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Antrim Township

Solar Infrastructure Assessment

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About CLUS

The Center for Land Use was originally established by Shippensburg University in July 2003 to provide technical, educational, research, and planning assistance to counties within the local region. In 2015, the Center was relaunched as the Center for Land Use and Sustainability (CLUS) as an organization committed to interdisciplinary research and sustainable solutions at local, regional, and global scales. The CLUS cooperates with communities, collaborators, and partners by leveraging faculty expertise and enthusiastic student fellows to provide consulting expertise in Geographic Information Systems (GIS), community sustainability, applied history and archaeology, physical and environmental sciences, and other areas. The CLUS is committed to empowering decision makers by providing information to support informed, sustainable policies, while fostering the next generation of resource stewards.

This work was supported, in part, through charitable donations to the CLUS and support from the College of Arts and Sciences of Shippensburg University. This assessment builds on previous work completed by Patricia Newdeck, CLUS Graduate Student Fellow, and includes contributions from Ben Stine, CLUS Undergraduate Student Fellow.

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Executive Summary

Many communities are exploring renewable energy sources as part of resilient energy strategies to reduce greenhouse gas emissions and long-term energy costs for community residents and businesses. This study evaluates solar resources relative to current electricity demand in Antrim Township and Greencastle Borough, located in south central Pennsylvania. Researchers evaluated regional solar insolation, electricity demand for the prior year, total land area for solar infrastructure necessary to meet current community demands, and electricity storage capacities required to overcome short and long term fluctuations in solar radiation, relative to seasonal demand.

Using electricity consumption data from the local electricity supplier, FirstEnergy Corporation, and calculated insolation values, current electricity demands for Antrim Township are met with 216.83 - 433.66 acres of land covered in solar panels during the summer peak for solar insolation (June). During the winter peak for energy consumption (January), much more land would be required, approximately 1,416.18 - 2,832.35 acres.

This study assumes that panels convert 15% of solar radiation into usable electricity, and evaluated a range of solar panel density factors from 0.50 (50% coverage) to 1.0 (100% coverage). The need for storage infrastructure based on short (day and night), mid (a series of rainy/cloudy days), and long (seasonal) range solar variations is discussed. Specific storage capacities for supplementing the grid with electricity on days of sub-par solar electricity production were found to be 600 MW/h for one summer day, and 860 MW/h for one winter day.

Background

Objectives

This study was conducted by the Center for Land Use and Sustainability of Shippensburg University on behalf of Antrim Township, Pennsylvania. An assessment of solar energy potential was requested by the township to inform drafting ordinances related to solar infrastructure as well as the potential development of a community microgrid to support energy resiliency. The purpose of this study was to answer the following questions:

- What is the current demand for electricity in Antrim Township and Greencastle Borough on an annual, monthly, and daily basis?
- How much land would need to be occupied by solar panels to meet this demand, given the daily and monthly variation in demand and insolation and current panel efficiency?

To answer the questions above, we obtained electricity consumption data for Antrim Township and Greencastle Borough (provided by zipcode) from FirstEnergy Corporation. Data were provided on a monthly basis for 2017-2018, allowing annual demand to be calculated directly and daily demand to be estimated. Based on previous work, solar insolation for the study area was estimated using the ArcGIS solar insolation tool on a monthly basis; daily estimates were derived from monthly estimates. Total land area required for solar panels to meet township needs was calculated based on assumptions about the installed panel density and panel efficiency; a range of densities were evaluated (0.5-1.0). Finally, we briefly address the need for long and short term energy storage and discuss candidate areas for solar panel development.

The box on the following page outlines key terms and definitions used in this report.

Key terms and definitions

Photovoltaic panels; solar thermal panels: Photovoltaic panels convert sunlight into electricity while solar thermal panels convert the sun's energy into heat. This study focuses on photovoltaic panels.

Kilowatt (kW): A unit to measure power; equal to 1,000 watts. Kilowatts are often used to measure electricity demand for large appliances and households. For example, a typical refrigerator consumes 1,000 kilowatts per hour.

Megawatt (mW): A unit to measure power; equal to 1,000,000 watts and 1,000 kilowatts, used to measure large quantities of power such as electricity for a city or small power plant.

Kilowatt hours (kWh): Used to measure electricity consumption, commonly seen on electric bills to display the amount of electricity used. A kilowatt hour equals one hour of using electricity at the rate of 1,000 watts.

Insolation: The occurrence of incident solar radiation onto an object, typically measured in kilowatt-hours or watt-hours.

Watts/kilowatts per square meter (W/m^2 and kW/m^2): The power in watts that is received by a surface per square meter. Watt or kilowatt hours per square meter (Wh/m^2 *and* kWh/m^2) express the energy per square meter per hour.

