Solar Energy Site Selection and Design in Madison, WI

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Abstract:

This project is an investigation of planning a ground mount solar energy system and consists of two key parts: site selection and system design. The site selection process involves analyzing significant criteria to ensure that the selected land parcel is suitable for a solar energy system. A comprehensive system design provides concise visual imagery of the community solar array. This investigation contributes to broader discourses about increasing the deployment of solar energy.

Introduction:

As solar materials become more inexpensive and the global average temperature begins to rise, the appeal of solar energy generation as a solution to the world's energy needs grows.[1] Solar installations assist in reducing the carbon cost of producing electricity at all levels: utility, community, and residential. Solar is also highly compatible with distributed generation, given its flexibility in scaling. The ease of scaling, minimal upkeep inputs, and simple construction are all contributing factors to an explosion in solar energy generation across the United States. Despite this rapid nationwide increase in solar deployment, the state of Wisconsin lags in solar production, ranking 41st in total capacity in 2018.[2] Additionally, several planned solar projects in Wisconsin are utility scale. At the utility scale, the advantages of distributed generation are lost, resulting in unnecessary transmission losses. Smaller scale ground mount solar offers the advantages of distributed generation while also occupying less space. Ground mount systems

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[1] Keij, Rob. "Turning sunlight into electricity." *World Pumps* 2010, no. 12 (2010): 25-27.

[2] "Wisconsin Solar." SEIA. Accessed September 16, 2019. https://www.seia.org/state-solar-policy/wisconsin-solar.

also avoid the technical and administrative difficulties of rooftop solar installations at a residential level.

Our research seeks to identify the feasibility of a ground-mounted PV solar installation in the Madison area. Through the generation of solar feasibility criteria, we will identify physical, environmental, and cultural variables contributing to solar suitability at prospective sites. Using these criteria, an optimal selected site will be paired with a comprehensive ground mount solar system design.

In terms of research design, there will be multiple computer programs we will use for data collection and design of the system. System Advisory Model (SAM) is a techno-economic software model that provides vital information in measuring the feasibility of renewable energy systems. A ground mount photovoltaic system will be the focus of our project and SAM will allow us to customize the entire system down to the brand of solar panels, type of inverter and so on. We will also use PVCAD for the physical design of our project. PVCAD is a commercial computer-aided design and drafting software application. We will also use the National Renewable Energy Laboratory (NREL) to find solar radiation data for the site.

Key terms for our research include: photovoltaic (PV), solar radiation, array, module and mounting hardware. PV technologies convert sunlight to electricity through a naturally occurring process in certain materials. Solar radiation is a general term for the electromagnetic radiation emitted by the sun. A module is another word for solar panel, which has PV technology. An array is a connection of multiple modules wired together. Mounting hardware is the racking equipment that is used to secure the panels together. More background information on solar photovoltaics will be included in the literature review.

Literature Review:

Introduction to Literature

In the initial literature investigation, we found numerous sources that will support our research design. The topic of solar siting and design has a wealth of literature resources to examine, especially considering the contemporary expansion in photovoltaic technology. As a result, our research is justified and guided through a collection of very recent articles covering the implementation of solar installations. To start our investigation, we identified sources that proved to be useful within each of the divisions of our research method. The key concepts of site characteristics and evaluation, system components, and system design govern the organization of the supporting research sources. Useful sources included technical descriptions of processes that assist in the accuracy and efficiency of workflow over all the concepts contributing to our research. Additionally, articles with details about specific software workflows and statistical methods significantly supported the legitimacy of our research.

Our literature review seeks to explore the potential for a ground mounted solar site in the Madison area. Historically, PV solar has been too expensive to implement due to module costs.[3] This economic restriction has been removed through technology developments and federal, state, and local incentives. Before establishing the framework for our site selection and design processes, our research needs to have a fundamental economic and technical justification for a ground mounted solar system design in the Madison area.

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[3] Morton, Oliver. "Solar energy: A new day dawning?: Silicon Valley sunrise." *Nature* 443, no. 7107 (2006): 19-23.

Solar PV Basics

A core concept to our investigation is photovoltaic (PV) technology. A journal published by the International Journal for Research in Applied Science and Engineering Technology (IJRASET) provides a succinct description of how PV technology works.[4] Solar panels are made up of solar cells that convert the sun's energy to direct current (DC) electricity. PV cells are made up of semiconductor material, which combines properties of metals and properties of insulators. When sunlight is absorbed by these semiconductors, the photons of light can transfer their energy to electrons which creates an electrical current. The PV cells are sealed in a protective laminate and together form the solar module. Solar modules are wired together and then feed into an inverter. The solar inverter converts the DC electricity from the modules into Alternating Current (AC) electricity which can be used by consumers.

Why Solar PV?

Integral to our system design project is the explanation of why employing solar photovoltaic technology is economically attractive and environmentally friendly. A chapter from the book *Solar Energy: Fundamentals, Technology and Systems* published by Delft University of Technology provides key insight on PV economics and ecology.[5] An important economic

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[4] Mohd. Rizwan Sirajuddin Shaikh, "A Review Paper on Electricity Generation from Solar Energy," *International Journal for Research in Applied Science and Engineering Technology* 5, no. 4 (2017): 1884-1889.

[5] Jäger, Klaus, and Olindo Isabella. "Economics and Ecology." In *Solar Energy Fundamentals , Technology and Systems*, 341–45. Delft, Netherlands: Delft University of Technology, 2014. https://courses.edx.org/c4x/DelftX/ET.3034TU/asset/solar_energy_v1.1.pdf.

concept is the Levelized Cost of Electricity (LCOE). LCOE is defined as "the cost per kiloWatt Hour of electricity produced by a power generation facility"(Delft). LCOE is used to compare the costs of different electricity generating systems over a period of time. It is typical for grid power prices to steadily increase over time, while the cost of electricity with a PV system steadily declines over time. In regards to the ecology of PV systems, the overall intention is to produce electricity without any considerable effect on the environment. A metric to analyze this concept is the Energy Payback Time (EPT). The EPT equals the total invested energy to produce and transport a solar module divided by the average annual energy yield of that module. After extensive data analysis, the authors concluded that no matter which PV technology was chosen, the energy payback time was significantly shorter than the projected lifetime of the system. In other words, the energy invested in the PV system is paid back several times throughout the lifetime of the system.

Solar PV Expansion - Federal Incentives

To provide further context for our project, the current trends in the solar energy industry must be explained. The Solar Energy Industries Association (SEIA) is the national trade association for the solar industry and works with over 1,000 companies to create jobs and educate the public about solar. In 2012, SEIA released an independent study projecting the economic impact of two initiatives passed by the federal government: the Treasury Grant Program (TGP) and the Solar Manufacturing Investment Tax Credit.[6] The independent study

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[6] "Seia.org." seia.org. Solar Energy Industries Association, May 21, 2012. https://www.seia.org/news/new-study-solar-industry-poised-create-200000-jobs-key-tax-policies.

concluded that these two programs would add 200,000 new domestic jobs to the solar workforce. Additionally, the study projected that these initiatives would result in 10 gigawatts (GW) of solar installations in the same time frame. SEIA's findings supplement research conducted by the Lawrence Berkeley Laboratory which further emphasized the economic value and job growth associated with the TGP. The independent study conducted by SEIA was reviewed by an independent consulting firm EuPD Research. The significant expansion of jobs and solar installations projected by SEIA provides justification for our design project. It is clear that the landscape for solar PV is trending in a positive direction and the time is now to implement systems anywhere that is feasible.

Solar PV Expansion - State Incentives

At a macro policy level, state policies have also proven to be determinants of success for solar. Federal incentives additionally complement state incentives, allowing solar to become economically or technically viable in many states.[7] Shrimali and Jenner's article on the impacts of both the deployment and costs of solar will be essential in staging our future research. The insights provided in the article will additionally provide a framing for processes we found to be restrictive when attempting to site and design a solar system. Notable findings in their study include an overall message that state incentives that reduce module and system costs do increase deployment of solar.[8] Specifically, cash incentives and property tax incentives were effective in increasing deployment. The article provided by Shrimali and Jenner bookends our research

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[7] Shrimali, Gireesh, and Steffen Jenner. "The impact of state policy on deployment and cost of solar photovoltaic technology in the US: A sector-specific empirical analysis." *Renewable Energy* 60 (2013): 679-690.

[8] Shrimali and Jenner, 679.

design by providing an economic foundation to initialize our project and a framework to expand upon in our future research relating to solar policy.

In justifying the potential for a solar site in the Madison area and more generally, Wisconsin, we found multiple recent and local sources detailing the unexploited potential for solar in the state. Myers, Klein, and Reindl from the Solar Energy Laboratory at the University of Wisconsin-Madison describe the continuing trend of increasing penetration of solar photovoltaics across Wisconsin.[9] In their assessment, the group comments on the specific increase in small-scale distributed solar photovoltaic installations. The article cites federal subsidies and a reduction in technology costs as impulses for an expansion in solar installations. These economic trends have continued to benefit solar installers throughout the 2010's. The paper also shows promise for the expansion of solar beyond 2020.[10] Myers, Klein, and Reindl's analysis of the potential for solar installation also considers the need for on demand energy systems, especially during Wisconsin summers. Their model from 2010 still shows the potential for solar to up to 20 percent of Wisconsin energy needs. Beyond 20%, the value of electricity produced by solar installations decreases as capacity factor decreases.[11] This justifies the expansion of solar in 2019 as the state has not yet reached 20% PV penetration into the energy generation system.

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[9] Myers, Kevin S., Sanford A. Klein, and Douglas T. Reindl. "Assessment of high penetration of solar photovoltaics in Wisconsin." *Energy Policy* 38, no. 11 (2010): 7338-7345.

[10] Myers, Klein, and Reindl, 7345.

[11] Myers, Klein, and Reindl, 7345.

Solar PV Expansion - Declining Costs

Another trend that has led to the growth of the solar industry is the decreasing costs of solar equipment. SEIA produced a report in conjunction with Wood Mackenzie Power and Renewables in 2018 regarding these decreasing costs.[12] In the last decade the cost to install solar has decreased by approximately 70%, which has allowed the industry to expand into a wide range of markets. Solar installations today occur on three scales: residential, commercial and utility. A typical residential installation (before incentives are factored in) has decreased from $40,000 to $18,000 since 2010. At the utility scale, current prices for solar electricity range from $28/MWh-$45MWh, which makes solar cost competitive with all other forms of electricity generation. Additional opportunity for decreasing costs of solar systems exists in soft costs which includes labor, permitting/inspection/interconnection, supply chain, customer acquisition and other overhead costs. SEIA's research further justifies the need for more solar energy systems. The sinking costs of these systems is allowing homeowners and business owners to employ renewable energy systems like never before.

Solar PV Expansion - Community Initiatives

At the core of solar energy deployment are community initiatives and local organizations pushing for change. Maartha Arentson and Sandra Bellekom published an article titled "Power to the people: local energy initiatives as seedbeds of innovation" in the journal *Energy,*

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[12] "Seia.org." seia.org. Solar Energy Industries Association, 2018. https://www.seia.org/solar-industry-research-data.

Sustainability and Society that investigates grassroots energy movements in Europe.[13] Arentson and Bellekom identified key motivations of community initiatives as “environmental concern, local economic development, strengthening social cohesion and disappointment with centralised government coordination”(Arentson and Bellekom 10). This research uncovers important drivers of grassroots clean energy movements that can be applied all over the world. In 2017, the city of Madison resolved to use 100% renewable energy sources by 2030 for all city operations. GreenPower is a local organization that has been heavily involved in making Madison’s goal become a reality. According to an article in the *Badger Herald* by Azul Kothari, GreenPower is a solar energy job training program that provides hands on training for students.[14] GreenPower has completed 12 solar installations so far and are projected to complete 2-3 per year. In the scope of our solar design project, it is essential to be aware of factors contributing to the solar landscape.

Site Selection

The site evaluation and ideal site characteristics division of our research design seeks to identify suitable siting for a solar installation. The identification of solar siting variables along with a process of selecting a site using those variables fits a GIS approach. In Al Garni and Awasthi’s article, "Solar PV Power Plants Site Selection: A Review.", they describe the

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[13] Arentsen, Maarten, and Sandra Bellekom. “Power to the People: Local Energy Initiatives as Seedbeds of Innovation?” *Energy, Sustainability and Society* 4, no. 1 (January 14, 2014): 1–12. https://link.springer.com/article/10.1186/2192-0567-4-2.

[14] Kothari, Azul. “Madison Closer to Reaching 100% Renewable Energy Goal as Program Installs Solar Panels.” *Badger Herald*, September 10, 2019. https://badgerherald.com/news/2019/09/10/madison-closer-to-reaching-100-renewable-energy-goal-as-program-installs-solar-panels/.

extensive potential for GIS approaches within photovoltaic site selection.[15] GIS will defend our approach to site evaluation by quantifying the desired variables and filtering the entire scope of examination under the same set of criteria. This quantitative GIS process will generate a consistent set of potential sites that are independent of human input. The replicable nature of the GIS workflow both accelerates the process of site selection in addition to producing a group of sites selected through the same procedure. Al Garni and Awasthi also mention the advantages of GIS applications with respect to time and resources consumed. Given the scope and timeline of our project, these advantages will serve to strengthen our project.

Once the GIS approach is selected, Al Garni and Awasthi detail a group of key concepts that are common amongst GIS-based site selection approaches. These concepts include solar irradiation, orientation of solar site, available flat ground, transmission losses, environmental siting concerns, and the exclusion of protected areas.[16] All these key concepts are applicable to the Madison area, and will be considered in our GIS site selection approach. Beyond the above-mentioned concepts, Al Garni and Awasthi expand on the potential solar criteria. The table of subcriteria within the paper offers our research a wealth of variables to consider when constructing our GIS workflow. A tabular examination of this criteria by application serves our research by informing us to select criteria matching our application. Once the criteria is solidified and the GIS model is created, uncertainties in conceptualization and data accuracy need to be addressed. Al Garni and Awasthi describe approaches to dealing with uncertainty in

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[15] Al Garni, Hassan Z., and Anjali Awasthi. "Solar PV Power Plants Site Selection: A Review." In *Advances in Renewable Energies and Power Technologies*, pp. 57-75. Elsevier, 2018.

[16] Al Garni and Awasthi, 66.

conceptualization, such as a fuzzy analytical hierarchy process.[17] Additional literature will justify our site selection criteria choices, while data accuracy will need to be assessed by source.

The fuzzy analytical hierarchy process is one construction of a multicriteria decision making method. This methodology lends itself to a raster workflow as variables can be easily compared at each pixel. Using fuzzy assignment of input data to suitability criteria will assist in operationalizing data into a suitability index. Fuzzy assignment also has the advantage of the ability to bin data when the raw data does not directly relate to the desired suitability index. Asakereh, Omid, and Sarmadian generate a raster solar suitability map for a region of Iran. In their methodology, the usage of a fuzzy multicriteria decision making method returns an informative map of differing levels of solar suitability in southwestern Iran.[18] The variables considered in the article also support our site selection process. Insolation, proximity to network infrastructure, and topography are all converted into fuzzy values contributing to an overall suitability index. The process of using interval assignment to suitability indices for the slope and aspect layers offers a strong foundation for our research. Asakereh, Omid, and Sarmadian also provide technical operations within a GIS software. The information included within the article will inform the implementation of all levels of our site selection process.

