficient)	990	0.99	Continuous	24	23.76		$509
Electric Water Harvesting Pump	84	0.084	Continuous	24	2.016		$100
Solar Garden Lights**	--	--	Intermittent	--	--		$40
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	26.977	kWh/d (Consumption/Connected Load)	$1,542.00
** Seperate PV panels attached to units, not powered by (A)PV systems					38.53857143	kWh/d (Upsized, 30% System Losses)	
					40.14434524	kWh/d (Inverter Efficiency of 96%)	
					11.9477218	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

MIDDLE RANGE (NO AC UNIT)							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.150	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	1	0.015		$70
1 Shed Lamp	10	0.01	Intermittent	2	0.02		$50
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Mobile Battery-Op Lamp	10	0.01	Instantaneous	3	0.03		$37
Standing Battery-Op Lamp	64	0.064	Continuous or Instantaneous	3	0.192		$100
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Phone 4	8	0.008	Instantaneous	1	0.008		--
Phone 5	8	0.008	Instantaneous	1	0.008		--
Phone 6	8	0.008	Instantaneous	1	0.008		--
Phone 7	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Laptop 2	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Electric Water Harvesting Pump	84	0.084	Continuous	24	2.016		$100
Solar Garden Lights**	--	--	Intermittent	--	--		$40
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	3.199	kWh/d (Consumption/Connected Load)	$1,033.00
** Seperate PV panels attached to units, not powered by (A)PV systems					4.57	kWh/d (Upsized, 30% System Losses)	
					4.760416667	kWh/d (Inverter Efficiency of 96%)	
					1.416790675	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

LOWER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.150	(1 hour/week)	$200
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Mobile Battery-Op Lamp	10	0.01	Instantaneous	3	0.03		$37
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Phone 4	8	0.008	Instantaneous	1	0.008		--
Phone 5	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Electric Water Harvesting Pump	84	0.084	Continuous	24	2.016		$100
Solar Garden Lights**	--	--	Intermittent	--	--		$40
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	2.526	kWh/d (Consumption/Connected Load)	$613.00
** Seperate PV panels attached to units, not powered by (A)PV systems					3.608571429	kWh/d (Upsized, 30% System Losses)	
					3.758928571	kWh/d (Inverter Efficiency of 96%)	
					1.118728741	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

D-Town Farm

UPPER RANGE							
Load	Wattage (W)	kW/day	Load Type*	h/day	Demand kWh	Notes	Upfront Cost
Corded Electric Push Mower	1600	1.6	Instantaneous	4	6.4	Requires Purchase of Electric Mower	$300
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.45	0.45	(Charging 3 hours/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.45	0.495	(Charging 3 hours/week)	$200
Week Whacker 1	500	0.500	Instantaneous	0.3	0.15	(Charging 2 hours/week)	$150
Week Whacker 1	500	0.500	Instantaneous	0.3	0.15	(Charging 2 hours/week)	$150
Week Whacker 1	500	0.500	Instantaneous	0.3	0.15	(Charging 2 hours/week)	$150
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	6	0.09		$70
2 Picnic Table Lamps	26	0.026	Continuous	6	0.156		$50
Mobile Battery-Op Lamp	10	0.010	Instantaneous	6	0.06		$37
Phone 1	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.100	Instantaneous	1	0.1		--
Electric Cooktop	1500	1.500	Continuous	3	4.5		$50
Microphone 1	0.259	0.000	Continuous	8	0.00207		$130
Microphone 1	0.259	0.000	Continuous	8	0.00207		$130
Speaker 1	1400	1.400	Continuous	8	11.2		$290
Sound Mixer***	700	0.700	Continuous	8	5.6		$100
Electric Pond Pump	306	0.306	Continuous	24	7.344		$270
Electric Pond Pump with Solar Panels**	--	--	Continuous	--	--		$295
Solar Porch Light**	--	--	Intermittent	--	--		$36
In-Ground Solar Path Lights**	--	--	Continuous	--	--		$40
* Continuous = +3 hours				TOTALS	36.8571472	kWh/d (Consumption/Connected Load)	$2,648
** Seperate PV panels attached to units, not powered by (A)PV systems					52.65306743	kWh/d (Upsized, 30% System Losses)	
*** Estimated					54.84694524	kWh/d (Inverter Efficiency of 96%)	
					16.32349561	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