Panel efficiency: The rate (percentage) that sunlight is converted into electricity. For example, current solar panels, on average, convert 15% of the sun's energy into electricity.

Solar Energy in Pennsylvania

Each year, the Earth makes one revolution around the sun. At the same time, our planet oscillates on its axis. These two movements change the distance of the Earth from the sun and the angle at which the sun's rays make contact with the Earth's surface, and therefore, the amount of solar energy Earth receives. In the Northern Hemisphere, the smallest amount of solar radiation reaches the surface in the winter (December, January, February) and the most reaches the surface in the summer (June, July, August) due to the Earth's angle to the sun.

Given the mid-latitude geographic location, Pennsylvania may not initially be considered a strong candidate for solar energy development. Nevertheless, mid- and high-latitude locations that have relatively short days during the winter months are successfully pursuing solar energy generation projects, as demonstrated by an ambitious investment into solar infrastructure made by some high-latitude nations such as Canada (HES PV, 2019). Photovoltaic solar panel installations are surrounded by misconceptions: that they will lower the value of a home, that they do not work well in certain climates, and that they are prohibitively expensive (Office of Energy Efficiency and Renewable Energy, 2016). While a lot of time and capital goes into keeping a coal fired power plant, wind farm, or nuclear power plant running, the investment in operating a solar farm or small residential array is comparatively small. With planning, a solar farm can also be used to grow native vegetation, pollinator-friendly plants, crops, or graze small animals such as sheep and goats (May, 2018).

The Pennsylvania Department of Environmental Protection (DEP) has written a Solar Future Plan for municipalities that outlines methods to implement solar energy, setting a goal of 10% of electricity generation supported by solar by 2030 (Pennsylvania DEP, 2018). Groups like SolSmart (SolSmart, 2019) are committed to supporting solar future planning in communities. The solar market in Pennsylvania and the US as a whole has undergone significant growth and economic efficiency gains in recent years. For example, the Solar Energy Industries Association (SEIA) reports that the price of solar in Pennsylvania has decreased 47% in the last 5 years. While only 0.24% of the state's energy is generated via solar, it is projected that 810 megawatts of solar capacity will be developed in the next 5 years, almost double the current state capacity of 410.2 megawatts (SEIA, 2019). The introduction of electric vehicles indicates an increasing need for more electricity generation. As electric vehicles become more common, electricity needs will increase, and once electric trucks enter the scene, the trucking industry will have an even greater need for electricity sources close to terminals and warehouses (North American Council for Freight Efficiency, 2018).

The increasing demand for electricity encourages the use of solar infrastructure as it is the only method of generation that can be rapidly developed and deployed. In Pennsylvania's Solar Future Plan (2018), the DEP outlines three major types of solar energy systems:

- Residential systems: installed on roofs or a similarly small scale
- Commercial or community solar arrays: larger in size, but do not generate enough electricity to be bought or sold on a very large scale
- Grid scale solar systems: solar farms providing large amounts of electricity to the grid.

Accounting for all three types of solar arrays is essential to the success of solar plan development, as each have specific considerations.

Study Area Description

Antrim Township was established in 1741, and is located in southern Franklin County in Pennsylvania. It is governed by a board of five elected supervisors. These supervisors are charged with balancing various interests in the township, and increasing the wellbeing of residents and economic growth of the municipality. Antrim maintains a rural atmosphere and agriculture as a cornerstone of Antrim's heritage and land use (About Antrim, 2019). Residents of Antrim Township benefit from large amounts of open space and views of rolling hills, as well as economic development in the urban areas of the municipality. Due to its proximity to multiple metropolitan areas such as Chambersburg, PA, and Hagerstown, MD, and given its location along the Interstate-81 corridor, the township has seen growth in business and transportation as a result of manufacturing and trade. Greencastle Borough is surrounded by Antrim Township and is included in this assessment as part of the study area. The 2017 population of Antrim Township is 15,370, with an additional 4,034 residents in Greencastle Borough (U.S. Census, 2019).

This study focused on the overall electricity needs and solar electricity capacity of Antrim Township and Greencastle Borough (the 17225 zip code). Particular attention is drawn to three properties of potential interest as case studies for solar development: property owned by Richard Weeden, the property of the Gayman Family, and the large warehouse structures within the Antrim Commons Business Park at Exit 3 on I-81 (*Figure 1*).