To select weights for our raster overlay our research needs to have a methodical approach to choosing these values. The selection of values based on industry practices and literature investigation defends the choices made when assembling a weight vector. The method most

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[17] Al Garni and Awasthi, 59.

[18] Asakereh, A., Mahmoud Omid, Reza Alimardani and Fereydoon Sarmadian. "Developing a GIS-based Fuzzy AHP Model for Selecting Solar Energy Sites in Shodirwan Region in Iran." (2014).

commonly identified in the research was a multicriteria decision matrix. This matrix method considers the comparison of variables with respect to independent solar suitability. The matrix allows for a methodical and calculated generation of a weight vector. Individual comparisons of each variable pair are assembled into the matrix. The eigenvector of the matrix is then calculated then normalized so that the sum of the vector components is one, leaving us with the weight vector. This method is documented in Al-Garni and Awasthi's "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia."[19] This article describes the mathematical and decision making steps necessary to construct the matrix. Through the use of a uniform comparison ranking our research can methodically generate the weight table. Furthermore the article considers options to verify the matrix decisions through a consistency index. This element is particularly important to maintain decision consistency between variables.

Cultural Considerations

Throughout our site selection process, the technical variables have been explored in many of these articles to great detail, however, a human viewpoint on the solar site as a place also has importance in our research design. We seek to identify a site that does not obscure or diminish a place while still being technologically feasible. Moore and Hackett's research on the relationship between technology and place focuses on this consideration when installing PV solar.[20] Their research describes the facets of place-making. Their analysis of the public interaction with the

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[19] Al Garni, Hassan Z., and Anjali Awasthi. "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia." *Applied energy* 206 (2017): 1232.

[20] Moore, Sharlissa, and Edward J. Hackett. "The construction of technology and place: Concentrating solar power conflicts in the United States." *Energy Research & Social Science* 11 (2016): 70.

siting of the Ivanpah solar installation in the desert of eastern California can be considered when selecting our small scale ground-mounted solar installation in the Madison area. We will be incorporating physical, legal, and cultural place-making into our solar site to make the design appealing beyond a strictly technical level.

Methodology:

Project Setting

Moving into the methodology of our research design, our project is organized between site acquisition and site design. This partition will not reduce dependency between the two sections of the research design, however. The site acquisition conceptualization of our project will both consider and generate additional data to inform the site design. Beyond the simple selection of the solar site, the contributions of the site data to the design of the project will assist in the generation of an informed solar installation design. The inclusion of this data will help to make our site design more robust in response to the physical characteristics of the site. The site design will also assist in informing site acquisition and evaluation. The requirements of a small-scale ground -mounted solar installation will be presented as variables within our site selection schema. Additional parameters such as module choice and the spatial organization of the array will also be present within our design. The iterative nature of our research design will ultimately generate the best possible solar installation.

In siting a ground-mounted solar installation, we need to identify and delineate the problem we are seeking to solve with our research. Our research will seek to site and design a 500kW to 1MW solar installation in the Madison area. This project is driven by a market changes in solar module prices as well as changing policy at the national, state, and local levels. Utilities such as Madison Gas & Electric (MG&E) have started to establish their own renewable energy systems. MG&E is investing in a 300MW solar installation in Iowa County, expected to be finished in 2020. Additionally, MG&E has a shared solar program. This program allows customers to invest in solar energy without having to place solar panels on their rooftops. This system closely models the community solar program that is becoming successful across several states in the U.S. including Minnesota, Maine, and Massachusetts.[21] Our research will identify and generate a solar system mimicking the output of the 500kW solar array on the roof of the City of Middleton Municipal Operations Center. Our ground-based solar array will be designed to be an economically inclusive clean energy option for the residents of the greater Madison area.

Site Selection Approach

Our solar system site selection begins with the identification of key concepts that restrict or attract solar installations. Informed by our research, the key concepts of technical, environmental, and cultural suitability group the selection criteria. The incorporation of the key concepts into GIS will be the keystone of the siting process. Within a GIS our research can quickly and equally assess all of the variables defined under the technical, environmental, and cultural key concepts. Establishing a concrete framework from which to select our site has the added effect of creating a mutable and repeatable process for future research.

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[21] Coughlin, Jason, Jennifer Grove, Linda Irvine, Janet F. Jacobs, Sarah Johnson Phillips, Leslie Moynihan, and Joseph Wiedman. "Guide to community solar: Utility, private, and non-profit project development." (2011): 1.

The technical demands of a ground-mounted solar PV array are numerous. The sensitivity of a solar installation to ground conditions at a site provoke a robust characterization of possible sites through our criteria. In these criteria we will be combining both raster and vector methods to obtain a suitable site. The first variable considered under the technical concept is the solar insolation received at a location. This value will be important in selecting a solar site as it will relate strongly to the amount of energy produced by the array. This variable will be operationalized by a linear transformation of the insolation at each raster pixel to a scale from zero to one. Transforming the radiation data in this manner will also allow for easy comparison of insolation across MG&E service territory.

Site Selection Criteria

The next variable considered to assess technical suitability will be slope and slope aspect. In siting a solar site having a slope less than 5% is critical for ease of construction. The operationalization of slope will be split into suitable slopes of under 5% and somewhat suitables sites of 5-15% slopes. Slope aspect is another critical variable to site the solar array. Having a south facing slope is ideal, however, east and west facing slopes are also acceptable for PV solar. Using the variable of slope aspect removes less productive north facing slopes from consideration. Incorporating this pair of variables into the selection model conserves our research resources by not requiring our group to physically investigate potential sites.

Land cover restrictions are another component of our site selection model. Open land is ideal from both an economic and environmental viewpoint. To reflect this, any forested or urban areas will be removed from consideration while open landscapes such as farmland and barren land will be identified as ideal. Data from the National Land Cover Database will be used to filter potential areas.

Identifying parcels of suitable size will also be important in selecting a suitable area for the 723kW solar installation. A solar farm of this size needs to be at least 4 acres in total area at the latitude of Madison. Land would be acquired by MG&E from owners, so a parcel based approach will suit our research. The parcels of the correct size and larger will be queried out of a county GIS application. Parcel use codes provide an additional filter. Using these codes to find vacant or open land narrows down the best sites.

Proximity to grid infrastructure is also essential to our workflow. Grid upgrades and interconnection applications are expensive and worth considering in our criteria. To reduce potential costs for our site an original data layer of the network infrastructure in Madison Gas and Electric service territory will be digitized. This data layer will include the three phase power lines across the service area. Connection to three phase ensures that the grid can support the scale of electricity our proposed project can output. The variables of grid proximity and parcels suitability fit the vector data model. These important variables combined serve as a binary indicator of a suitable site. Any suitable site will need to fit criteria for these two variables.

From an environmental and legal standpoint, we need to exclude land types and areas with protections applied to them. Wetlands cannot be built upon from both a technical and environmental perspective. Areas susceptible to soil runoff will also be considered to maintain the environmentally conscious status of our design. A solar installation of the scale of 500kW will also disrupt the vegetation that exists within the selected site. Our research will identify parcels that can sustain and recover from that disruption.

Cultural features cannot be ignored when considering any large construction project, including solar arrays. Nearby areas need to be considered in addition to the parcel that will host the solar installation. Concerns such as nearby neighborhoods, sun reflection angles, noise, and the fit of the solar site to the place will all inform our selected location for our array. Much of the literature investigation disregards the cultural component of a place when identifying solar suitability. Moore and Hackett's research on place-making, even in a desert setting, portrays the importance of respect for a place.[22]

The different concepts of technical, environmental, and cultural suitability restraints will be combined using both quantitative and qualitative methods. The technical variables combined in a GIS overlay generate a solar suitability map for our project.[23] Once possible sites have been viewed using the technical suitability map we can investigate the environmental and cultural components of each specific site. A site by site analysis of all contributing variables informs our research to select the best possible site that considers multiple inputs. Once a suitable site is

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[22] Moore and Hackett, 70.

[23] Asakereh et al., 38.

identified we will design a ground-mounted solar array.

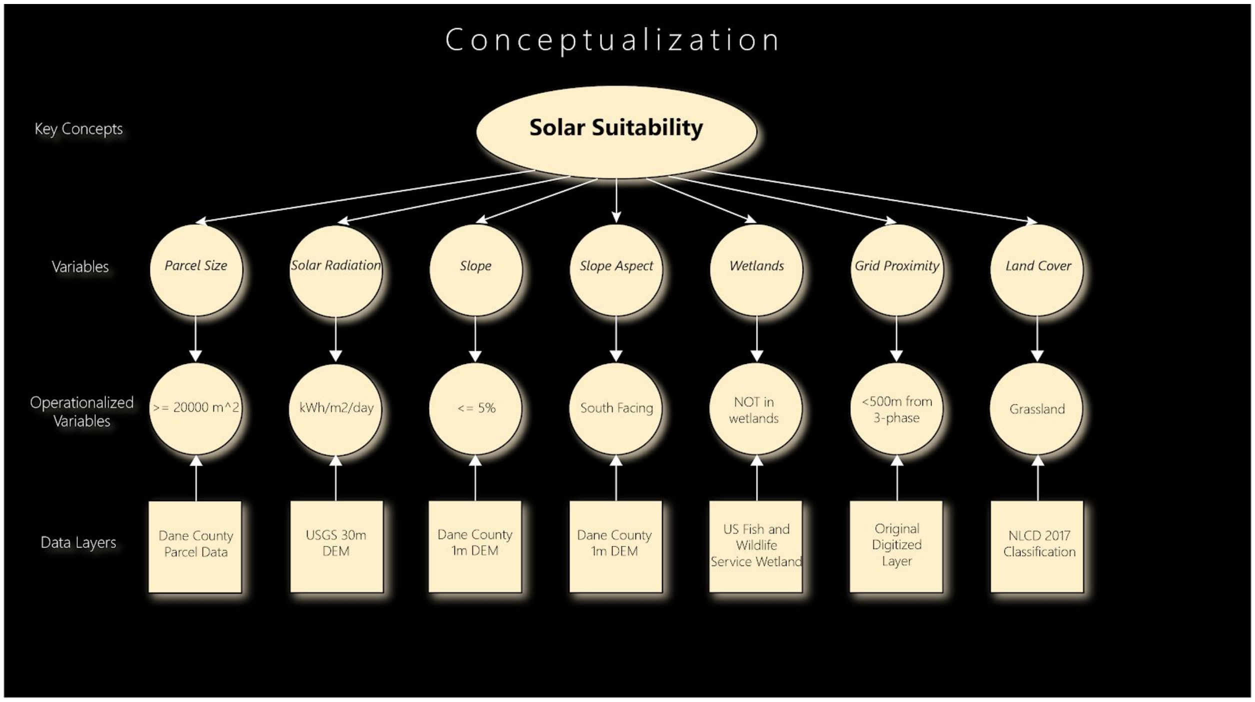

Figure 1. Conceptualization Diagram of Site Selection Process

Solar Design:

Methodology

To solve the problem, we will be using a solar system design tool called PVComplete.[24] PVComplete consists of two separate programs: PVSketch and PVCAD. PVSketch is meant for a first rough draft of a system, and allows the user to estimate the number of modules that will fit in a given space. This PVSketch file can then be imported into PVCAD. PVCAD is the only solar PV specific program created by AutoDesk (publishers of AutoCAD). PVCAD allows the user to create exact measurements for the system and completely customize every detail.

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[24] "Solar Design Software." PVComplete. Accessed October 23, 2019. https://pvcomplete.com/.

PVCAD also creates an energy simulation Excel file that will project the energy production of the system in the span of multiple years. In order to determine the system components of the system, we will conduct informational interviews with various solar contractors to find out which equipment will best suit our project.

System Components

The solar energy system breaks down into four main components: module, racking system, inverter and AC Panel.

Module:

The solar module that we selected is the SunPower X 21 - 335 BLK. This module was chosen based on its high efficiency, maximum performance and premium aesthetics[25]. The SunPower specification sheet for the module notes that the X series module produces up to 45% more energy than conventional modules in the first year. Over the 25 year lifetime of the module, the X21 panels continue to perform better than conventional modules by producing up to 60% more energy on an annual basis. The X21 module contains Maxeon(Restricted sign) Solar Cells, which is the only solar cell to be built entirely on a solid metal foundation. This attribute boosts the reliability of the module over its lifetime and prevents corrosion from occurring.. Along with the reliability of the module, it comes with the SunPower warranty which guarantees no more than 0.25% degradation of energy production per year. The SPR X21 335 BLK has a nominal power rating of 335 Watts. It is designed to operate in the temperature range of -40 degrees Fahrenheit to 185 degrees Fahrenheit.

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[25] SunPower. “PDF ,” December 2016.

Racking System:

The racking system that will be used in the installation of the modules is the Terrasmart GLIDE Fixed Tilt system[26]. The GLIDE system utilizes Terrasmart's Ground Screw technology, which allows the ground mount system to be installed without digging trenches or pouring concrete. This system was chosen because of its' versatility in various soil conditions, proven performance and its' labor and cost efficiency. Below is an image of the Ground Screw technology.

Image source: https://www.terrasmart.com/products/ground-screws/

The patented spiral thread of the Ground Screw increases ground displacement and reduces foundation costs by minimizing embedment depth below grade. The screw is driven into the ground by a Terrasmart drilling machine. Four Ground Screws are installed per 3X10 solar table.

Inverter:

The inverter that will be used in the system will be a SMA America Central 720 CP. We are using one central inverter versus multiple string inverters because central inverters are less

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[26] "GLIDE - FIXED TILT." TerraSmart. Accessed December 16, 2019. https://www.terrasmart.com/products/terraglide/.

expensive for large scale community solar projects[27]. Central inverters are physically larger than string inverters and can convert more power per unit and use longer wires. This particular size of inverter (720 CP) was chosen based on the annual output of the system (roughly 723 kW). There are 216 strings of 10 modules (2160 modules). SMA is a global leader in cutting edge photovoltaic technology.

AC Panel:

The size of the AC Panel was determined by taking the maximum output current of the inverter (given on the spec sheet) multiplied by 1.25. This calculation abides by the National Electrical Code (NEC)[28]. Thus, 1411 Amps X 1.25 = 1763.75. NEC demands that the size of the breaker be rounded up from this figure.

