Site Suitability Study for Electric Vehicle Charging Stations in Rural America

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GEOG 596B

May 10, 2022

Abstract

Electric vehicles are quickly becoming more prevalent in our society, with the idea of decreasing greenhouse gas emissions at the forefront of this movement. Unfortunately, the current electric vehicle infrastructure is mainly located in urban areas, leaving significant gaps concentrated in rural areas. Furthermore, the lack of charging stations in rural areas leads to range anxiety for drivers and lower EV adoption rates in rural communities. Therefore, it is essential to find the most suitable locations for EV charging stations to help maximize EV usage among current and potential EV owners. This paper represents the culmination of the research efforts to identify the most suitable locations for an EV charging station to be located in Northwestern Rural Electric Cooperative's service territory using a GIS-based multi-criteria decision making analysis. A three-step approach was used to help determine the optimal locations in NWREC's service territory. The first step was determining the criteria to be analyzed. The second was using an AHP calculator to determine the importance and weights of the factors, and the third step was using the weighted overlay analysis in GIS to create a map showcasing the most suitable locations for a charging station.

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List of acronyms

ACS – American Community Survey

AHP – Analytical Hierarchy Process

EV – electric vehicle

GIS – geographic information system

MCDM – multi-criteria decision making

NWREC – Northwestern Rural Electric Cooperative

ZCTA – ZIP Code Tabulation Area

1. Introduction

There is a growing need to decrease our reliance on fossil fuels and reduce greenhouse gas emissions. We can begin to lessen our fossil fuel dependence and the environmental impacts by focusing on the future of electric vehicles (EVs). According to the Environmental Protection Agency, the transportation sector accounted for 28 percent of greenhouse gas emissions in 2018. Pennsylvania is one of the many states that have set forth policies and goals to reduce greenhouse gas emissions. According to the Pennsylvania Climate Action Plan 2021, the state has set a goal to reduce greenhouse gas emissions by 26 percent in 2025 and 80 percent in 2050. One of the strategies listed in the plan to help reduce greenhouse gas emissions is implementing sustainable transportation. Even though electric vehicles produce fewer emissions than gasoline-powered vehicles, there are challenges associated with EV ownership. A fully charged battery range might not be sufficient for some motorists, especially those living in rural areas who drive more miles than those living in urban areas. Another concern for electric vehicle ownership is the inadequate public charging station infrastructure available. In November 2021, President Biden signed the Bipartisan Infrastructure Law, which allocated $7.5 billion to fund public EV charging stations over the next five years. This funding is set to deploy 500,000 EV charging stations across the country to create an interconnected network of charging stations that will increase the reliability and feasibility of anyone owning an electric vehicle. A portion of this fund will support charger deployment in rural areas, which is essential in closing the charging station infrastructure gaps.

This study aims to identify the optimal location for one level 3 charging station in Northwestern Rural Electric Cooperative's service territory (Figure 1). The service territory of NWREC covers approximately 1,000 square miles, contains 2,650 miles of electric line, and serves more than 20,000 members. In 2020, NWREC began an electric vehicle project to educate the co-op members on the benefits of EVs and increase usage rates within the rural service territory. The beginning stage of this project involved purchasing an electric vehicle to join their fleet and then installing a level 2 public charging station at their headquarters. The next part of NWREC's electric vehicle project is deploying a level 3 charging station within their territory. This study also supports the mission statement of NWREC, which reads as follows: Northwestern Rural Electric Cooperative, as a member-owned electric service utility, will seek innovative ways to provide reliable and economical services to improve the overall quality of life in our areas of influence.

The remainder of this paper will better understand the importance of expanding charging station infrastructure and the criteria used to select optimal locations for electric vehicle charging stations within NWREC's service territory.

Figure 1: Northwestern Rural Electric Cooperative's service territory.

2. Literature Review

Researchers have used different approaches and criteria to determine optimal locations of electric vehicle charging stations. Typically, the strategies used are a combination of spatial analysis and multi-criteria decision-making methods. Semih and Seyan (2011) acknowledged that a poorly placed gas station could ultimately cause that business to fail. In the study conducted by Semih and Seyan, the Analytic Hierarchy Process (AHP) was used to determine what factors are the most important when identifying potential gas station locations. This study did not use spatial analysis techniques to identify specific locations. Semih and Seyan concluded that the number of competitors in the area is the most critical factor to consider when determining potential locations. More competitors in an area can impact the number of drivers selecting that gas station. Other important factors identified in this study were road access in both directions to the gas station, the speed limit of the road, if it is located on a state or local road, the average age and income of residents living in the area, and the visibility of the gas station from approaching roads. Although this study focuses on gas station site locations, some of the same factors can be applied to determining electric vehicle charging station locations.