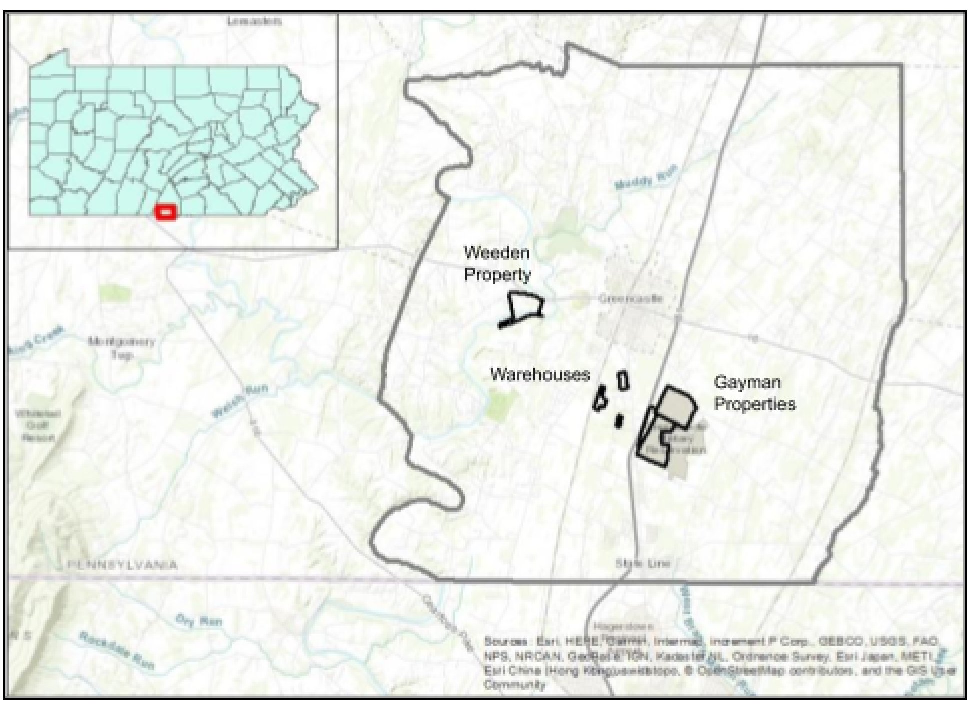

Figure 1. Location of Antrim Township and identified areas of interest: Richard Weeden property, Gayman properties, and Exit 3 Warehouses.

Electricity Storage Considerations

The most frequent critiques of solar electricity are related to its intermittence: this method of electricity generation is only effective while the sun is up. While true, this criticism emphasizes the fact that solar energy production has different requirements than other electricity generation methods, the need for electricity storage infrastructure in particular.

Given that solar energy is only productive during the day, solar electricity systems benefit greatly from integrated or nearby storage infrastructure. Stored electricity can be used to supplement overnight demand as well as for a few days of inclement weather, given the system is large enough. Pumped hydroelectric storage facilities, which store energy in the form of water in an upper reservoir, pumped from another reservoir at a lower elevation, are already widely used in the U.S., accounting for 95% of all utility-scale energy storage (US Department of Energy, 2019; Energy Storage Association, 2019). Recent breakthroughs in electric battery storage technology have allowed for the development of electric energy storage on a large scale using lithium-ion batteries (RenewableEnergyWorld, 2017).

The most notable large scale battery energy storage is in Australia, where a 100 MW lithium-ion battery system was built by the company Tesla in 2016 (Eniday, 2018). The system was designed to prevent power outages during hurricanes and heat waves, and is charged with excess electricity generated by a nearby wind farm. This serves as an excellent example of synergizing intermittent energy sources with energy storage infrastructure to create a reliable system.

Data and Methods

Antrim Electricity Consumption

FirstEnergy Corporation provided monthly electricity consumption data for the 17225 zip code (Antrim Township and Greencastle Borough) from August 1, 2017, through July 31, 2018. These monthly data were divided by the number of days in each month to estimate average daily consumption. Daily consumption values were needed for later calculations of solar infrastructure requirements to meet current daily electricity demand.

We note that having only one year of data is a potential limitation of this study. However, electricity demands are largely driven by heating and cooling needs. The monthly average temperature for the time period for which we have electricity consumption data is similar to 1932-present average conditions (Figure 2). Another limitation is the lack of daily electricity consumption data. While we were able to estimate daily consumption values, we were not able to estimate unusually cool or warm days that might have occurred during the study time period.