Results:

Site Selection Results

The initial output of our solar implementation design process is the site selection suitability map for the Madison Gas & Electric Service Territory. This final raster map ranking the suitability across the project scope generates a final optimal site when combined with the selected parcels of appropriate size. Before discussing the final results of this map the suitability of each component considered in the site selection process needs to be detailed. The numerical

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[27] Misbrener, Kelsey, Kelsey Misbrener, Neeraj Mathur, Neeraj Mathur, Hitendra Shah, and Hitendra Shah. “How to Choose between String and Central Inverters in Utility-Scale Installations.” Solar Power World, December 20, 2018. https://www.solarpowerworldonline.com/2018/12/choose-between-string-and-central-inverters-utility-scale-solar/).

[28] List of codes & standards. Accessed December 8, 2019. https://www.nfpa.org/Codes-and-Standards/All-Codes-and-Standards.

inputs from each data set along with how each data set was classed will establish a reference for what the final suitability map contains. Through assessing each of these criteria, our research can identify patterns in the landscape that contribute to solar suitability. The outputs of each of these criteria maps will additionally allow for our future research improvements to be justified using the criteria maps as a reference.

The execution of the data processing was governed by an implementation diagram that organizes the structure of the GIS workflow. Our research requires many different sources of data to be overlaid into a raster sum, requiring a significant amount of data organization. Using the implementation diagram, our research abides by a defined framework to conduct GIS operation. The implementation diagram also serves to make the GIS workflow easily and rapidly understandable to a reader.

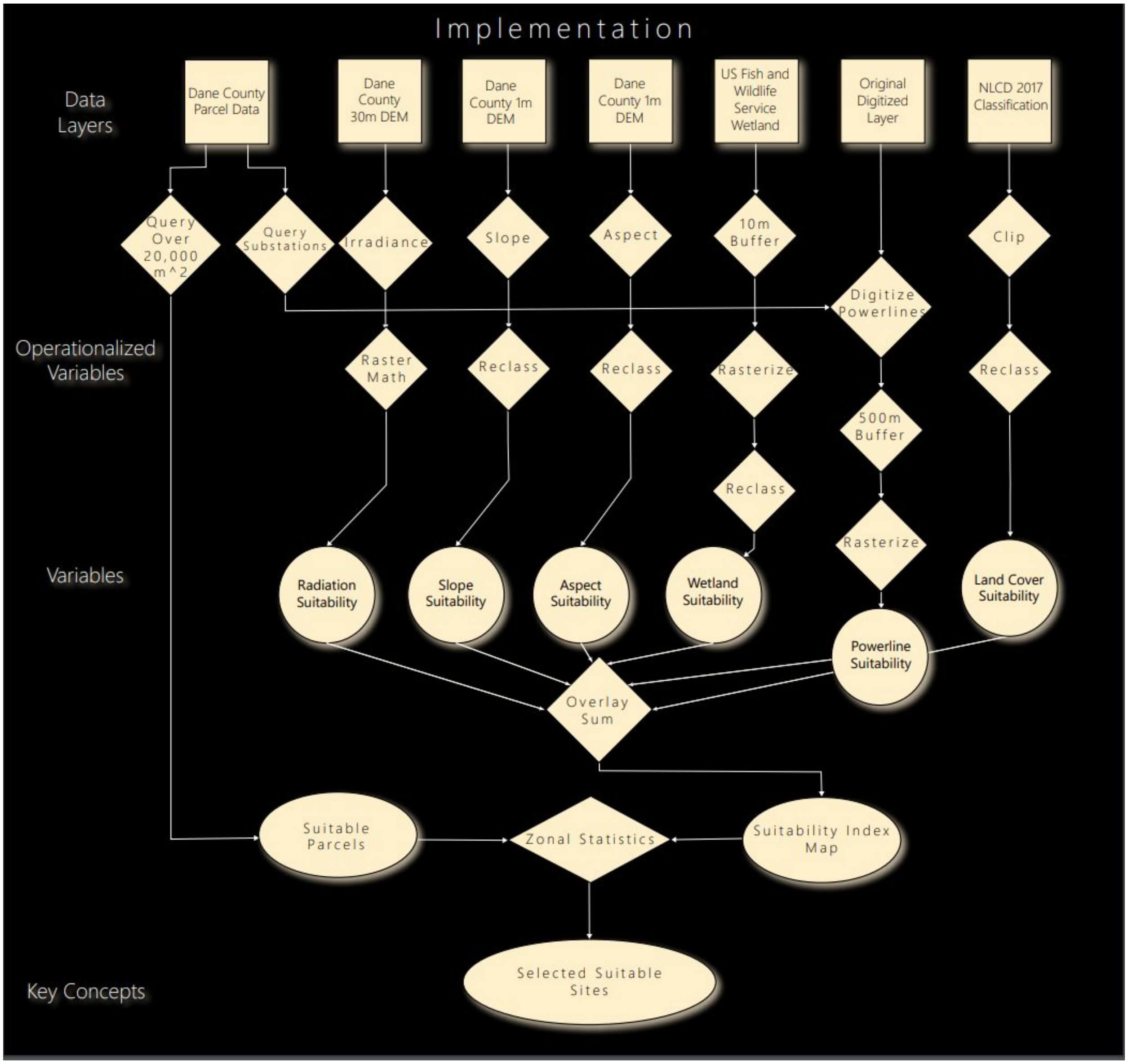

Figure 2. Implementation Diagram of the Site Selection Process

To generate the final suitability index map, the raster overlay requires the weights of each criterion and the classification within criteria to be defined. The scoring table is based on findings and industry practices identified in the literature review.[29]

Criteria Scoring

Classification	Wetlands	Wetlands Category	Score
1	<10m of Wetlands	Too Close	0
2	>10m of Wetlands	Distanced	1

Classification	3PH	Powerline Category	Score
1	>500m from 3Phase	Not Proximal	0
2	<500m from 3Phase	Proximal	1

Classification	Insolation		Score
1	kWh/m2/day		Equal to kWh/m2/day

Classification	Land Cover	Land Cover Categories	Score
1	Water, Wetlands, Barren	Unsuitable	0
2	Forests	Potentially Suitable	1
3	Grassland, Cultivated Areas	Suitable	2

Classification	Slope	Slope Category	Score
1	15-90	Strongly Sloping	0
2	5-15	Moderately Sloping	1
3	0-5	Gently Sloping	2

Classification	Aspect	Aspect Categories	Score
1	NE-NW	Unsuitable	0
2	NE-E,NW-W	Poor	1
3	SE-E,SW-W	Fair	2
4	SW-SE	Good	3

Figure 3. Criteria Scoring and Categories

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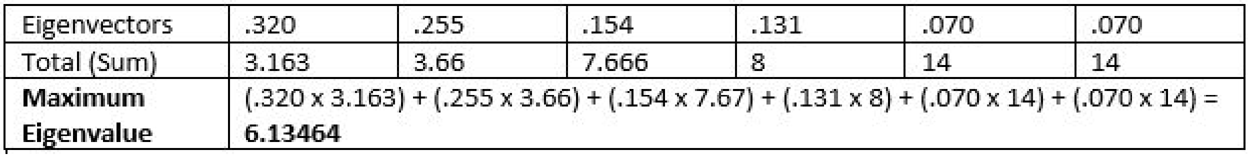
[29] Al Garni, Hassan Z., and Anjali Awasthi. "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia." *Applied energy* 206 (2017): 1232-1234.

To combine these variables, a weight comparison matrix is constructed through a decision making matrix. Then each criterion is individually compared to every other criterion. The location in the matrix is assigned a value quantifying how much more important the considered criteria is when compared to the other criterion. These values are scaled from 1 to 9 with 1 representing an equal importance and 9 indicating strongly more important. This method was applied to each criterion comparison, generating the comparison matrix. If a variable was considered to be less important, a value of less than 1 was assigned equal to the reciprocal of reversed comparison value.

	Grid	Slope	Irradiance	Land Cover	Wetland	Aspect
Grid	1	1	3	3	4	4
Slope	1	1	2	2	3	3
Irradiance	0.33	0.5	1	1	3	3
Land Cover	0.333	0.5	1	1	2	2
Wetland	0.25	0.33	0.333	0.5	1	1
Aspect	0.25	0.33	0.333	0.5	1	1

Table 1. Multicriteria Decision Making Matrix

Finally, using this comparison matrix, the weight table is then computed using an approximation of the eigenvector. To compute this value each value is transformed by being divided by the sum of the column to normalize. Next, these values are summed across the row for each criterion and divided by the total number of variables. This value is now the final eigenvalue approximation for each criterion and is the value that will be used in the comparison matrix. The final vector of weights also needs to be verified for consistency of the decision matrix. Using this equation for consistency index where λ max is the maximum eigenvector of the matrix and n is the number of variables. λ max was calculated using the values for each component and the sum of the column.



Eigenvectors	.320	.255	.154	.131	.070	.070
Total (Sum)	3.163	3.66	7.666	8	14	14
Maximum Eigenvalue	(.320 x 3.163) + (.255 x 3.66) + (.154 x 7.67) + (.131 x 8) + (.070 x 14) + (.070 x 14) = **6.13464**					

Table 2. Maximum Eigenvalue Calculation

Using this eigenvalue our final comparison CI was found to be .027, well within the acceptable range of 0-.10.[30] We now have the necessary criterion computed weights to conduct our raster overlay.

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

Eq. (1). Consistency index calculation

The most important criterion in our results is the proximity of the raster to three phase power infrastructure. This variable is a prerequisite to a successful solar site, receiving the most impactful scoring in the raster overlay sum. To generate this criterion, we digitized the powerlines of the project area using aerial and street view imagery. One important note is the absence of digitized three phase within the highly urbanized areas surrounding Madison, even though there are powerlines with this level of hosting capacity in these areas. Our digitization method found limits in that it cannot identify the underground grid infrastructure which is so

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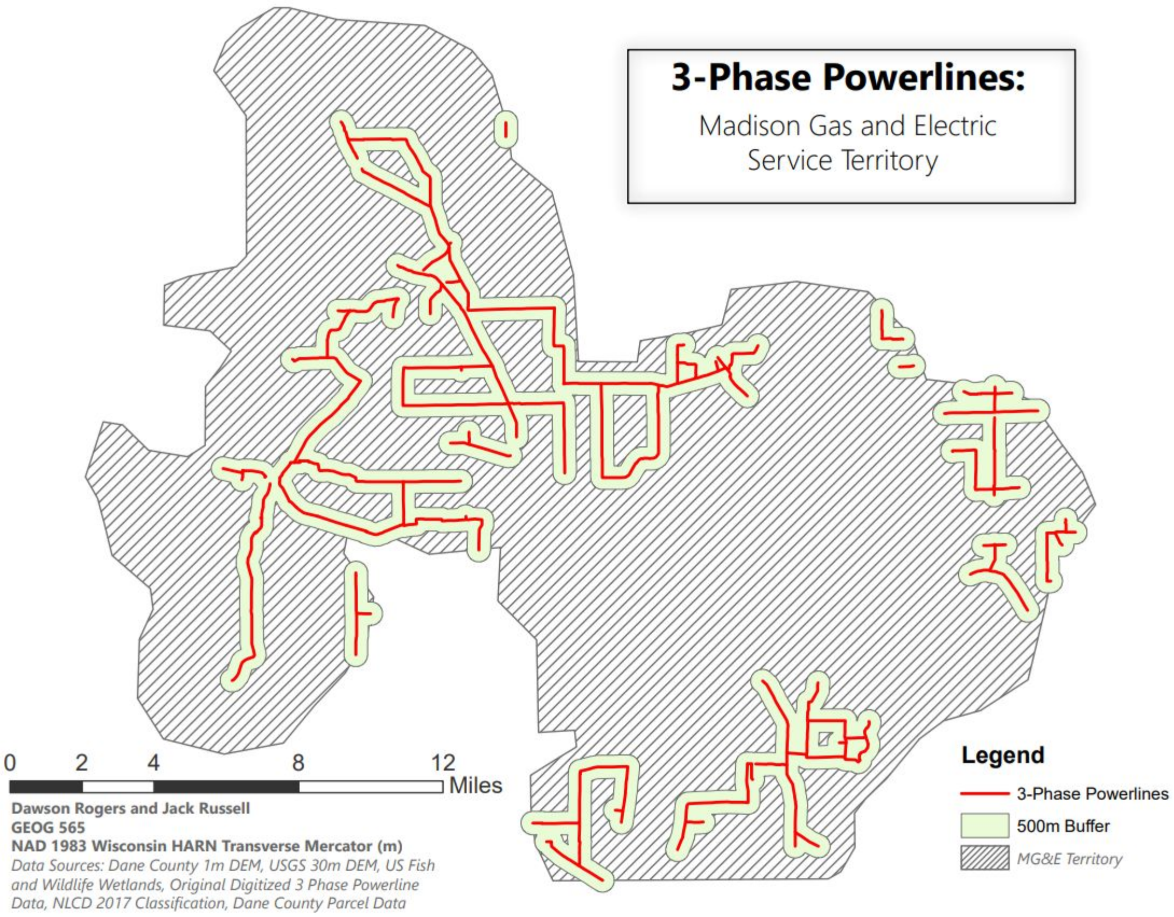
[30] Al Garni, Hassan Z., and Anjali Awasthi. "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia." *Applied energy* 206 (2017): 1232.

prevalent in the urban area of Madison. The three phase powerlines within the city of Madison are also extremely dense. The time constraint of the project forces our research to omit digitizing these powerlines. The omission of these powerlines is primarily justified by the extremely poor large scale solar suitability of urban areas. Future research would seek to assess grid infrastructure in more detail. Using the digitized powerline layer, we constructed a 500m buffer to identify regions that are suitable. The output map from this layer clearly illustrates the regions that our solar site must be within to avoid prohibitive interconnection grid upgrade costs.


3-Phase Powerlines:
Madison Gas and Electric
Service Territory

Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data

Figure 4. Map of Digitized Three Phase Power Infrastructure

After the original data layer was constructed, the remaining data layers were processed into classified raster data based on the criteria scoring table. The results of each of these reclassification allows us to identify site suitability for each individual variable. Classifying each variable also assists to inform future research. Recursively modifying and identifying any changes to the solar site selection model can be conducted with respect to each criteria. The maps detailing the physical features considered in the reclassification are in the appendix A. The land cover map and its reclassification are presented as an example of the reclassification results.

