Determining the Most Suitable Sites for Large Scale Ground Mount Solar Arrays in Tompkins County, NY Using GIS-Based Fuzzy Logic

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Pledge

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Abstract

Climate change is a global danger that must be addressed through reducing carbon emissions. Many global initiatives have been created through groups like the United Nations, but these have had limited impact as seen in the United Nations climate reports. Local governments have been more successful in passing and implementing green policy that seeks to decarbonize their region. In Tompkins County New York, the city of Ithaca has passed a green new deal which seeks to use renewable energy as part of the decarbonization initiative. Geographic information systems combined with multi-criteria evaluation techniques are a common and successful method for determining ideal locations for renewable energy facilities to be built. This study uses GIS-based multi-criteria evaluation practices, combined with fuzzy set theory, in order to determine the most suitable locations in Tompkins county for the construction of large scale ground mounted solar arrays of approximately 10 acres in size. The fuzzy set model uses multiple economic variables such as proximity to roadways and proximity to powerlines. The model also considers environmental variables such as solar irradiance or land cover in order to make decisions that will consider multiple important criteria at once. The model identified 5 potential sites in the study region, and 3 of them were recommended for further study. Highly suitable areas represented 37% of the study region. With more than a third of the county considered highly suitable for solar installations, it is likely that stricter models could be successfully used to refine results. This model provides a resource for decision-makers in Tompkins County, and also created a reproducible model for use in studies on other regions.

Introduction

Climate Change Response

Anthropogenic climate change is an issue that impacts the whole world. The Intergovernmental Panel on Climate Change (IPCC), who is considered the largest and most authoritative voice on climate science, recently released a report in 2021. The report states that it is no longer possible for the world to stop the globe from warming past 1.5 degrees Celsius in the next one to two decades (Levin et al., 2021). There are many projected and potential courses of action that could be taken in response to this fact. Some actions may successfully halt and reverse emissions, and thus avoid the worst effects of climate change, others, might continue to emit en-masse and lead to warming past 4 degrees Celsius bringing the extremes of climate change by the end of the century (Levin et al., 2021). These two opposite paths emphasize that bold and real action must be taken during this decade to even stop the warming at about 1.6 degrees Celsius (Levin et al., 2021). Climate change is a global issue that affects many aspects of life, so it must be addressed at almost every level of society. Because of this, climate change has been discussed at the highest levels in the United Nations and at events such as the Paris Agreement (United Nations Framework Convention on Climate Change). It was also discussed in the creation of the sustainable development goals also known as the SDGs (United Nations Department of Economic and Social Affairs) and many other global leader meetings over the past half century. Sustainable Development Goal #13 aims to "take urgent action to combat climate change and its impacts" and states "rising greenhouse gas emissions require shifting economies towards carbon neutrality" (United Nations Department of Economic and Social Affairs, n.d.). Shifting away from greenhouse gas emitting fossil fuels and towards carbon neutrality is most directly addressed through changing to renewable energy which produces energy with no associated emissions.

Renewable Energy

Renewable energy sources will play a key role in meeting SDG #13 as they tap into unlimited energy resources like solar energy, hydroelectric energy, geothermal energy, and wind energy, all of which do not cause fossil fuel emissions beyond manufacturing of materials and installation. Solar energy is uniquely flexible compared to other renewables in terms of the broad locations it can be utilized, its reduced cost through government incentives and comparatively simpler design, and the low environmental impact it causes compared to other renewables, which often makes it easier to get approved for construction compared to other options (Tavana et al., 2017). In 2019, fossil fuels supplied 84.3% of the global energy, while the share of renewable energy and nuclear energy was 11.4% and 4.3%, respectively (Ao et al., 2022). This shows that renewable energies like solar still only comprise a relatively small portion of energy generation compared to fossil fuels. Panwar et al. (2011), in their study reviewing the role of renewable energy sources in environmental protection, state that solar panels are a promising source of energy generation and CO2 emission reduction, even using current solar panel technologies. It is important to note that Panwar et al. had found solar energy promising in its current form in 2011 when the study was complete. Solar technology has since then continued to grow more productive, efficient, and cost effective (Choudhary & Srivastava, 2019; and Gunerhan et al., 2008; and Hernandez et al., 2014; and Kavlak et al., 2018; and Turney & Fthenakis, 2011). Studies agree that solar is a promising energy resource, but it is still unclear how it can transition from a only a promising resource to an actual majority of power generation soon enough to help reduce or even reverse the rate of global warming. Because of this, it is clear that utilizing solar power will play a key role in meeting SDG #13 in the decarbonization of energy production, but it is still unclear how exactly solar panels will quickly get to a higher level of utilization without initiatives to support this.

Power of Local Government Initiatives

There are many state and local governments in the United States that have begun to take on bold climate action, and lead the charge in addressing climate change through new initiatives (Ricketts & Oduyeru, 2020). These small scale changes may be of limited global impact on their own, but when grouped together their cumulative impact is indisputable. One such group is the local government of the City of Ithaca, New York. The city has passed a bold green new deal and is ready to lead the charge on climate action for its region of Tompkins County. The green new deal has some significant goals including: “Targeting community-wide carbon-neutrality by 2030, meeting the electricity needs of City government operations with 100% renewable electricity by 2025, reducing emissions from the city vehicle fleet by 50% by 2025, ensuring benefits are shared among all local communities to reduce historical social and economic inequities, and facilitating a comprehensive public engagement process” (Steecker, 2021). These are bold goals that still need to be fleshed out as to how they will be achieved, but in the meantime this study seeks to provide a resource to help with identifying potential locations for ground mount solar arrays. This will help officials meet renewable electricity goals and take advantage of a promising renewable resource that fights climate change and works towards meeting global efforts.

Multi-Criteria Evaluation and GIS

In order for solar energy to go from a promising idea, to a widely adopted technology, methods of selecting where to build them must be considered. Where to construct solar arrays is a complicated decision that involves many factors ranging from economic, technical, social, and environmental variables. For example, the best location for a solar array in terms of light exposure may not be the best economically or socially (Charabi & Gastli, 2011; and Tavana et al., 2017). Because of this complexity, a multi-criteria evaluation (MCE) that considers many variables should be used (McHarg, 1969). The first geographic information system (GIS), and the term itself, was developed by Roger Tomlinson in 1963 (Goodchild, 2018; and Tomlinson, 1999). Geographic information systems are software systems where users can create, manage, analyze maps, and have built in tools for integrating location data with descriptive data from datasets. GIS software, when combined with multi-criteria evaluation, is a practice termed GIS-based MCE. Malczewski (2004; and 2006) defines GIS-based MCE as the process of using map data and combining it with value judgments from stakeholders and decision-makers to obtain information for decision-making. This process has evolved over time and is being used and expanded upon today to continue to address complex questions that involve many variables. “Where are the most suitable locations to build a solar array in Tompkins county?” is one such question that is perfect for being answered using these decision making methods.

Objective

This study to aid the local officials and decision makers in meeting their sustainability goals, which ultimately will contribute to the global effort to combat climate change and to meet the objectives of SDG #13. This study uses GIS-based MCE and specifically fuzzy logic approaches to create a suitability map that highlights prime locations in Tompkins County for utility scale ground mount solar arrays. This ultimately provides a resource for decision-makers by giving specific site recommendations for further inspection, as well as a model that can be altered or expanded on for locating additional sites.

Methods

Study Region

The study region, Tompkins County (Figure 1), is located centrally in New York state and is 492 square miles in size and about 1,000 feet above sea level. The county has a population of approximately 100,000 with a median age of 31 years old and median household income of about $60,000 (Deloitte et al., n.d.). The region is known for the presence of Cornell University located in the City of Ithaca and also for its proximity to Cayuga Lake, one of the Finger Lakes. The region is characterized by its many hills and is famous for its waterfalls and gorges, which were shaped and formed by glacial erosion. Based on the National Land Cover Dataset (NLCD) of 2019 (MRLC 2019), the region is made up primarily of forests and farmland, which account for a combined 80% of the region. The region is 46% forested, and is primarily deciduous forest. Farmland is split between cultivated crops and hay/pasture and makes up 10% and 24% respectively. Developed land ranging from open space to high intensity collectively makes up 10% of the region. Finally the remaining 10% of the region is a mix of wetlands, open water, shrub/scrub land, and barren rock sand or clay.

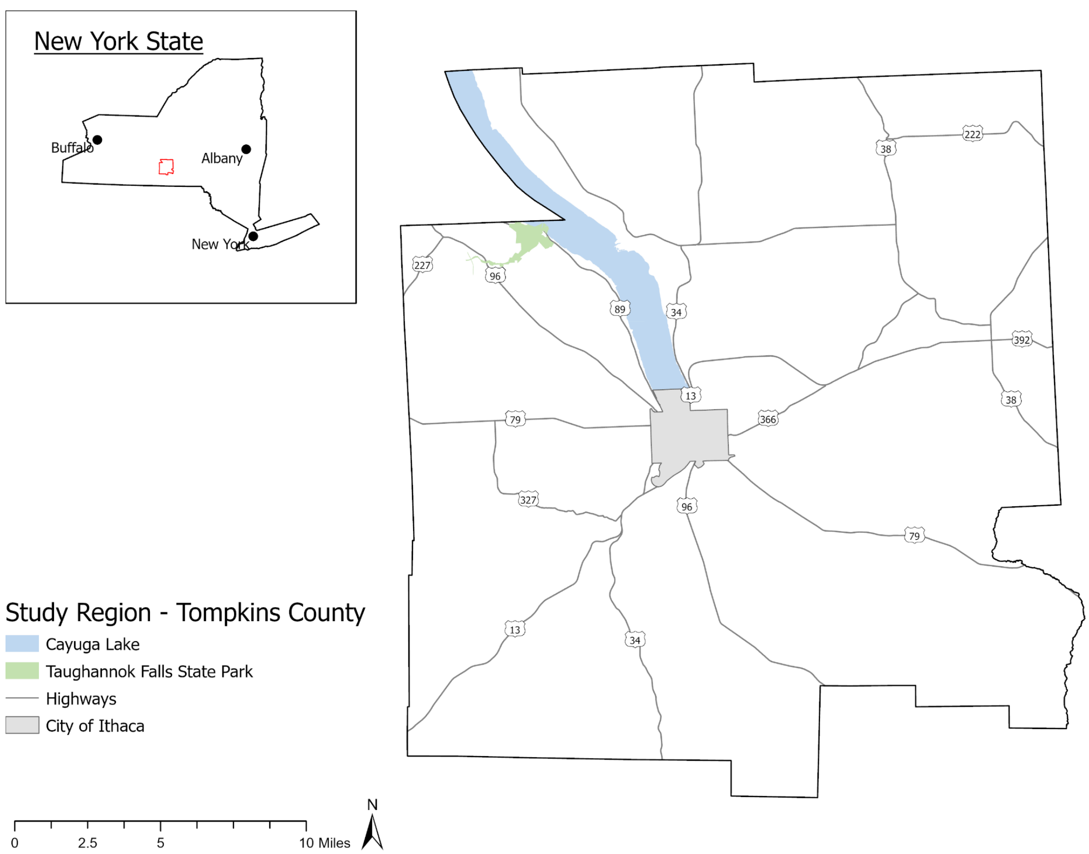

Figure 1: Tompkins County, New York study region map.