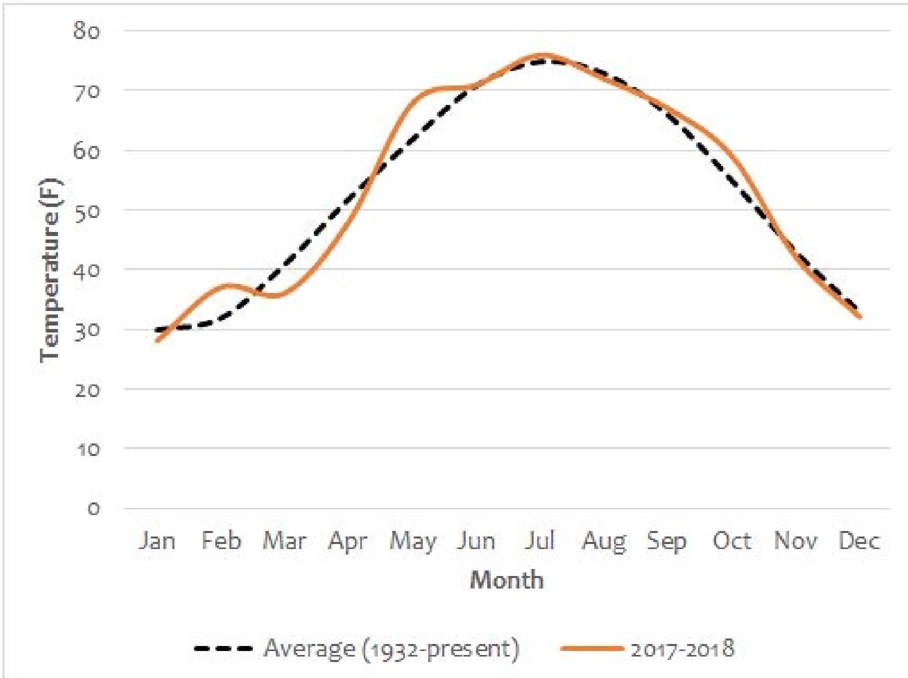

Figure 2: Monthly average temperature (1932-present) compared to the 2017-2018 time period that coincides with the FirstEnergy Corporation electricity consumption data. These data are from a weather station at Shippensburg University (http://webspace.ship.edu/weather/).

Antrim Solar Insolation

Solar insolation models estimate the amount of solar radiation (energy) that reaches the earth's surface. Insolation values are based on the angle of the sun's rays at the surface; therefore, Geographic Information Systems (GIS) can model a location's solar insolation based on latitude, slope, and aspect (direction the slope faces). Insolation values are generated for a specified period of time and reported in units of kWh/m^2.

Previous work by the CLUS included the development of a webmap that estimates average annual solar insolation values for Antrim Township at the parcel level (Newdeck 2018, and *Figure 3*). Insolation values represent August 1, 2017, through July 31, 2018, to match the time period for energy use data provided by FirstEnergy Corp. Daily, monthly, and annual insolation values were generated at the parcel level using the parcel's terrain and latitude.

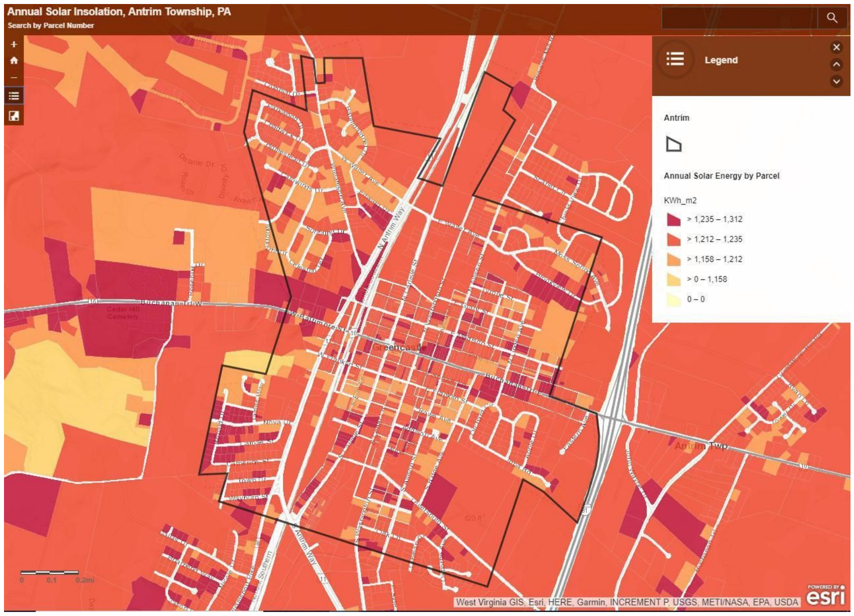

Figure 3. Screen image of web map displaying average annual solar insolation in Antrim Township.

Solar Infrastructure Needs

Solar infrastructure requirements for Antrim Township and Greencastle Borough were estimated by calculating the total land area necessary for solar panels to generate sufficient electricity from solar insolation to meet current consumption.

Electricity consumption in Antrim Township and Greencastle Borough follow the same general trends observed throughout mid-latitude regions of the world: consumption is highest in the winter due to home heating demands, with a lower peak in summer as people use more energy to cool their homes; spring and fall (the "shoulder seasons") have lower energy demand because heating and cooling demands are lower. It should be noted that the season of highest demand corresponds with the season of lowest insolation.