Erbaş et al. (2018) acknowledged that the lack of electric vehicle charging stations could negatively affect the growth of electric vehicle adoption. A four-step approach was used in the study conducted by Erbaş et al. to identify potential charging station locations. The steps used in this approach were evaluation, mapping of geographic information, weighting the criteria using the Fuzzy Analytic Hierarchy Process (FAHP), and ranking potential charging sites using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) techniques. The criteria analyzed for this study were the distance to vegetation, distance to water, distance to landslide risk, slope, the possibility of expansion, earthquake risk, land cost, electric vehicle ownership, distance to substations, service area population, proximity to junctions, proximity to main roads, proximity to gas stations, and distance to other electric vehicle charging stations.

Guler and Yomralioglu (2020) recognize the need for more charging stations to increase electric vehicle use. This study used an approach that integrates Geographic Information Systems (GIS) techniques and Multi-criteria Decision-making (MCDM) methods to effectively determine suitable locations for electric vehicle charging stations in the northwest region of Turkey. The Analytic Hierarchy Process (AHP) and the Fuzzy Analytic Hierarchy Process (FAHP) methods were used to calculate the weights of the criteria. The criteria used in this study include population density, shopping malls, proximity to roads, income rates, transportation stations, proximity to gas stations, park areas, green spaces, slope, and land values.

The study conducted by Csiszár et al. (2020) focused on electric vehicles and potential charging station locations along roadways that would help support long-distance trips in an electric vehicle. They first selected candidate charging station sites and rest areas within a certain distance of main roads. Once those sites were determined, they were evaluated using a weighted multi-criteria location optimization method. A multi-criteria method was used for this study because it takes several parameters into account simultaneously compared to running each one separately. This study considered neighborhood, traffic information, average electric vehicle ranges, user demand, population, installation costs, and available services, such as restrooms and restaurants.

The study completed by Kaya et al. (2020) used GIS to identify suitable alternative charging station locations in Turkey. This study also used the AHP method for weighting the criteria. Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) was used to rank and evaluate the current and potential charging station locations. This study analyzed nineteen factors: number of EVs, number of vehicles, land cost, household income, forested areas, water resources, landslide potential, earthquake potential, slope, current charging stations, gas stations, solar energy potential, substation proximity, air quality, service area population, social areas, roads, junctions and parking lots.

The literature reviewed here shows that the lack of electric charging stations presents significant obstacles to electric vehicle adoption. It is also apparent that identifying optimal charging station locations is critical for expanding the needed infrastructure. Without the proper infrastructure in place, owning an electric vehicle would be unrealistic for most. The reviewed literature focused on urban areas and neglected to explore rural areas. According to the 2017 National Household Travel Survey, the daily miles traveled for urban drivers is 23, while the daily miles traveled for rural drivers is 33.5. This survey also stated that rural areas have a higher vehicle ownership percentage than metro areas. Considering that more miles are traveled daily and a higher percentage of households own vehicles in rural areas, it is crucial to involve rural areas in electric vehicle adoption if we want to achieve the goal of reducing global emissions. There is a pressing need to identify locations and deploy charging stations in rural areas. Figure 2 below shows the current EV charging stations within Pennsylvania and illustrates that much of the existing infrastructure is concentrated within urban areas. Adding charging stations to rural areas will help alleviate range anxiety, make long-distance trips a more viable option, and increase the interest and practicality of rural residents in owning an electric vehicle.