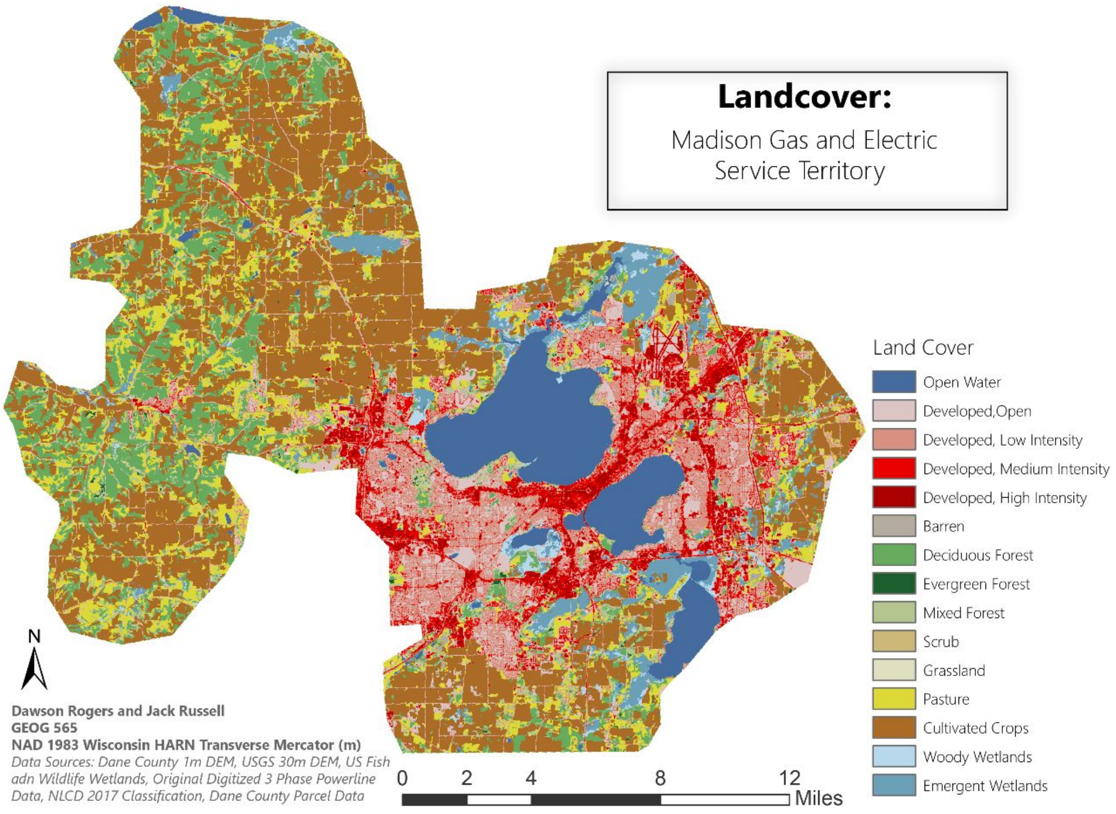
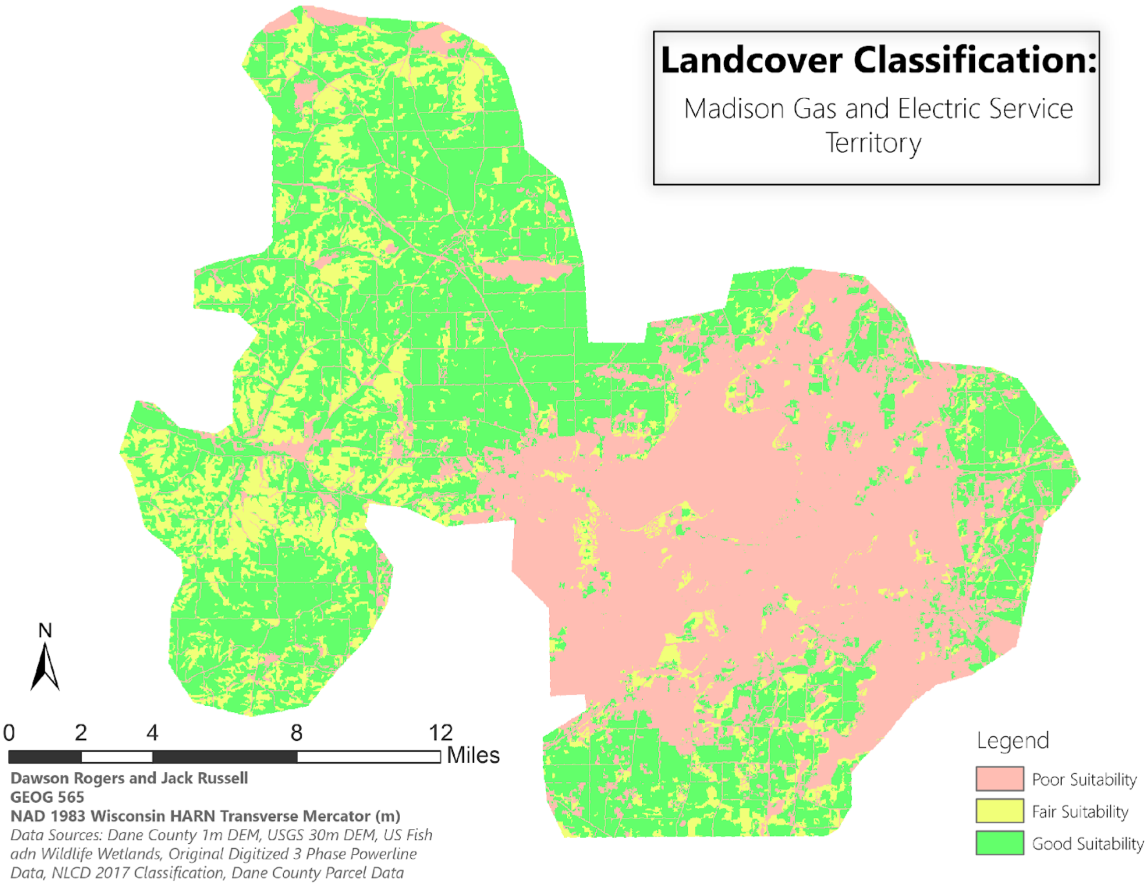


Figure 5. Map of Landcover Classifications

The unclassed landcover map is informative thematically, however, it is not readable from a solar site selection viewpoint. The reclassed map places all the land cover categories into the scoring bins detailed by the criteria scoring table. We can now see the patterns of solar suitability across the study area quickly.



Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish adn Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data

Figure 6. Map of Land cover Reclassification by Suitability

This classed land cover map displays patterns of solar suitability across space. Notable patterns include a high level of suitability in the regions northwest and to the south of Madison. This pattern is present across multiple criteria and ultimately in the final suitability map. The flat farmland close to existing three phase power infrastructure dominates the makeup of the final selected sites. The separate suitability maps for each variable are now independently accessible. The advantages of a GIS approach are also apparent at this stage of data processing. For variables such as slope and slope aspect, GIS offers the advantage of identifying the landscape characteristics when an individual inspection may not be able to discern these features through forest cover. The variable of land cover also benefits from a consistent categorization of land classes. After processing and classification of all variables, the final site suitability map can be constructed through raster overlay sum.

The final raster overlay sum map processes the raster values of each variable and sums them into one ultimate solar suitability index across the scope area. The variables are combined using a weighting schema based on the existing literature and industry practices.[31] Each pixel will receive a value from 0 to 1 with 1 representing the maximum solar suitability in our selection model.

Now using the criteria weights computed earlier in the analysis, we can overlay the rasters and examine the solar suitability map across the project range.

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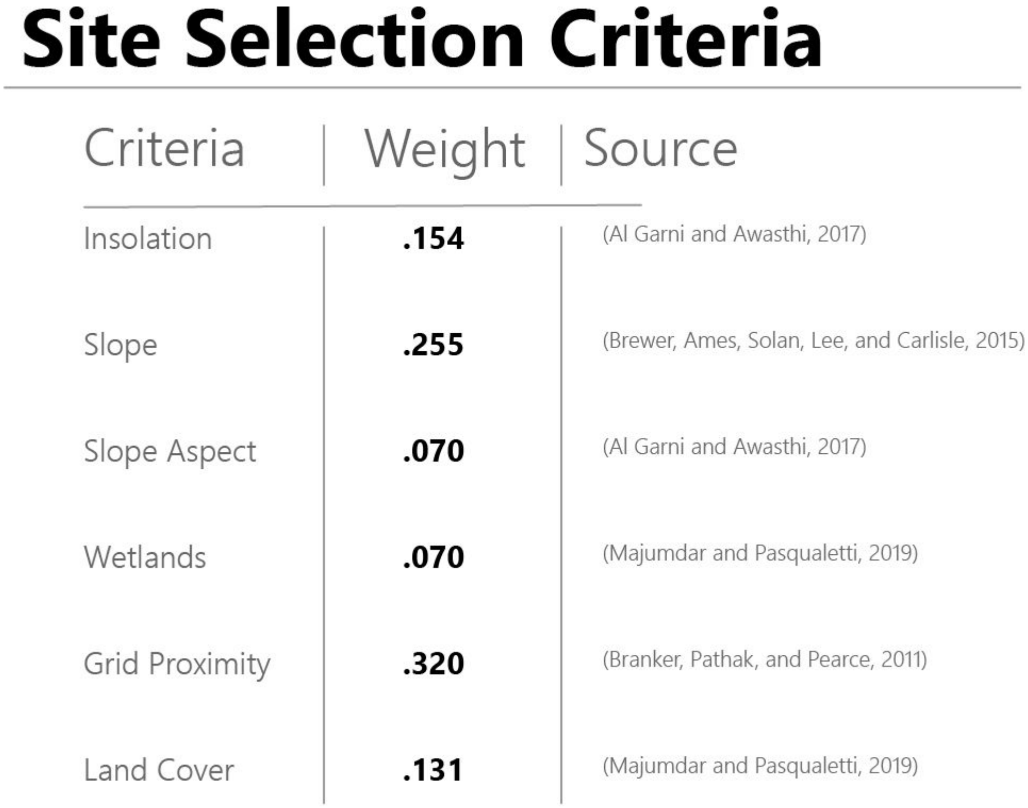
[31] Al Garni, Hassan Z., and Anjali Awasthi. "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia." *Applied energy* 206 (2017): 1232-1234.



Site Selection Criteria

Criteria	Weight	Source
Insolation	**.154**	(Al Garni and Awasthi, 2017)
Slope	**.255**	(Brewer, Ames, Solan, Lee, and Carlisle, 2015)
Slope Aspect	**.070**	(Al Garni and Awasthi, 2017)
Wetlands	**.070**	(Majumdar and Pasqualetti, 2019)
Grid Proximity	**.320**	(Branker, Pathak, and Pearce, 2011)
Land Cover	**.131**	(Majumdar and Pasqualetti, 2019)

Figure 6. Criteria Weight Table

Grid proximity and slope are the most influential components of the overlay. The strong techno-economic effects of these variables on the suitability of a site govern their strong weights. The variables of insolation and land cover follow in importance, relating to productivity and construction suitability, respectively. Finally, the variables of wetlands and slope aspect are still relevant to the site selection process. Slope aspects that face north and wetlands areas are impactful enough with the assigned weights to remove them from the final selected parcels.

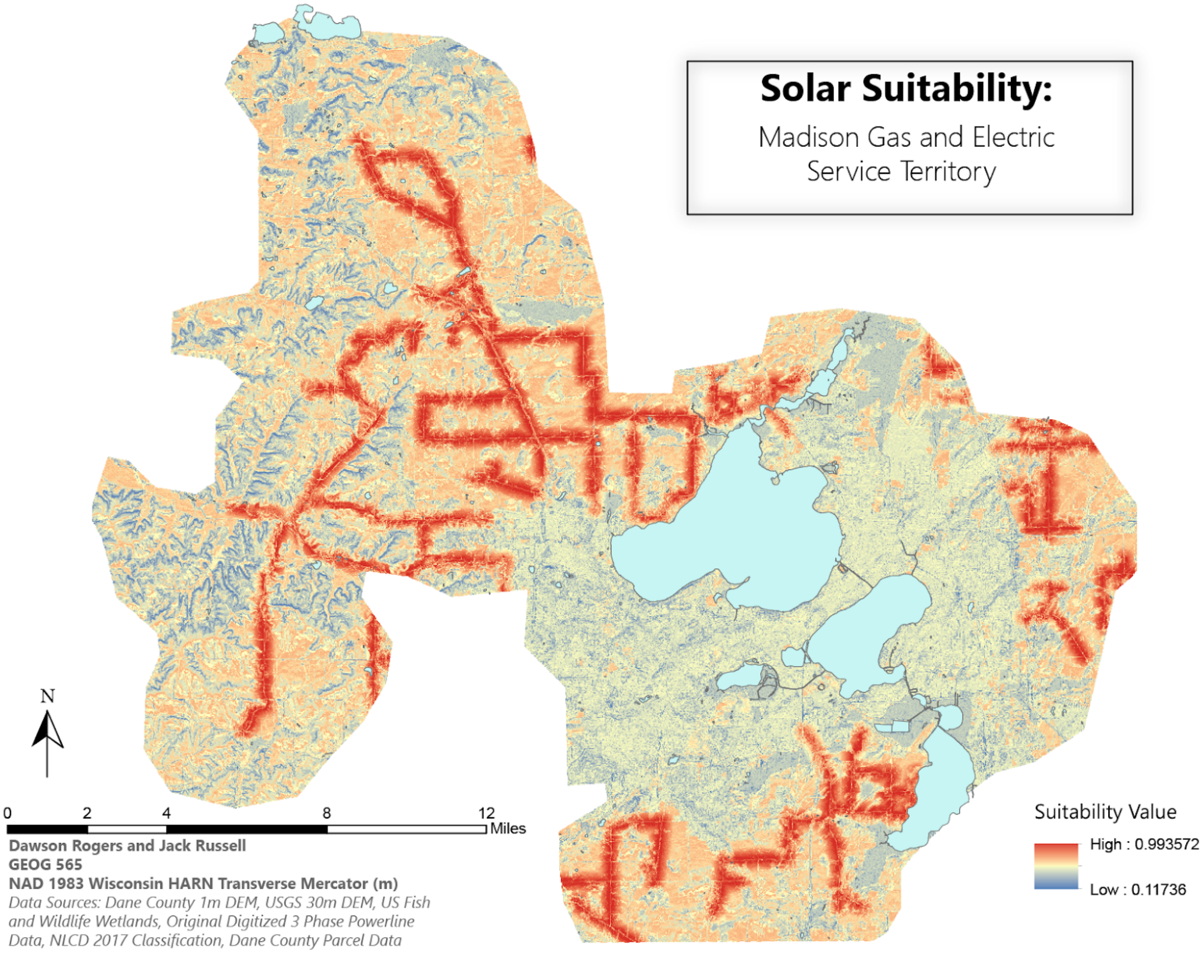
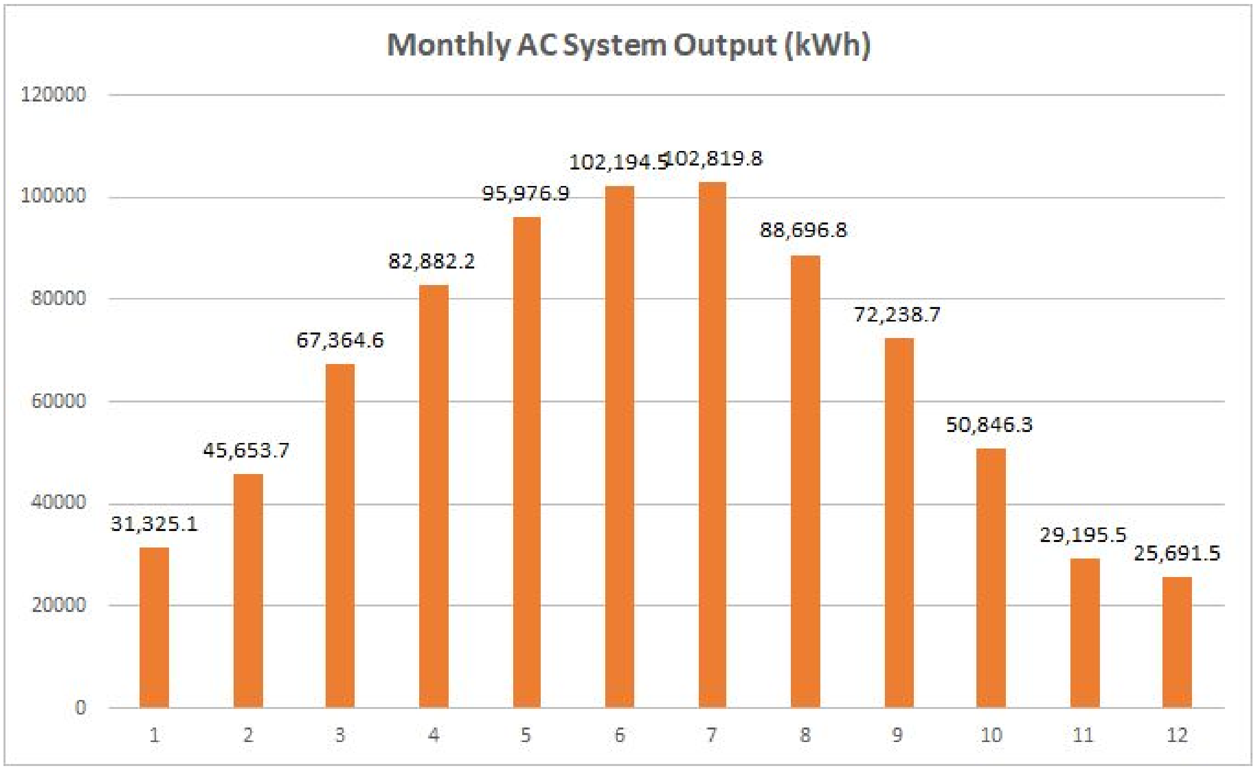


