Qualitative Analysis of Potential Locations for Agrivoltaic System Implementation on Dalhousie's Agricultural Campus in Truro, Nova Scotia

Andrea Hebert, Emily Kushner, Jayne Borrens, Samantha Rebitt, Zongze Li
Department of Earth and Environmental Science, Dalhousie University
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Dr. Caroline Franklin
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Given that the energy sector contributes to over one-third of all anthropogenic greenhouse gas emissions, there is a clear need to transition away from unsustainable fossil fuels to a more renewable-energy-powered world. One source of renewable energy that has recently received attention for its energy generation capabilities is photovoltaics (PV), or solar energy. However, large-scale photovoltaic systems often take up a lot of valuable land, which, with increasing global food insecurity and a growing population, poses challenges for justifying the allocation of land resources to the energy sector instead of for agricultural purposes. Agrivoltaics is a relatively novel technique of farming that combats this issue; these systems pair the installation of solar panels with shade-tolerant crops underneath, therefore minimizing the wasted space while still satisfying the need to transition to cleaner energy sources. Dalhousie's Agricultural Campus (AC) located in Truro, Nova Scotia, offers a promising location for the implementation of agrivoltaic systems as it supports successful agricultural practices and has suitable land and space for PV systems. The use of agrivoltaics on the AC would help Dalhousie satisfy their Green Building plans and reach their goal of 100% renewable energy by 2030. Previous student research groups have identified shade-tolerant crop species that could successfully grow in the shaded-regions underneath the solar panels. Building on this previous research, our project aims to identify suitable locations on the AC where agrivoltaic systems could be implemented to both satisfy energy requirements for proximal building operations and support successful production of shade-tolerant crops. Qualitative data was collected through focus group discussions with Truro campus staff and coded using NVivo software to determine key benefits, limitations, and considerations regarding agrivoltaics. Twenty locations were suggested and the energy generation potential of a PV system at each site was calculated using the website PVWatts. From this, eight ideal locations were chosen and further analyzed based on their proximity to buildings, energy capacity, and space constraints. The Demonstration Garden was chosen as the top location for current implementation of an agrivoltaics pilot project which could the provide real-life analysis of agrivoltaic potential on the AC and inform further research regarding the potential for large-scale implementation of these systems.

Keywords: Agriculture, Photovoltaics, Agrivoltaics, Energy Sustainability, Land Use, Food Security, Shade-Tolerant Crops, Focus Group, Nova Scotia

Introduction

Around the world, non-renewable resources are a prominent supply of energy, with 75% of the world's energy coming from these sources (The World Counts, 2024). This high use of non-renewables is a major contributor to global warming as the energy sector was responsible for more than 34% of the greenhouse gas (GHG) emissions in 2019 (Intergovernmental Panel on Climate Change [IPCC], 2023). Considering the widespread implications of global warming such as sea level rise, extreme weather conditions and fluctuations, ecosystem degradation, and exacerbating socioeconomic inequities, among many other issues (NOAA, 2021), it is important to mitigate the effects of fossil fuels in the atmosphere by investing in renewable energy infrastructure. One growing renewable alternative is the use of solar panels, also known as photovoltaic (PV) systems. These systems harness the sun's energy by converting sunlight into electrical charges that move as electricity flow (United States Department of Energy, n.d.). As the costs of PV systems decrease, they are becoming increasingly accessible. This has led the Intergovernmental Panel on Climate Change (IPCC) to identify solar panels as the most effective potential mitigation strategy for reducing net carbon dioxide emissions (IPCC, 2023). Based on this knowledge, solar panels offer a promising pathway to reduce reliance on non-renewable infrastructure and promote more sustainable energy practices.

The Dalhousie University Energy and Green Building Plan (Dalhousie University Office of Sustainability, 2022) highlights goals for the current decade (2020-2030). Dalhousie University is a public research institution located in Nova Scotia, Canada, which has two main campuses in Halifax and Truro. For this project, we focus on the Truro campus which excels in agricultural education and is surrounded by various fields and research facilities dedicated to student learning (Figure 1). The Energy and Green Building Plan considers using natural systems more effectively and addresses target areas such as space utilization, ensuring the right-sized efficient systems and equipment, generating energy on and off campuses from renewable sources, and building resilient outdoor spaces that can contend with warmer and wetter climates. Dalhousie hopes to be running on 100% renewable electricity by 2030. Currently, 70% of the energy used by buildings on the Agricultural campus is produced from a District Central biomass cogeneration plant while two main Nova Scotia power feeds provide electricity to the rest of the campus. Although biomass is considered a renewable energy, it still causes emissions of GHGs and therefore is generally not as “green” as other renewable options (Rice & Ainslie, 2019). The school’s current lack of renewable energy gives rise to the need for Dalhousie to implement alternative energy sources on campus to reach their sustainable energy goals for the decade. Photovoltaics provides a practical option to support this transition.

Figure 1 Study area showing the Dalhousie Agricultural Campus in Truro, Nova Scotia, Canada. Polygon was created by A. Hebert in ArcGIS Pro. The basemap was created by ESRI with a NAD 83 spatial reference. The map was created on April 7th, 2024.

Although photovoltaic systems have proven to be feasible sources of sustainable energy, one downside of their implementation to generate large-scale energy is that the system requires a large amount of physical area, taking up valuable land. Our world’s population continues to rapidly increase, causing food security to become a growing concern (Hall, 2022) and highlighting the need for space dedicated to efficient agricultural systems. With photovoltaic systems causing such a hindrance on land use for agricultural practices, solutions are emerging that combine this renewable energy source with productive agricultural systems to minimize the amount of wasted land. Agrivoltaics is a technique used to combat the space issue, which involves growing crops underneath solar panels raised a couple meters off the ground. Research has shown that agrivoltaic farming addresses the problem of unsustainable energy sources while dealing with malnutrition and hunger concerns, increasing land-use efficiency and leading to the creation of climate-resilient food systems (Hall, 2022). As such, agrivoltaics offers a promising opportunity for Dalhousie to tackle multiple environmental and sustainability challenges, hitting their aforementioned objectives of effective space utilization, generating energy on campus, and building resilient spaces that can adapt to the changing climate, all within the implementation of one system.