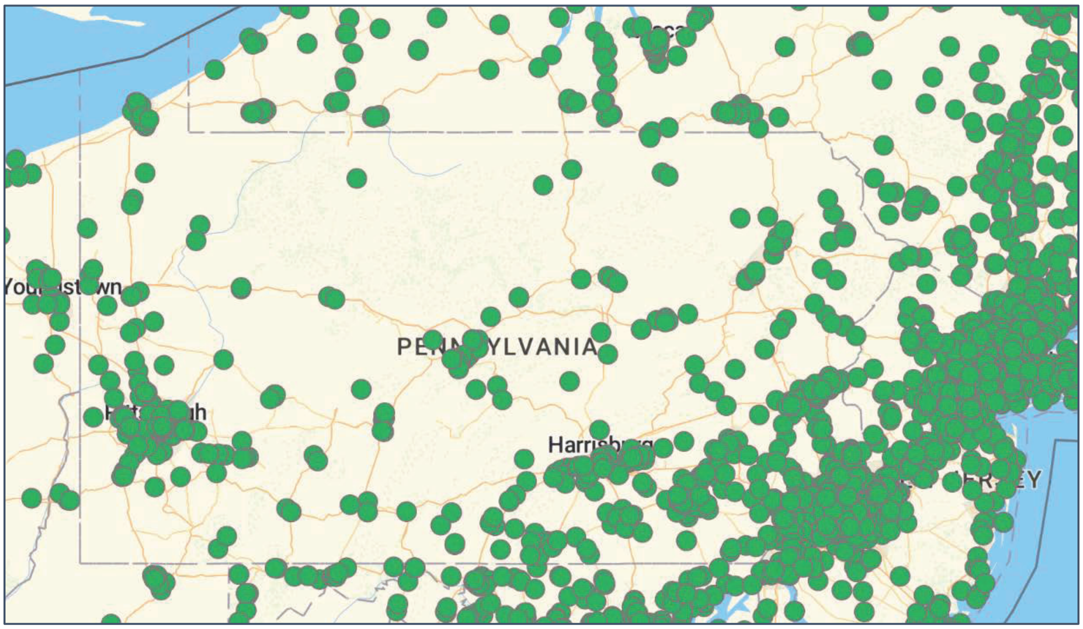

Figure 2: Current EV charging stations in Pennsylvania
https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC&ev_levels=all

Table 1: Combined site suitability criteria list.

	Reviewed Literature Authors			
	Semih and Seyan	**Erbaş et al.**	**Guler and Yomralioglu**	**Csiszár et al.**
Economic Factors	Number of competitors	Proximity to gas stations	Proximity to gas stations	Available services
		Distance to other charging stations	Transportation stations	Existing charging stations
		Expansion potential	Shopping malls	
		Land cost	Park areas	
		Proximity to the substation	Green areas	
			Land values	
Traffic Related Factors	Road access	Proximity to junctions	Proximity to roads	Traffic information
	Speed limit	Proximity to main roads		
	Local/state road			

	Visibility from road			
Environmental Factors		Distance to vegetation	Slope	
		Distance to water		
		Distance to landslide risk		
		Slope		
		Earthquake risk		
Socio-economic Factors	Average age	Service area population	Population density	Neighborhood information
	Average income		Income rates	Population
Other Factors		EV ownership rates		EV range
				User demand
				Installation costs

3. Methodology

Identifying suitable locations is a multifaceted challenge for any project. This study proposes an approach that will result in the optimal EV charging station locations within NWREC's service territory. The analytic hierarchy process (AHP) and geospatial information system (GIS) will be used to help identify suitable electric vehicle charging station locations within the rural areas that Northwestern REC serves. Combining these two methods provides more detailed information to help aid in the decision-making process.

3.1. Criteria

The criteria used in this research project were taken from previous studies (Table 1) that identified suitable locations for gas stations and EV charging stations. These factors include distance to main roads, distance to existing electric vehicle charging stations, electric vehicle ownership rates, distance to power supplies, and population density. This section will explain each criterion and how it will be used in this study.

3.1.1. Main roads

Higher traffic main roads are a factor that can be used to determine suitable charging station locations. A shapefile of state roads was obtained from the Pennsylvania Department of Transportation. The Euclidean distance tool was used on this data set to create a raster image from the vector data. The raster was then reclassified with classes ranging from 1 to 5, 1 being the least suitable and 5 being the most suitable. The areas closer to the main roads will be considered more suitable than those further away.