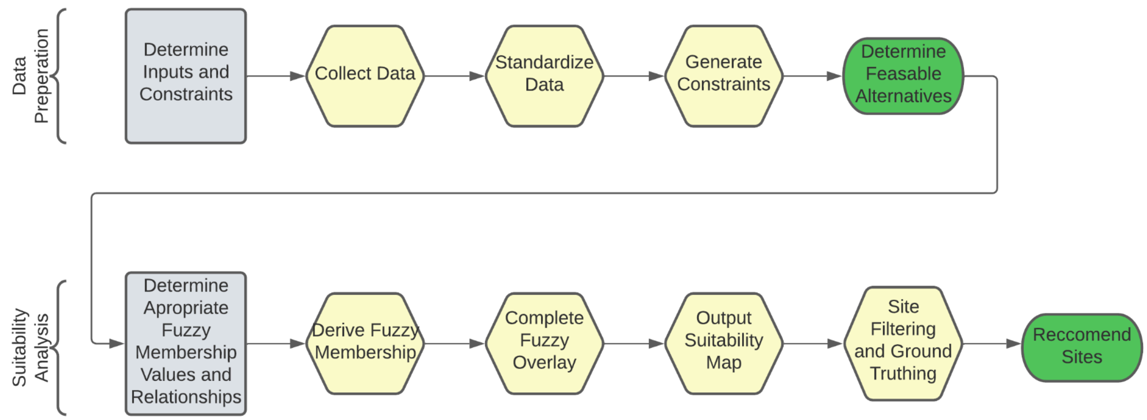

Figure 2: Methods flow chart.

Input Variables

This suitability analysis used various datasets (Table 1) based on the literature. Kwak et al. (2021), has completed one of the latest studies on large scale solar site selection which includes a literature review and also its own recommendations. The study developed a large-scale multi-criteria suitability analysis for identifying solar development potential in Illinois. This study echoed similar decisions of inputs found in various prior studies (Brewer et al., 2015, and; Charabi & Gastli, 2011and; Doljak & Stanojevic, 2017 and; Suganthi et al., 2015 and; Tavana et al., 2017 and; Zoghi et al., 2017) with a common focus on inputs such as transmission line proximity, road proximity, solar irradiance, slope (some use aspect and elevation, though these are factored into the solar irradiance data in this study), and lastly land cover. Transmission line proximity, road proximity, and land cover all influence the overall costs of solar development in terms of the construction of additional infrastructure and site modification. Solar irradiance is directly correlated with the maximum productivity of a given area, and is therefore an important consideration when seeking maximum power generation (Akkas et al., 2017; and Al Garni & Awasthi, 2018; and Kwak et al., 2021; and Turk et al., 2021).

Data Sources

All datasets (Table 1) were standardized to the same coordinate system, converted from vector data to raster data, resampled so that all rasters shared the same cell size, and subset to the study region. A slope raster was generated from the elevation dataset. Euclidean distance layers were generated from state road, transmission line, and wetland datasets. Lastly, a solar irradiance layer was generated from the elevation dataset.

Table 1: Data sources for input criteria and constraints.

Dataset	Derived Criteria	Data Source	Originator	Year Published
Land Cover	Land cover	NLCD 2019	MRLC	2019
Flood Zones	Flood zones	County Flood Zones Map	Tompkins County GIS Division	2019
State Roads	Distance from roads	New York State Roadway Inventory	GIS.NY.GOV	2021
Transmission Lines	Distance From Transmission Lines	Transmission Lines Map	DHS-HIFLD	2021
Wetlands	Distance from wetlands	Wetlands Mapper	USFWS	2020
Elevation	Slope, Solar Irradiance	National Map v2	USGS	2021
Protected Areas	Protected Areas	PAD-US 2.1	USGS	2021
County Municipalities	County Boundary	County Municipalities	Tompkins County GIS Division	2018

Constraints

An important step in conducting a suitability analysis is the application of constraints before assigning fuzzy membership values (Malczewski, 2004). This involves marking any raster pixels that contain one or more constrained values on any other raster, as “restricted” for all inputs. This is so that only the range of values for feasible alternatives is scaled between 1 and 0. The new inputs that are created through this process are called feasible alternatives. The flood zones, wetlands, and protected areas datasets were all used as constraints. County codes state that large scale solar installations must not be built within a flood plain or within a protected zone and must have a 100 foot buffer from streams and wetlands (Tompkins County GOV, 2017). Slope, distance from roads, and the land cover datasets all had some constrained values. For slope, any raster pixel that had a higher slope than 14% was deemed as restricted in order to meet county recommendations (Tompkins County GOV, 2017). County codes require road setbacks for large scale photovoltaic systems (Town of Ithaca, 2016). To meet this, distances from roads of less than 140 feet were constrained. Lastly, certain land cover values were constrained including open water, wetlands (woody and herbaceous), and any developed land (ranging from open, low, medium, or high intensities). Water and wetlands were constrained because of local codes previously mentioned (Town of Ithaca, 2016) and developed land was constrained due to the purpose of the study focusing on large scale ground mount solar which falls outside of developed zones.

Table 2: Restricted values for each variable.

Variable	Full Restriction?	Restricted Values
Flood Zones	Yes	All
Wetlands	Yes	All, 100 foot buffer added
Protected Areas	Yes	All
Slope	No	Slopes steeper than 14%
Distance from Roads	No	Distances of less than 140 feet
Land Cover	No	Open water, wetlands, developed land

Feasible Alternatives

Feasible alternatives are maps that are generated by considering every restricted raster pixel from the constraints and removing those pixels from every input criteria map. This is analogous to a stamp formed from a composite of every restricted pixel on every map that is then used to “stamp” out those pixels in the same location for all input maps so that only pixels that are feasible will be analyzed. All of these maps are the final versions of the inputs before they are assigned fuzzy membership values and go through the fuzzy overlay process to generate a suitability map.

What is Fuzzy Logic?

Past studies provide insight into potential methods. Suganthi et al. (2015), in a literature review on the applications of fuzzy logic for finding suitable locations for renewable energy systems, highlighted that over time more complex and computation heavy methods have been developed that seek to accommodate heuristic reasoning and ultimately obtain better results that are more accurate and precise. They concluded that fuzzy based methods are a better analysis method than other common methods such as weighted linear combination (WLC) championed by Malczewski (2004), even when combined with the analytical hierarchy process (AHP) developed by Saaty (1987). This is because fuzzy logic better models real life where spectrums or degrees of suitability are more realistic than crisp thresholds or boolean values found in methods like WLC (Suganthi et al., 2015). They listed many possible fuzzy methodologies including neuro-fuzzy, fuzzy AHP, fuzzy ANP, fuzzy DEA, fuzzy GA, fuzzy PSO (Suganthi et al., 2015). For this study, fuzzy set theory (Zadeh, 1965) was selected as it was commonly used for site selection in other studies (Suganthi et al., 2015).

Fuzzy logic is a mathematical tool developed by Zadeh (1965) where disparate data values are converted to a fuzzy membership value ranging from 0.0 to 1.0 (ie. numbers such as 0.2 or 0.72247). In fuzzy sets, 0 is the value with no fuzzy membership and 1 is the value with full membership. Instead of only using Boolean “yes” (1) and “no” (0), fuzzy logic seeks to better model the real world in which there are not always crisp thresholds and where the answer can fall somewhere between yes and no. The fuzzy membership process facilitates conversion of many variables that were originally quantitative or qualitative and using different units of measure, and turning their values into just one type of value. This allows for direct comparison by overlaying the data in the fuzzy overlay process to find the “composite” or overall suitability between all variables.

Fuzzy Membership and Overlay Process

Land cover was manually assigned fuzzy membership values because it is qualitative in nature. Open spaces like grassland and pasture were given the highest fuzzy membership as they have the least site modification required and are recommended by the county guidelines (Town of Ithaca, 2016). Cropland and regions with shrub/scrub vegetation were assigned slightly lower values as there are some increased site modifications and costs (Tompkins County GOV, 2017). Forested regions were given low fuzzy membership values as the county states that large scale solar arrays must avoid clearing large extents of forest (the size of which was not defined). Low fuzzy membership value was also assigned because this is a study aimed at assisting the sustainability oriented green new deal, so recommending cutting down important carbon sequestering forests is counter-productive and socially unpopular (Steeker, 2021; and Tompkins County GOV, 2017). Finally, barren land made of rock, sand, or clay were deemed highly unsuitable due to them being impractical and expensive to build on (Choudhary & Srivastava, 2019; and Gunerhan et al., 2008; and Hernandez et al., 2014; and Kavlak et al., 2018; and Turney & Fthenakis, 2011).