Agrivoltaic farming is not only an appealing idea; it has been proven to be feasible. In South Korea, it was successfully executed by growing broccoli plants underneath solar panels (Chae et al., 2022). The use of this technique increased profits to the local farmers without causing significant changes in yield or crop characteristics compared to open-field grown broccoli (Chae et al., 2022). Another important benefit of agrivoltaic systems is the resulting altered environment, which generates more shade that can reduce heat stress and water loss in hot climates that are becoming more dominant in our changing world (Hall, 2022). There are many examples and studies of agrivoltaics implemented in Europe and Asia (Mamun et al., 2022); however, implementation in North America, particularly Canada, is not common yet. Thus, our research provides an opportunity to investigate the potential of these systems here in Nova Scotia to provide important information that can inspire and guide implementation in other parts of Canada.

The Dalhousie Office of Sustainability has identified agrivoltaic farming as a project they are interested in exploring and potentially undertaking. Previous student research has identified crops that can grow effectively in the shaded regions beneath solar panels and can thrive in Nova Scotia's climate (McRae et al., 2022). This research formed the basis of our study, leading us to investigate the research question of "What are suitable locations on Dalhousie University's Agricultural Campus to implement agrivoltaic systems to both provide energy for building operations and to support the successful growth of previously identified shade tolerant crops species that utilize wasted space underneath the solar panels?" To gather data, we conducted focus groups with staff and faculty members of the AC and used PVWatts to calculate the energy capacity of photovoltaic systems in suggested locations. This research will provide Dalhousie University with critical information about the feasibility of and opinions surrounding agrivoltaics on the AC and can help guide their future towards a more sustainable campus.

Methods

Focus Groups

To gain insight on the AC in Truro and to investigate local perspectives regarding agrivoltaic implementation in this area, we conducted focus group discussions with faculty and staff who work on the AC. We recruited these participants through the Office of Sustainability, along with personally reaching out to AC faculty by email. The focus group meetings were held virtually through Microsoft Teams, where we had guiding questions (Appendix C) but also allowed participants to have open discussion time. There were three focus group discussions in total, which occurred on March 18th, 19th, and 21st. The qualitative data obtained from these focus groups were coded using NVivo, with both *a priori* and *a posteriori* methodology; parent code was chosen before looking at the results (*a priori*), to narrow down the data, but following this initial coding, the sections were further refined into child code (*a posteriori*). It is important to note that the coders were present during the focus group discussions, so there was some background knowledge on the transcripts that were being coded prior to creating the parent code, and thus it should be considered quasi-*a priori* methodology.

Focus group participants revealed their thoughts on potential locations that could be suitable for agrivoltaics on the AC. These locations were analyzed for solar capacity and spatial characteristics using PVWatts and ArcGIS.

PV Watts

The locations suggested through focus group discussions were analysed using PVWatts Calculator (U.S. Department of Energy, n.d.). This is an open-access website that calculates the energy generation potential of a PV system at specific system sizes and locations. The website was created by the United States National Renewable Energy Laboratory (NREL), however Canadian locations still generate accurate results. Through focus group discussions, potential locations were suggested and described by Truro campus professors and Truro Office of Sustainability members. They communicated their ideas through markings on maps that they created and sent during focus groups to help clarify their explanations (Appendix B).

Coordinates of suggested locations were determined using the maps provided by focus group participants and the open-access website Google Maps. To calculate the energy potential for all locations, PVWatts and ArcGIS Pro were used. ArcGIS Pro was used to create polygon shape files for the potential locations. The maps drawn by focus group participants (Appendix B) were used to base polygon placements and their sizes, however, the layout of each area, such as the proximity to buildings and the size of the space was also considered. It is important to note that the chosen sizes were not meant to represent what will be implemented, they were only drawn to give a general idea of their energy generation capacity. With the polygons drawn, their individual areas were identified and documented through attribute tables.

PVWatts was used to calculate the energy potential of each agrivoltaic system drawn in ArcGIS. The coordinates for each location were placed into the "Enter a Home or Business Address" search bar which brought up the next pane, "Resource Data", showing weather information based on this location. In the next pane, "System Info", the information was modified based on the area of each polygon and Truro's latitude. The DC System Size (kW) and the Tilt (deg) were altered, everything else was left at default settings. The Tilt (deg) was calculated based on the latitude of Truro as the website informs that to receive the most accurate results and increase energy generation; the Tilt should be equal to the latitude which is 45 degrees for Truro. To calculate the DC System Size (kW) the polygon areas from ArcGIS Pro were used. The calculations were carried out as follows: $\textit{Size (kW)} = \textit{Array Area } (m^2) \times 1\ kW/m^2 \times \textit{Module Efficiency } (\%)$, where array area is the size of a polygon and module efficiency is 19% as stated on the website for the Standard Module type. This equation was provided by PVWatts in the information tab beside the DC System Size title. After inputting this information for all locations, the energy generation was determined in kWh/year (Appendix A1). To display our results, we used ArcGIS Pro to create maps that demonstrates the size of potential agrivoltaic systems and their locations in Truro.

Results

Focus Group Discussions

The first part of the focus group discussions involved gauging respondents' perspectives and opinions on agrivoltaics systems. There were ten total respondents in the focus groups, representing a range of positions on the Dalhousie Agricultural Campus from farm management to engineering professors. Three of the participants were associated with the Office of Sustainability, while the remaining seven were professors from either the Engineering Department or the Department of Plant, Food, and Environmental Science. The discussions totalled over two hours, but analysis of these discussions through NVivo revealed broad themes of key benefits, considerations, limitations, and other suggestions (Figure 2).