Figure 7. Final Solar Suitability Raster Map

The final site suitability map clearly represents the weighting of the grid proximity variable. The red and orange colored regions surrounding this infrastructure is appropriately more suitable to large scale solar installations. Regions of poor solar suitability include any water feature, wetlands, north facing slopes, and urban areas. The final output also shows how contiguous areas of high solar suitability are. For example, the southwestern region of the study area has some areas of high suitability, but these areas are broken up by numerous smaller areas of lower suitability. Other trends include consistent solar suitability rankings across the region to the northwest of Middleton, WI and to the south of Madison. This trend will be apparent in the final selected sites. With the final solar suitability result, our research can proceed into the analysis and final parcel selection.

Solar Design Results

Based on the land parcels determined by our site selection process, we have designed a 2160 module solar energy system. The system has an estimated annual production of 723 kiloWatts according to the PVWatts Hourly Performance database. Below is a monthly breakdown of the projected alternating current production of the system.

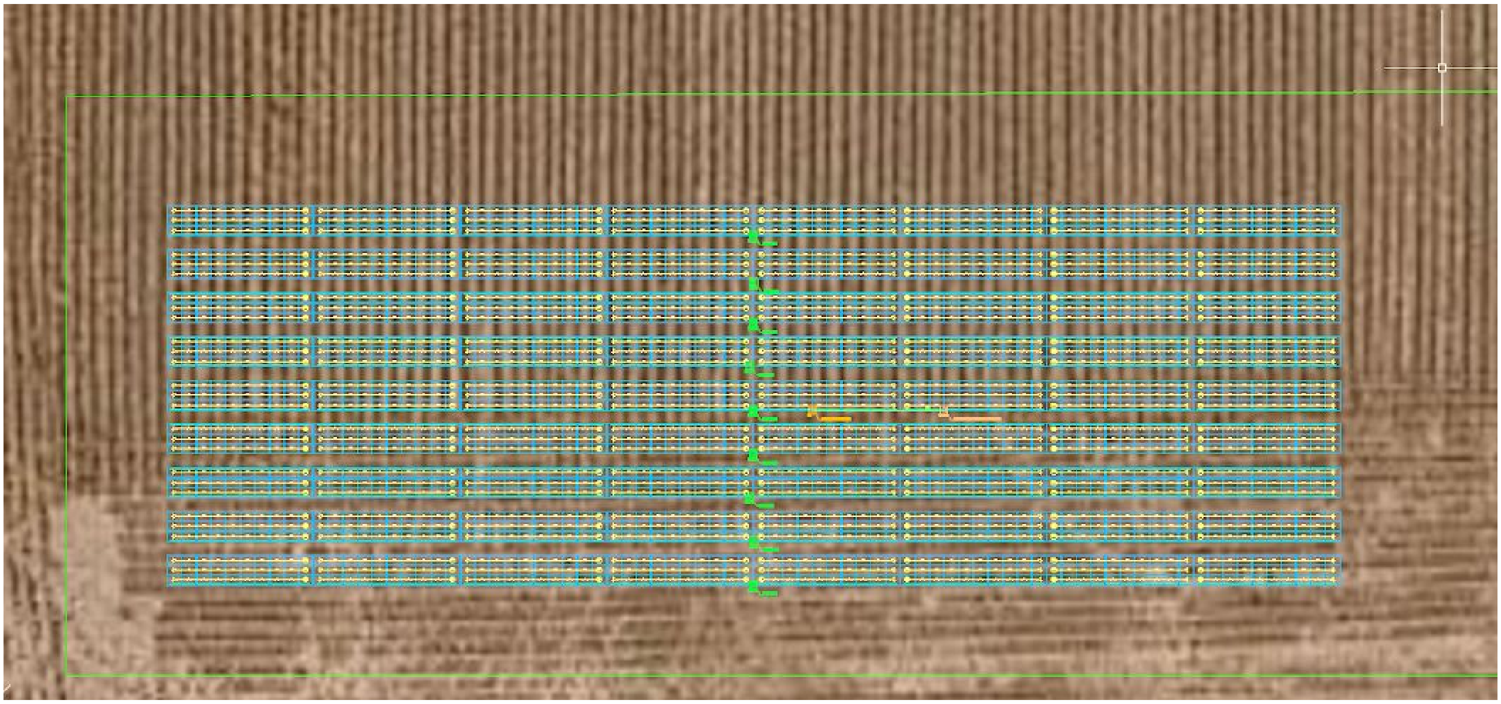


The system is divided into 3 x 10 tables of SunPower X21 335 modules. The mounting system used is Terrasmart GLIDE Fixed Tilt. The entire array is tilted at an angle of 25 degrees facing due south. The ground coverage of the system is 39061.6 square feet. Based on the expansive size of the system, we will use one central inverter to convert the direct current electricity to alternating current. We will use an SMA America SC 720 CP - US (480) inverter. This decision was made based on industry knowledge of Justin Martinez of Sunsense Solar.

Below is more detailed data of the DC and AC output, solar radiation and plane of array irradiance:

Month	AC System Output(kWh)	Solar Radiation (kWh/m^2/day)	Plane of Array Irradiance (W/m^2)	DC array Output (kWh)
1	31325.13	1.70816875	52.95323	33213.44
2	45653.7	2.64021873	73.9261246	47938.74
3	67364.58	3.60005	111.601547	70571.0547
4	82882.23	4.706298	141.188934	86714.18
5	95976.88	5.42603254	168.207016	100352.445
6	102194.492	6.17092466	185.127747	106797.922
7	102819.805	6.072431	188.245361	107422.539
8	88696.77	5.23357248	162.240753	92781.61
9	72238.68	4.31777	129.5331	75588.53
10	50846.3242	2.85313272	88.44711	53457.91
11	29195.5254	1.65933716	49.7801132	31023.5684
12	25691.4512	1.407056	43.6187363	27364.44
Total:	794885.5678	45.79499204	1394.869772	833226.3791

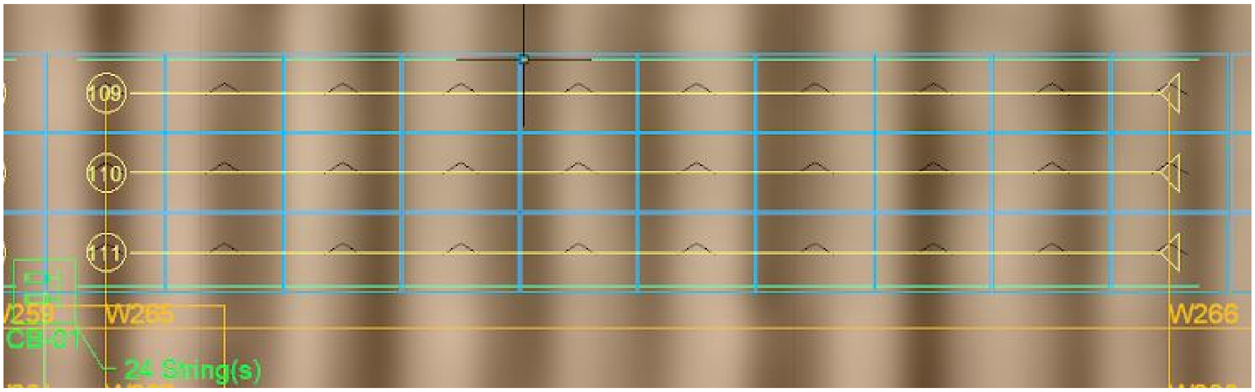
Below is a 2 dimensional rendering of the array:



The system has 9 combiner boxes (shown in green) which feed the direct current electricity directly into the central inverter. The inverter (shown in orange) then feeds into the 1800 Amp AC Panel. From the AC Panel, the electricity is sent to a three phase transformer where it goes to the MGE grid.

The size of the AC Panel was determined by taking the maximum output current of the inverter (given on the spec sheet) multiplied by 1.25. This calculation abides by the National Electrical Code (NEC). Thus, 1411 Amps X 1.25 = 1763.75. NEC demands that the size of the breaker be rounded up from this figure.

Below is a 2 Dimensional rendering of one 3 x 10 Table of Modules:



The yellow lines running through the modules represent the electrical wiring. The wires from each row of tables feeds into a combiner box, which is the green item in the bottom left hand corner of this image. Below is a 3 Dimensional rendering of a 3 x 10 table of modules.

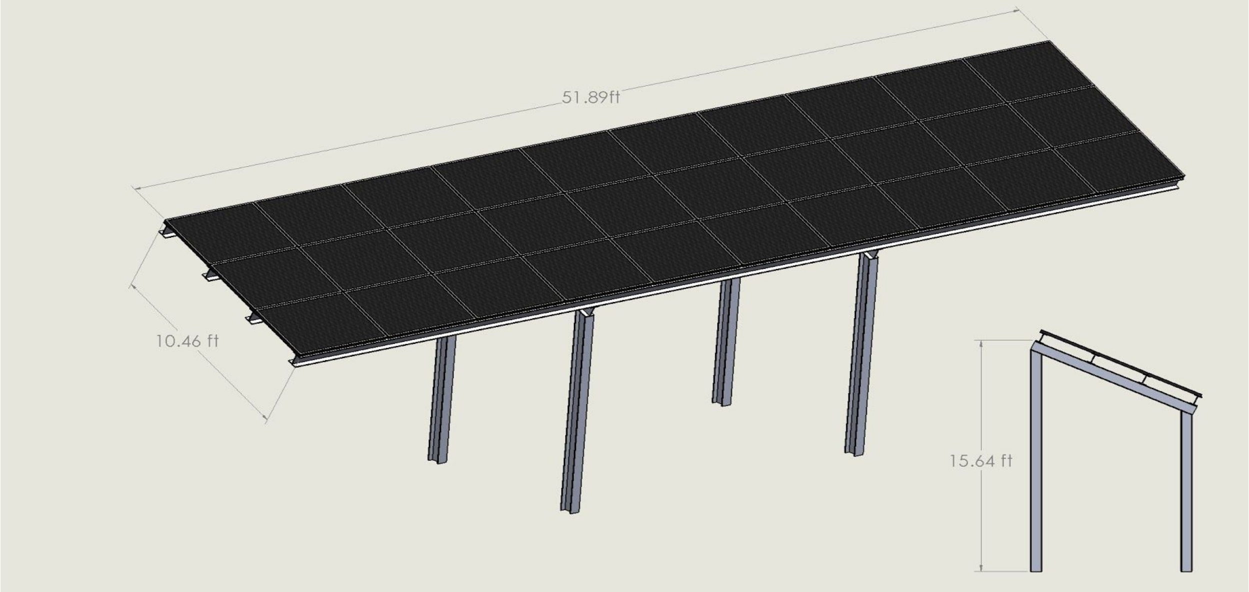


Image Source: (SolidWorks Design Software, Paul Lema 2019)

1 table of modules is approximately 51.89 feet long by 10.46 feet wide. The height of the system is 15.64 feet tall, and is tilted at an angle of 25 degrees.

Analysis:

Site Selection Analysis

To select the best parcels for our solar installation, the parcels of suitable size are assessed by the underlying solar suitability map pixels. A zonal statistics table was computed for each parcel over 20,000 meters squared, generating means of the solar suitability pixel values underlying each parcel. The mean pixel value for each parcel is the final rating assigned to each parcel of acceptable size. Our research can now compare parcels numerically using the parcel rating.

