4-20-2023

A GIS and Economic Analysis into Solar Electricity Generation Siting within the Greater Kalamazoo Area

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Honors Thesis Essay

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Senior Honors Thesis - HNRS 4990

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Date: May 28th, 2023

Definitions and Abbreviations:

US: The United States.

IRA: The Inflation Reduction Act

Economy-wide emissions: Emissions caused throughout the entirety of a state, region, or country's economy, including all factors of production, transport, and trade.

Municipal emissions: Emissions caused by the direct operations of the municipality.

Carbon Neutrality: Achieving net zero greenhouse gas emissions by balancing emissions so they are equal (or less than) the emissions that get removed through the planet's natural absorption (Unfccc, 2021).

GHG: Greenhouse gas

Suitability map: A map showing the areas that are suitable for a specific use in form of a thematic (theme-based) map.

Parcel: A tract or plot of land (Merriam-Webster).

Dynamic map: A navigable map that allows for the evaluation of spatial information in a dynamic way.

ArcGIS: ArcGIS Pro.

Solar PV: Solar Photovoltaic system, used synonymously with solar energy, solar panel, and solar cell.

Brownfield: A property, in which the expansion, redevelopment, or reuse may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant (EPA, 2023).

HVDC: Refers to High-Voltage Direct Current transmission lines.

AC: Refers to Alternating Current transmission lines.

NREL: National Renewable Energy Laboratory.

HIFLD: Homeland Infrastructure Foundation-Level Data.

Unit Abbreviations:

W: Watt, equal to 1 joule per second of energy transfer **kW:** Kilowatt, equal to one thousand watts

MW: Megawatt, equal to one million watts **GW**: Gigawatt, equal to one billion watts

TW: Terawatt, equal to one trillion watts **mi^2:** Square Mile **km^2:** Square Kilometer **Sq. ft:** Square Feet

MWh/km^2: Megawatt hour per square kilometer, a measure of energy consumption

I. Introduction

In August of 2022, the US federal government signed the largest ever clean energy investment into law. This investment, the IRA, has over $369 billion of climate-related grants and tax incentives slated to be invested across the US for its transition to clean energy (McKinsey, 2022). A significant portion of the IRA's incentives are grants for state and municipal governments to institute clean energy-related projects. However, many of these municipal grant incentives are exclusively available to cities that are taking action to address economic and environmental challenges with their investments. Two such prominent challenges are poverty rate level and having a documented history of environmental injustice.

The City of Kalamazoo, which has great potential to meet these requirements - as it ranks in the top ten for cities in the US with the highest poverty rate (Beveridge, 2011) and has a history of environmental injustice (Krafcik, 2022) - has not currently publicized any plans to utilize these incentives. The city also does not have a finalized date to attain carbon neutrality nor any publicized carbon reduction goals. This lack of a carbon neutrality pledge contrasts sharply with the plans of other major cities in Michigan, and even the State of Michigan itself. In April of 2022 the State of Michigan pledged to attain "economy-wide" carbon neutrality by 2050 - four months before the IRA, with its promising incentives, was passed (SOM, 2022). Cities like Detroit, Jackson, Grand Rapids, Lansing, and Ann Arbor have all released planned carbon neutrality dates for their own municipal operations, scheduled between 2030 and 2050, (McWhirter, 2022).

These carbon neutrality pledges are themselves motivating progress, too (Liang, 2021). Many pledges have catalyzed actionable climate-related plans and have spurred municipal leaders to implement clean energy projects. For example, two years after instituting its 2020 carbon neutrality goal, the City of Ann Arbor approved a solar project that will cover 80% of its current total municipal energy consumption (A2ZERO, 2020). The frequently touted main benefit of this investment in clean energy is the decrease in GHG emissions from municipal energy use, which reduces overall contributions to global warming. A secondary, and often overlooked benefit to municipalities is that increased clean energy generation, by way of decreased “dirty” energy generation, will help lower the levels of asthma, lung disease, cancer, and other negative health outcomes for residents that are attributed to coal and other fossil fuel generation facilities (Buchanan, 2014). Additionally, investments in clean energy generation are associated with increased employment and have billions of dollars of economic impact for cities (Michaud, 2020), have become a cheaper means of generation than traditional sources (Lazard, 2019), and attract more potential tax-paying citizens and businesses, whom altogether prefer to live or site themselves in cleaner, safer, and more sustainable metropolitan areas (Ke, 2021).

Although lacking specific carbon reduction goals to hold itself accountable to, the City of Kalamazoo has made initial efforts in planning for a more sustainable future. In June of 2022, the city approved its comprehensive Community Sustainability Plan (CSP) - which outlines the steps that the city intends to take to become more sustainable, livable, and green. Included in this plan is a specific goal of “*accelerating local renewable energy investments”*, and an actionable step within this goal of “*developing decision-making support tools (e.g., suitability assessment, map, guides)”*. Here, I add to the development of such tools by creating a ground-mounted solar project suitability map with a development siting potential “hot spot” map for the entire Greater Kalamazoo Area (GKA). The goal of this map is to provide beneficial information to the City of Kalamazoo to help them make more informed and economical solar development decisions.

The intended significance of this comprehensive siting analysis is that the City of Kalamazoo will have the necessary suitability and project siting information to make a confident and effective investment in ground-mounted clean energy generation to meet a significant portion of its municipal energy consumption. Other constituents, such as Consumers Energy or external third-party energy generators, will also be able to access this information to locate the most effective potential siting locations for solar development in the GKA. Through this research I hope to show that there is underutilized potential within the Kalamazoo area that could be used for solar electricity generation siting, as well as the specific parcels of land that have the highest potential for solar project development. The rest of this paper is laid out as follows. In section II I provide a brief literature review in support of solar potential mapping. In section III I explain the methodology taken to successfully complete this analysis. In section IV the results of the analysis are explained, and in section V conclusions and recommendations for further action are offered to the City of Kalamazoo and other stakeholders.

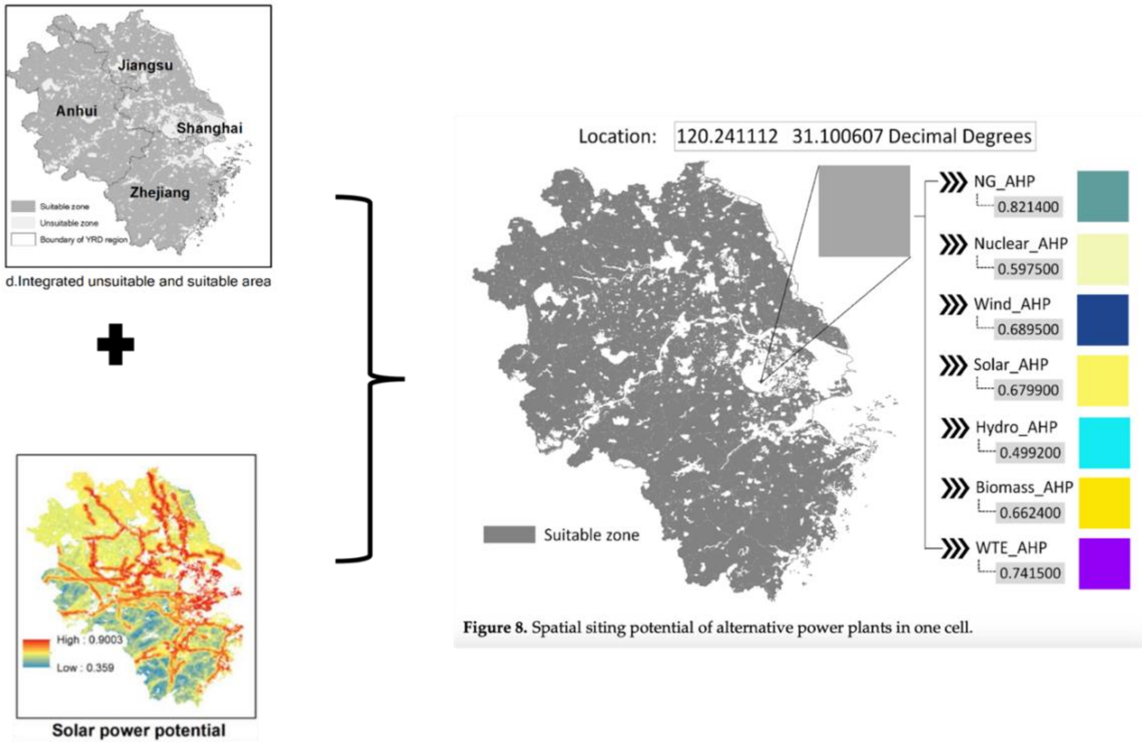
II. Literature Review

The current energy siting literature has begun to center around the use of GIS technologies, loaded with relevant data, to output maps of the relative siting potential of each parcel of land within the region under analysis. Suitability and siting analyses are an important function that GIS technologies possess and have proven exceptionally accurate (Malczewski, 2003). For the siting of energy resources specifically, GIS analyses are effective as most of the data needed are publicly available and can be applied with minimal changes to most regions of the planet. This is what my research intends to do: take an established energy siting methodology, using GIS, and apply it to the area surrounding the City of Kalamazoo to identify, preliminarily evaluate, and offer recommendations for optimal solar siting locations. The purpose of this literature review is thus to establish the context of my study based on the preeminent literature.