To evaluate how electricity usage compares to solar insolation values, the monthly electricity consumption was divided by the number of days in each month to find daily insolation and average consumption for a single day within each month. Calculations were done using daily data to determine the area required to produce enough energy to meet consumption demands. This calculation was made conservatively using *Equation 1*, where A is the total area of solar panels, E is total electricity consumption, r is panel efficiency, H is solar insolation, and D is the panel density factor. A density factor of 1.0 would indicate that solar panels cover 100% of the site, while a density factor of 0.50 indicates that panels cover 50% of the site (for example, due to spacing requirements or topographic site factors).

Equation 1 $$A = \frac{E}{rHD}$$

Calculations for total required area of coverage (A) were done using a density factor of 0.50, 0.75, and 1.0 and assumed 15% panel efficiency (i.e. that 15% of total isolation is converted into electricity). By solving for E, the same equation can be used to determine solar electricity output for locations of interest (E=ArHD).

Storage Capacity

Electricity storage needs were considered based upon potential reduced solar insolation for three time intervals - one, three and seven days. Storage needs were considered for each month to capture seasonal fluctuations in demand and electricity production. These calculations were made by multiplying the duration (in days) of energy withdrawal from batteries by the average daily consumption for a given month.

Results

Antrim Electricity Consumption

Average daily energy consumption ranged from a low of 487,217 kWh in May 2018 to a high of 859,211 kWh in January 2018 (*Figure 4*).

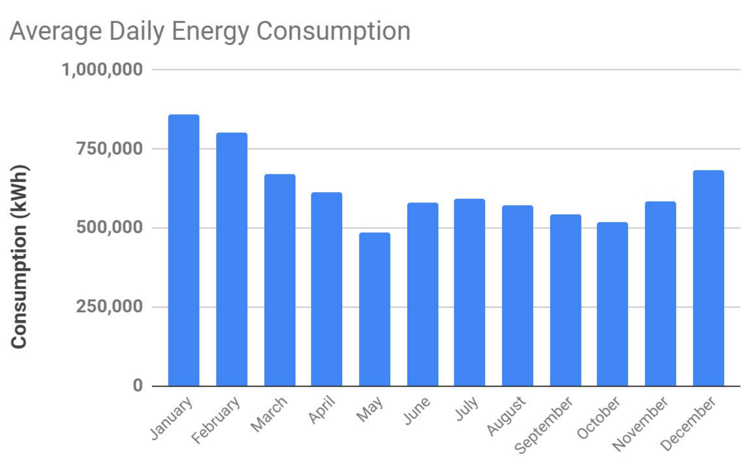

Figure 4. Estimated daily electricity consumption (kWh) by month.

Antrim Solar Insolation

Average daily insolation ranged from a low of 0.85 kWh/m^2 in December 2017 to a high of 4.40 kWh/m^2 in June 2018 (*Figure 5*).

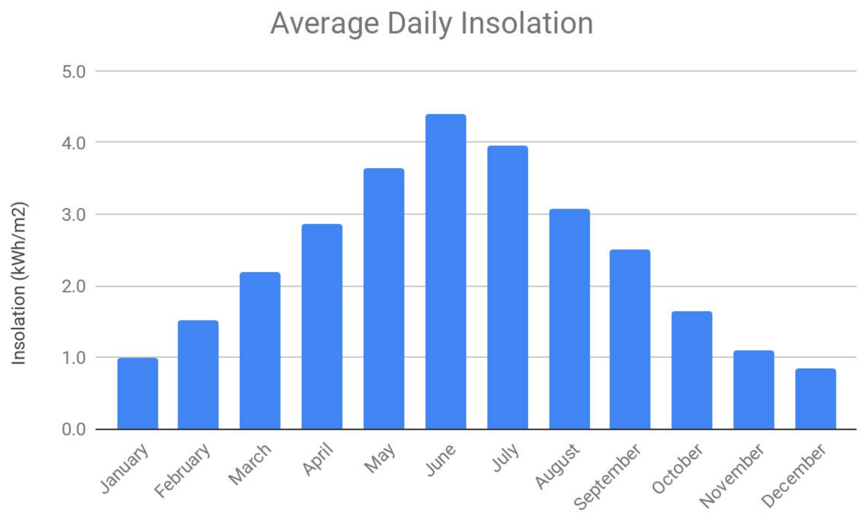

Figure 5. Average daily insolation for each month of the year.

Solar Infrastructure

Assuming density factors of 0.50, 0.75, and 1.0, estimated solar electricity output from solar panels (kWh/m^2) was calculated throughout the year based on average daily insolation (*Figure 6*). Estimated land area required for solar panel output to meet average daily consumption was calculated by month for Antrim Township (*Table 1*).