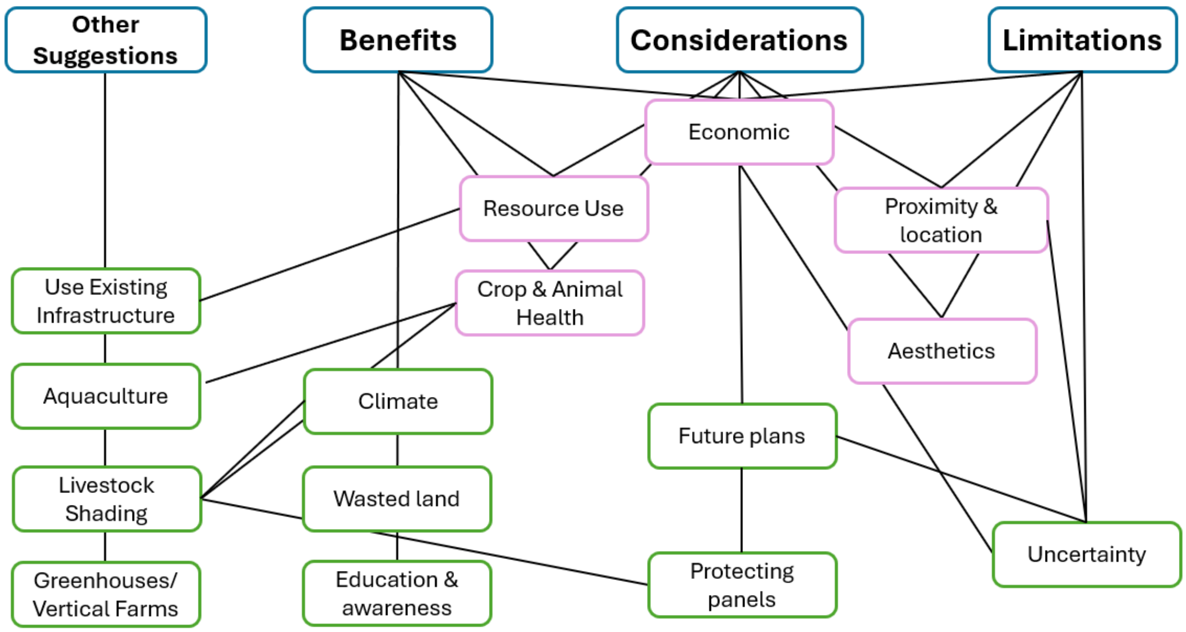


Figure 2 Main themes and sub-themes identified from the focus group discussions with Dalhousie Agricultural Staff members; blue borders represent broad topics of discussion, purple borders indicate sub-categories shared between multiple main themes, and green borders represent child code identified under each main theme. Discussions occurred virtually on Microsoft Teams over three different meeting times from March 18th-21st, 2024 and transcripts were coded using NVivo software. PowerPoint was used to create this coding tree by S. Rebitt on April 7th, 2024.

Within the broad key benefits theme, the discussions diverged in a few different directions, leading to the development of sub-themes of benefits. These sub-themes included economic implications that photovoltaics and agrivoltaics can cause (mentioned fifteen times), the potential of agrivoltaic farming to use otherwise wasted land (twelve mentions), the climate adaptation ability that agrivoltaic systems can generate (ten mentions), the capacity for agrivoltaics to improve crop health or animal welfare (eight mentions), the opportunity for education and awareness on agrivoltaics and sustainable practices (six mentions), and a more efficient use of resources on the campus (mentioned four times) (Figure 2).

Similarly, within the considerations theme, there were various thoughts discussed and thus child code was created in this category as well. These sub-themes had some overlap with benefits and included animal and crop health (mentioned eight times), location or proximity of the system to buildings (seven mentions), financial commitment of the systems (mentioned twice), potential need for protection of the panels (two mentions), use of resources in an efficient way (two mentions) and consideration towards future plans the university may have that could conflict with implementation of agrivoltaics in some locations (also mentioned twice) (Figure 2).

The discussions regarding the limitations of agrivoltaics also revolved around a few key ideas, again with overlap between both previous main themes. Sub-themes that we found in this category are uncertainty within the project design (mentioned ten times), typically regarding its scope and scale, financial concerns regarding implementation (ten mentions), challenges arising from the location and proximity requirements of the agrivoltaic systems (six mentions), and the aesthetic drawbacks of photovoltaics (mentioned once) (Figure 2).

Many ideas involving photovoltaics that did not fit our definition of agrivoltaics were also discussed within the focus groups, which we grouped into a broad “other suggestions” theme. The four main areas of discussion regarding these other suggestions including using existing infrastructure for installation of PV systems, powering greenhouses or vertical farms, providing shading for livestock, and adapting these methods to suit aquaculture environments (Figure 2). We will briefly discuss the potential of these and how they could benefit the sustainability and productivity of operations on the Truro campus.

Locations

Through guided questions, focus group participants suggested various locations where they thought agrivoltaics could be successfully implemented; fifteen sites were identified and described. Prior to the focus groups, our team also chose five locations for agrivoltaics based on characteristics of the AC that we could analyze through Google Maps. These characteristics included proximity to buildings and the size of the field, however, the locations were limited by our lack of knowledge of the AC layout. Together, the faculty, staff members, and our team came up with twenty potential locations where the system could be installed (Figure 3).