Many researchers have begun to focus their efforts on the energy siting sphere to help alleviate information asymmetry or bad development decisions by government planners during a transformational period for the energy industry. Global clean energy production, which has already grown exponentially in recent years, is predicted to grow by over 60% from 2020 levels to over 4,800 GW (4.8 TW) total in 2026 (IEA, 2021). This is approximately enough energy to power 4,800 medium-sized cities (SunRun, 2020) for an entire year. The aim of the current siting research literature is to help streamline the efficiency and cost-effectiveness of the decision-making process and implementation associated with this monumental increase in renewable energy.

The focus of this literature review will be on the research undertaken in the paper titled "Assessing the siting potential of low-carbon energy power plants in the Yangtze River Delta: A GIS-Based approach" published by Peng, Azadi, Yang, Scheffran, and Jiang in 2022. I felt comfortable focusing this literature review and my methodology on this paper, referred to as Peng et. al throughout, because it is a thoroughly robust study that was posted in the *Energies* journal - one of the more accredited journals in the energy industry. The first step taken in Peng et. al, along with in most other siting studies, was to determine the "suitability zone" of the region under analysis. This zone can be defined as the zone in which it is technically feasible, or suitable, to site the resource being analyzed. The second step is to calculate the siting potential, or the level of potential that a given area has for siting the resource, in this case low-carbon energy facilities, of the entire geographical extent. This result is then applied to the suitable zone output, to compare the relative potential of each parcel of land for siting said resource out of the total area in which it is possible to do so. An example of how this was done in Peng et. al is shown below.

Figure 1 - Summary of Peng et. al analysis and outcomes.



The researchers of this paper accomplished this feat by combining - using the AHP scoring methodology discussed in the **Methodology section -** a variety of geographical, demographic, economic, and energy-generation specific data with ArcGIS, which is often ranked the best GIS software currently available (GISGeography, 2023). The rightmost map in Figure 1 shows the successfully produced dynamic map which allows for a parcel-by-parcel evaluation of the optimal siting locations for seven different low-carbon energy generation facilities. Through their analysis the researchers were able to portray the fact that low-carbon energy development in the Yangtze River Delta (YRD) region of China was feasible and provided information as to which power plant at which sites would be most effective to construct. This is extremely relevant to my research, as I hope to emphasize the feasibility and parcel-by-parcel effectiveness of solar development to City of Kalamazoo decision-makers.

The analysis conducted in Peng et. al is significant because the researchers were able to discern which energy plant would be most effective based on its perceived economics, transmissibility, production capacity, and ease of construction, among other variables, for a large and complex region in China. This encouraged me to conduct a similar GIS analysis, which would evaluate the extent of a single energy resource, solar, in the context of a much smaller geographical area - 1,500 km^2 (580 mi^2) - which is 0.42% of the YRD paper's study area of more than 358,000 km^2 (138,224.6 mi^2). The researchers discovered that there were large swaths of land in which low-carbon power plants could be sited, and that, specifically, "distributed solar PV and WtE plants should be encouraged to be established." So, of all the viable low-carbon energy resources that were considered, the outcome was that distributed solar PV was one of the most viable resources to develop. This conclusion was beneficial in the finalization of my research topic.

Another study which was impactful in the development of both my research topic and methodology was a report completed by two researchers in Peru. Rios et. al (said paper) utilized the same methodological process, AHP-GIS, that Peng et. al did. However, they only analyzed large-scale solar projects as opposed to seven different low-energy projects. Its focus on solar projects was helpful in parsing out solar-specific siting considerations for use in this thesis.

Although comprehensive and successful studies, there are drawbacks of the analyses completed in Peng et. al and Rios et. al that should be discussed. First, the market price of land was not considered in either the suitability or siting potential sections of either paper. The price of the land in which an energy generation facility could be sited is an imperative factor in the economics of energy generation projects (NREL, 2020). For example, land near China's Pacific coastline, where nuclear energy facilities have the highest siting potential, may cost significantly more than inland parcels of land due to the high demand of said parcels by industrial manufacturers or Chinese citizens. This could have a negative impact on the economics of instituting nuclear facilities, but, as this variable was omitted, the potential relationship is unknown. As I have realized though, land price data is difficult to acquire and tough to estimate, and thus my research also contains this weakness. Multiple steps were taken to overcome this issue, however. For instance, brownfield redevelopment sites were included in this analysis as these sites have the potential to be significantly cheaper than non-brownfield sites. Also, data on the parcels of land that the City of Kalamazoo already possesses was included in the extent of this evaluation, as these parcels of land represent essentially costless land that could be adapted for clean energy development.

The second major weakness of the related papers, and the current energy siting literature in general, is the "weighting" or application of weight-based rankings of the criterion used in the analyses. This is indicative of an AHP analysis, in that weights are applied in a hierarchical fashion to the criterion in which the "hot spot" or potential analysis is based on. This methodology allows for flexibility in the analysis in that each variable can be weighted to its relative importance to its overall siting potential, but also means that the findings in these analyses rely heavily on the subjective weights and importance imputed to each criterion. If unrealistic weights are assigned to any of the relevant variables, the findings of the AHP analysis could be dramatically skewed. This weakness is something that I have noted from the start, and as such, have taken much care in the selection and adjustments of the weighting of variables. Further explanation is included in the **Methodology section** of this paper.

Although Peng et al., as well as other GIS-AHP energy siting analyses, have their limitations and drawbacks, their research remains significant and effectively contributes to their intended purposes. In particular, Peng et al. synthesized an extensive amount of data using a complex methodological process to conduct a parcel-by-parcel analysis of siting seven different low-energy generation facilities. Rios et al. utilized a similar methodology to complete a parcel-by-parcel analysis of siting large-scale solar developments throughout the entire country of Peru. These analyses, which were performed for each parcel in the energy resource suitability zone, hold great potential for facilitating long-term growth and the effective development of clean energy in the YRD region of Eastern China and the entire country of Peru. I believe that my research can have the same impact for the Greater Kalamazoo Area.

III. Methodology

The methodology that is employed in analyzing the potential for ground-mounted solar siting in the GKA, known as Analytical Hierarchical Process - Geographic Information Systems (AHP-GIS), has been utilized by researchers exploring clean energy generation siting in the Mediterranean (Giamalaki, 2019), Africa (Rekik, 2023), South America (Rios, 2021), and most notably, the Yangtze River Delta in China (Peng, 2022). The consistent use of this GIS methodology highlights its robustness and importance to the energy siting sphere. The AHP-GIS approach that I have modeled my analysis most closely to is the Peng et. al paper, of which is detailed in the **Literature Review** section above.

Drawing upon the methodology presented in Peng et al. and Rios et al., a comprehensive analysis of the ground-mounted solar project suitability zone and solar siting potential within the Greater Kalamazoo Area was conducted. My analysis not only applies the positive outcomes and benefits of the aforementioned research to a new geographical area and regulatory environment, but also aims to address a research gap concerning small-scale solar developments. Moreover, I aim to address a gap in specifically assisting municipal decision-makers in the US in siting clean energy resources. To achieve this, secondary focuses of this paper will be on identifying parcels of land that are less than 20 acres in size, considering pertinent regulatory barriers, and incorporating often overlooked advantages available to municipalities, such as, again, the utilization of brownfields and municipal-owned land.

The first step taken in this analysis is the definition of the study area and of the relevant infrastructure and resources in question. As this evaluation's focus is the City of Kalamazoo, the best way to capture all the potential development opportunities was to evaluate all of Kalamazoo County. The reasons that development opportunities are hereby limited to Kalamazoo County are due to prohibitive distances between the electricity's source of generation and its source of consumption, as well as the fact that energy development which crosses county lines may face stiff regulatory challenges as the energy industry is a notoriously strict and jurisdiction-based system.

Figure 2 - Research Study Area.