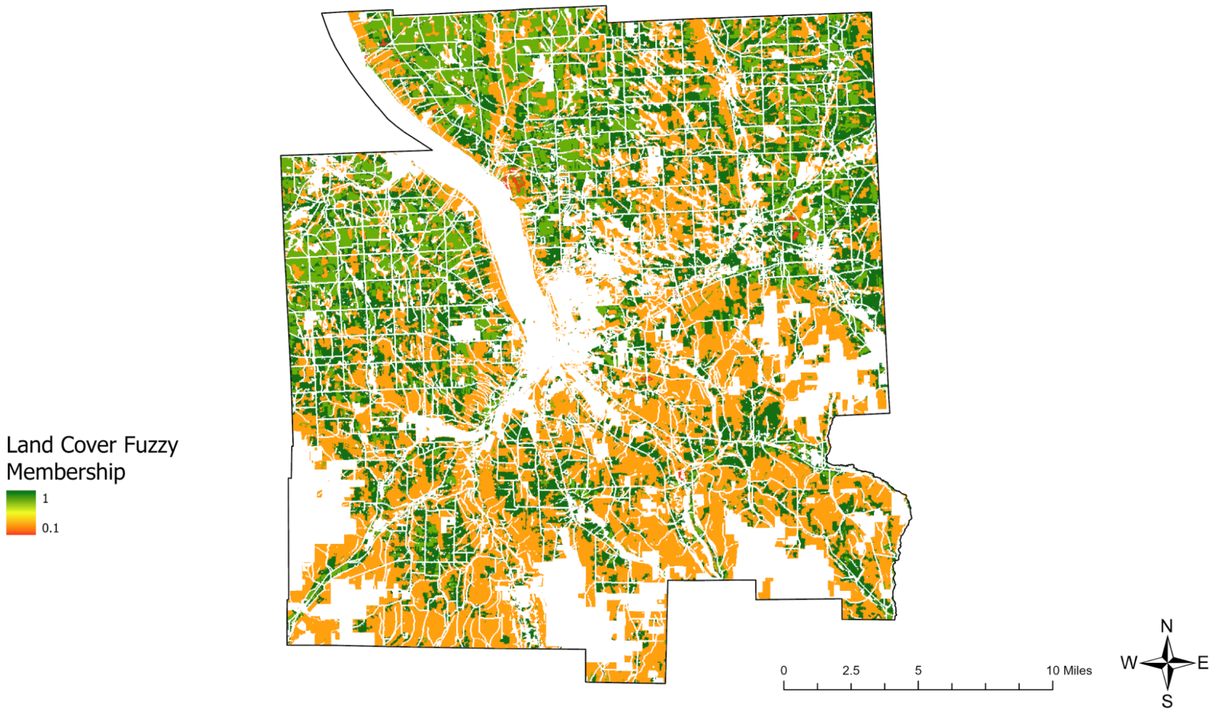

Figure 3: Land cover fuzzy membership.

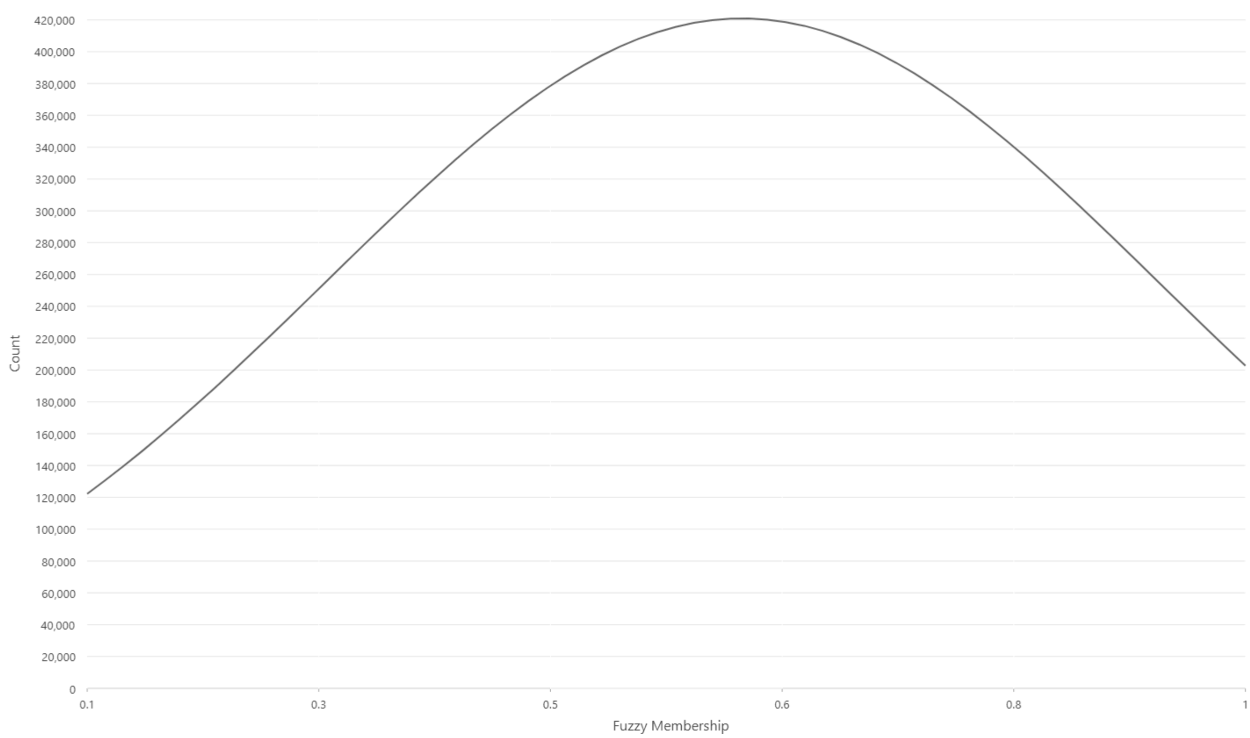

Figure 4: Land cover distribution curve.

Distance from roads was given a fuzzy membership relationship where smaller values are deemed as having high fuzzy membership and decrease in value exponentially as distance increases. This relationship seeks to replicate the rapidly increasing costs of scale associated with building access roads for the construction and maintenance of the solar arrays (Charabi & Gastli, 2011; and Tavana et al., 2017; and Turk et al., 2021).

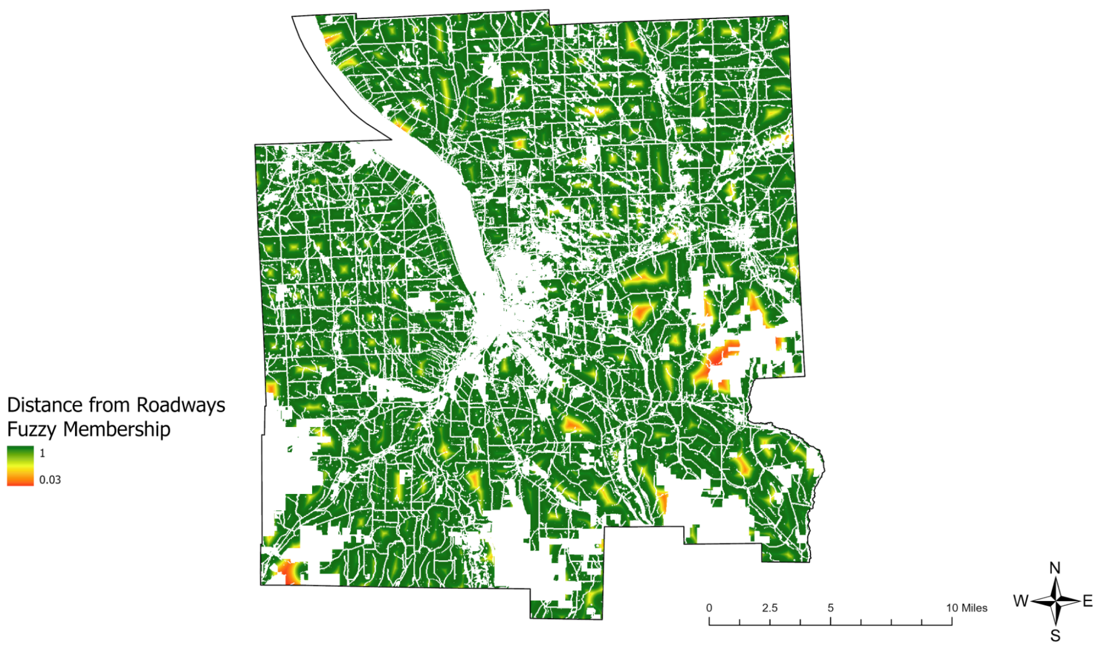

Figure 5: Distance from roads fuzzy membership.