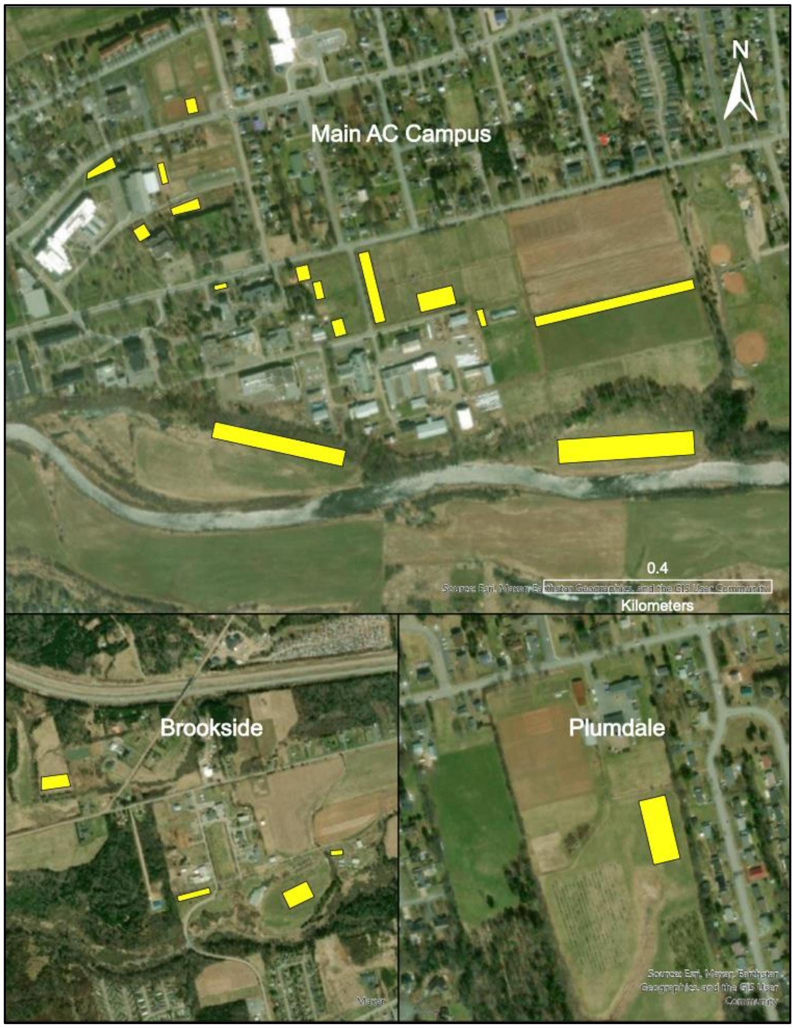


Figure 3 Twenty locations with potential for implementation of agrivoltaic farming on the Dalhousie Campus in Truro, Nova Scotia, Canada. Locations were identified by both our research team and by university staff through focus groups. The PV system size is identified by yellow rectangles, where smaller rectangles generate less energy than larger rectangles. The polygons and titles were created by A. Hebert. The basemap was created by ESRI with a NAD 83 spatial reference. The map was created on March 26th, 2024.

The twenty locations were narrowed down to eight locations that we consider to be optimal sites for the installation of agrivoltaics (Table 1; Figure 4).

Table 1 Site name, description, system size, and PVWatts calculated energy production value of eight optimal locations chosen for the implementation of agrivoltaics on the Dalhousie Truro Campus, Nova Scotia, Canada.

Location	Site description	System Size	kWh/year
Plumdale	- Large horticultural fields used by the university for research purposes. - High energy consumption as buildings next to the field are used to operate oven dryers year-round. - Existing greenhouse framing infrastructure.	5543.27m²	1,221,568
Collins Building	- Campus landscape architecture building. - Shape and size of a two-story house.	420m²	91,695
Orchard	- Located beside Farm Lane Road (proximity to power lines)	4966.23m²	1,077,971
Demonstration Garden	- Actively maintained field with a variety of crops and plants. - Small scale sheds located in between fields.	1021.06m²	221,726
Chef's Garden	- Organic demonstration farm that provides seasonal and storage crops. - Located next to the agricultural engineering annex (one-story building)	847.47m²	184,247
Water tower	- Open field of unused space not likely viable for other development. - Smaller scale buildings are located near the field.	1,223.18m²	265,559

Perennia Food and Agriculture Centre	- Large-scale research fields operated through the university campus.	5000.53m²	352,835
Bio-Environmental Engineering Complex	- 400-ha research farm with a feed preparation facility, large pasture, experimental orchard, and a diverse greenhouse complex. - Operated jointly by the Faculty of Agriculture's Engineering Department and Dalhousie University's Department of Biological Engineering.	1600.69m²	352,835

Discussion

The respondents of the focus groups provided a large amount of information for us to analyze, including extensive discussion around the benefits and limitations of agrivoltaic systems, and considerations that coincide with these technologies. They also provided suggestions of locations to implement agrivoltaics on the AC, and their opinions on alternative ways to implement photovoltaics in combination with other initiatives or resources to promote sustainable use of space. It is important to consider these insights and perspectives, as they lead to a more nuanced understanding of agrivoltaic farming potential on the AC, and thus an increased change of successful implementation.

Key benefits

Overall, there was a positive outlook on agrivoltaics and their ability to be implemented on the AC. The main benefits of these systems that were discussed within the focus groups revolved around topics of economics, land use, climate adaptation, animal and crop health, and education and awareness.

The long-term financial benefits of photovoltaic power and energy potential were the most discussed benefits of agrivoltaics in the focus groups, being mentioned fifteen times across the three meetings. Most of the conversations on economic benefits revolved around how it is a free and passive source of energy once installed and therefore can provide financial advances. For example, one participant mentioned how it could offset some electricity costs of heating. The photovoltaic part of agrivoltaics could help offset some of the energy demands such as barns or other farm equipment and facilities, research buildings, or greenhouses, sheds, or other small structures. One participant mentioned the potential of using PV power to combat losses of data and samples from power outages, which has both economic and educational impacts; the PV power generation could be used as a backup/emergency source of power to avoid these large losses of material.

Tied to economic losses, a lack of productivity on some marginal and underused lands around campus was mentioned by several participants as well. They stated that some areas00 within the campus farm fields are not being used for much as they cannot support sufficient agricultural yield due to poor growing conditions, such as nutrient-poor soil. The installation of solar panels on these lands would not be taking away from any current productivity of crop yield, and could potentially improve conditions for certain crop species, so this was identified as a major benefit of agrivoltaics potential without many obvious trade-offs. Similarly, some sloped areas that are overrun by invasive weeds were also mentioned as potential locations for the installation of solar panels that could be paired with certain crops to both generate energy and remove the presence of invasive species. By putting space-intensive solar panels in areas that are not being used, we could achieve more efficient use of space, which is one of Dalhousie's goals in their Green Building Plan Dalhousie University Office of Sustainability, 2022).

A notable discussion that took place within the focus group was the referencing of our future climate reality, which led to discussions around how agrivoltaics could potentially be used to address these challenges posed by climate change-induced heat stress on agriculture. One participant talked about projections of extreme heat days, which they said are expected to rise from the current five days a year to around thirty days a year. These projections would lead to significant stress on crops, potentially over an extended period, which could impact crop yield production and quality. Agrivoltaics has been proven to aid in combating this climatic stress by not only decreasing direct heat by providing shading to the crops, but also by reducing water loss through a decrease in evapotranspiration (Hall, 2022; Omer et al., 2022; Fagnano et al., 2024).