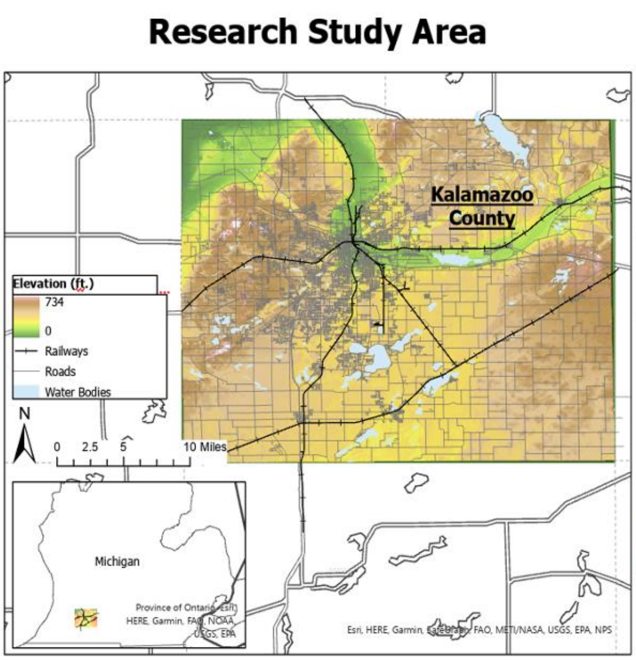


Figure 3 - Relevant Infrastructure and Resources.

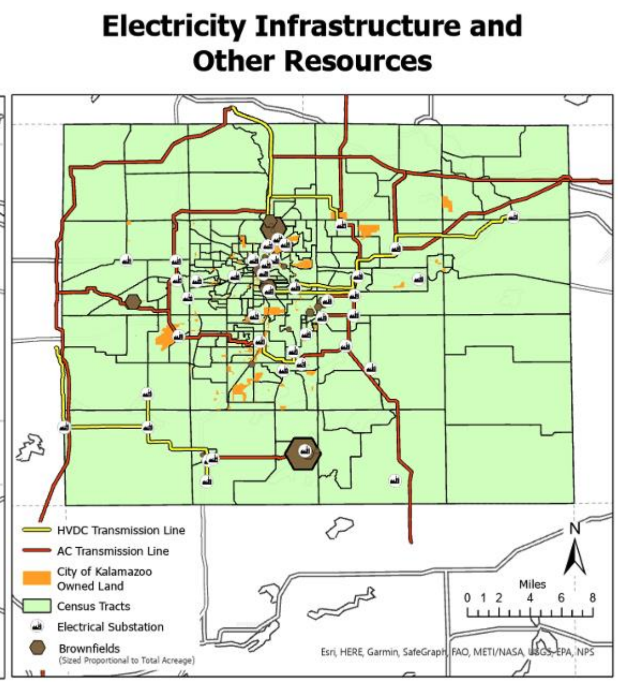


Figure 2 depicts the extent of Kalamazoo County, the county under analysis, as well as its railways, roads, elevation, and major bodies of water. These topographical and infrastructure entities all play important roles throughout this analysis. Figure 3 exhibits some of the important electricity infrastructure and other considerations that will also impact the rest of the analysis. All the data shown on the maps, and used throughout the GIS analysis, are open and accessible to the public. The sources include the NREL, the Bureau of Transportation Statistics, the HIFLD, and the US Geological Survey, among other US government sources. The only data source not publicly available in this paper are qualitative primary interviews that I conducted with subject matter experts in the field of renewable development. This qualitative information was utilized in the ranking and discerning of weights for the evaluation criteria sections of this study.

The methodological framework that the Peng et. al researchers utilized in their research, and that is followed closely in this analysis, is included below in Figure 4. The framework begins with Phase 1: "Suitable Zone Definition". To find and define the suitable zone, all factors that make land "unsuitable" for solar development are defined. The first blue box highlights the defining of the unsuitable zone through the clarification of all developmental constraints. In Peng et. al, these constraints are Environmental, Land Use, Infrastructure and Geographic, and in this analysis, they are the same. However, the specific parameters considered in these overarching constraint factor groups differ in this research as the construction and siting specifics differ. Land is unsuitable for solar development for a variety of reasons, but one of the recurring reasons is that the construction of a project, like a new solar farm, cannot be located within a certain distance of existing structures, infrastructure, or other topographical inhibitors for legal and construction-viability reasons.

After these unsuitable constraints are defined and collected, they are analyzed and prepared for "layer aggregation". What layer aggregation means is that the different map layers, or objects on a map that are manipulated as a single unit, are merged into one large, and often final, layer. In this case, the final layer in Phase 1 is the "Spatial suitable map for power plant installation".

Figure 4 - Spatial Energy Siting Methodological Framework proposed in Peng et. al.

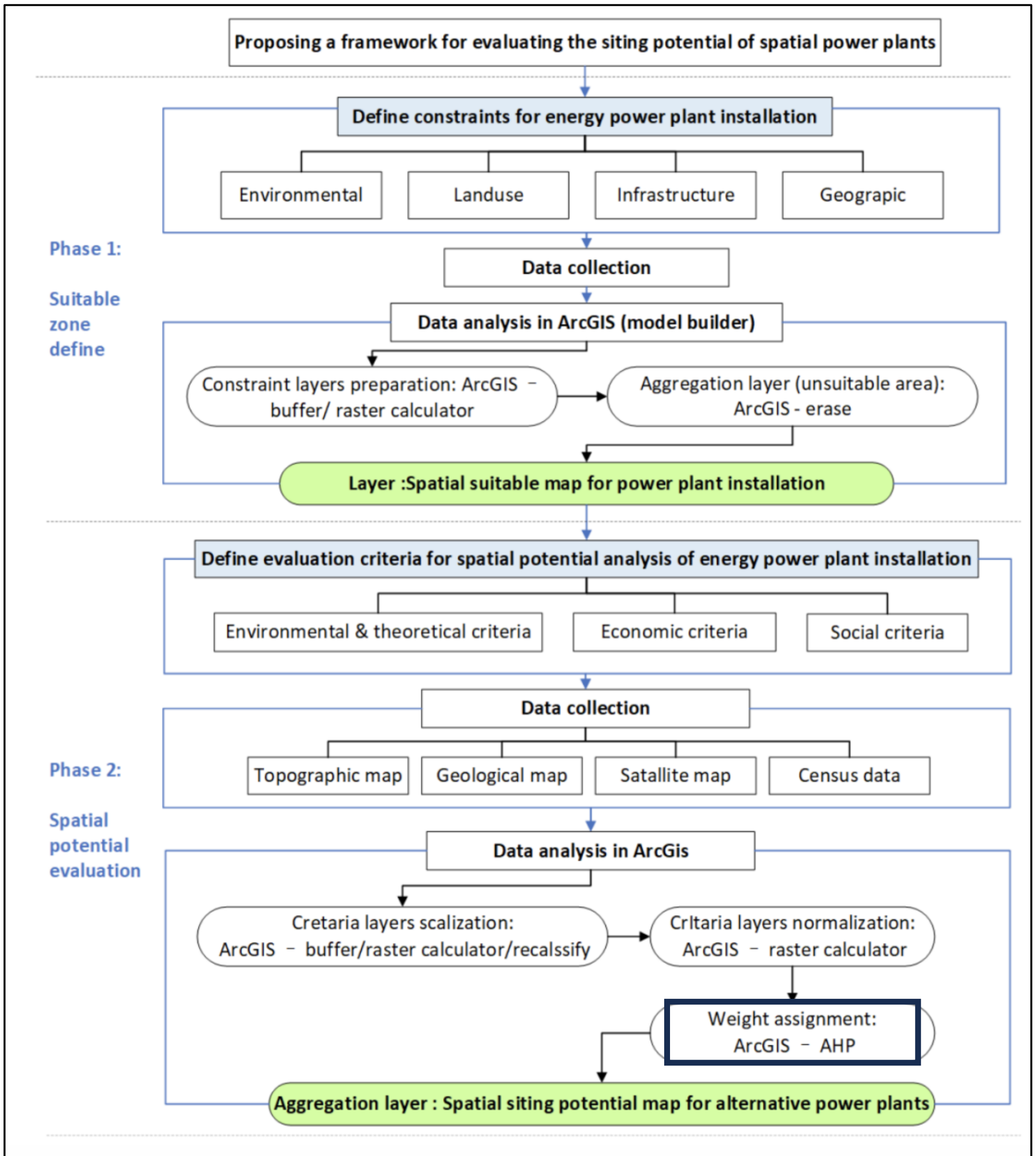


Figure 2. Flowchart of the methodology (adapted from Siefi et al. [44]).