LOWER RANGE							
Load	Wattage (W)	kW/day	Load Type*	h/day	Demand kWh	Notes	Upfront Cost
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.45	0.45	(Charging 3 hours/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.45	0.495	(Charging 3 hours/week)	$200
Week Whacker 1	500	0.500	Instantaneous	0.3	0.15	(Charging 2 hours/week)	$150
Week Whacker 1	500	0.500	Instantaneous	0.3	0.15	(Charging 2 hours/week)	$150
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	6	0.09		$70
2 Picnic Table Lamps	26	0.026	Continuous	6	0.156		$50
1 Laptop or 12 Phones	100	0.100	Instantaneous	1	0.1		--
Electric Cooktop	1500	1.500	Continuous	3	4.5		$50
Microphone 1	0.259	0.000	Continuous	8	0.00207		$130
Speaker 1	1400	1.400	Continuous	8	11.2		$290
Sound Mixer***	700	0.700	Continuous	8	5.6		$100
Electric Pond Pump with Solar Panels**	--	--	Continuous	--	--		$295
Solar Porch Light**	--	--	Intermittent	--	--		$36
In-Ground Solar Path Lights**	--	--	Continuous	--	--		$40
* Continuous = +3 hours				TOTALS	22.8930736	kWh/d (Consumption/Connected Load)	$1,761
** Seperate PV panels attached to units, not powered by (A)PV systems					32.70439086	kWh/d (Upsized, 30% System Losses)	
*** Estimated					34.06707381	kWh/d (Inverter Efficiency of 96%)	
					10.13901006	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

DPFLI

UPPER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type*** **	**h/day**	**Demand kWh/day**	**Notes**	**Upfront Cost**
Building Electricity Consumption*	--	0.01	Continuous	24.00	0.30		--
Corded Electric Push Mower	1600.00	1.60	Instantaneous	1.50	2.40	Requires Purchase of Electric Mower	$300
Battery-Op Power Drill (1")	1000.00	1.00	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100.00	1.10	Instantaneous	0.30	0.33	(Charging 2 hours/week)	$200
Battery-Op Weed Wacker	500.00	0.50	Instantaneous	1.00	0.50		$150
2 Picnic Table Lamps	26.00	0.03	Continuous	3.00	0.08		$50
Mobile Battery-Op Lamp	10.00	0.01	Instantaneous	3.00	0.03		$37
Phone 1	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 2	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 3	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 4	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 5	8.00	0.01	Instantaneous	1.00	0.01		--
Laptop 1	100.00	0.10	Instantaneous	1.00	0.10		--
Laptop 2	100.00	0.10	Instantaneous	1.00	0.10		--
Wifi Router & Modem (Service Not Included)	14.00	0.01	Continuous	8.00	0.11		$150
Electric Water Harvesting Pump	84.00	0.08	Continuous/ Intermittant	24.00	2.02		$100
In-Ground Solar Path Lights**	--	--	Continuous	--	--		$40
* Taken from 2021 utility bill				**TOTALS**	6.16	kWh/d (Consumption/Connected Load)	$1,227
** Seperate PV panels attached to units, not powered by (A)PV systems					8.79	kWh/d (Upsized, 30% System Losses)	
***Continuous = +3 hours					9.16	kWh/d (Inverter Efficiency of 96%)	
					2.73	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

LOWER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type*** **	**h/day**	**Demand kWh/day**	**Notes**	**Upfront Cost**
Building Electricity Consumption*	--	0.01	Continuous	24.00	0.30		--
Battery-Op Power Drill (1")	1000.00	1.00	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100.00	1.10	Instantaneous	0.30	0.33	(Charging 2 hours/week)	$200
Battery-Op Weed Wacker	500.00	0.50	Instantaneous	1.00	0.50		$150
2 Picnic Table Lamps	26.00	0.03	Continuous	3.00	0.08		$50
Mobile Battery-Op Lamp	10.00	0.01	Instantaneous	3.00	0.03		$37
Phone 1	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 2	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 3	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 4	8.00	0.01	Instantaneous	1.00	0.01		--
Phone 5	8.00	0.01	Instantaneous	1.00	0.01		--
Laptop 1	100.00	0.10	Instantaneous	1.00	0.10		--
Laptop 2	100.00	0.10	Instantaneous	1.00	0.10		--
Wifi Router & Modem (Service Not Included)	14.00	0.01	Continuous	8.00	0.11		$150
Electric Water Harvesting Pump	84.00	0.08	Continuous/ Intermittant	24.00	2.02		$100
In-Ground Solar Path Lights**	--	--	Continuous	--	--		$40
* Taken from 2021 utility bill				**TOTALS**	3.76	kWh/d (Consumption/Connected Load)	$927
** Seperate PV panels attached to units, not powered by (A)PV systems					5.37	kWh/d (Upsized, 30% System Losses)	
***Continuous = +3 hours					5.59	kWh/d (Inverter Efficiency of 96%)	
					1.66	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