One study indicates that there is up to a ten-degree Celsius cooling benefit that solar panels provide in an agrivoltaic setting (Williams et al., 2023).

These projected rising temperatures would not only affect crops grown on the AC but would also pose a threat to the health of livestock that are kept on the farmland. Although livestock were not originally part of our research question, using solar panels as shading for livestock fits into many definitions of agrivoltaic farming, sometimes being called animal agrivoltaics; therefore, there is very little natural shading available in the livestock fields in Truro, as explained by participants, so the projected rising temperature would create stressful conditions for animals, causing concerns about animal welfare. Participants mentioned the potential for shading in the cattle or sheep pastures, however stating a higher chance of success if used with sheep herds. The cooling benefits of agrivoltaics were quantified in a recent study involving Holstein Heifers in Sao Paulo, Brazil; researchers assessed the thermal comfort and wellbeing of dairy cows and documented a reduced heat load on the cows in an agrivoltaic farming situation, with decreased body surface and skin temperatures (Faria et al., 2023). Not only did this reduce thermoregulation costs for the animals, but it also improved the ecological footprint of the farm as solar energy can help offset the methane emissions released by the cattle. A large-scale solar farm in Southern Ontario converted to an animal agrivoltaics system recently, housing hundreds of ewes from a nearby farm during the summer months (Norman, 2022). Not only are the sheep benefitting from shaded grazing areas in the hot summer months, but they are helping the photovoltaics farm by reducing maintenance costs, and ensuring the panels are not impeded by tall plants. These examples show the potential for animal agrivoltaics to give rise to improved living conditions for livestock along with providing additional energy and maintenance benefits to the system as a whole.

The final theme discussed by participants that fell within the benefits category was the opportunity that agrivoltaic farming provides in terms of a learning/education experience, along with increased awareness on campus of renewable energy and sustainable practices. Participants mentioned that having an agrivoltaic system on campus could be utilized in experiential learning through data collection, observation, and installation/maintenance of both the PV systems, but also the impacts on the crops including their responses to the microclimate generated by the solar panels. For example, one participant suggested that the system could be used to conduct an experimental project to assess crop infrastructure design and potential constraints of the system.

Considerations

There are wide reaching benefits of agrivoltaics that influence a diverse range of applications; however, because they are still relatively novel systems, there is a lot of questions surrounding their potential, and thus many considerations arose within the focus group discussions. These generally fell into four main themes: animal and crop health, location, or proximity of the system to buildings, financial commitment of the systems, and the use of resources in an efficient way.

Health and welfare of the crops or animals, respectively, that would be paired with the solar panels were a major concern for focus group participants. For crops, questions arose about whether the shading would be beneficial, or if it would hinder the current efficiency of agriculture on the AC and thus decrease yield. Recent studies have shown that there does appear to be an alteration of the microclimate underneath the solar panels (Weselek et al., 2021), typically leading to a reduction in the yield of some plants grown under solar panels due to decreased light available for photosynthesis (Andrew et al., 2021; Fagnano et al., 2024; Weselek et al., 2021). However, in hot and dry climates, this yield reduction can be offset by an increased quality of crop (such as increased plant height) (Weselek et al., 2021). Soil temperature and moisture, rainfall distribution, and air temperatures under the panels can also be impacted by the installation of PV panels (Weselek et al., 2021). Wind speed was also shown to be reduced in agrivoltaic systems (Fagnano et al., 2024). Because agrivoltaics systems may impact the health and number of crops produced and alter the land characteristics, it is important to consider these changes and whether agrivoltaic farming would be compatible with current practices on the AC. The animal welfare considerations arose from discussions around the use of PV panels for livestock shading, as previously mentioned. Most of these had a positive view on the potential for improving welfare, but there were some comments on whether it should be further researched. Protection of the panels from livestock damage was also mentioned by one participant as something to assess, because cattle tend to rub themselves on objects. Overall, these health-related concerns are important to ensure the system is not compromising crops or animals to achieve the energy generation aspect of the system.

Location and proximity were the focus of a lot of the discussions, with respondents worried about storage challenges in trade-off with energy efficiency. Proximity to buildings would mean eliminating the barriers of storage and tying into the grid, however it would not provide a consistently reliable energy source if conditions were not suitable for power generation. Storage and tying into the grid are costly and more challenging so it is important to understand what these variables look like in the location of implementation. Size constraints of the location were also mentioned, as there would need to be sufficient room for an appropriate number of panels to ensure energy generation is useful and impactful on surrounding energy requirements. Exposure of the location was also mentioned, with south-facing areas being the most optimal for energy generation potential. One other consideration related to location selection that was mentioned involves the future plans of the university. A couple respondents mentioned that in some of the areas that they suggested as suitable for agrivoltaic systems currently have proposed plans for construction of a new building, which would hinder the benefits of agrivoltaics by taking away any long-term gains. Additionally, we were informed that some of the farmland that the university uses are leased from outside sources, and thus the implementation of agrivoltaics, which is a relatively permanent system, could be disrupted in the future based on decisions made by owners of the land.

The efficient use of resources theme closely follows these financial and production concerns of proximity and location; participants questioned whether the conventional agrivoltaics set-up would be the most efficient and effective way to integrate photovoltaics into the campus setting.

Limitations

While this study offers valuable insights into the feasibility of agrivoltaic installations on the Dalhousie Truro campus, it is important to acknowledge certain limitations that may impact the feasibility of this project. One significant limitation is the uncertainty of the project, both in terms of the scope/scale of actual implementation along with unknowns about the long-term performance of agrivoltaic systems in Nova Scotia's changing climate.

The scale of the agrivoltaic system can have a large impact on the energy generation, however some suitable locations are limited by the amount of space they have to accommodate such systems. Similarly, uncertainties in the future climate and weather patterns of the area give rise to significant amounts of uncertainty, meaning that predicting the exact energy output and crop yields from the agrivoltaic system over an extended period remains challenging. A recent paper that investigates the agrivoltaic potential in different regions of Canada states that Nova Scotia has a low to moderate photovoltaic potential in its farmland regions (Jamil et al. 2023); this is not ideal for the implementation of agrivoltaic farming, but with climate projections showing warming conditions in the future (IPCC, 2023), it is unknown how suitable Nova Scotia's climate will be for agrivoltaics.