Figure 5 below displays all the constraining parameters which were decided make land unsuitable in the GKA, along with its "Buffer Zone". A buffer zone is a zone calculated by measuring a distance on either side of the constraining parameter via ArcGIS. This buffer zone is the entire zone in which development is deemed unsuitable. The buffer zone used in this analysis does not correspond directly to solar project construction codes in the Greater Kalamazoo Area but were estimated to give more than enough distance between a proposed project and the corresponding parameter.

Figure 5 - Constraining factors of unsuitable zones.

Table 1. Constraining factors of unsuitable zones

Constraining Factor	Constraining Parameter	Constraining Map Layer	Buffer Zone
Environmental Reason	Distance to water and rivers	Constraining map to distance from permanent rivers and lakes	200 feet
	Distance to current and future wetlands	Constraining map to distance from areas with enlarged biodiversity importance	150 feet
Land Use Reason	Distance to nearest structure	Structure	125 feet
	Distance to residential area (Downtown Kalamazoo)	Structure	10.75 miles
	Land Use	LULC	Non-developed
	Area of land parcel	Area of suitable land	.75 acres minimum
Infrastructure Reason	Distance from transmission line	Constraining map to distance from electricity grid	150 feet
	Distance to roads	Constraining map to distance from roads	100 feet
	Distance to railways	Constraining map to distance from rail lines	250 feet
Geographic Reason	Slope	Constraining map to slope percentage	75 ft from all slopes > 30%

These developmental constraint data layers are first uploaded into ArcGIS and analyzed. Then, the buffer zone is applied to the area surrounding the constraints using the **"buffer"** analyzing tool. Finally, after aggregating all the constraints and their buffers, the unsuitable zone is found. The unsuitable zone is then utilized to find the suitable zone using the "**erase**" function in ArcGIS, which is used to erase the unsuitable zone from the original study area. This elimination of the unsuitable area leaves us with a comprehensive suitable zone for solar development.

Next, in Phase 2 of the framework, "Spatial Potential Evaluation", the evaluation criteria in which the spatial potential of solar sites will be analyzed are defined and collected. These are again uploaded into ArcGIS and, for many of the variables, the **"distance accumulation"** and **"reclassify"** tools are used to quantify the distance and create ranges from the relevant infrastructure. A score is then applied to each of the defined distance ranges or criteria "levels".

The evaluation criteria and the scores assigned to each level or ranking are included in the table below. The distance ranges and their assigned scores were decided upon using a sensitivity analysis of each map layer as well as a statistical model and qualitative insights from energy experts. A higher score means that the criteria and relative distance, level, or measure is better for, or has a higher potential for, productive solar project development.

Table 1 - Scoring scheme of criteria map layers.

Scoring scheme of criteria map layers

Criterion	Map Layer			Low		Medium		High
Index			0	1	2	3	4	5
C1	Proximity to HVDC Transmission Line		12000+	8000-12000	4000-8000	2000-4000	750-2000	<750 feet
C2	Proximity to AC Transmission Line		12000+	7500-12000	3000-7500	1500-3000	500-1500	<500 feet
C3	Proximity to Electrical Substation		15000 feet+	10000-15000	7500-10000	3000-7500	1500-5000	<1500 feet
C4	Census Track Poverty Rate Level		0-.1	.1-.15	.15-.25	.25-.4	.4-.6	.6-.8666
C5	Estimated Energy demand ranking		0	.7-1.6	1.6-2.6	2.6-3.2	3.2-4	4-4.6
		Class 1	Percentile Rankings					
C6	Land Acreage	Class 2	0-16	16-32	32-48	48-64	64-80	80-100
		Class 3						
C7	Annual GHI (kWh/m2)		<3.889	3.889-3.888	3.889-3.936	3.937-3.96	3.961-3.984	3.985-4.008
C8	Slope (%)		>20	15-20	9-15	4-9	2-4	<2

Class 1 = parcel .75 - 1.5 acres, Class 2 = parcel 1.5 -20 acres, and Class 3 = 20+ acres of land (based on project regulations)

Before applying the AHP weighting to the criteria, the criteria must first be ranked based on their relative importance to the economics, production capacity, and ease of construction of solar projects. The ranking of the criteria is in order of their labeling, C1-C8, and as follows:

1. C1 - Proximity to HVDC Transmission Line
2. C2 - Proximity to AC Transmission Line
3. C3 - Proximity to Electrical Substation
4. C4 - Census Track Poverty Rate Level
5. C5 - Census Track Estimated Energy Demand
6. C6 - Land Acreage (w/in class scheme)
7. C7 - Annual GHI
8. C8 - Slope Percentage

This ranking and the following weights were decided upon for a factor of reasons. First, from multiple primary interviews with energy experts in the GKA it was understood that the three variables referring to distance from electricity infrastructure, C1-C3, were the most cost-prohibitive variables to project development and thus the most important. As was mentioned previously, the IRA contains generous subsidies for siting clean energy resources near or in marginalized neighborhoods, which is why Census Track Poverty Rate Level (C4) was given the 4th spot and is included in this analysis. Estimated Energy Demand (C5) is next as it is important economically, but not imperative, to site energy generation near where it is consumed (Park, 2004), and Land Acreage (C6) follows as the larger the parcel that can be used for constructing ground-mounted solar, the more production capacity said project should have (Fthenakis, 2009). C7, or Annual GHI, which was ranked highest in the Peng et. al analysis, is ranked as the second least-important variable in this study as there is only a minute change (.012 per year) in this variable across the entire extent of Kalamazoo County, and thus a minute change in the potential generation of solar projects. Lastly, Slope, C8, is ranked last as the slope range which would make solar project construction impossible (>30%) was already removed in the unsuitable zone phase of the paper, and although making construction more expensive, a slight slope (<10%) in the land does not affect the technical feasibility of solar siting significantly (Yousefi, 2018).

After this ranking was completed, weights were calculated and applied to the variables associated with each criterion's estimated relative importance. For example, proximity to HVDC is estimated to be 2.5x more important than Annual GHI (0.09 → 0.2269) for solar siting. The differences between the weighting of the variables in this research and in Peng et. al, as well as the differences in the ranks of the criterion, are shown below in Figure 6. As an example of this ranking process, proximity to HVDC transmission lines was ranked as the most important variable and assigned the highest weight, by far, as it has unique synergies with renewable energy development that make it extremely attractive for siting and grid interconnection over both C2 and C3 (Wang, 2017). Additional reasons that changes were made in the methodology are explained further below.

Figure 6 - Weighting of criteria for solar energy development.

Weighting of criteria for solar energy development						
YRD Label	Map Layer from YRD	New?	Criterion	My Map Layer	YRD Weights	My Weights
C1	Annual GHI		C7	Annual GHI (kWh/m2)	0.247	0.09
C3	Slope		C8	Slope (%)	0.1207	0.0511
			C2	Proximity to AC Transmission Line		0.2
C6	Proximity to powerline		C1	Proximity to HVDC Transmission Line	0.2118	0.2269
			C3	Proximity to electrical substation		0.14
C7	Energy Demand		C5	Estimated Energy demand**	0.0471	0.092
C8	Population Density				0.0335	
C2	Elevation*	Y	C4	Census Track Poverty Rate Level**	0.0811	0.11
C4	Proximity to Road*	Y	C6	Land Acreage (w/in class scheme)**	0.0664	0.09
C5	Proximity to waterbody*				0.0253	
C9	Protected zone buffer*				0.1672	
					Total: 1	1

** = Criteria not used in my analysis* *** = New or Different Criteria*

After the weighing of each criterion, the individual map layers with their newly weighted scores were aggregated and the siting potential throughout the entirety of Kalamazoo County is returned. This siting potential map is then integrated with the suitability map, to output the final siting map of the comprehensive "Siting Potential in the Suitable Zone". This integration step is not mentioned in the framework utilized in Peng et. al (Figure 4) but was an important step in this research's completion.

Although following closely to the methodological framework proposed in Peng et. al, the final methodology that was undertaken in this thesis did deviate slightly on a few topics. First, and most evident, is that this analysis focuses solely on solar (PV) project development, while Peng et. al analyzes a variety of "Low-Carbon Energy Power Plants", including natural gas, solar (PV), nuclear, wind, hydro, biomass, and waste-to-energy (wTe). However, by parsing out the individual solar analysis method of this paper, along with the added guidance of Rios et. al, a distinct yet proven methodology was developed and applied in this study.