UM CAMPUS FARM

UPPER RANGE							
Load	Wattage (W)	kW/day	Load Type*	h/day	Demand kWh/day	Notes	Upfront Cost
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Battery-Op Weed Wacker 1	500	0.5	Instantaneous	0.3	0.15		$150
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Electric Water Harvesting Pump	84	0.084	Continuous	24	2		$100
Carbon Offsetting Estimation**	--	--	--	--	217		--
* Continuous = +3 hours				TOTALS	219.724	kWh/d (Consumption/Connected Load)	$700
** Calculated seperately. 79,158 kWh/year divided by 365					313.8914286	kWh/d (Upsized, 30% System Losses)	
					326.9702381	kWh/d (Inverter Efficiency of 96%)	
					97.31257086	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

LOWER RANGE							
Load	Wattage (W)	kW/day	Load Type*	h/day	Demand kWh/day	Notes	Upfront Cost
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.3	0.3	(Charging 2 hours/week)	$200
Carbon Offsetting Estimation**	--	--	--	--	217		--
* Continuous = +3 hours				TOTALS	217.3	kWh/d (Consumption/Connected Load)	$200
** Calculated seperately. 79,158 kWh/year divided by 365					310.4285714	kWh/d (Upsized, 30% System Losses)	
					323.3630952	kWh/d (Inverter Efficiency of 96%)	
					96.23901644	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

WTPOF

UPPER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Corded Electric Push Mower	1600	1.6	Instantaneous	1.5	2.4	Requires Purchase of Electric Mower	$300
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	3	0.045		$70
1 Shed Lamp	10	0.01	Intermittent	3	0.03		$50
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Standing Battery-Op Lamp	64	0.064	Continuous	3	0.192		$100
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Window AC Unit (12,000 BTU, Efficient)	990	0.99	Continuous	24	23.76		$509
Coolbot/Cooling	5	0.005	Continuous	24	0.12		$375
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	27.341	kWh/d (Consumption/Connected Load)	$2,040
** Seperate PV panels attached to units, not powered by (A)PV systems					39.05857143	kWh/d (Upsized, 30% System Losses)	
					40.6860119	kWh/d (Inverter Efficiency of 96%)	
					12.10893211	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

MIDDLE RANGE (NO AC UNIT)							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Corded Electric Push Mower	1600	1.6	Instantaneous	1.5	2.4	Requires Purchase of Electric Mower	$300
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$200
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	3	0.045		$70
1 Shed Lamp	10	0.01	Intermittent	3	0.03		$50
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Standing Battery-Op Lamp	64	0.064	Continuous	3	0.192		$100
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	3.461	kWh/d (Consumption/Connected Load)	$1,156
** Seperate PV panels attached to units, not powered by (A)PV systems					4.944285714	kWh/d (Upsized, 30% System Losses)	
					5.150297619	kWh/d (Inverter Efficiency of 96%)	
					1.532826672	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	

LOWER RANGE							
Load	**Wattage (W)**	**kW/day**	**Load Type***	**h/day**	**Demand kWh**	**Notes**	**Upfront Cost**
Battery-Op Power Drill (1")	1000	1	Instantaneous	0.15	0.15	(Charging 1 hour/week)	$300
Battery-Op Power Chain Saw (12")	1100	1.1	Instantaneous	0.3	0.33	(Charging 2 hours/week)	$200
Portable Solar Charging and Lighting System	15	0.015	Instantaneous	3	0.045		$200
1 Shed Lamp	10	0.01	Intermittent	3	0.03		$50
2 Picnic Table Lamps	26	0.026	Continuous	3	0.078		$50
Phone 1	8	0.008	Instantaneous	1	0.008		--
Phone 2	8	0.008	Instantaneous	1	0.008		--
Phone 3	8	0.008	Instantaneous	1	0.008		--
Laptop 1	100	0.1	Instantaneous	1	0.1		--
Wifi Router & Modem (Service Not Included)	14	0.014	Continuous	8	0.112		$150
Solar Porch Light**	--	--	Intermittent	--	--		$36
* Continuous = +3 hours				**TOTALS**	0.869	kWh/d (Consumption/Connected Load)	$986
** Seperate PV panels attached to units, not powered by (A)PV systems					1.241428571	kWh/d (Upsized, 30% System Losses)	
					1.293154762	kWh/d (Inverter Efficiency of 96%)	
					0.3848674887	kW (DC System Size, 4 Sun Hours and 84% Derate Factor)	