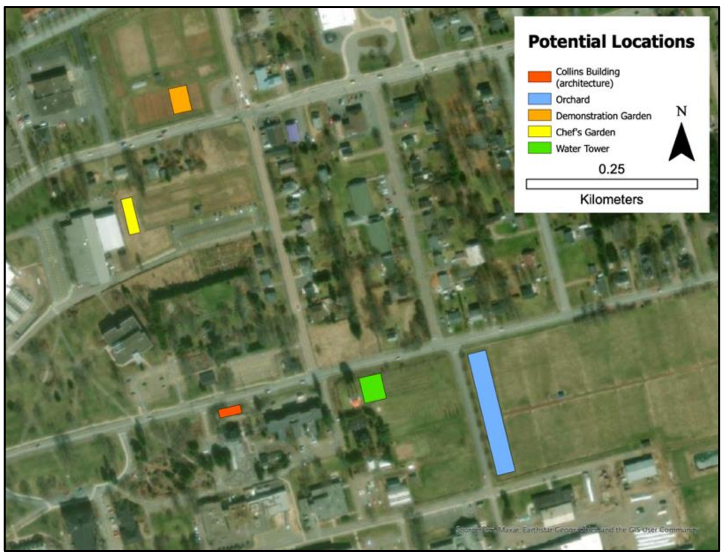
Financial limitations arise from the high costs of implementation and the uncertainty surrounding these costs. Tying into the grid or storing energy is costly, however it provides the most reliable source of energy. Also, costs of implementation have the potential to impede the productivity of the system by limiting the scale of the project and thus how much power it can generate. Maintenance costs, as well as the party responsible for the costs of the system were also important topics mentioned. Participants were not necessarily claiming the project was unachievable; however, cost is a potential barrier to consider, and it is important to assess the options before undertaking any implementation steps. Because finance was not a focus of our project, further research into the cost implications of agrivoltaics could help diminish some of this uncertainty.

Aesthetics and public perception of agrivoltaics could be another challenge in the steps of implementing this project. One participant mentioned how solar panels may not be visually appealing for the university if they are in a highly noticeable spot. There also could be negative opinions on photovoltaics or agrivoltaics in general, which would create a difficult situation to navigate. Public opposition is frequently noted as a barrier to the implementation of photovoltaics (Norman, 2022; Pascaris et al., 2022); however, a recent perception survey study revealed that over 80% of respondents would be more likely to support PV systems if combined with agriculture (Pascaris et al., 2022), highlighting the potential for agrivoltaics.

All these conflicting and overlapping benefits, considerations, and limitations show the complicated nature of agrivoltaics. They justify our research into further understanding the implications that these systems could have on the AC, and how these systems could be implemented beneficially.

Optimal Locations

Another aspect of the focus group discussions involved participants recommending potential locations for agrivoltaics systems; twenty sites were identified across all the discussions. These locations are differentiated by their surroundings, agriculture benefits, and potential energy production. Based on the benefits, considerations, and limitations of agrivoltaics that were mentioned by participants in the focus groups, the twenty locations were narrowed down to eight (Figure 4). These top eight locations all provide important and unique benefits; however, each have their own set of limitations.



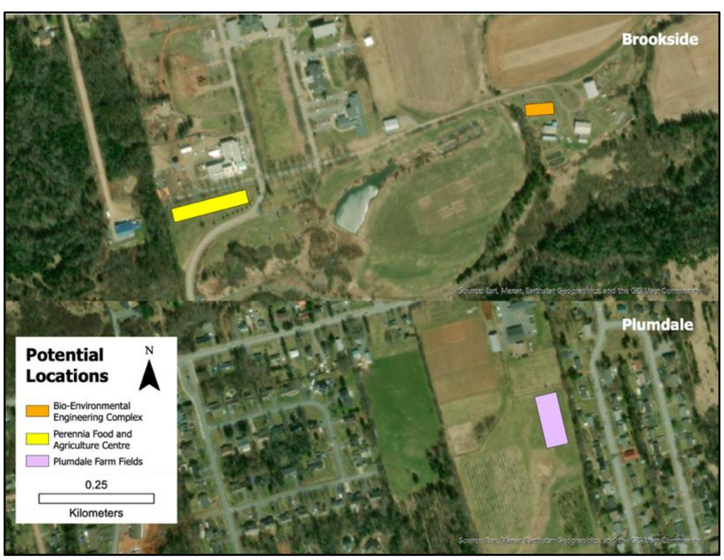


Figure 4 Maps displaying the locations that our team determined to be the optimal locations to implement agrivoltaics. Locations were chosen based on proximity to buildings, the benefits they provide to the surrounding area, and what was said about them in focus group discussions. The location of this map is Truro, Nova Scotia, Canada. The polygons and titles were created by E. Kushner. The basemap was created by ESRI with a NAD 83 spatial reference. The map was created on March 26th, 2024.

Plumdale is a beneficial location as it is surrounded by large horticulture fields and has a research lab that could benefit from a renewable energy source. A participant identified that the research facility has a high energy consumption as it operates oven dryers year-round for harvested crops. The large energy requirements and costs of maintaining this building could be reduced with the implementation of solar panels. The fields surrounding the buildings would also be a prime location for agrivoltaics as the soil is fertile and there is so much versatility for the size of system that could be implemented. Another positive to Plumdale is that there may be existing infrastructure from a greenhouse frame that can be incorporated into the construction of solar panels to reduce costs.

The Collins building is another optimal location for agrivoltaics due to the smaller scale building size and potential learning opportunities for architecture students. The building is a two-story house that consumes less energy than other campus buildings and therefore most, or all, of its energy could be generated through solar panels. Additionally, this building holds the architecture classes, and it was mentioned in the discussions that incorporating agrivoltaics into the outside landscape could expose students to sustainability infrastructure, offering learning opportunities which may heighten interest in collaborating with the Office of Sustainability for this implementation. One limitation is that the Collins building is located very centrally on campus and energy generation would be restricted by space availability.