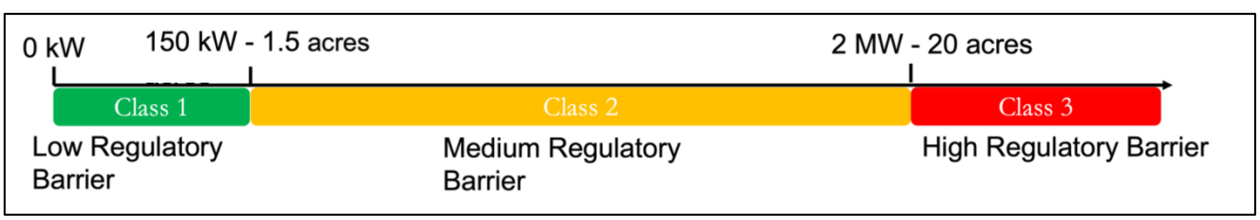
The second major difference between the methodology undertaken in this paper and in Peng et. al is in the evaluation criteria chosen for the siting potential. First, since Kalamazoo

County is much smaller than the YRD region (roughly 1/238th the size), different criteria had to be considered. Three criteria were included in Peng et. al so as to ensure the construction of proposed power plants sites would be economical: distance to roads, waterbodies, and elevation. These criteria are not relevant to this study and were thus dropped as all parcels under analysis were within a relatively short distance to all the construction infrastructure and materials needed, and do not contain any prohibitively elevated surfaces. Additionally, the criterion "distance to protected areas" was considered in Peng et. al as a siting potential variable, but, as this is a variable particular to China's classification of a protected area, my research contained "distance to current and potential wetlands" in its place as an unsuitable parameter in the first phase of this research. Wetlands were determined to be an accurate estimator of "ecologically-rich" areas in the GKA, and no inclusion of this variable in the siting potential criteria was deemed necessary. Finally, as was already discussed, the criteria Census Track Poverty Rate Level (C4) and Land Acreage (C6) were a novel inclusion in this analysis for their own reasons.

Also, as was mentioned above, Estimated Energy Demand (C5) rather than actual energy demand (in MWh/km^2) was used in this study. This is because, unlike in Peng et. al and Rios et. al, real energy demand for the Kalamazoo area could not be procured. In estimating energy demand in this research, the sources of energy demand were considered - namely population density and structural density. Population density is an important consideration to energy demand as areas where population density is high will most likely have larger total energy consumption (Ohlan, 2015). When considering how to estimate industrial energy demand, as opposed to consumer demand above, the inference of the location of large industrial factories was decided as the best strategy. As such, structural density, or the percent of area out of the total land area (in this case, the census tract) that is taken up by "structures", or buildings, was used as an estimator of industrial activity and thus energy demand by the industrial sector. As the industrial sector uses more energy than consumers (EIA, 2021), this component of energy demand was weighted as 60% of the Estimated Energy Demand variable; compared to 40% from population density.

The third major difference in the methodology undertaken relates to the differing regulatory environment and authority differential between China's Central Government and the municipal government of Kalamazoo. Due to the special powers given to state-regulated utilities in the US, Kalamazoo's local utility, Consumers Energy (CE), has legal authority to stop any energy project depending on its intended electricity output (CE, 2021). Any planned energy project that expects to produce over 150 kW (approximately 1.5 acres of solar development) of electricity must be approved by CE. However, this approval is not especially difficult to receive until a planned project reaches 2 MW (20+ acres) of potential electricity generation. At this level, the approval process becomes much less likely to be approved unless a partnership with CE on the implementation of the project is reached. Because of these differing regulatory barriers based on the intended project's generation - which is a function of the size of the parcel of land - each potential site in the suitable zone has been separated into the three classes depicted below. No such regulatory barriers were present in Peng et. al, as it is assumed that China's Central Government has more authority to construct projects as they please.

Figure 7 - Regulatory Barrier likely to be faced depending on the size of the project.



In summary, the methodology employed in this paper incorporates much of the methodology employed in Peng et. al. However, some variables, including those that influenced the potential of solar sites, and considerations, including regulatory barriers specific to the Kalamazoo area were changed, added, or dropped to make this as comprehensive and impactful of an analysis as possible.

IV. Results

Figure 8, which contains 4 separate maps, displays all the constraints (with their attached buffer zones) that make land unsuitable for solar development. All the constraints were then pieced together to find the total unsuitable area. Undeveloped land, wetlands and potential wetlands, and the 10.75 mi radius from the city center of Kalamazoo were the constraints in this analysis that had the greatest effect on the unsuitable, and thus the suitable, zone that was identified.

Figure 8 - Unsuitable Zones in Kalamazoo County.

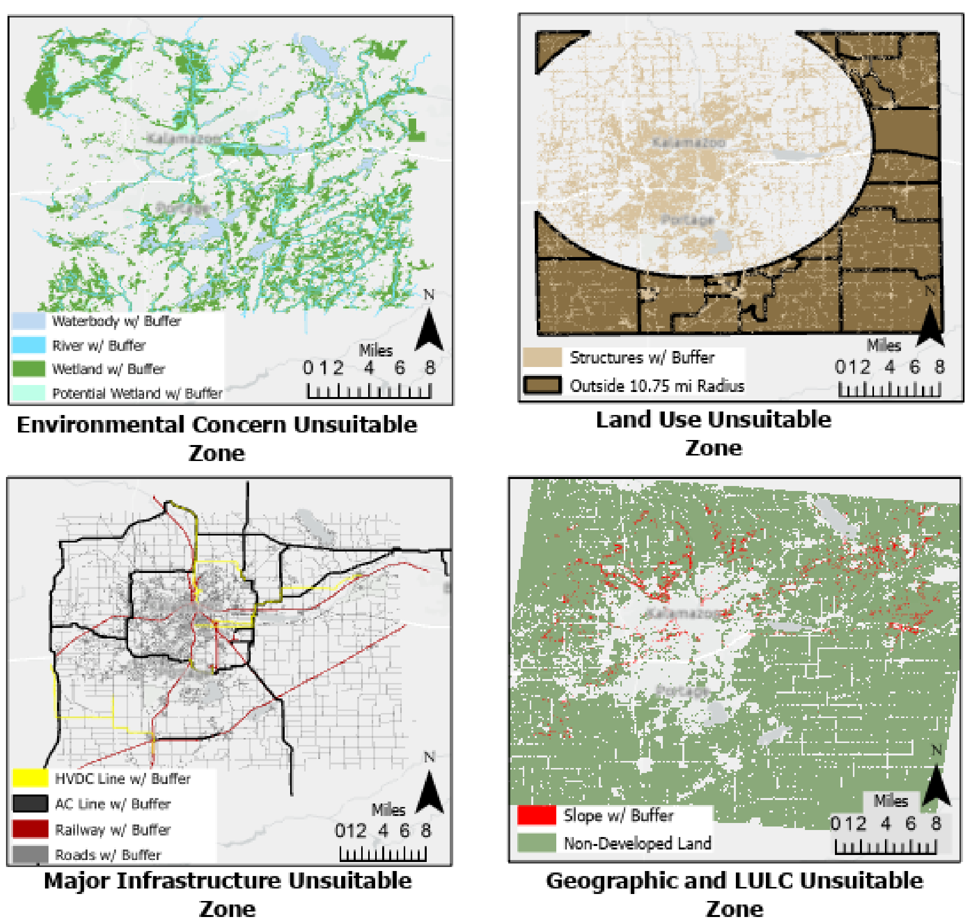


Figure 9 - Finalized suitable zone in Kalamazoo County.

Finalized Suitable Zone in Kalamazoo County

Figure 9 depicts the finalized "Spatial suitable map for power plant installation" within Kalamazoo County. This is the final output in Phase 1 of the methodology explained above. The finalized suitable zone in Kalamazoo County shows that most of the feasible land for solar development lies around 6 miles to the north, east, and west of Kalamazoo proper - in the undeveloped and agriculturally based outlying areas. The total suitable zone that was calculated, as a percentage of all the land within a 10.75 mi radius of the city center of Kalamazoo, is 36.93%. This calculation, among others, is shown in Table 2 below.

Table 2 - Percentage of areas in each potential scale out of the suitable area.