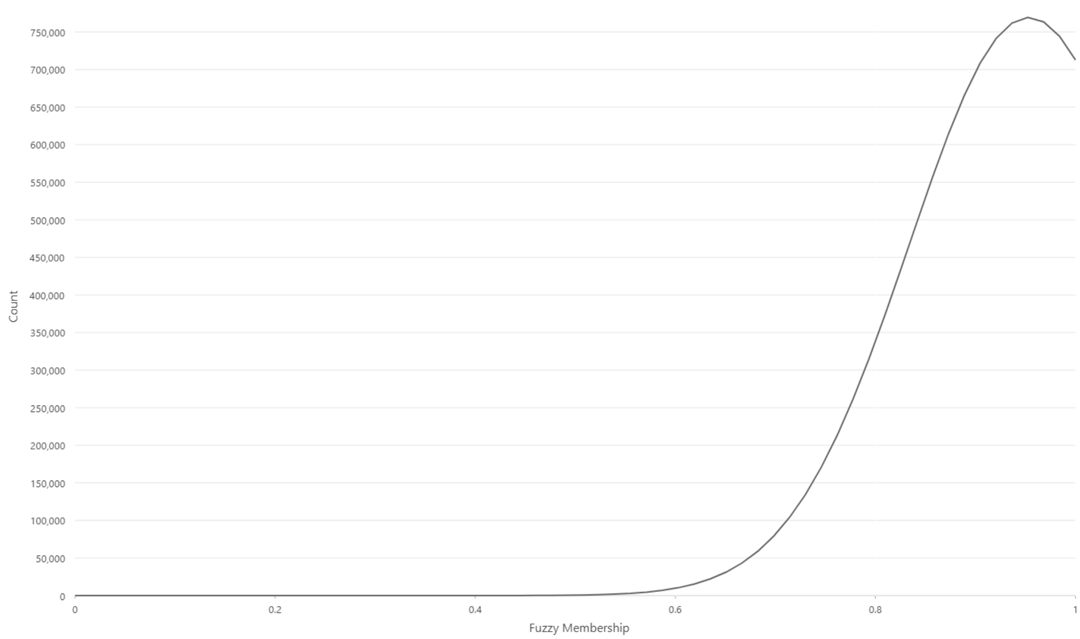

Figure 6: Distance from roads distribution curve.

Distance from transmission lines has two considerations. The first is the cost of building power infrastructure for the array to connect to the grid. The second is that the further the energy produced by the array has to travel before reaching a transmission line, the more energy is wasted, making the system less efficient and cost effective. In this case, an exponential relationship was used so that raster pixels closer to transmission lines are given high fuzzy membership, which decreases exponentially as distance increases (Charabi & Gastli, 2011; and Tavana et al., 2017; and Turk et al., 2021).

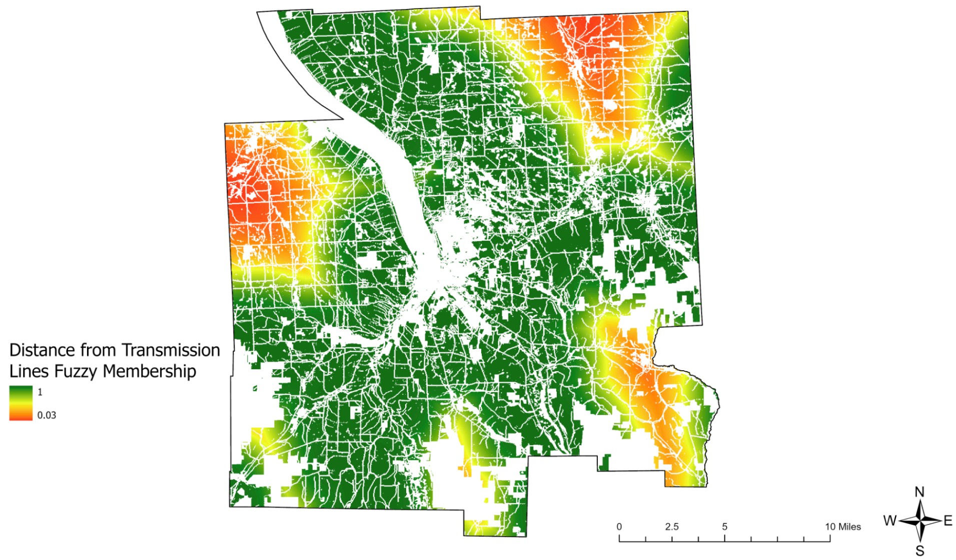

Figure 7: Distance from transmission lines fuzzy membership.

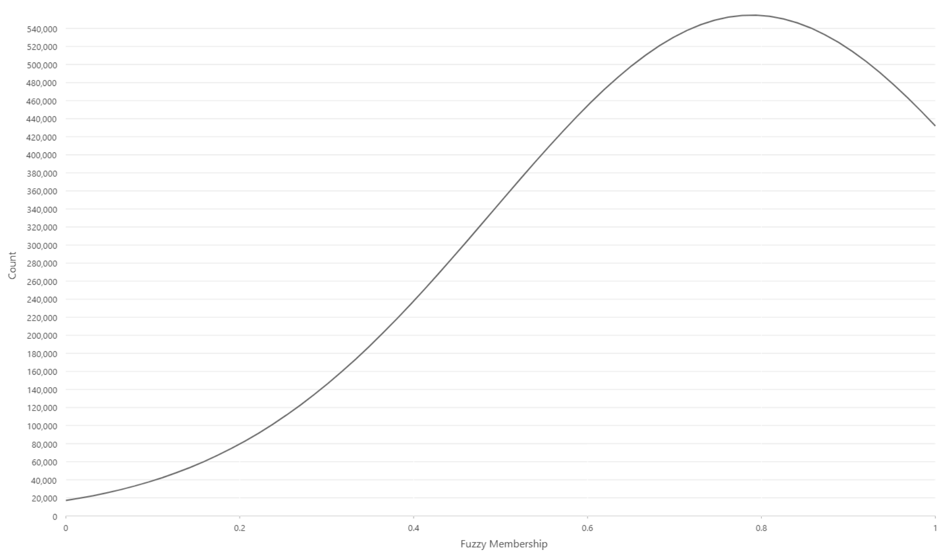

Figure 8: Distance from transmission lines distribution curve.

High slope values, while still within usable ranges, are not financially practical due to increasing difficulty and the increased associated costs in constructing the array and its supporting infrastructure, along with maintaining the system itself. An exponential relationship was chosen so that small values of slope are assigned high fuzzy membership, which decrease exponentially as slope increases (Charabi & Gastli, 2011; and Tavana et al., 2017; and Turk et al., 2021).

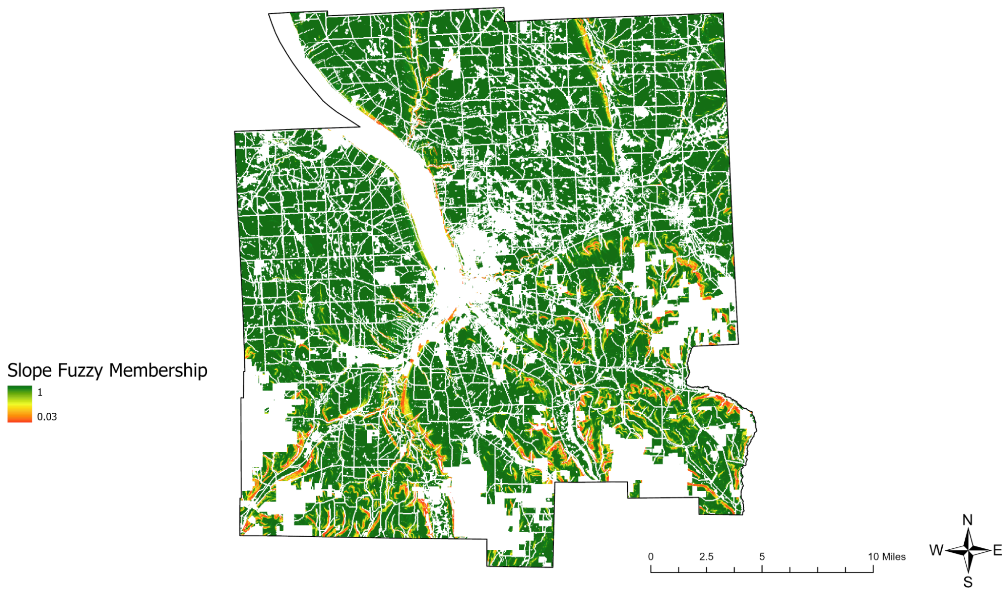

Figure 9: Slope fuzzy membership.

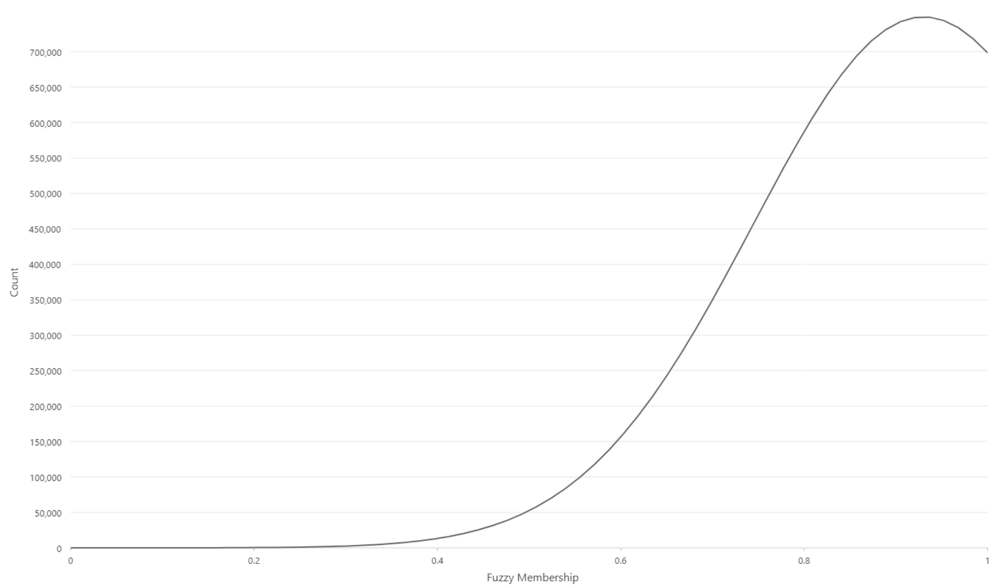

Figure 10: Slope distribution curve.

Solar irradiance is the measure of how much solar energy (measured in watts) is reaching the ground (units of square feet) per unit of time (units of one year to best model sunlight throughout all seasons). This means that the input is showing data in units of watts per square feet per year. For this input, a linear relationship was modeled. This is because the range of values between the maximum and minimum in a small region like a county is not very large and so an exponential relationship is not practical. A linear relationship was chosen, meaning that as the level of sunlight increases, suitability gradually increases with it (Charabi & Gastli, 2011; and Tavana et al., 2017; and Turk et al., 2021).