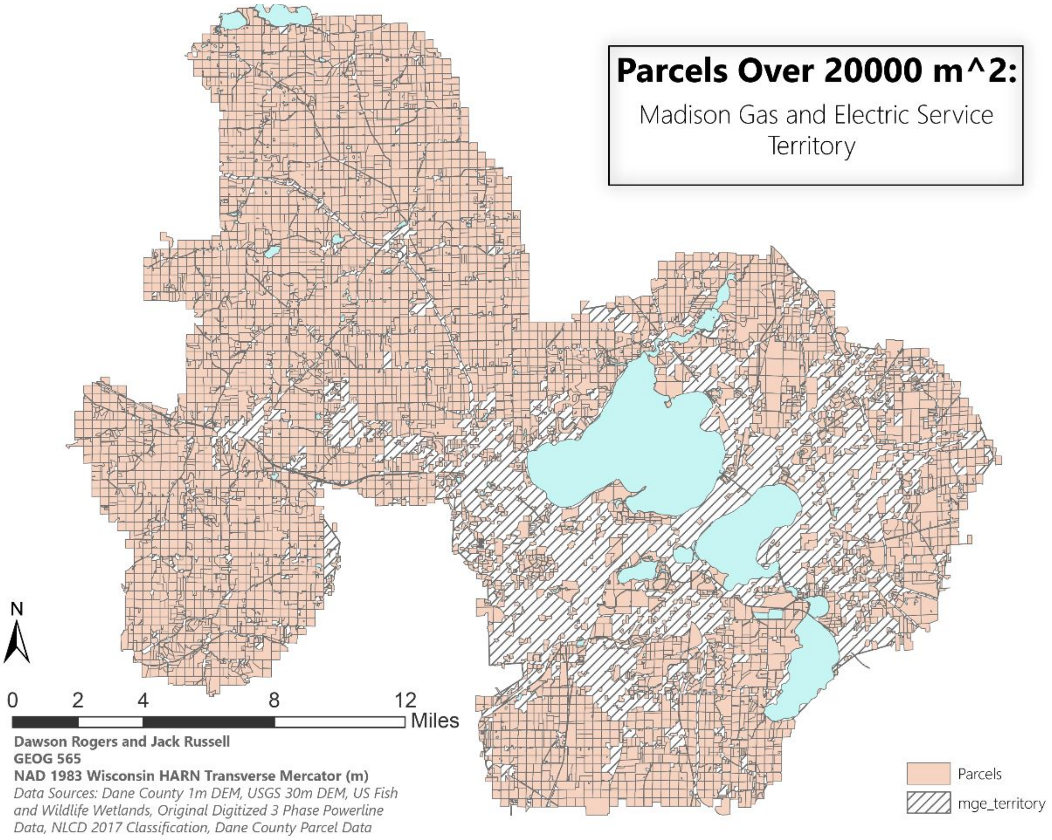


Figure 8. Parcels of a suitable size for our solar installation

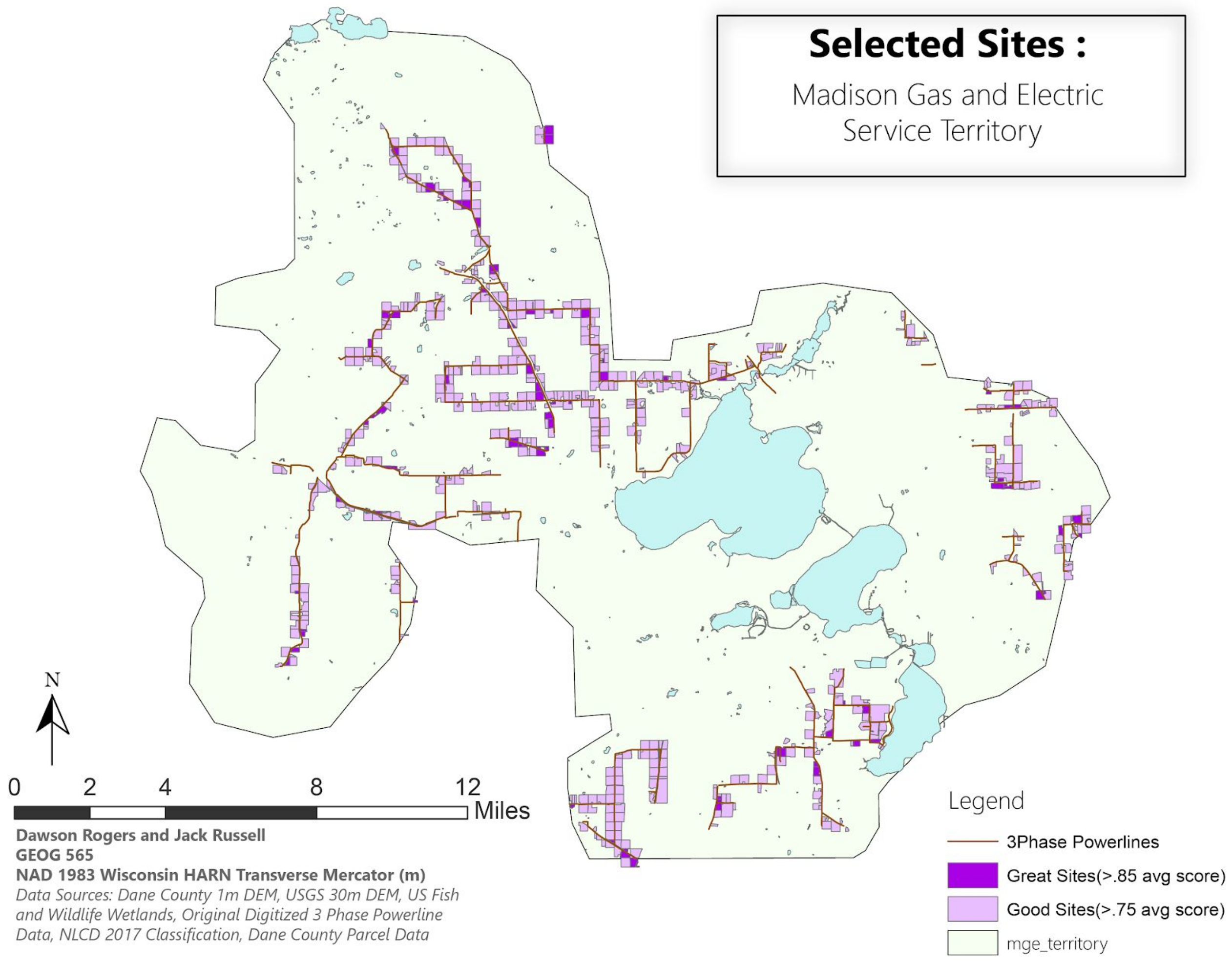


Figure 9. Selected Sites

Querying the parcels by mean solar suitability value returns a subset of all parcels. Good sites were identified by having an average value of above .75. This value ensures that large north facing slopes, unsuitable land cover, insufficient insolation, steep slopes, wetlands, and an absence of three phase powerlines are not the dominant features within the parcel. The .75 level of selection still returns a large subset of parcels, returning 599 out of the 15145 total parcels within the study area. The creation of a much more selective mean pixel value of .85 reduces the identified sites to 78. Upon inspection, all these sites exhibit the best categories of each variable across a large majority of the parcel. Our final site to conduct a design study on will be from at least the selection of sites identified as good.

Solar Design Analysis

According to the U.S. Energy Information Administration, the typical U.S. customer uses 909 kWh per month of energy, which is equivalent to approximately 10,909 kWh per year[32]. Based on the projected total annual production of the system in kiloWatt hours (794885.5678), the system will provide cover electricity demands for roughly 73 people per year. Over the course of the 25 year life of the system, the system will produce enough annual electricity for roughly 1825 people. In theory, this system will be apart of MGE's Shared Solar program. The Shared Solar program allows customers who are not able to install solar systems on their homes to add solar to their energy mix. Customers pay a one-time, up front fee to reserve a portion of the solar electricity. The program specifies that participants will pay $0.109 per kilowatt-hour for up to 50% of their annual electricity demands. The price is held constant for customers for 25 years who stay in the MGE service territory. This community solar program allows residents to reduce their carbon footprint without installing their own system and is an attractive option for many homeowners. This partnership between the City of Middleton and participants supports MGE's initiative of net zero carbon electricity by 2050.

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[32] "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." How much electricity does an American home use? - FAQ - U.S. Energy Information Administration (EIA). Accessed December 11, 2019. https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

Discussion:

Site Selection Discussion

The completion of the site selection process across the Madison Gas and Electric service territory is significant in that it offers a reference for future large scale solar installations. The site selection model is clearly detailed throughout our workflow to allow others to replicate the process if necessary. The level of detail present also creates an opportunity for modifications to the site selection process. Any of the scoring within the raster overlay sum and the fuzzy membership classification can be changed if the desired scale, environment, or technology of the solar PV installation is different than our configuration. The development of technology in the future can also be considered within the solar model, however, additional variables may be needed.

Strengths of our site selection model include the mutable nature of the GIS model, potential for the expansion of the scope of the process, and the pace of site identification. If the selected sites are found to be unsuitable with respect to one of the variables, the overlay can be edited to better represent the desired site characteristics. Other geographic scopes can also be explored with the model accompanied by modifications to better represent differences in the landscape being examined. Finally, the site selection model quickly identified sites, saving time dedicated physical site inspection.

Weaknesses of the model relate to the fuzzy nature of the raster overlay. Though the criteria are justified by relevant industry research, the physical and economic conditions at a potential site will not directly correlate with the solar suitability value produced by the model. Miscategorization or overvaluing of different variables may remove potential sites or suggest sites that are unsuitable. Refining the model over time iteratively with an inspection of the selected sites would be necessary. An additional weakness of the proposed site selection model is the difficulty in acquiring electric grid data. The digitized powerlines layer has gaps where the digitizing methodology could not verify the presence of three phase infrastructure. The quality control applied to the original data layer was a visual inspection using aerial imagery, so there is small potential for missing data. Another concern with respect to data availability is the feeder and substation hosting capacity at a given location. Substation and feeder data is private and requires a project capacity screen to be completed at the suggested site. The cost to conduct the capacity screen with the utility is prohibitive for our research. Having substation and feeder capacity information would support or site selection model to a far greater degree than the three phase power line data layer.

Future Research

Future research regarding the site selection model would address the mentioned weaknesses of the model. Investigating the costs relating to each variable and attempting to translate those directly into the model weights would strengthen the results. Creating different models for multiple configurations of the solar array is also worth exploring. Varying project size, module, and tracker configurations each having their own model would serve to diversify the available options for the desired solar array. Finally, a field-tested solar regression model for the Madison area is an improvement over the solar radiation toolset. Given the time, implementing this improves the legitimacy of the solar regression variable.

Additional future research could also relate to the addition of other variables that were not considered in the initial investigation. Variables that could be added to the site selection model could include road proximity, distance to cultural features, and grid distance from the electric substation. All of these variables could be explored in more detail to potentially add them to the raster overlay if given more time to expand the study.

Solar Design Discussion

Community solar systems have become a significant part of the solar energy movement. While rooftop residential and commercial PV systems continue to be installed at a fast pace, there is a portion of the population that is unable to install such systems. The utility scale PV system that we designed allows people of all living situations to invest in clean energy. The components of the system were carefully chosen to maximize energy production while minimizing installation costs. The Terrasmart Ground mount system is versatile and does not require trenches or concrete to be poured. We consulted with solar professionals at Sunsense Solar regarding all phases of the project to ensure that this system is as realistic as possible.

Conclusion:

In setting out to identify the feasibility of a ground-mounted PV solar installation in the Madison area, our research was driven by recent trends in Solar PV expansion. Through the generation of solar feasibility criteria, we managed to identify physical, environmental, and cultural variables contributing to solar suitability at prospective sites. Using these criteria, we found a site and paired that with a comprehensive ground mount solar system design. Overall, our research was successful in finding a site, however, the success of the model would truly be determined over the lifetime of the project. The main goal of the site selection model is to quickly find a site and reduce the costs of the project at the selected sites. Without physically constructing the project, our research cannot be fully certain of the complete success of the model. If implemented commercially, the model would become fully mutable and responsive to identified difficulties at the selected sites. A further exploration of the project finances following a community solar model would also offer a more expansive summary of the potential for the project.

In addition to the preliminary success of the site selection model, the solar design component of the research lays out an array and mounting system that will be able to support around 100 homes in the Madison area. The solar design also considers expenses and climate effects on the array, constituting a substantial first step in constructing a project. The inclusion of extensive industry practice into the design solidifies our array as feasible.

Ultimately, the research design succeeded in a preliminary exploration of solar suitability in Madison & Gas and Electric service territory. The subsequent completion of the solar design initializes the exploration of a solar array design at the selected site. Together these components comprise a model for implementing a solar installation. The research was successful, however, there is the potential for various avenues of future research.

Acknowledgements:

Thank you to Justin Martinez from Sunsense Solar in Carbondale, Colorado. Justin provided key insights into the system components and aided in the physical design of the project.

Thank you to Paul Lema for assisting in the 3 Dimensional Rendering of a solar table.