Another optimal location is the Orchard as it has existing crop infrastructure that could benefit from shade. One participant was enthusiastic about this idea as "putting the panels adjacent to the orchard would cool the soil without taking light away from the orchard. [It] may even help with the weed control underneath". Although this model is not completely consistent with our more rigid definition of agrivoltaics, it entails key benefits to crops and the orchard as it would be protected from weeds and soil health could improve. It would also avoid the concern of light limitation that was discussed by a few participants. A limitation to this location is that it is across the street from the nearest building and would potentially require costly construction to run energy to the building.

The next beneficial location is Chef's Garden as agrivoltaics can be implemented directly beside the engineering building, which is one story, while simultaneously being included in the garden. Chef's garden is an organic demonstration farm that could create an opportunity for education on sustainable agriculture methods. The placement beside a popular campus building would also increase awareness for the practice. This location is limited by size as there is minimal space to implement a large system and therefore it would generate less energy.

Similarly to Chef's Garden, the Demonstration Garden is a beneficial location for agrivoltaics. The system would also be limited in size, but it is a great place to showcase this modern form of energy generation and agriculture. The garden is not close to a building; however, the discussion group mentioned that there are a few sheds that could be powered through panels. One important idea that was brought up is the Garden's potential for an agrivoltaic pilot project. The participants explained that the location is actively maintained, and a small-scale experiment could be run to further analyse the solar capacity for Truro and the shade-tolerant crops to be planted underneath. The focus group was very enthusiastic about this project and thought it could be the next step towards the actual implementation of a large system in Truro.

The fifth location is behind the water tower which was a suggestion made both by the focus group and our team. This is a beneficial location as the open field is already occupied by a water tower, making it unlikely that it would be used for other purposes. The fields behind the tower are also used for crop production, indicating fertile soil that can be further promoted by agrivoltaics. The location is also beside a small building that could benefit from an energy cost reduction through solar panels.

The final two locations identified in the focus groups were the Perennia Food and Agriculture Centre and the Bio-Environmental Engineering Complex. The agrivoltaic systems implemented in this location would provide energy for each of these large buildings but would probably not be able to offset their whole consumption due to space constraints. These complexes do require a lot of energy and would still benefit from a cost reduction through solar panels. The sites are surrounded by crop fields and are locations of agricultural research which could enable skillful individuals to develop and run a successful system.

Overall, the locations we suggest are heavily based on the inputs of knowledgeable individuals who are a part of the Dalhousie faculty and staff and work on the Truro Campus. Their suggestions were the basis of our eight chosen locations and therefore these sites need to be further researched. Our team also lacks a full understanding of what agricultural projects are currently ongoing in these locations and therefore the sites may also not be available. However, the criteria and considerations laid out by participants provide an important base for what should be looked at when implementing agrivoltaics on the Truro Agricultural Campus.

Future study

As highlighted by participants of our focus group discussions, agrivoltaics is an emerging solution that serves a dual-purpose of generating renewable energy while still supporting productive agricultural settings. However, there remains uncertainty about its outcomes and potential to provide an efficient system on the AC, both in terms of energy capacity and crop production, giving rise to the need for further research and understanding of any implications. For one, energy outputs and system sizes that were calculated in this study do not represent accurate photovoltaic systems that we would recommend for implementation; the variables were considered to only provide a rough estimate of the energy potential that the Truro microclimate can produce, so further exploration is needed to provide a more accurate understanding of energy potential. Along with this, energy requirements of building operations on the AC and appropriate system sizes should be considered. Financial consequences should also be explored, as there was no assessment of costs completed in our research. Other opportunities to implement photovoltaics in combination with another resource or initiative on the AC should also be considered, as many innovative and promising solutions were offered by participants in the focus group. For example, a couple of participants mentioned the potential for using PV panels to generate energy that could power lighting or heat sources in greenhouses or vertical farms. As previously mentioned, animal agrivoltaics offers a feasible and well-supported alternative to using crops, which appeared to seem favourable to several participants. The use of existing infrastructure on campus, whether that be buildings or other unused structures was also heavily discussed in the focus groups as it offers a system that still satisfies the objectives of utilizing wasted or underused space while not compromising the effectiveness of current agricultural production. The suggestion of transitioning these ideas into an aquacultural setting, and generating an aquavoltaic system, was also briefly mentioned by respondents, showing the diversity of PV systems and their applications with space utilization.

Conclusion

Given all these uncertainties and unknowns, our current recommendation is the development and implementation of an agrivoltaics pilot project located within the Demonstration Garden on the AC. Previously identified shade-tolerant crop species that could survive in the Truro climate can be used in combination with a single-panel PV system to create a model for larger-scale agrivoltaic operations. This small-scale project would allow for an accurate investigation of the potential for agrivoltaics in Truro without giving rise to extensive costs or risks. Data collection could be performed to assess the energy potential, changes in microclimate, effects on crop production, and any other implications from the system could be observed. It could also serve as an effective way to gauge public interest in agrivoltaics and could offer a unique educational experience for students on campus. The results obtained from this pilot project could help inform the Office of Sustainability and other decision-makers about the future potential for larger-scale agrivoltaic farming on the AC, or act as leverage to investigate other opportunities for PV systems if the results are not overwhelmingly supportive of agrivoltaics. We hope that our research will not only push Dalhousie University towards its sustainability goals, but that it will also increase awareness around agrivoltaics and inspire others to investigate the potential of these systems in Canada. This could help transition the energy sector to more sustainable practices while simultaneously promoting food security.

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Appendices

Appendix A

Table A1 Screenshot of Microsoft Excel Table, showing background information on the 20 potential locations. Rows highlighted in green indicate that they are preferred locations for the implementation of agrivoltaics. Solar capacity is the result from PVWatts showing how much energy can be generated for each location based on the size of system we chose. The cells that say “repeat” indicate a calculation that was already performed and a location that has been identified by more than one group.