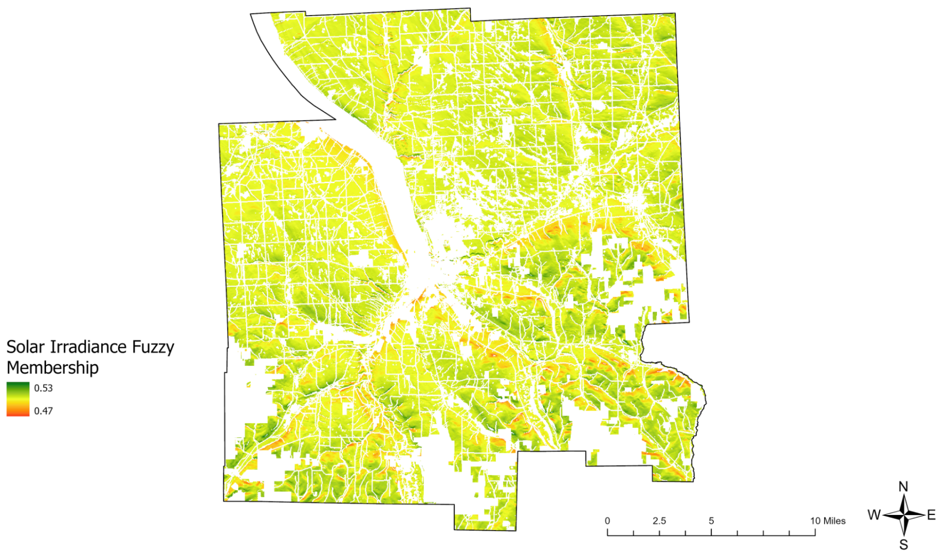

Figure 11: Solar irradiance fuzzy membership.

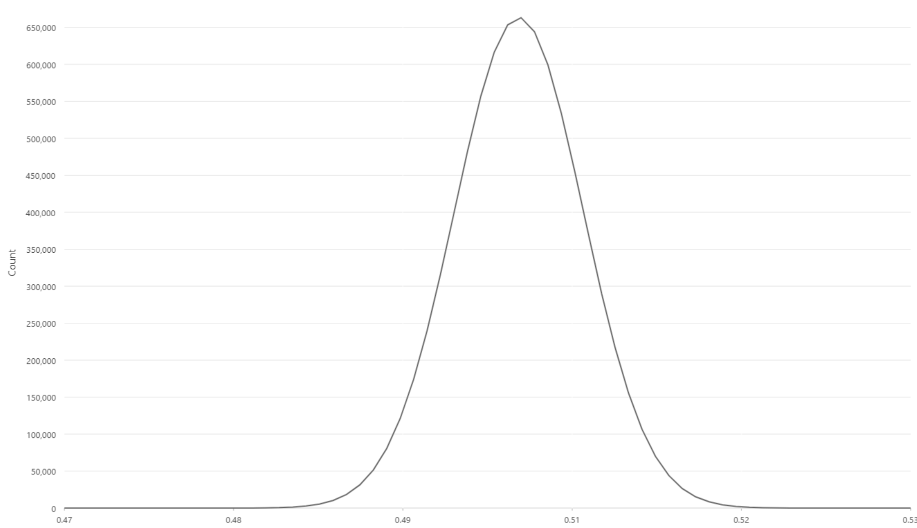

Figure 12: Solar irradiance distribution curve.

Once all layers were assigned fuzzy membership, the fuzzy overlay process that combines maps into a single output suitability map was completed. This output generated "exclusive" results, which essentially means that pixels on the output suitability map were given the lowest value of all input pixel values that overlapped that location. This was done so that the "weakest link" represents each pixel in the map in order to ultimately find areas of the highest suitability between all variables.

Site Selection

Site selection was completed by selecting five groups of contiguous pixels with the highest average suitability values. Local government specifies that large scale solar installations are classified as greater 7,000 square feet (or 0.16 acres), but cannot exceed 10 acres (Tompkins County GOV, 2017; and Town of Ithaca, 2016). These two values were used as the minimum and maximum size for site selection. A stipulation that the areas must be at least 2000 feet apart was set to ensure that sites are spread out from each other rather than clustered within just one area of high suitability. The selected areas were then inspected using aerial photo-imagery from the ArcGIS Pro basemap dataset in order to visually ground truth the areas for discrepancies such as the zone being over top of a house, agricultural building, or dense forest. Finally site observations, including discrepancies, were recorded, and recommendations were given.

Results

The results of the analysis produced a suitability map with values between 0 and 1 displayed across approximately 830,000 pixels. The output has a minimum value of 0.03 and a maximum value of 0.52. Refer to Figure 13. below to see the distribution of values where we see that the majority of values fall into two ranges. The largest range is between 0.29-0.31 with an area of approximately 81,000 acres. While the range of 0.50-0.52 with an area of approximately 68,000 acres. These two ranges account for 44% and 37% of the county respectively, and for a combined total of 83%. Only 18.8% of fuzzy membership values fall outside of these two ranges with a total area of approximately 34,797 acres.

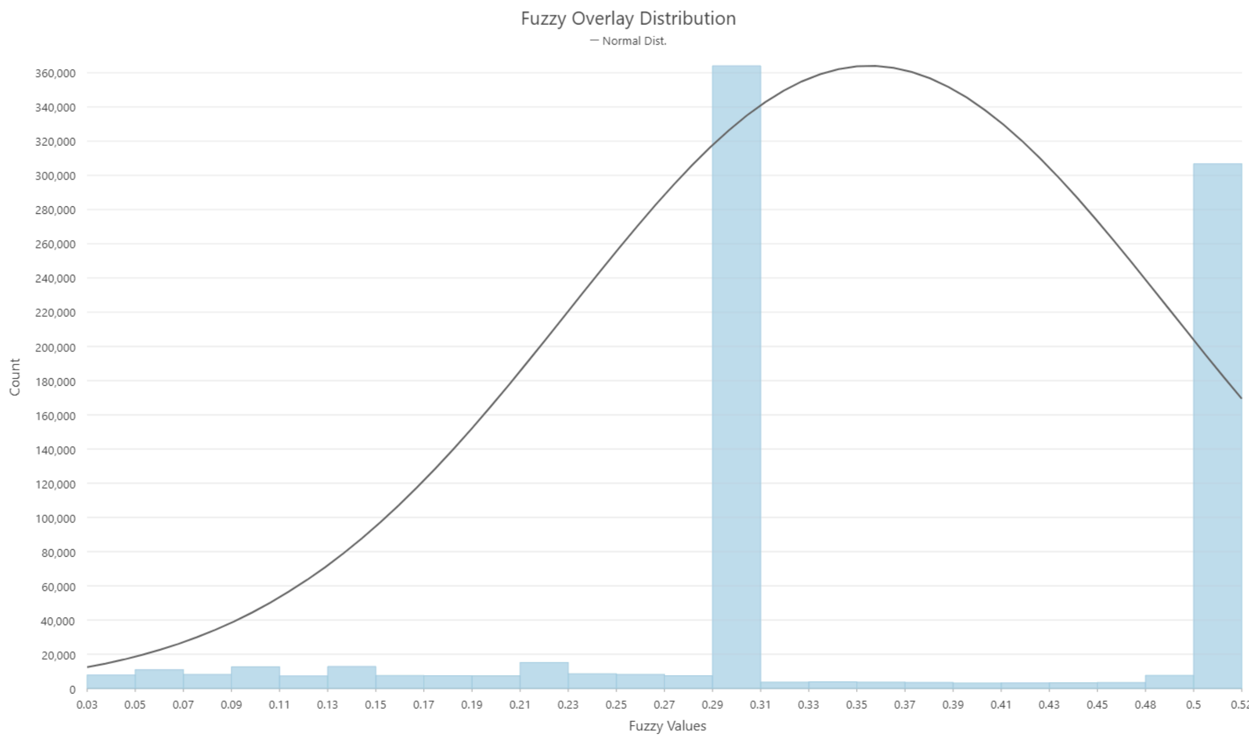

Figure 13: Distribution of output values.

Looking at the output suitability map in Figure 14. below, there are some distinct features to take note of. The most general observation is that areas in the center of the map that are directly around the city of Ithaca are generally of low suitability. It is also worth noting that there are three distinct and quite large patches of highly unsuitable areas on the map. One is descending down from the northern border in the northeastern corner. Another is coming up from the southern border in the southeastern corner. The last one is coming in from the western border in the northwestern corner. There are large patches of moderate suitability in the northern portion of the map between Cayuga lake and the northeastern patch of high unsuitability. Between the same unsuitable patch and the eastern border are also many high and very high suitability patches.