Table 2. Percentage of areas in each potential scale out of the suitable area

Total Sq. ft (w/in 10.75 mile radius):	9,451,785,402
Total Suitable Sq. ft:	3,490,843,713
% Suitable:	36.93%

Class	# of parcels	Median sq. ft	Mean sq. ft	Mean Acreage	Total sq. ft	Total Acreage	% of Total Suitable
1	263	45,858	47,260	1.08	12,429,354	285	0.36%
2	668	196,711	290,806	6.68	194,258,608	4,460	5.56%
3	546	3,167,473	6,014,937	138.08	3,284,155,711	75,394	94.08%

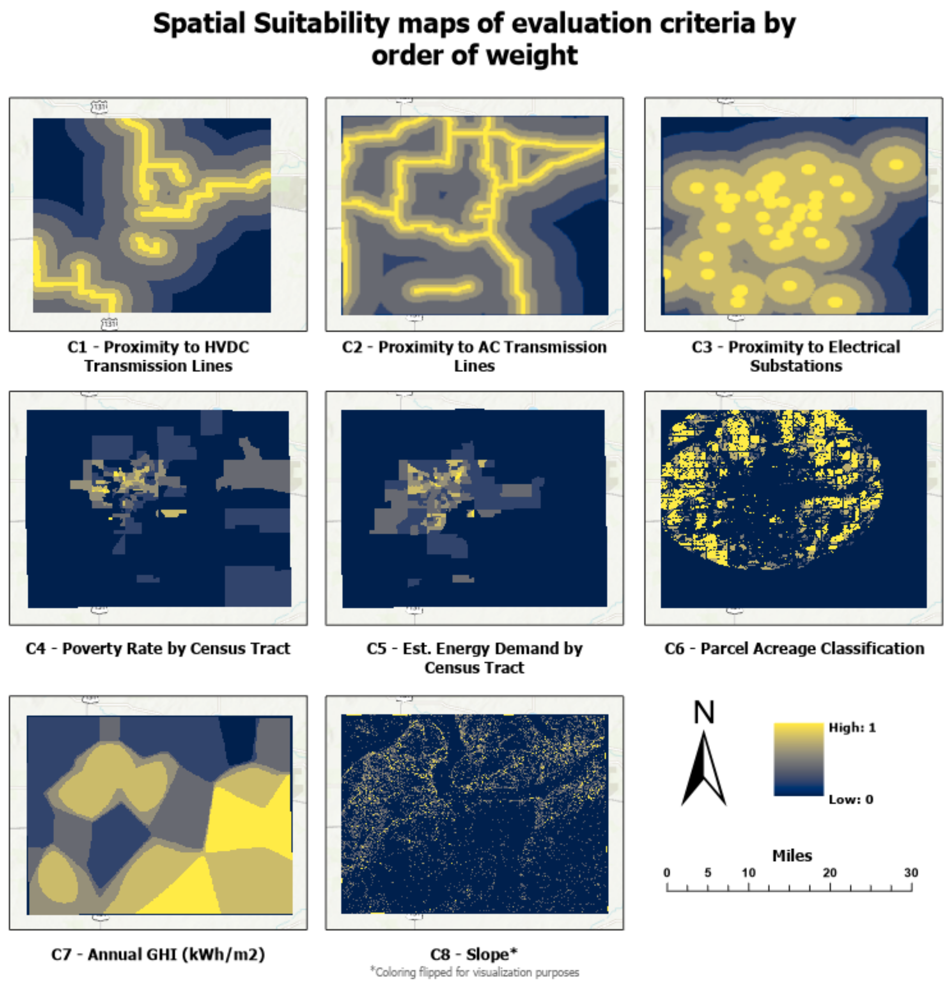
As an additional insight, the "**zonal geometry**" tool in ArcGIS was used to find the percentage of suitable land that is contained within each of the three parcel size classifications. As is shown in Table 2, a vast majority of the suitable area (94.08%) is from class 3 (20+ acre, 2 MW+) parcels of land. The potential MW of generation from the three classes was also estimated (in Table 3 below) using the 10 acres per 1 MW of generation rule-of-thumb that is used by most of the renewable energy industry (SEIA, 2022). Using this rule-of-thumb I was able to approximate that over 8,000 MW (8 GW) of energy could be generated if all the suitable land was transformed into solar projects. Although unrealistic, this finding supports the primary hypothesis that there is a significant amount of suitable land for solar development in the Kalamazoo area.

Table 3 - Potential MW of Generation for each land parcel class.

Potential MW Generation	
1	29
2	446
3	7539
Total:	8014

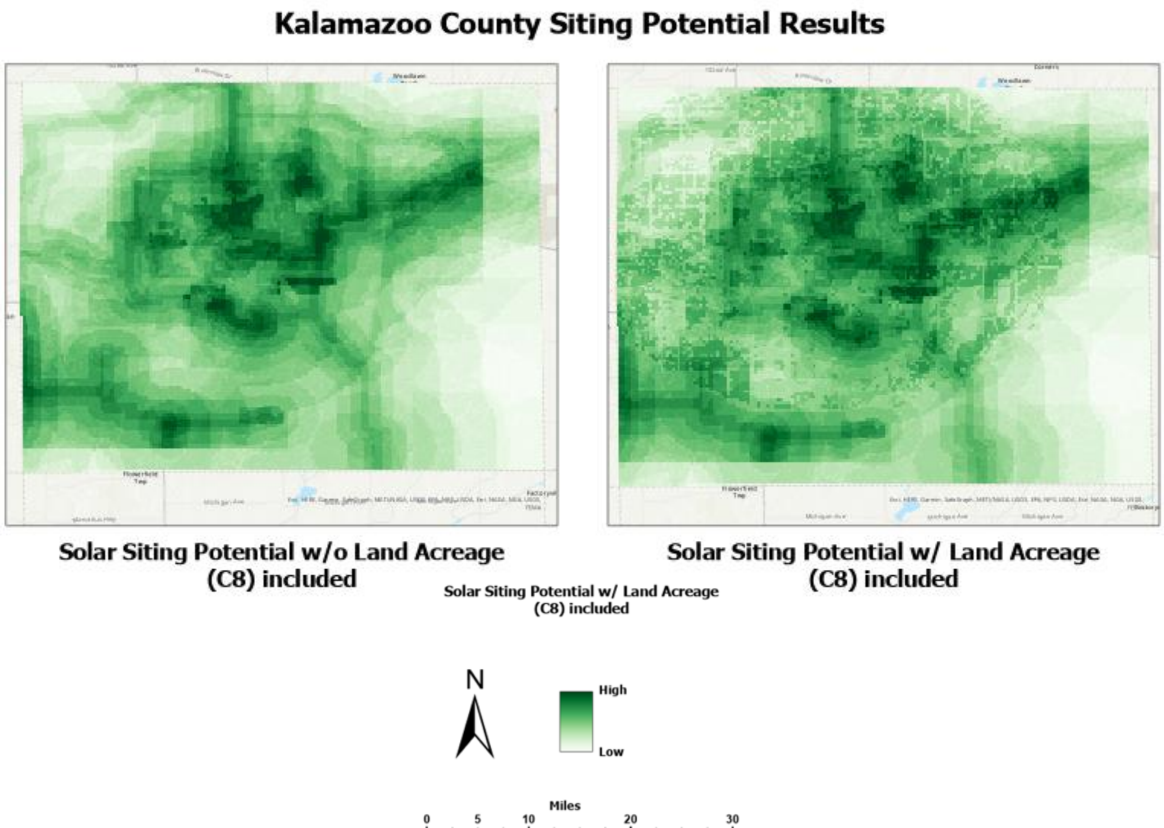
Next, a map of each of the nine evaluation criteria for the solar project siting potential - the location and evaluation of optimal solar project siting - are shown in Figure 10 below. The areas highlighted in dark yellow are the areas given the highest siting potential score for each criterion, and dark blue are the areas given the lowest rating. As is shown in the first three maps, the farther away the land is from the C1-C3 criteria, the lower the score the land was given for its siting potential. Then, for the rest of the variables, the parcels, tracts, or geographical extents are highlighted and scored relevant to each criteria's specifications. The scores of each of the spatial suitability scores, which above are shown as 0-5, are indexed and distributed evenly from 0 (low) to 1 (high) below for easier comprehension.

Figure 10 - Spatial Suitability maps of evaluation criteria by order of rank.