Who suggested it	Location	Description	Size (kW) = Array Area (m²) × 1 kW/m² × Module Efficiency (%)	Solar Capacity
ENVS 3502 Team	45.372931, -63.260211	Behind water tower	1,223.18m x 1 x 0.19 = 232.37	265,559 kWh/Year*
	45.372681, -63.260065	Behind english building	972.29m x 0.19 = 184.74	211,143 kWh/Year*
	45.372080, -63.259458	Beside building 83	1273.86m x 0.19= 242	276,555 kWh/Year*
	45.372490, -63.257501	1 Farmstead Ct	4416.28m x 0.19 = 839.09	958,617 kWh/Year*
First session	45.374525, -63.263363	Chefs garden	847.47m x0.19= 161.02	184,247 kWh/Year*
	45.374733, -63.264155	Agricultural engineering annex	1771.99m x 0.19 = 336.68	384,722 kWh/Year*
	45.373604, -63.263881	Macrae Library	1161.91 x 0.19 = 220.76	252,291 kWh/Year*
	45.373933, -63.263007	Behind Agricultural engineering annex	1715.58 x 0.19 = 325.96	372,473 kWh/Year*
	45.372931, -63.260211	Behind water tower	REPEAT	
Second session	45.376193, -63.263170	Demonstration Garden	1021.06 x 0.19=194	221,726 kWh/Year*
	45.372244, -63.256166	Behind farm, infront of water	721.54 x 0.19= 137.09	156,698 kWh/Year*
	45.371806, -63.252873	Large field not close to buildings	10709.24 x 0.19 = 2034.76	2,324,301 kWh/Year*
	45.374809, -63.238262	Plumdale	5543.27 x 0.19 = 1053.22	1,221,568 kWh/Year*
	45.386229, -63.240171	Agritech	12120.51 x 0.19 = 2302.9	2,630,566 kWh/Year*
	45.390389, -63.250279	Brookside	9223.73 x 0.19= 1752.51	2,001,922 kWh/Year*
Third session	45.372753, -63.258699	Orchard	4966.23 x 0.19= 943.58	1,077,971 kWh/Year*
	45.370394, -63.252901	By river	20759.90 x 0.19 = 3944.38	4,505,353 kWh/Year*
	45.370599, -63.262845	Invasive crop replacement	14007.76 x 0.19 = 2661.47	3,040,103 kWh/Year*
	45.376073, -63.262972	Demonstration Garden	REPEAT	
Coding data	45.386752, -63.243710	perennia food and agriculture centre	5000.53 x 0.19 = 950.1	1,085,420 kWh/Year
	45.388099, -63.237504	Bio-environmental engineering complex	1600.69 x 0.19 = 304.13	352,835 kWh/Year
	45.372678, -63.262240	Collins Building (architecture)	420.74 x 0.19= 79.94	91,695 kWh/Year

Appendix B

Drawings Created by Focus Group Participants

Figure B1 Drawing created by focus group participant on March 18th, 2024. The red circles highlight locations mentioned in the focus group discussion that would be suitable for the implementation of agrivoltaics. Map location is Truro, Nova Scotia, Canada.

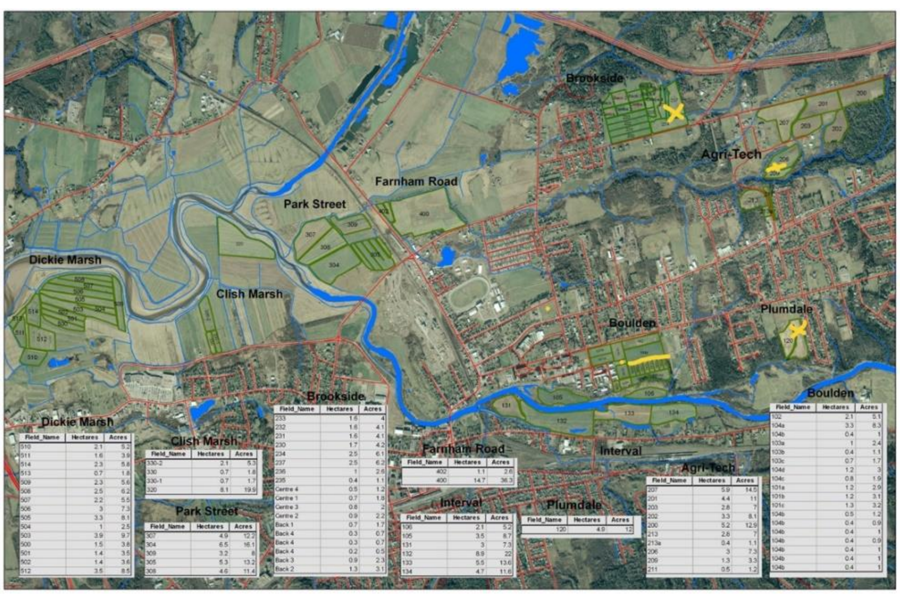

Figure B2 Drawing created by focus group participant on March 19th, 2024. The yellow markings identify potential locations for agrivoltaic implementation on the Dalhousie Truro Campus in Nova Scotia, Canada. The locations were mentioned during focus group discussion.

Figure B3 Drawing created by focus group participant on March 21st, 2024. The red circles display potential locations for agrivoltaics on the Dalhousie Truro Campus in Nova Scotia, Canada. The blue circle shows the Demonstration Garden, and the yellow circle shows an area mentioned in focus group discussion where weeds are growing.

Appendix C

Focus Group Questions

1. What is your position/connection with the Dalhousie agricultural campus? (e.g. Grad student, professor, groundworker, etc.)
2. What is your current and/or past area of expertise or research?
3. Do you have any background knowledge and/or experience with agriculture, photovoltaics, or agrivoltaics?
4. What are your opinions on the implementation of an agrivolataic system on the Dalhousie Truro campus?
5. Based on your current understanding, what are some key benefits of agrivoltaic systems in general? On the Truro campus?
6. In your opinion, what are some main limitations of agrivoltaic systems in general? On the Truro campus?
7. Are there any specific locations on the Truro Campus that you think would be optimal for agrivoltaics? Why these locations?
8. Are there any specific locations on the Truro Campus that you think would be unsuitable for agrivoltaics? If so, why these locations?
9. Do you have any additional comments regarding this project?