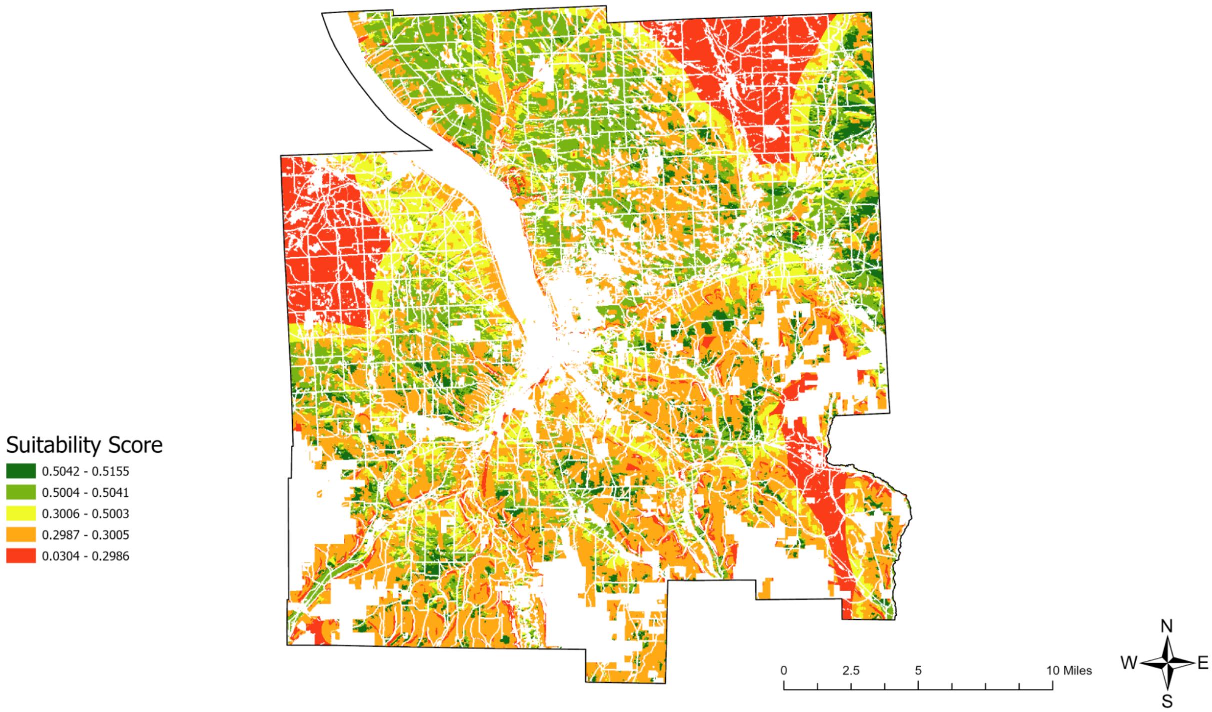

Figure 14: Suitability map generated by fuzzy overlay using a quantile classification.

Discussion

Recommendations and Interpretation of Results

This study, using GIS based MCE and fuzzy logic, set out to provide decision makers with site recommendations for the creation of large scale solar installations in support of the City of Ithaca's climate change fighting green new deal. The study resulted in the selection of five sites deemed most suitable. Out of these five sites, sites B, C, and E are recommended, while sites A and D were not. As secondary results, this study found that under this fuzzy model, 37% of the study region is deemed highly suitable for solar installation, which is promising for the selection of more locations and indicates that a stricter model could be made to find locations that meet more strict requirements. The results of high general suitability in this study were expected because slope, proximity to roads, and proximity to transmission lines all had generally large areas of suitability that would make them unlikely to cause an area to be deemed less suitable. Secondly, the study region's land cover is 80% farmland, which was deemed as a highly suitable criteria, meaning that 4 out of the 5 inputs had relatively high values. This left solar irradiance as a primary decider of ultimate suitability, assuming that the other four had been met. This ultimately explains how 37% of the region was deemed as highly suitable. Site A's low suitability was unexpected. Its unsuitable conditions were clearly missed by the model. This likely happened due to the tree lines being used as fence-like property lines and because of this being too low in total area to be counted as forested in the NLCD dataset when the adjacent farmland had more area. This made it so the trees did not "exist" in the dataset and were missed by the model.

Below in Figure 10., the 5 selected locations are shown. Note the cluster of sites found in the northeastern corner along the eastern border that was observed previously to have the most high suitability locations.

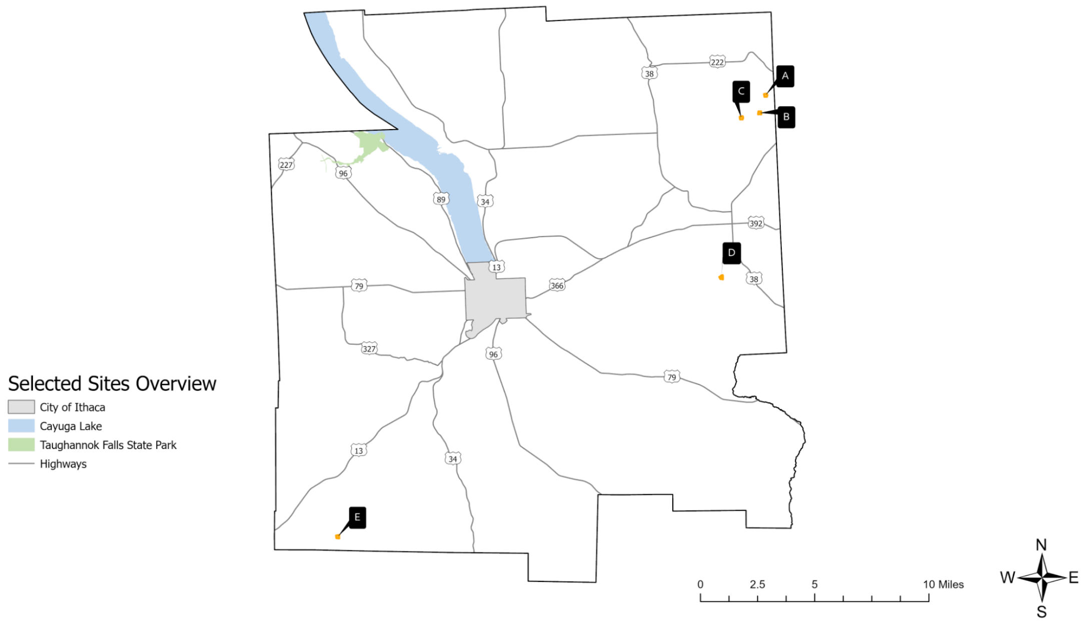

Figure 15: Selected sites overview.

Site A seen in Figure 16. below, is located on the northeast along the eastern border and appears to be either farmland or pasture. This location has three property tree lines bordering it from the west, south, and east, respectively. These treelines, especially the southern tree line, risk shading a solar array. One solution would be to cut the trees down, but there are social and monetary costs to cutting the trees down that makes this site not recommended for further consideration in light of better options.

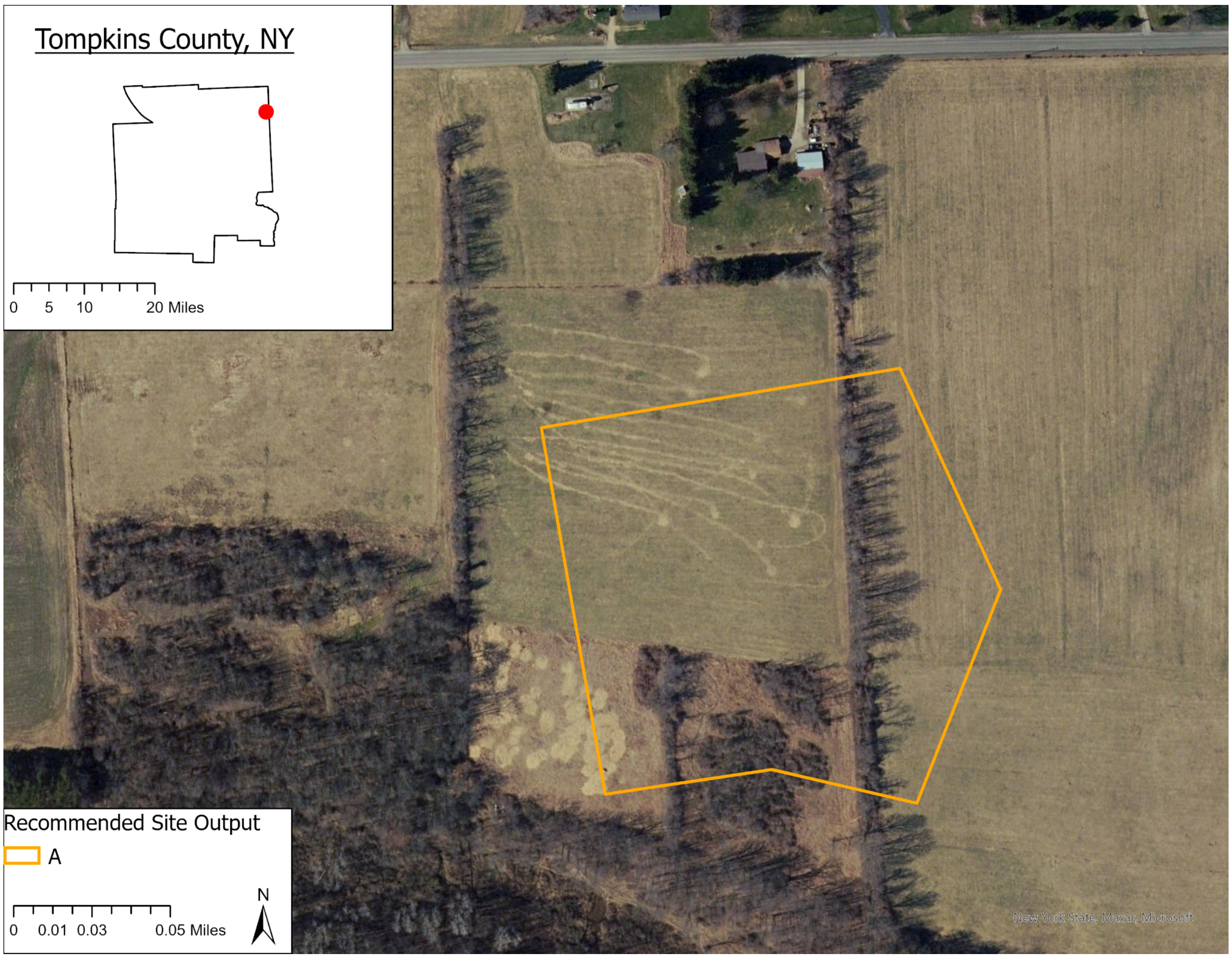

Figure 16: Output site A close up.

Site B seen in Figure 17. below, is located on the northeast's eastern border, and appears to be primarily farmland that is close to the road. This site has some shading risk from the south eastern corner, but could easily be adjusted to be slightly deeper into the field to avoid shading as there is a lot of space. There are also pre-existing dirt access roads and very little tree blockage between the site and the road. This would support construction and lower costs. This site is recommended for further investigation.