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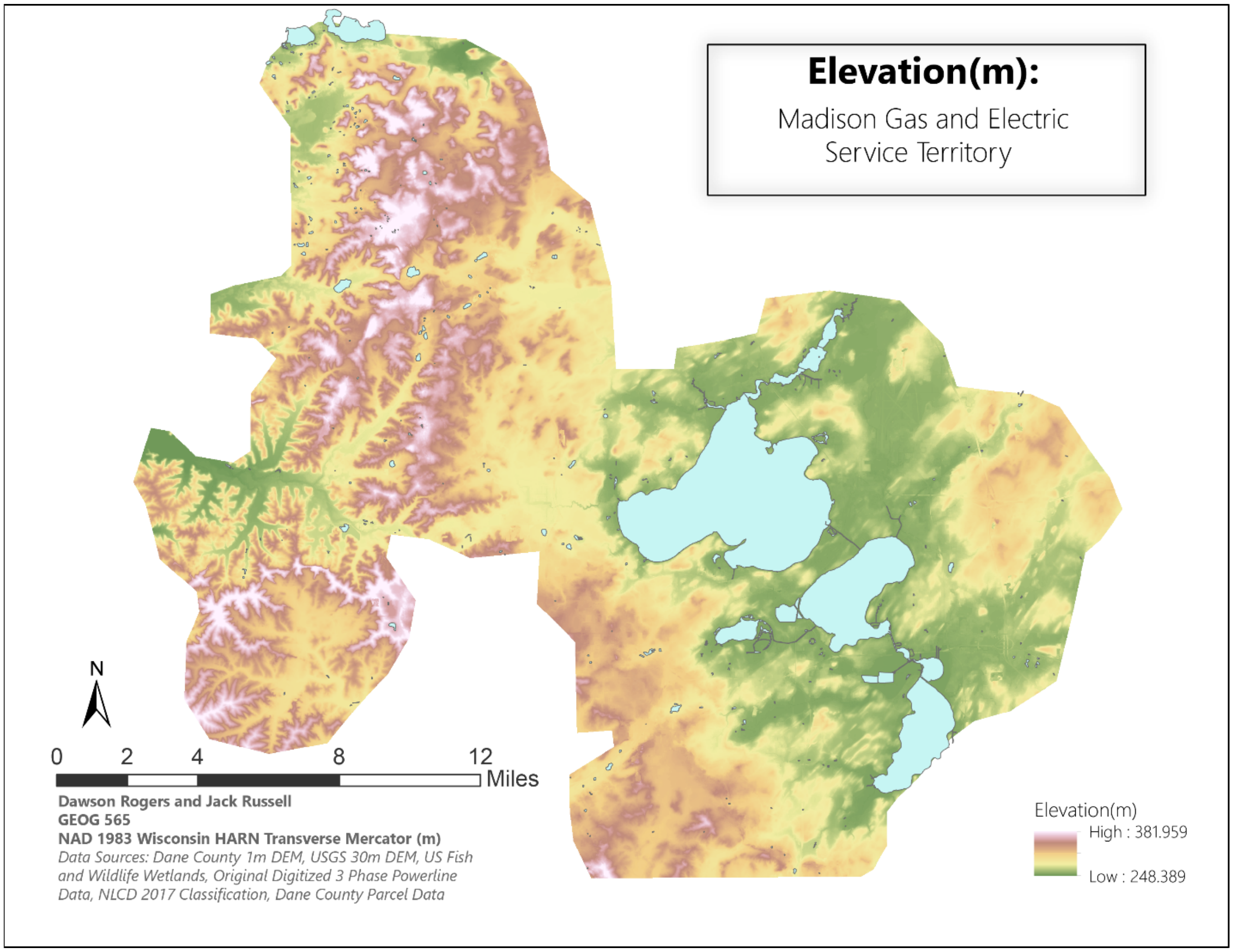
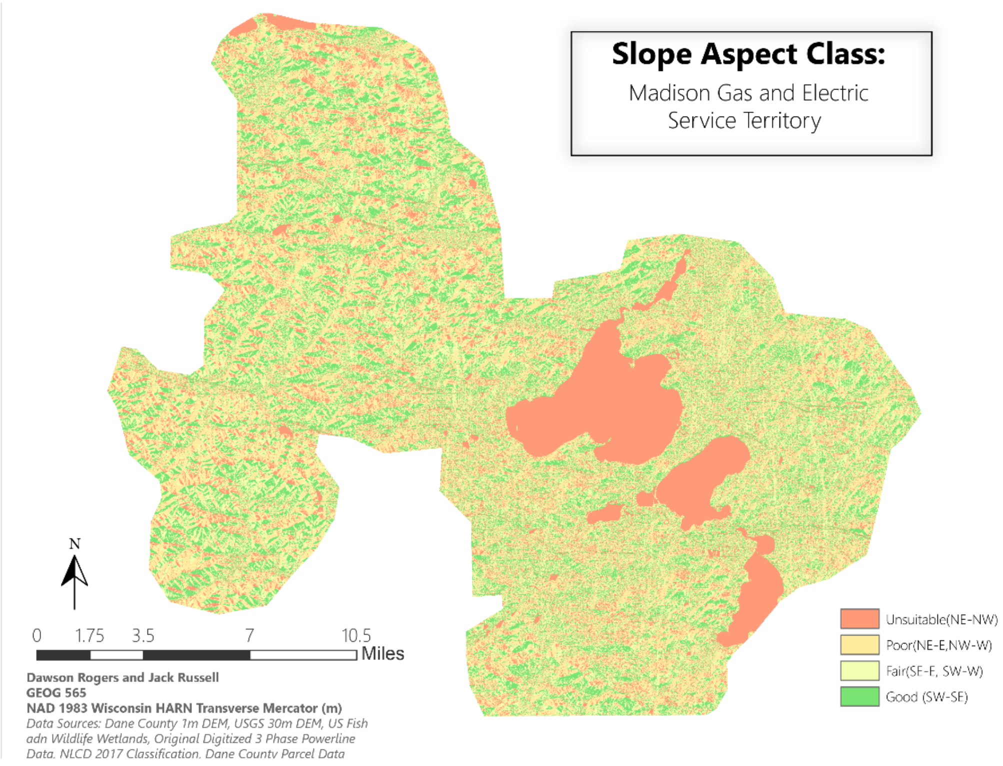
Appendix A: Maps



Elevation(m):

Madison Gas and Electric Service Territory

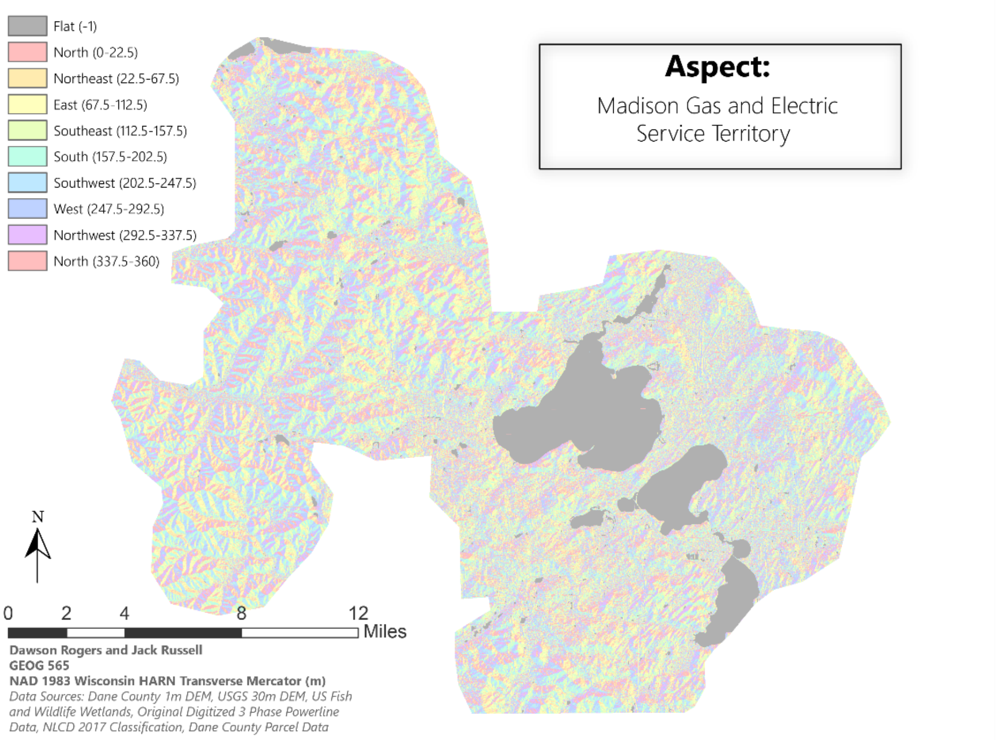
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data



Slope Aspect Class:

Madison Gas and Electric Service Territory

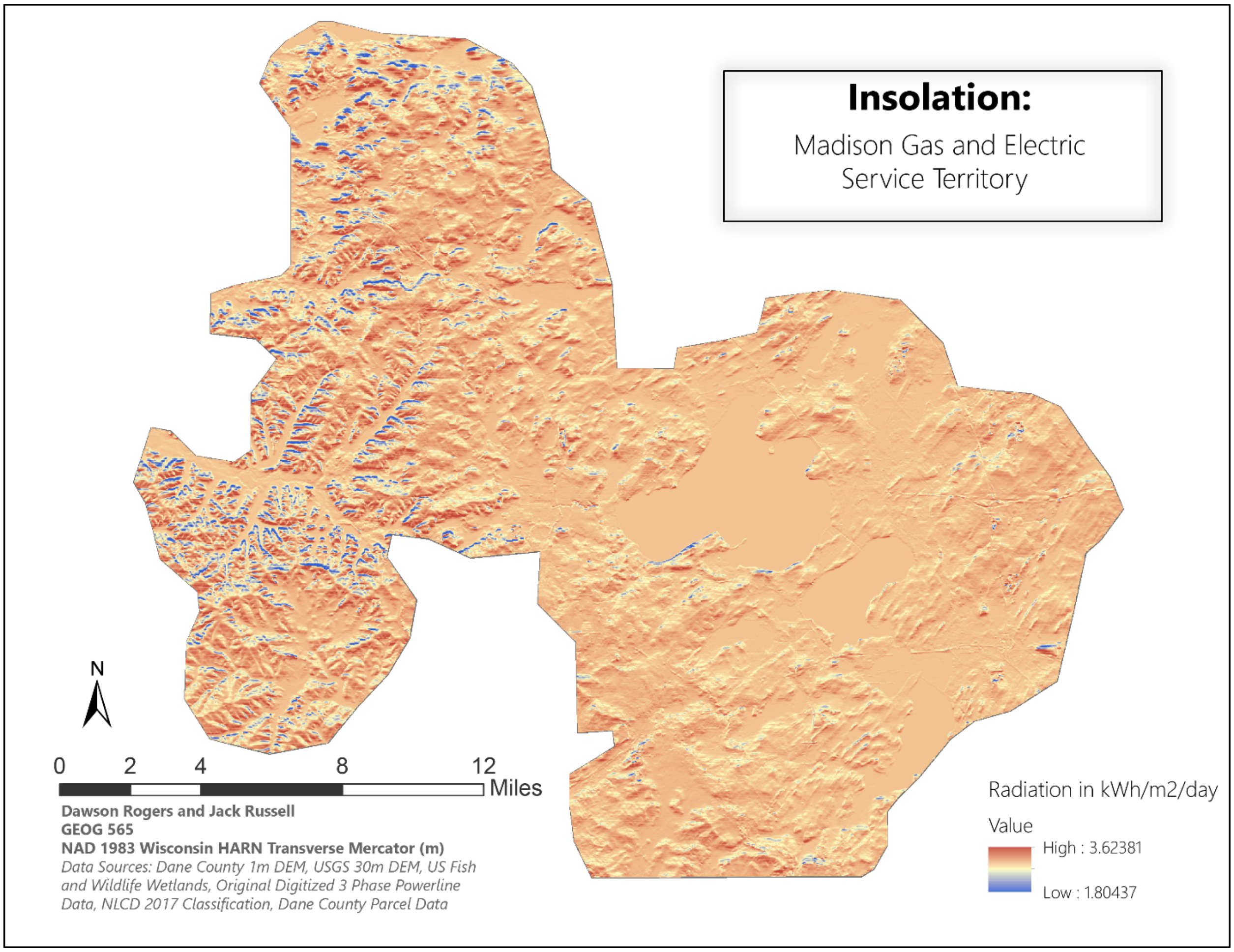
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish adn Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data

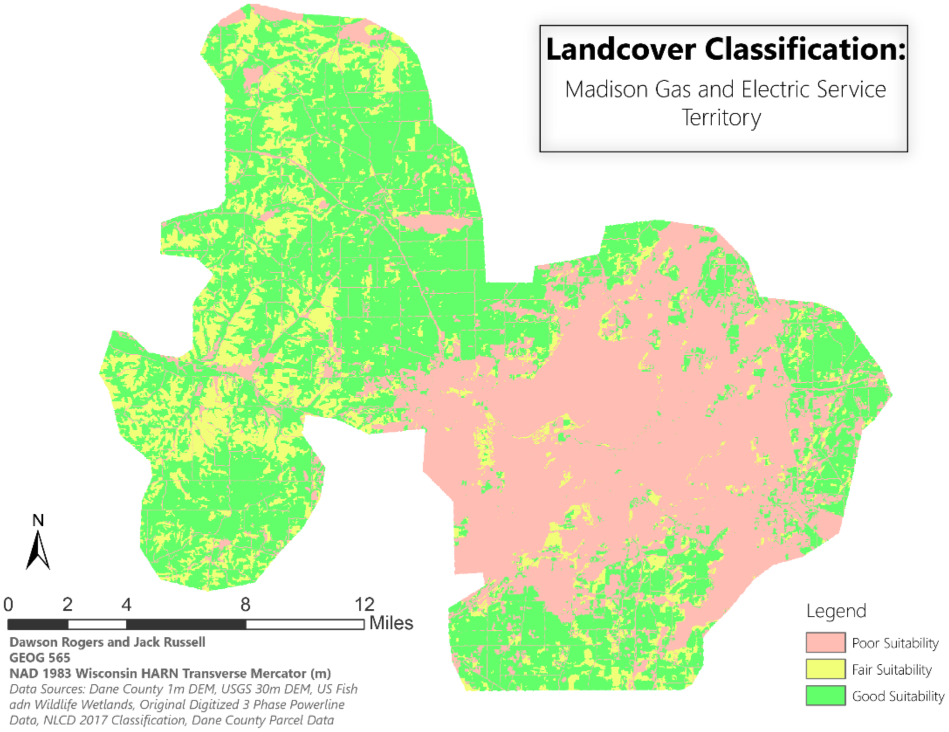


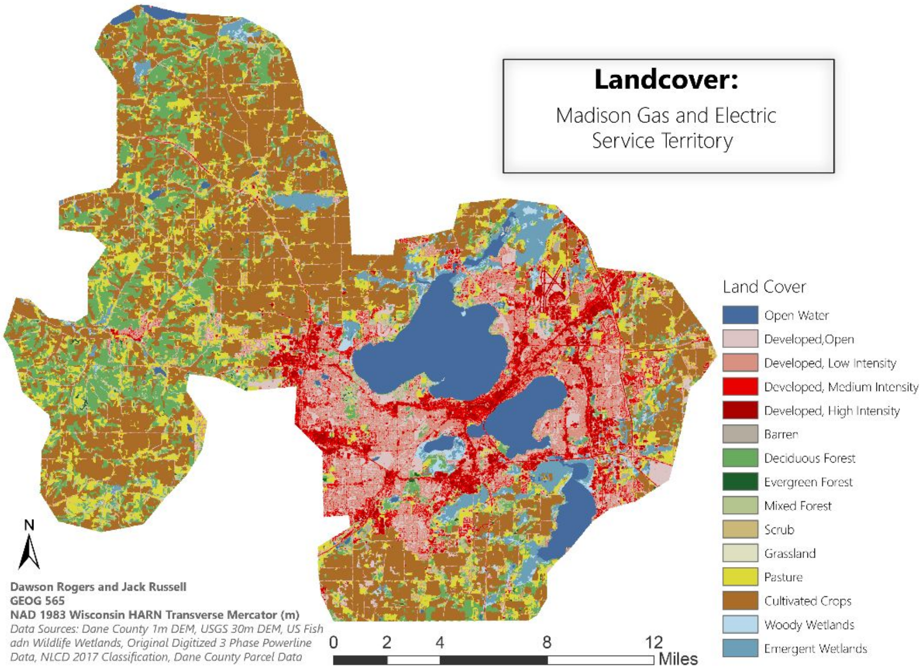
Aspect:

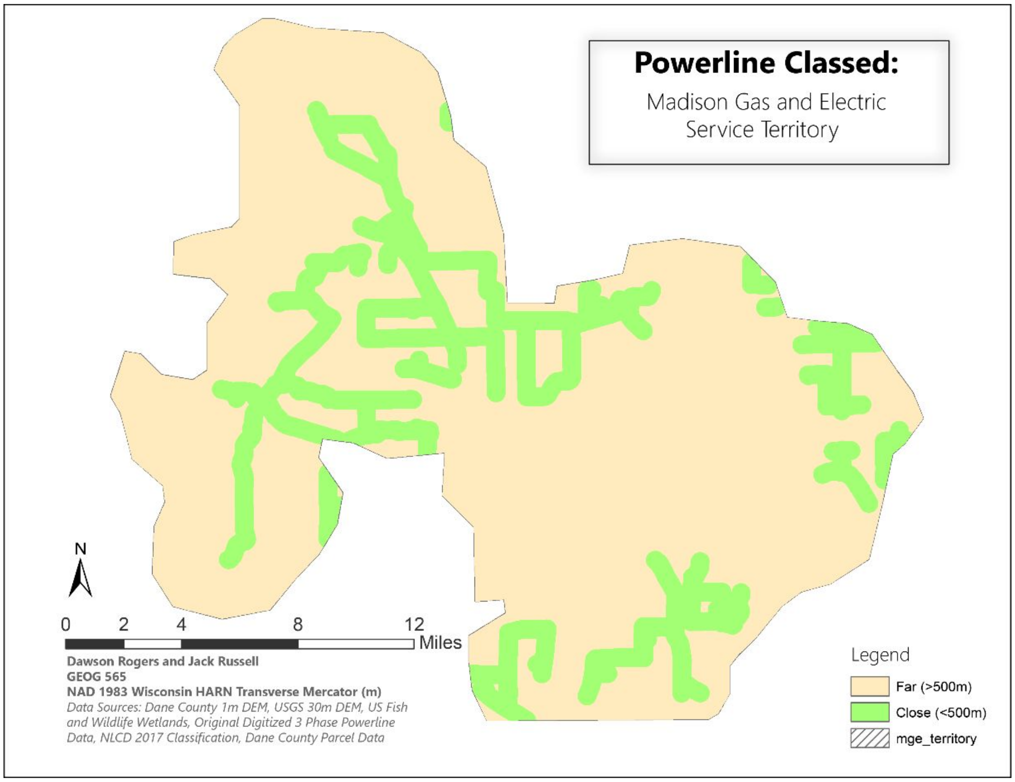
Madison Gas and Electric Service Territory

Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data


Insolation:
Madison Gas and Electric Service Territory
N
0
2
4
8
12
Miles
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data
Radiation in kWh/m2/day
Value
High : 3.62381
Low : 1.80437

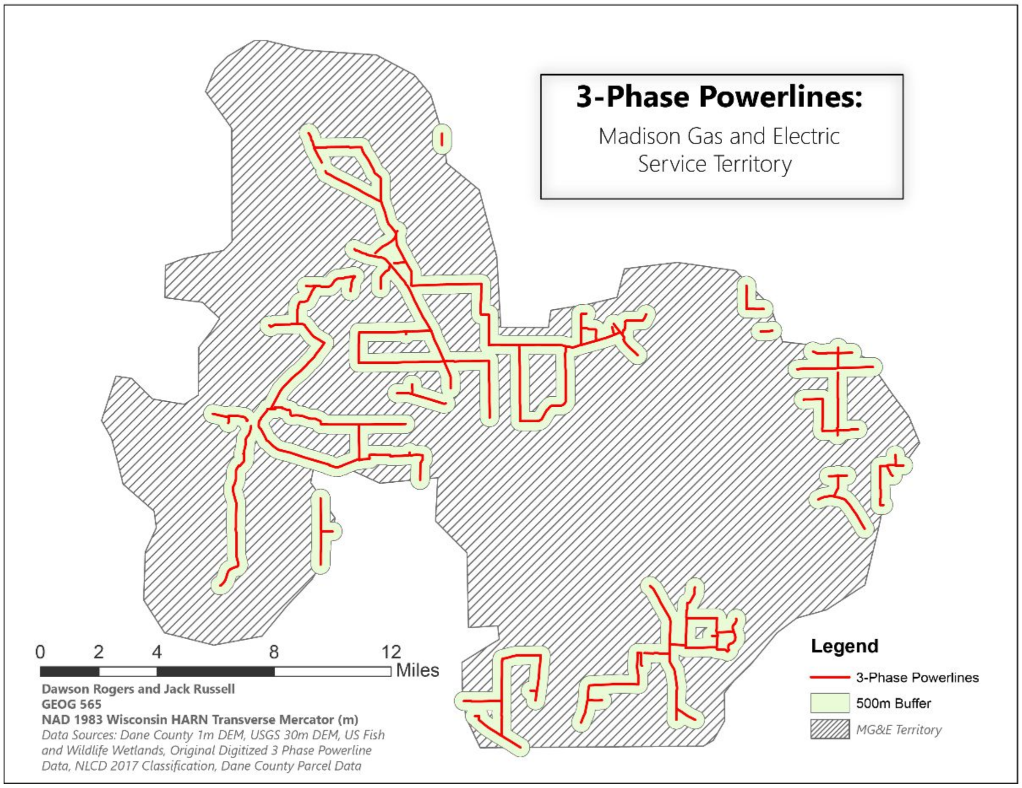

Landcover Classification:
Madison Gas and Electric Service Territory
N
0 2 4 8 12 Miles
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish adn Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data
Legend
Poor Suitability
Fair Suitability
Good Suitability


Landcover:
Madison Gas and Electric Service Territory
N
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish adn Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data
0 2 4 8 12 Miles
Land Cover
Open Water
Developed,Open
Developed, Low Intensity
Developed, Medium Intensity
Developed, High Intensity
Barren
Deciduous Forest
Evergreen Forest
Mixed Forest
Scrub
Grassland
Pasture
Cultivated Crops
Woody Wetlands
Emergent Wetlands



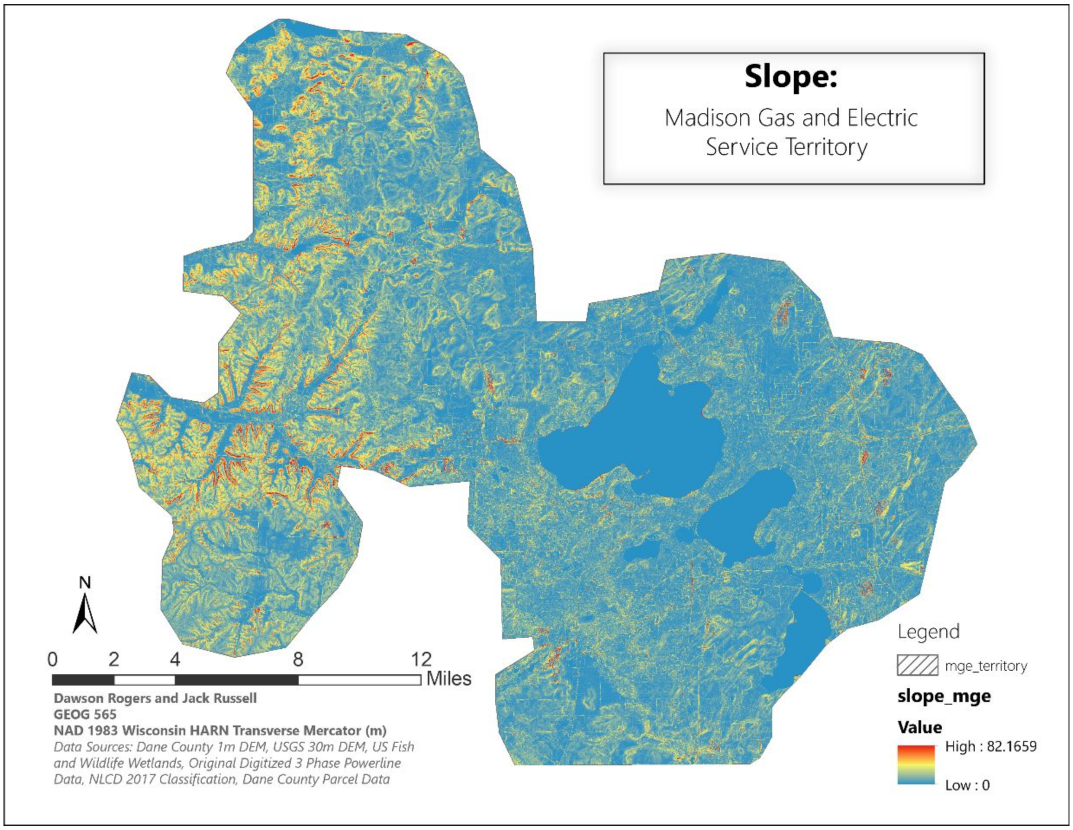
Powerline Classed:
Madison Gas and Electric
Service Territory

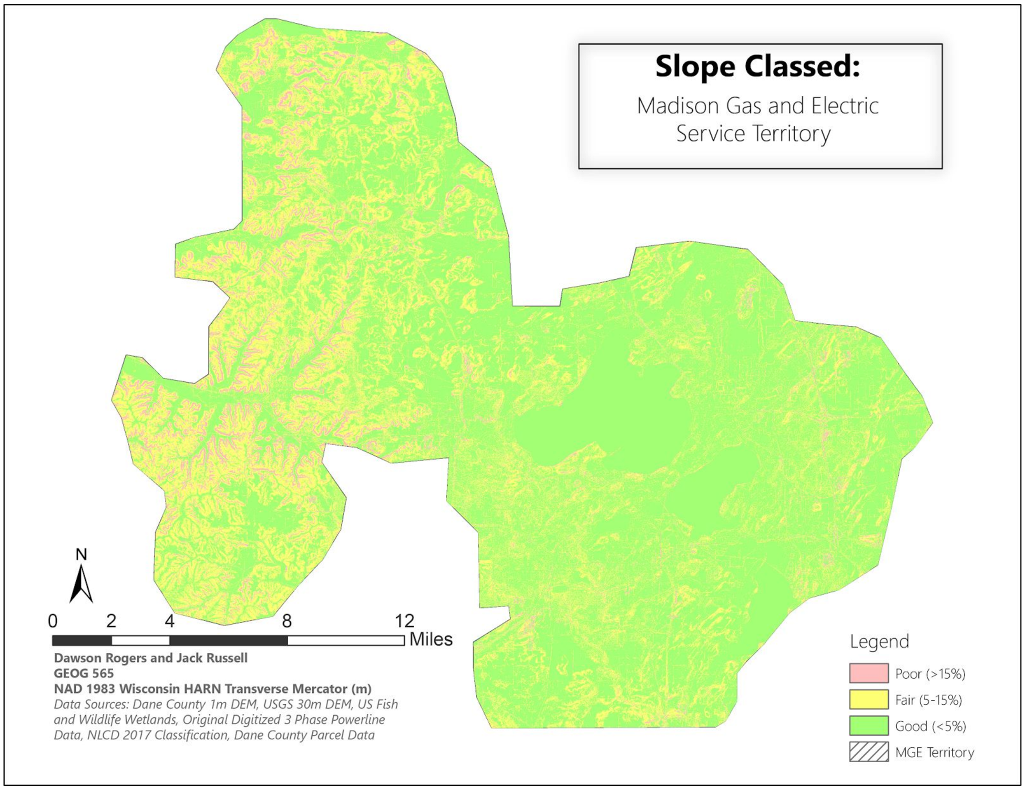
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data

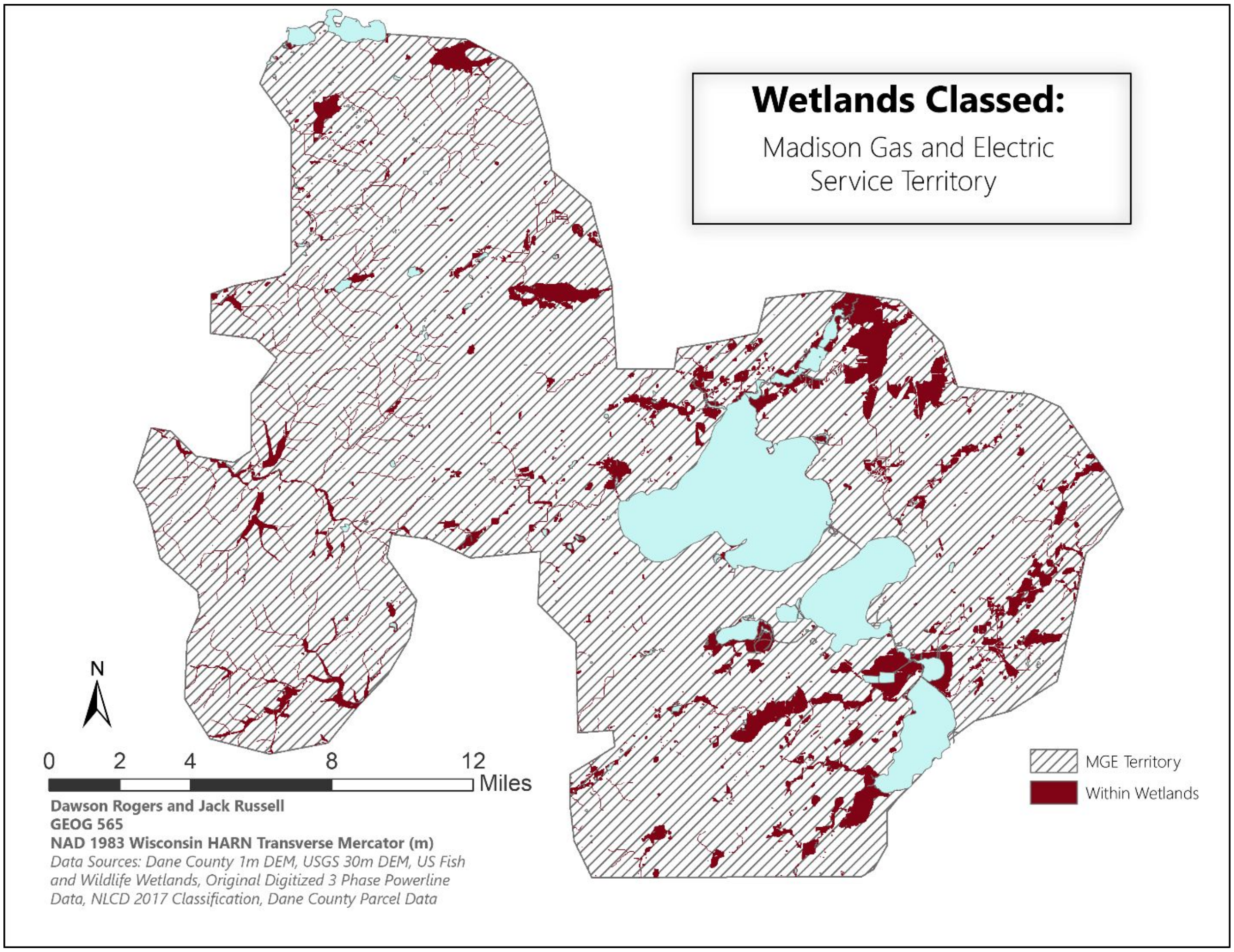


3-Phase Powerlines:
Madison Gas and Electric
Service Territory

Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data


Slope:
Madison Gas and Electric Service Territory
N
0 2 4 8 12 Miles
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data
Legend
mge_territory
slope_mge
Value
High : 82.1659
Low : 0


Slope Classed:
Madison Gas and Electric Service Territory
N
0 2 4 8 12 Miles
Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data
Legend
Poor (>15%)
Fair (5-15%)
Good (<5%)
MGE Territory



Dawson Rogers and Jack Russell
GEOG 565
NAD 1983 Wisconsin HARN Transverse Mercator (m)
Data Sources: Dane County 1m DEM, USGS 30m DEM, US Fish and Wildlife Wetlands, Original Digitized 3 Phase Powerline Data, NLCD 2017 Classification, Dane County Parcel Data