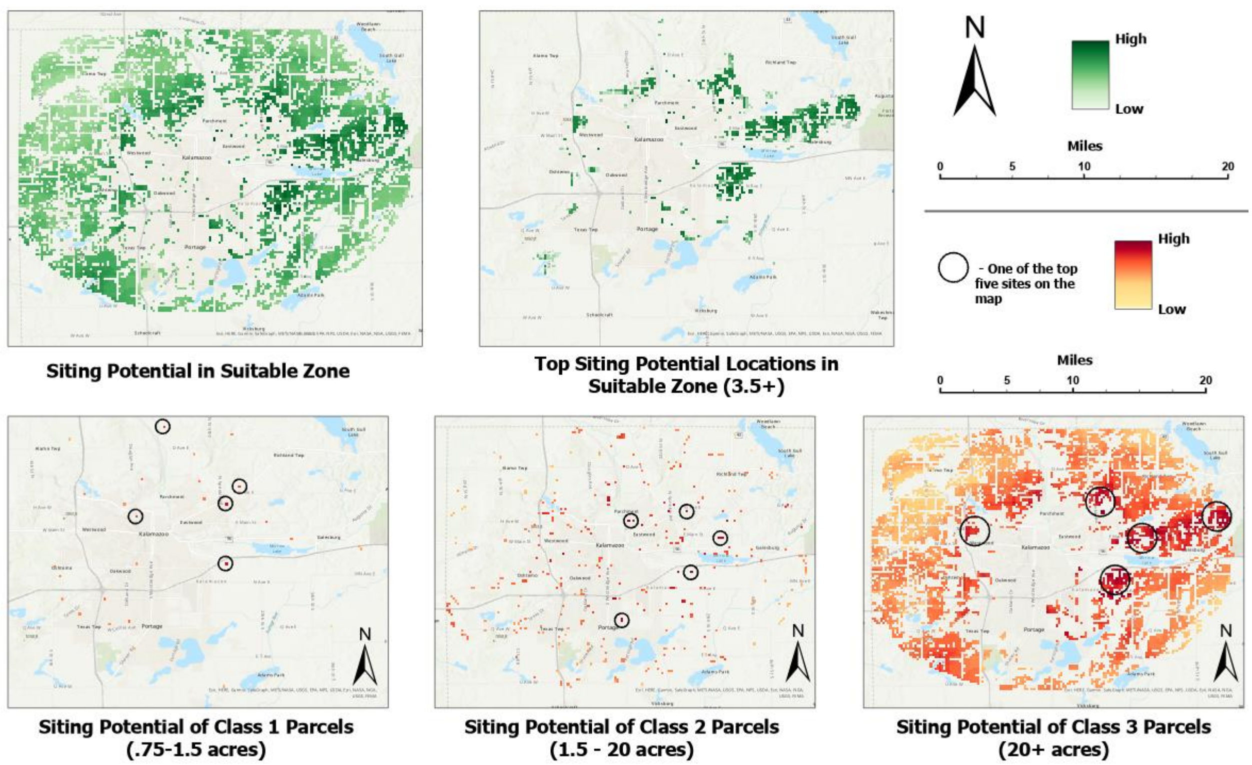
The scores within these 9 maps are first weighted and then combined to output the siting potential results for all of Kalamazoo County. The two maps in Figure 11 show, on a scale from low potential, in white, to high potential, in dark green, the results of this aggregation. The leftmost map shows the county siting potential without criterion C8 - Land Acreage - included mostly for visual purposes, but also if the size of the parcel of land in which the project is to be considered is deemed unimportant. These maps are the second major achievement of this research - as they detail the optimal solar project siting locations, or hot spots, for each parcel of land in the county. This is the finalized "Spatial siting potential map for [solar sites]", as is described in Phase 2 of the methodology. The parcels of land located within the dark green coloring should be the locations in which the siting of solar generation facilities should provide the most effective - technically viable, economical, and energy efficient - benefit.

Figure 11 - Kalamazoo County Siting Potential Results.



Finally, the results shown in Figure 11 are integrated with the suitable zone results and zone classifications that were already discussed to produce all the maps in Figure 12, our final and most important discovery of this analysis. Now all the suitable, or feasible, parcels of land that are especially promising for ground-mounted solar development based on economic, constructability, and transmissibility reasons can be visualized. The figure situated in the top left of Figure 12 depicts the comprehensive siting potential for each parcel in the suitable zone. Additionally, the second graph in the first row, labeled "Top Siting Locations in Suitable Zone", only displays the parcels of land that are of highest potential for solar siting (ranked 3.5+ out of 5) within the suitable zone. Although this scoring schema is an arbitrary index of the relative siting potential of each plot of land and does not correspond to any expected energy production, it is believed that the parcels of land shown on this "filtered" map are of utmost priority to evaluate further as the most optimal sites for solar development throughout all the GKA.

Figure 12 - Suitable Zone Siting Potential Results, ancillary maps included.



Additionally, the suitable zone siting potential for each classification of parcel size was extracted and visualized above in the three red maps for further use by developers and municipal decision makers. "High" and "Low" siting potentials for each of these three maps are only relevant to the parcels within each class, not compared to parcels in other classes. The top 5 sites in each category are circled, as these locations should be the first parcels investigated for development depending on the intended size of the solar siting project. As is evident, Class 3-sized parcels have the largest potential area for solar siting.

V. Conclusion and Recommendation

In the completion of this research there is considerable support for the hypothesis that there is underutilized potential within the GKA that could be used for solar electricity generation siting. As was shown above, over 3.4 billion sq. ft (36% of the total area) within a 10.75 mi. radius of the city center of Kalamazoo is suitable for solar project siting. This is a significant amount of land as only about 370,260 sq. ft of suitable land (1.06%) within the GKA is currently being used for ground-mounted solar arrays. Also, it has been estimated that over 8,000 MW of electricity generation could be realized if all the land that is suitable for solar siting is converted to do so. This, although unrealistic, shows the vast potential of solar development in the GKA as 8,000 MW approximately equates to the powering of 4.8 million homes every day (Olivero, 2020).

Not only is a significant amount of land feasible for solar development within the GKA, but there is also a large proportion of said land that is attractive for solar siting. This is shown in Table 4, included below, which details the percentage of land within the suitable zone that is within each categorical ranking of solar siting potential. As is evident from the table, most, 69.38%, of the suitable land has medium-to-high potential (ranked 3-5) for solar siting. This means that the suitable parcels of land in question are proximate enough to electricity infrastructure and its source of consumption (HVDC, AC, substations, and energy demand), receive enough sunlight each year (GHI), may garner financial subsidization (poverty rate), and are both sized and topographically adequate (land acreage and slope) to rate the project sites as medium-to-high attractiveness.

Table 4 - Percentage of areas in each potential scale out of the suitable area.

Potential Scale	Low		Medium		High	
	0	1	2	3	4	5
	0.00%	0.02%	30.60%	59.57%	9.81%	0.00%

The output of my analysis - the attached figures, tables, and results interpretation - should help the City of Kalamazoo make better investment decisions in solar projects to decrease their carbon emissions and utilize clean energy generation sources for all their energy consumption needs. Even if the City of Kalamazoo were not to make the necessary carbon reduction pledges, solar energy investments, or did not make use of the information in this research, there are yet other parties who could make positive use of the insights derived in this research. These parties include the local utility, Consumers Energy, whom has already been quoted as searching for large swaths of land for solar development (McWhirter, 2022), or other third-party developers who aim to make a positive financial profit from the implementation and sale of the clean energy generation.

Besides supporting the hypothesis of feasible land and the secondary hypothesis of attractive suitable land, this analysis also reveals some ancillary patterns and discoveries within the solar development sphere of the Greater Kalamazoo Area. One such discovery is that there is ample land to the east, northeast, and southeast of Kalamazoo proper that is both feasible and has high potential for solar project siting. This area, illustrated best in Figure 12 by its large dark green coloring, has high solar siting potential because of its abundance of substations and interconnecting HVDC and AC transmission lines, its high average solar global horizontal irradiance, and the large plots of land (mostly farmland), that it contains. This land should look extremely promising for all the above parties mentioned for future solar project development. Also, because of the outsized importance (and thus AHP weighting) applied to electricity infrastructure, due to its impact on project economics, the relationship between the prevalence of energy infrastructure and the highest siting potential locations throughout this research is prominent. This is one of the reasons that the eastern half of the GKA has such high potential for solar siting; it sits at the nexus of crisscrossing

HVDC lines, AC lines, and electrical substations. This abundance of electricity infrastructure is exactly what is needed for inexpensive and uncomplicated interconnection to the electricity grid.

Another discovery in this analysis, this time purposeful in its finding, is the overlapping of land that is owned by the city of Kalamazoo (in orange) and land that is both feasible and has high potential for solar development. The map showcasing these synergies - with prominent areas circled - is included below in Figure 13. These circled areas highlight locations that have a high probability of being especially economical for ground-mounted solar siting in the Kalamazoo area. Since the City of Kalamazoo already owns this land, and the land has been found to be both feasible and as having high potential for solar projects, the City of Kalamazoo could institute projects here without worrying about the often-prohibitive fixed cost of purchasing the land for the construction of the solar project. This is also what the City of Ann Arbor has done in instituting solar projects on land that it already owns to decrease, dramatically, the cost of the clean energy project in total (A2ZERO, 2022). The overlapping of potential brownfield re-development land (in brown) and feasible solar siting land was also analyzed, but there was minimal overlap as most brownfields in Kalamazoo are located in the heavily industrialized and developed downtown area.