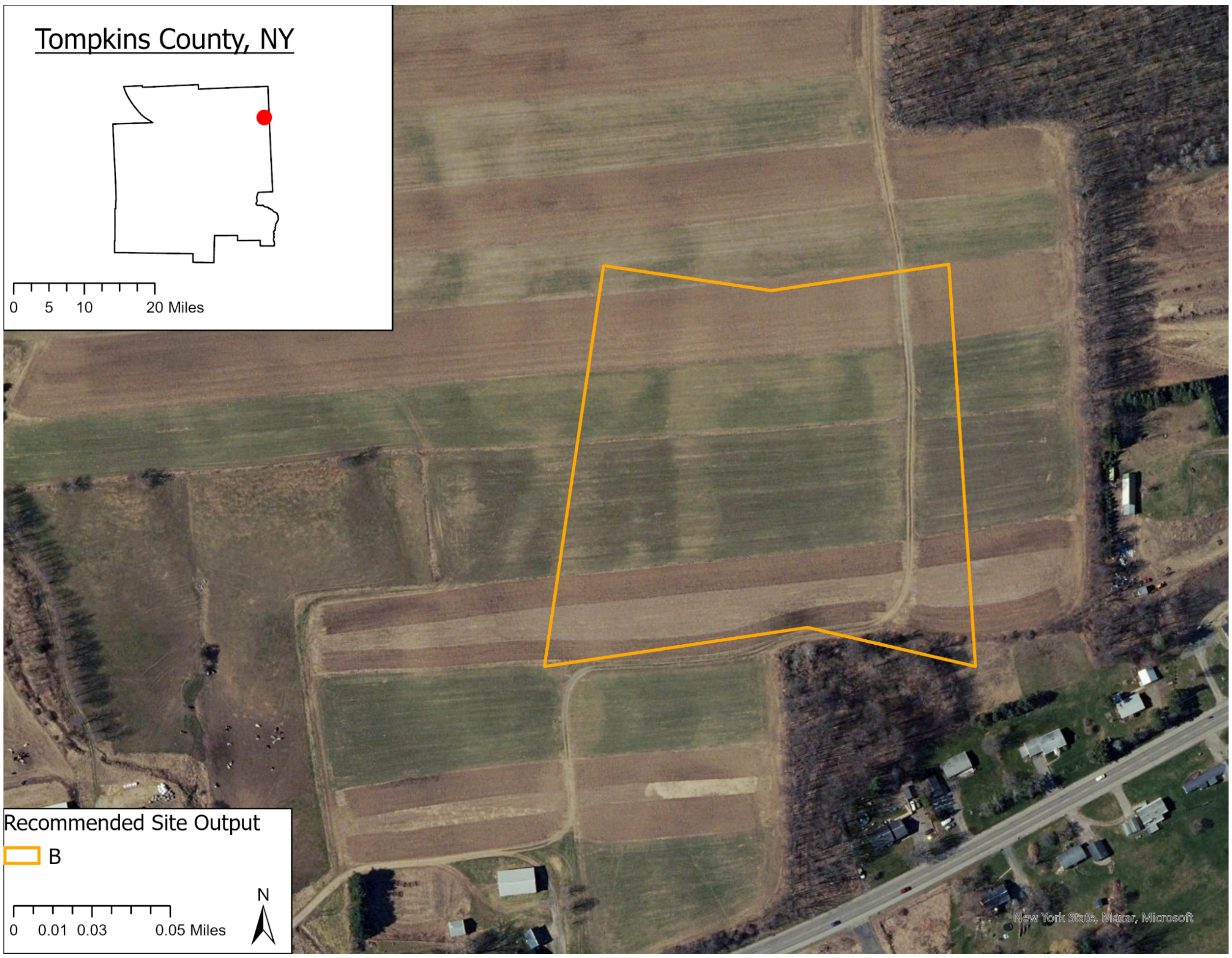

Figure 17: Output site B close up.

Site C seen in Figure 18. below, is located on the northeasts eastern border and appears to be primarily farmland that is close to the road. This location has minimal shading risks, with only a few trees along the western border and plenty of room to adjust the site to avoid the shading. This site has little to no obstruction, and some pre-existing dirt roads that provide access to the site and would save costs. This site is recommended for further inspection.

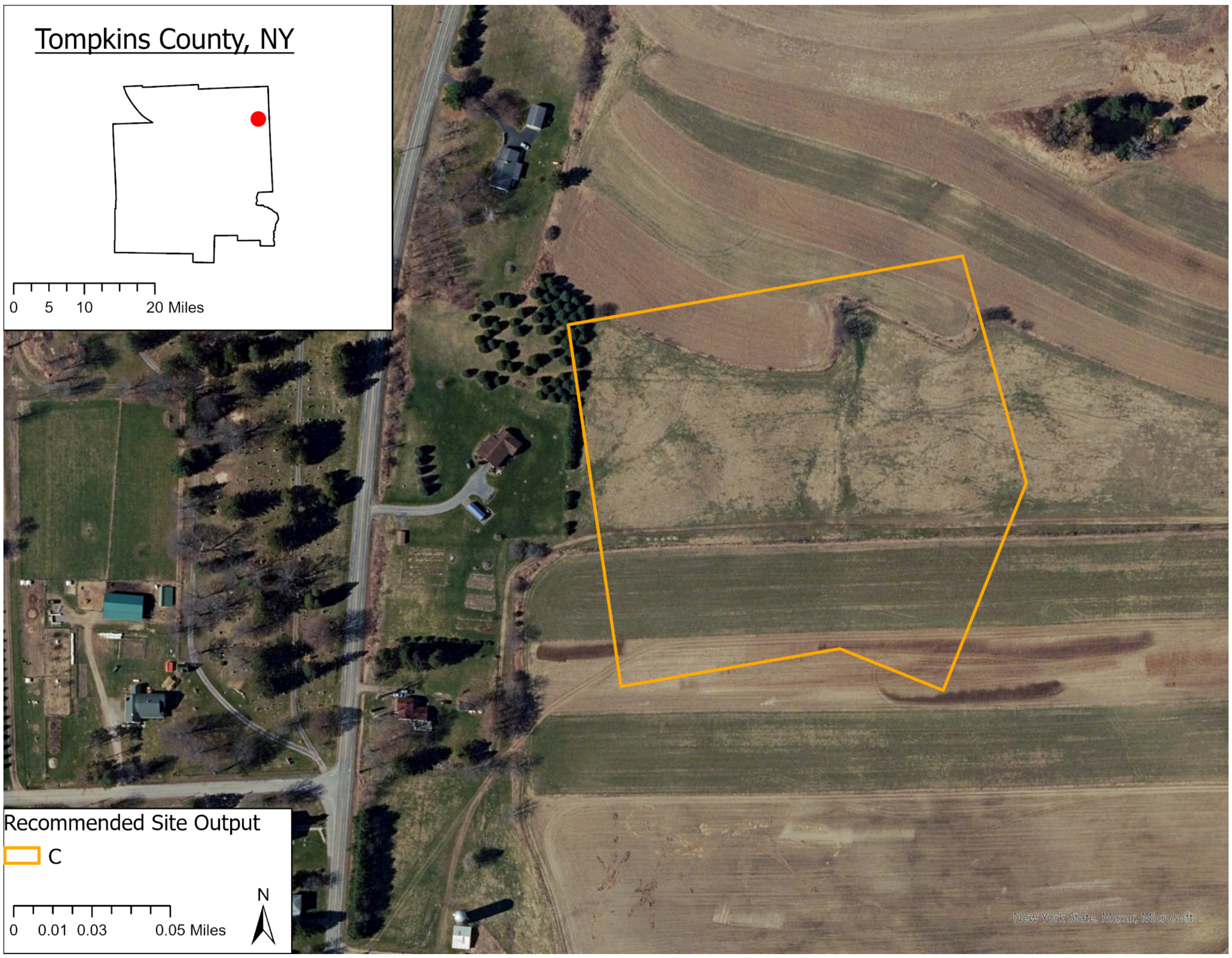

Figure 18: Output site C close up.

Site D seen in Figure 19. Below, is located in the northeast near the eastern border, and appears to be grassland or pasture with some shrubs. There is shading risk from tree lines on the western border. The clearing in the property itself has a non-uniform shape that makes construction more complex. The site is quite close to the road, but this also makes it very close to a home. Ultimately, this site is not recommended for further inspection.