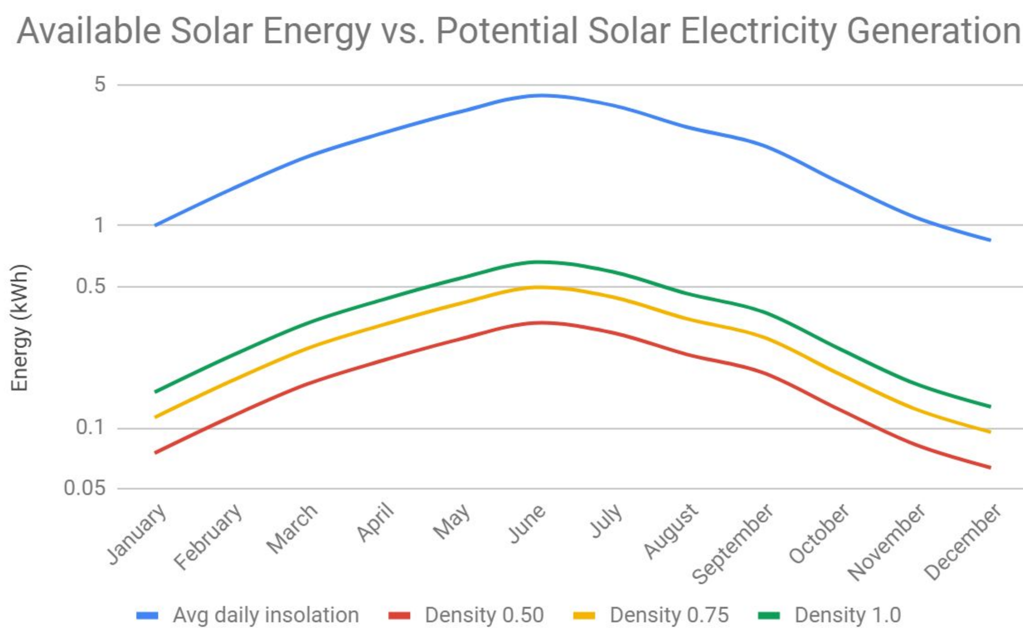

Figure 6. Insolation (kWh/m^2) against the total potential electricity output of solar panels (kWh/m^2)

Month	Avg. daily insolation (kWh/m^2)	Avg. daily consumption (kWh)	Land area (acres) at 0.50 density	Land area (acres) at 0.75 density	Land area (acres) at 1.0 density
January	1.00	859,211.00	2,832.35	1,888.24	1,416.18
February	1.51	800,893.00	1,749.03	1,166.02	874.52
March	2.19	672,319.00	1,012.70	675.13	506.35
April	2.87	611,870.00	702.44	468.30	351.22
May	3.65	487,217.00	440.16	293.44	220.08
June	4.40	579,201.00	433.66	289.10	216.83
July	3.96	594,441.00	494.77	329.84	247.38
August	3.08	572,903.00	613.66	409.11	306.83
September	2.50	541,191.00	713.62	475.75	356.81
October	1.64	518,106.00	1,038.52	692.35	519.26
November	1.10	585,786.00	1,750.98	1,167.32	875.49
December	0.85	682,451.00	2,658.70	1,772.46	1,329.35

Table 1. Average daily insolation, electricity consumption, and land area required for solar panels to meet energy demand, assuming density factors of 0.50, 0.75, and 1.0..

Storage Capacity

Electricity storage capacities required to meet community demands due to short term (1 day) or mid term (up to a week) weather events are summarized in *Table 2*. Storage needs are lowest when solar insolation is high and energy consumption is low (e.g. May) and during periods of lower energy consumption in the Spring and Fall (e.g. October).

		Required Capacities (kWh) for:		
Month	daily consumption (kWh)	1 Day	3 Days	7 Days
January	859,211	1,718,422	2,577,633	6,014,477
February	800,893	1,601,786	2,402,679	5,606,251
March	672,319	1,344,638	2,016,957	4,706,233
April	611,870	1,223,740	1,835,610	4,283,090
May	487,217	974,434	1,461,651	3,410,519
June	579,201	1,158,402	1,737,603	4,054,407
July	594,441	1,188,882	1,783,323	4,161,087
August	572,903	1,145,806	1,718,709	4,010,321
September	541,191	1,082,382	1,623,573	3,788,337
October	518,106	1,036,212	1,554,318	3,626,742
November	585,786	1,171,572	1,757,358	4,100,502
December	682,451	1,364,902	2,047,353	4,777,157

Table 2. Daily energy consumption and storage capacities for one, three, and seven days.