Figure 13 - Suitable Zone Siting Potential with added cost-effective siting locations.

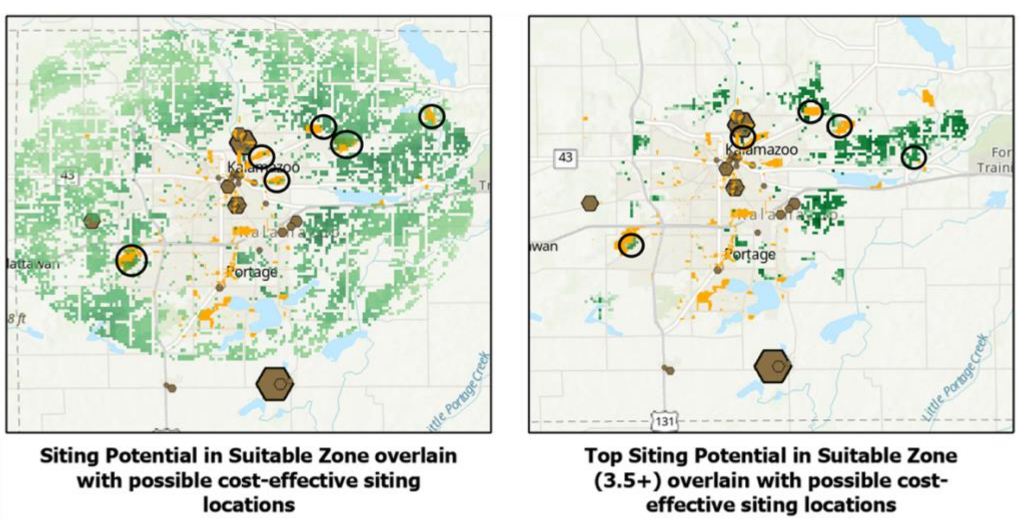
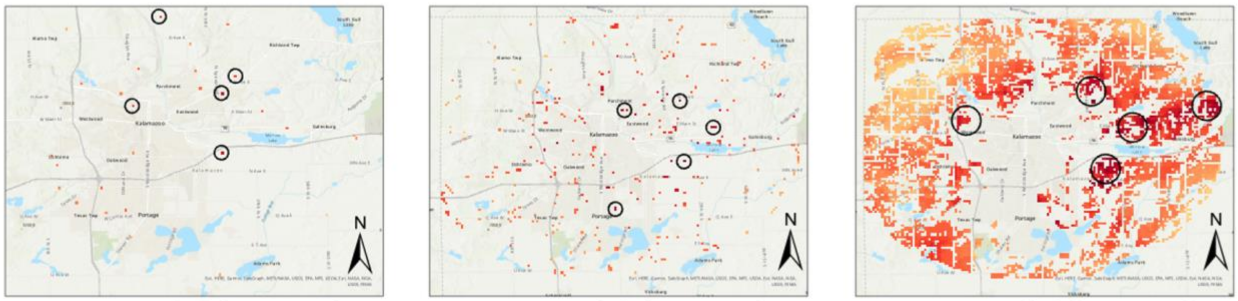


Figure 14 - Ancillary Suitable Zone Siting Potential maps.



Siting Potential of Class 1 Parcels (.75-1.5 acres) | **Siting Potential of Class 2 Parcels (1.5 - 20 acres)** | **Siting Potential of Class 3 Parcels (20+ acres)**

One final, and especially important, takeaway from this analysis are the solar siting results corresponding to the land area classifications which were explained earlier. As is shown in the maps above, the three different land classifications with their respective siting potential (dark red belonging to the parcels with the highest potential, and the top 5 sites circled), allow for a siting evaluation dependent upon the intended size of the solar project. This also corresponds with the expected regulatory barrier that would be faced in the development of solar projects depending on their size. Again, this regulatory barrier is not based on the size of the parcel in question, but due to the expected kW or MW of generation that the solar project would generate as a function of the size of the parcel of land. Unfortunately, as is shown below, most of the land that has potential for siting solar projects is in Class 3 (20+ acre) parcels. The class with the next largest next total land area and count of parcels is contained within class 2 (1.5-20 acres), followed finally by class 1 (0.75-1.5 acres). The unfortunate part about this discovery is that parcels of land that would be most feasible for siting and would have the most impact on Kalamazoo's transition to clean energy, class 3 parcels, are also the parcels in which it is most difficult to utilize for solar development. However, these maps are still beneficial for the City of Kalamazoo and other developers to evaluate before making any siting decisions and may spur legal action to change this seemingly harmful regulatory barrier.

As the fundamental goal of this project was to provide insight into and encourage investments in ground-mounted solar energy in Kalamazoo, it seems fitting to touch on the current investment environment for clean energy and how my research applies to this sphere. The IRA could provide the municipal government of Kalamazoo with profoundly supportive grants and loans to increase its clean energy and solar energy generation. As was already noted, the City of Kalamazoo is a metropolitan area that is inundated with high rates of poverty and has a history of environmental injustice, which matches perfectly with the special provisions in the IRA for such municipalities. However, these clean energy federal subsidies could go to waste, as considerable amounts of federally available stimulus funds do (Coughlin, 2021), if the City of Kalamazoo, in its inevitable clean energy transition, is not purposeful with its investments. This consideration was included in my research by both the inclusion of brownfields - sites of old, usually contaminated commercial zones (potential instances of past environmental injustice) - and the inclusion of census tracts delineated by relative poverty rate. As such, my research includes information that could be of great importance for use by the City of Kalamazoo in making optimal solar siting investments using federal funds.

Regarding future applications of this research, it seems obvious that the use of the suitable siting zone map, solar potential maps, and the other ancillary analyses that were completed should be utilized by energy planners and urban planners of the City of Kalamazoo to make more informed decisions for solar investment and development into the future. A secondary application of this research is its replication across similar geographical areas or areas with similar cost considerations and electricity parameters. For example, other municipalities across Michigan and the greater Midwest region, where the constraints and project development considerations are likely to be similar, could utilize the same GIS data sources, comparable buffer zones, and similar weightings and other methodology specifics utilized in this research for a streamlined approach to aid future solar project development in their own communities.

Finally, there are a few avenues of research that were discovered that would expand upon this subject and provide more benefit to the City of Kalamazoo's energy transition and clean energy development more generally. First, the feasibility and economics of commercial ground-mounted versus commercial roof-mounted solar should be compared. Ground-mounted solar was the focus of this research as it was assumed that it was more cost-effective than roof-mounted as it can be constructed at a larger scale. However, since it is unnecessary to connect a roof-mounted solar array to the grid and it is usually cheaper to install (Matasci, 2022), roof-mounted solar could be both a cheaper and easier option for some point sources of Kalamazoo energy consumption. Additionally, commercial-scale roof-mounted solar would circumvent the obstructive regulatory barriers that pose such a difficult challenge to solar development in Michigan. So, comparing the economics of ground-mounted versus roof-mounted solar for municipal governments, or the GKA specifically, seems like a great potential research pathway.

Another interesting research pathway to evaluate is the economics of siting solar projects based on their parcel sizes. To precisely compute and understand the level of economies of scale that are realized from larger solar projects, compared to multiple individual projects, would be very beneficial to the City of Kalamazoo and other municipalities in their future project decision making. Again, this is relevant as larger projects in Michigan have larger regulatory barriers to overcome compared to smaller solar projects. If larger projects are significantly more economical than multiple smaller projects with the same MW of potential output, it may spur the City of Kalamazoo or other stakeholders to take legal action in addressing the existing regulatory environment for grid interconnection.

The final research pathway involves exploring the feasibility of integrating land conservancies with clean energy projects. The hypothesis is that incorporating protected land with low-impact clean energy development can contribute to the clean energy transition while also preserving biodiversity. This research is relevant as it was realized that a significant portion of high-potential solar siting land in the GKA is situated on land off-limits to most forms of development as it is preserved for its nature-based endowments. By exploring strategies to balance clean energy generation and environmental preservation on the same land, the study could offer a novel pathway for increased sustainable energy development and land preserves in the region, coinciding with a more efficient use of land in general.

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