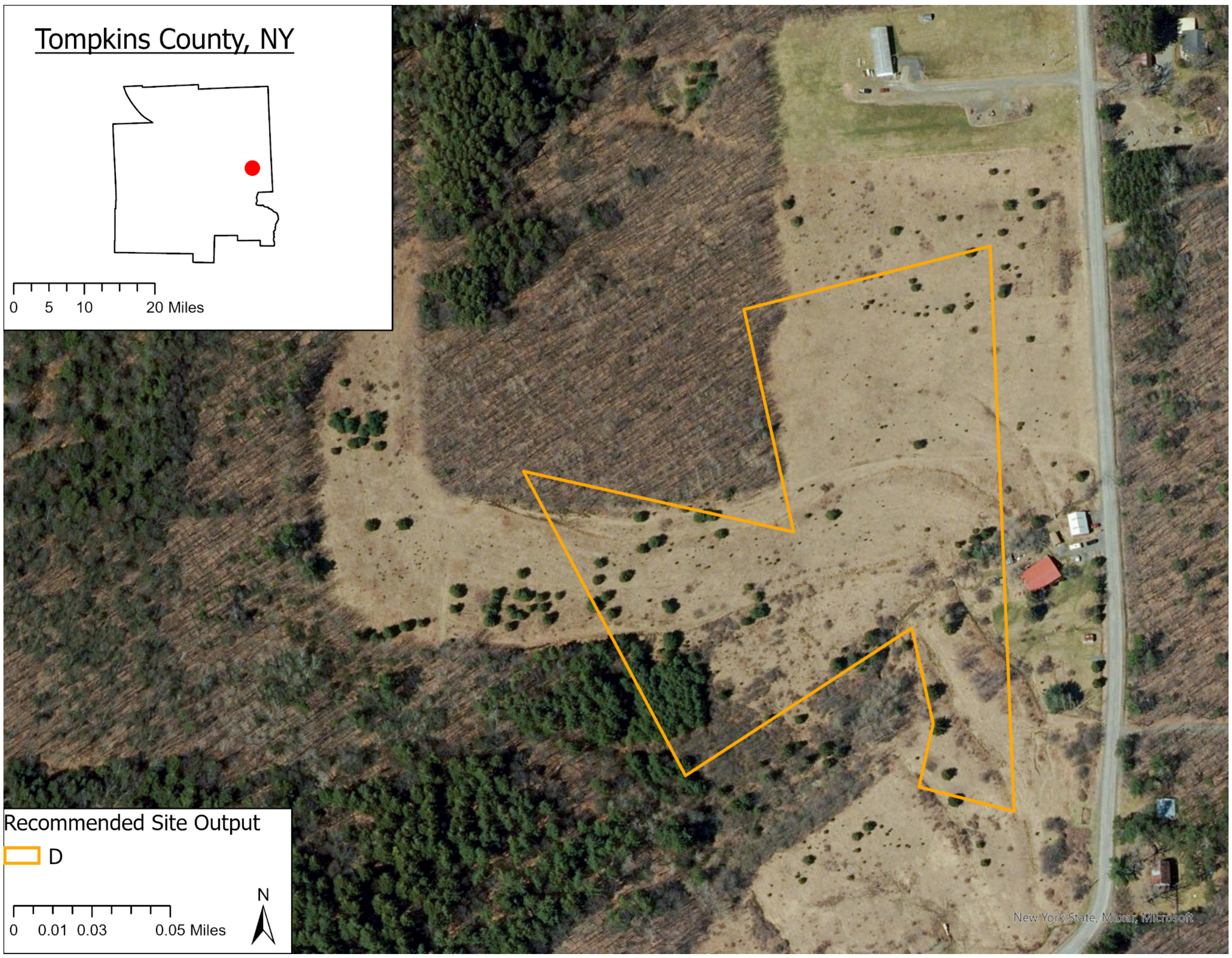

Figure 19: Output site D close up.

Site E seen in Figure 20. below, is located on the southwestern corner along the southern border and appears to be grassland. This site is uniquely not in the northeast of the study region. It has no specific notable shading risk, and minimal shrubs or trees. It is somewhat more distant than the other sites from any nearby homes and roads. This site would require some modification to remove trees as well as the construction of an access road. This site is recommended for further inspection.

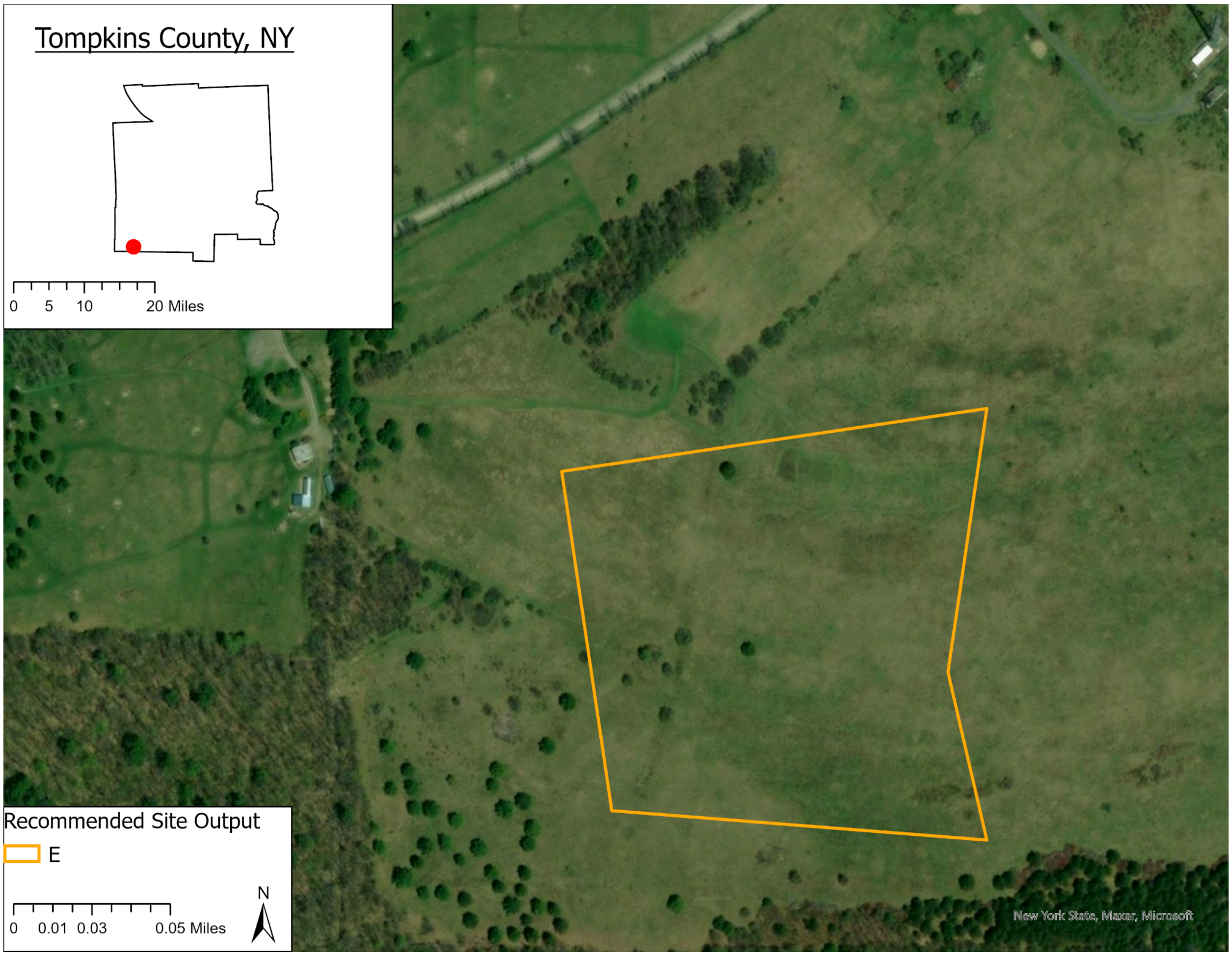

Figure 20: Output site E close up.

Related Literature

Related studies done in Oman by Charabi & Gastli (2011) followed the same principles and had very similar input criteria, with some variation specific to arid regions like dust and temperature. The key difference appears in fuzzy methodology, with the authors using a method called Fuzzy Logic Ordered Weight Averaging (FLOWA) accompanied with analytical hierarchy process principles. This similar philosophy and core practice was also the case when comparing with another study done by Sanchez-Lozano et al., (2013), in which they performed a GIS based multi-criteria evaluation to locate an optimal location for a solar farm in south-eastern Spain. The authors gathered geographic data for discarding areas that prevent the creation of solar panels such as archaeological sites and mountains, as well as data that would favor construction in certain locations such as solar irradiation potential and temperature. Using MCE and AHP methodologies, they were then able to determine within the many selected datasets an area in the region that was highly suitable in all datasets. A study done by Tavana et al., (2017), used MCE practices and a fuzzy-AHP model to create a decision support system for finding locations in Iran for solar arrays. Turk et al., (2021), like others followed the core principles of GIS-based MCE and like the other studies mentioned, the method of analysis is a primary distinguishing factor because this study used intuistic fuzzy-sets. This significant variety in the analysis method between similar studies is highlighted by Suganthi et al., (2015) in their literature review that covers dozens of analytical methods used both within and between fields for GIS-based research. One last distinguishing factor from the literature was that this study sought to recommend specific locations, while many other studies opted to leave their results as simply a general area selected from their suitability map (Charabi & Gastli, 2011; and Tavana et al., 2017; and Turk et al., 2021).

Limitations and Future Study

There are key limitations of this study that must be acknowledged. The first limitation is that no direct stakeholder could be found for this study and so decisions around the fuzzy model had to be compiled generally based off of the literature. Because of this, it was designed to be broad, which potentially weakens its usefulness in meeting region and stakeholder specific requirements. The second limitation is that this study did not break up its site recommendations by parcels of land, which could theoretically cause all recommended sites to be fractured between multiple properties. A site split between two or more properties would likely not be logistically favorable for any stakeholder. A split site would require negotiating with two or parties that can have conflicting or differing interests instead of just needing to negotiate with one party. Third, the model did not account for proximity to homes as it was ultimately undecided what stakeholders would want and this could be a major weakness if stakeholders do in fact want to avoid proximity to homes. Fourth, this study did not account for the current available capacity of transmission lines which could in some cases lead to a suitable site being located only near transmission lines that are already near maximum capacity and could not handle the added electrical load from a large scale solar array. Finally, this study did not have a method for reducing potential human error and bias in assigning values to qualitative data sets, nor for assigning membership curves for all inputs. Future research should seek to acquire more specific needs from the city or from stakeholders in order to make a more directed and useful study. Using more advanced fuzzy models could also be more precise and flexible and allow more control through added specificity to locate the most desirable sites, as well as reduce the possibility of human error by using methods like AHP.

Conclusion

In conclusion, this study located 5 potential locations for large scale solar installations. It found three of those sites to be worthy of deeper consideration by any stakeholders seeking to proceed with the City of Ithaca's green new deal objectives. This study also highlighted that there is evidence of the region having high general suitability, which indicates that more specific and stringent needs could be modeled and would likely be able to be met by some locations due to the large pool of general suitability.

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