Summary of results

Estimated solar electricity generation requirements were calculated based on a year of data provided for energy usage in Antrim Township and Greencastle Borough from August 1, 2017, through July 31, 2018. Average peak daily electricity consumption is 859,211 kWh in the winter (January), and average daily consumption for the summer peak is 594,441 kWh (*Table 1*).

To meet average daily energy consumption during the summer peak for solar insolation (June), 217-434 acres of land covered in solar panels would be required, considering a panel density range of 0.50-1.0. Conversely, during the winter peak for energy consumption (January), much more land would be required, approximately 1,416-2,832 acres. True total land area required for panels is likely to fall between calculated panel density ranges, and is also dependent on panel efficiency. The values above reflect an assumption of 15% efficiency, given current technology.

Case Studies for Developing Solar Infrastructure

Three areas of interest were identified for evaluating solar energy potential: property owned by Richard Weeden, property of the Gayman Family, and three large warehouse structures within the Antrim Commons Business Park at Interstate-81 Exit 3 (*Figure 1*).

The Antrim Commons Business Park is a prime location for solar development, as the large buildings present a vast surface area of unobscured space for panels. The recent construction of three large warehouses at Exit 3 present potential surface area for panels and the possibility for electrical output to support infrastructure and economy in the area. Warehouses are constructed to be solar ready, that is, structurally capable of supporting solar panels on their roofs. Solar panels can be installed directly after completion of a warehouse, but the additional costs of solar arrays, the demand for more warehousing structures, and lack of federal, state, or local policies to incentivise solar electricity, solar insolation on warehouse roofs often goes uncaptured.

The combined warehouse rooftop area available for solar panels is 33.35 acres. This area calculation assumes 60% of the rooftop is available to accommodate solar panels. Based on these assumptions, daily solar energy production for these three warehouses would range from 40,489 - 80,978 kWh in the summer months (May-July) (meeting approximately 7-15% of peak summer electricity demand) and from 10,122 - 20,244 kWh in the winter months (November-January) (meeting approximately 1-3 % of peak winter electricity demand).

The Gayman property to the southwest of Greencastle is another example of a large land area that could be developed for solar energy infrastructure, and has been identified as an area of interest by commercial solar energy companies. Occupying 415 acres, development of the Gayman property as a solar farm could produce 503,834 -1,007,668 kWh per day in summer energy output and 125,959-251,917 kWh in winter energy output. These solar energy yields would provide approximately 91-182% of calculated electricity demands in the summer, and could generate 18-36% of winter electricity consumption.

Richard Weeden intends to build a retirement community on his land, complete with a small medical facility and solar array. A solar array could benefit the community by providing energy security and reducing electricity costs, with the added benefit of offering a means of charging emergency batteries for the medical facility. Backup energy storage is important for any facility that must function constantly. Some facilities are switching from fossil fuel generators to electric battery banks due to the convenience and decreased maintenance of batteries compared to generators (EnergySage, 2019). On the Weeden property, solar energy and battery storage have been considered to increase longevity and convenience of the storage system.

Unfortunately, this property is poorly located for solar energy generation as it is in a lowland area next to the Conococheague Creek (*Figure 7*); however, if electric batteries were installed, it could benefit from solar energy generation in other areas of the township - especially if solar electricity is generated in excess of needs, as is potentially the case with the Gayman property.

Figure 7. Exit 3 warehouses (left) and Gayman property (right)

These three examples evaluate prospective grid scale or community scale solar projects, but there is also growing interest in residential solar, as evidenced by the overall growth of solar across the state. Many houses in Antrim Township and Greencastle Borough already have residential scale solar arrays installed on their roofs. Given this, implementing a solar ordinance that addresses residential, community, and grid scale solar would be advantageous at this time in order to encourage and guide the development of solar electricity infrastructure in a way that is consistent with the character of the community.

Storage Capacity Considerations

Electricity storage capacity should be considered for short, mid, and long term horizons. Short term storage can accommodate electricity needs for single day weather events or overnight needs. Mid term storage can address demand during longer weather events, up to a week, while long term storage can support electricity fluctuations throughout the year. As previously noted, electricity demands fluctuate throughout the year, with the highest needs in winter, followed by summer, fall and spring.

While this study does not address long term storage needs related to seasonal fluctuations, or short term storage needs related to overnight energy use, it is worth noting some important challenges related to solar electricity generation. In particular, it has been well documented that solar electricity floods the market during daylight hours while the sun is shining and energy use is low, then drops off rapidly as electricity demands peak in the evening and the sun sets, eliminating energy contributions from solar (*Figure 8*) (USDE 2017).

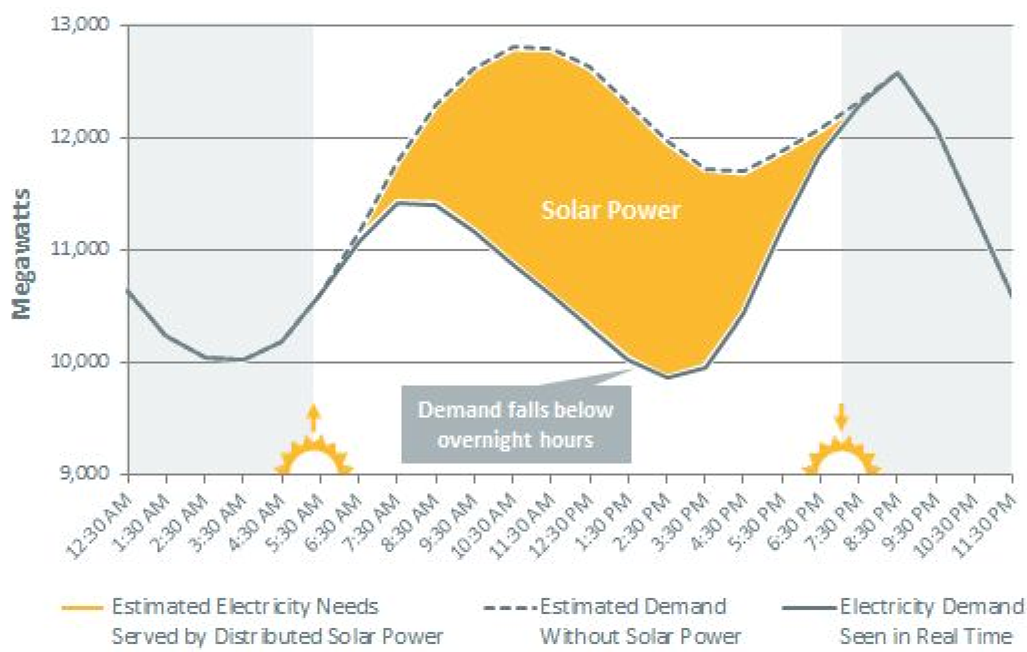

Figure 8: An electricity supply and demand curve for April 21, 2018, in New England when demand for electricity from the electric utility company was largely offset by solar electricity (from Burger 2018).

This phenomenon occurs because as solar panels are added, electricity input to the utility grid increases while power plants continue to supply the same amount of electricity. Oversaturation of energy on the grid is problematic because much of it will go unused. Even more problematic is the rapid increase in demand to the grid that occurs as solar electricity generation drops off. These issues highlight the importance of intentional planning for solar by utilities, municipalities, and states, as well as the need to integrate storage infrastructure into the system.

Storage capacity required to supply electricity into the night will be nearly proportional to the total energy consumed over the day because demand is highest when solar output is waning. As for energy storage over multiple days, we find that to meet demand fully on unproductive days, an energy storage system should have a capacity equal to or greater than average consumption for a day. Large scale storage of electricity is uncommon in the United States, but with the rise of intermittent renewable energies such as solar and wind electricity, the need for large scale electricity storage has become apparent. Batteries have historically been impractical for use in large scale storage, thus methods such as compressed air, hydrogen storage, and pumped hydroelectric storage have been more common. That said, recent improvements in battery efficiency and production have increased the practicality of large scale battery based energy storage - which is much more efficient and quick in its response to grid demand.

Conclusion

The purpose of this research was to evaluate the potential for solar electricity in Antrim Township and Greencastle Borough by understanding local solar insolation values, electricity demand, infrastructure requirements, and necessary storage capacity. Based on monthly electricity consumption data from FirstEnergy Corp and calculated solar insolation, the land area required for solar panels to meet current peak consumption (January) would be 1,416-2,832 acres, depending on panel density. This value is significantly higher than the land area required to meet the lowest levels of consumption in the summer (June), 217-434 acres.

Based on the assessment of the three areas of interest for solar development within the township, it appears feasible to support electricity requirements of Antrim Township by using solar energy. Potential solar energy yields from developing the Gayman property as a solar farm could fully support township electricity requirements in the summer, and partially support the requirements in the winter. Additional solar arrays placed on Exit 3 warehouse rooftops have the potential to contribute to the township electricity requirements throughout the year.

Although outside the scope of this study, total land required for solar panels has the potential to be reduced by introducing electricity storage infrastructure to offset long and short term storage needs. Improved technology in the future may also contribute to higher efficiency panels and/or reduced electricity loss as compared to current solar infrastructure. As Antrim Township moves forward in developing solar ordinances and considering a community microgrid, it will be important to consider seasonal variation in electricity needs and address short, mid, and long term electricity storage requirements.

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