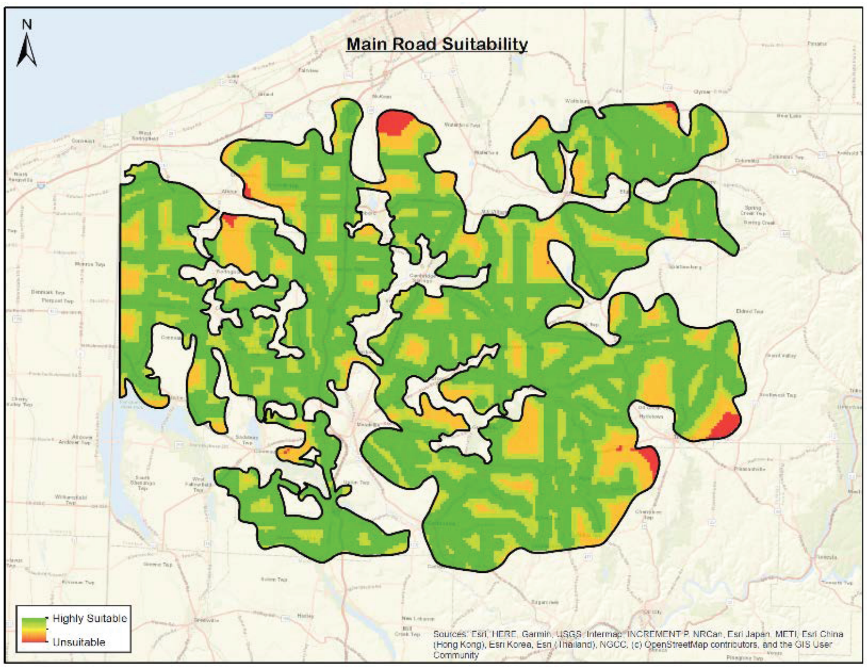

Figure 3: Main road suitability map

3.1.2. Existing EV charging stations

Identifying current electric vehicle charging station locations is another important factor in determining suitable new locations. More charging stations in one area gives consumers more choice as to where they can charge their vehicle. Nearby electric charging stations can lead to a loss of potential revenue. The US Department of Energy's alternative fueling station locator was used to create a shapefile of existing charging stations. The multiple ring buffer tool was used in GIS to create buffers of 1, 5, 10, 20, and 30 miles around the existing charging stations. The polygon to raster tool was used to create a raster image, which was then reclassified using a scale of 1 to 5, 1 being the closest distance from existing charging stations. The areas farther away from the existing charging station infrastructure are considered more suitable.

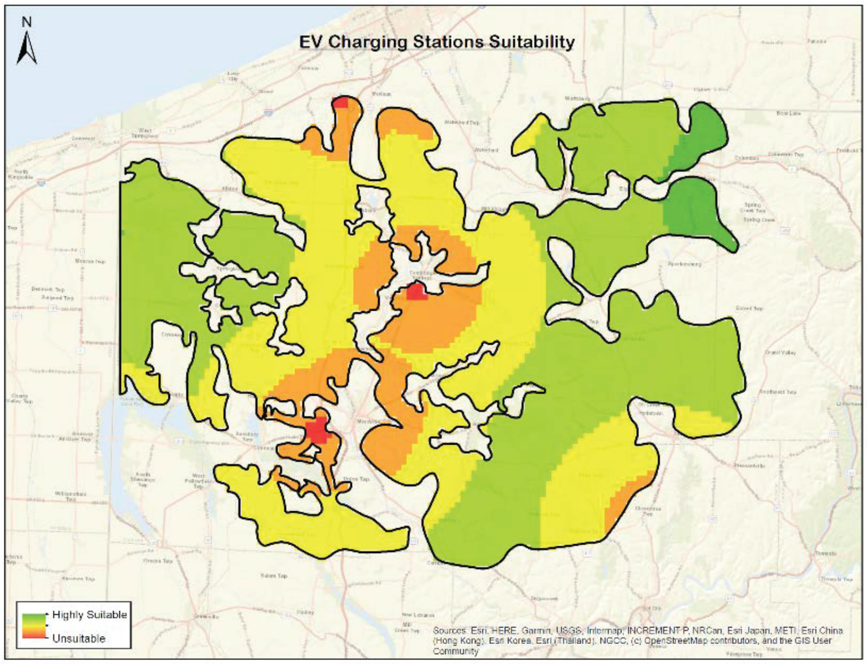

Figure 4: Existing EV charging station suitability map

3.1.3. EV ownership rates

An analysis of the electric vehicle ownership rates within NWREC's service territory was performed in this study. The areas with higher EV ownership rates are more likely to utilize an EV charging station. The EV ownership data was obtained from the Pennsylvania Department of Environmental Protection's *Pennsylvania Electric Vehicle Roadmap: 2021 Update*. This document provides a link to the interactive map, *Pennsylvania Registered Vehicles by Fuel Type and Zip Code*. The information, filtered only to show registered electric vehicles, was exported as an excel spreadsheet. Using GIS, that information was then joined to the ZIP Code Tabulation Areas (ZCTA) shapefile downloaded from the US Census Bureau. Once the join was complete, the polygon to raster tool was used to create a raster of the ownership rates. The raster was then reclassified using a scale of 1 to 5, with 1 indicating areas with low EV ownership rates and 5 representing areas with high ownership rates.

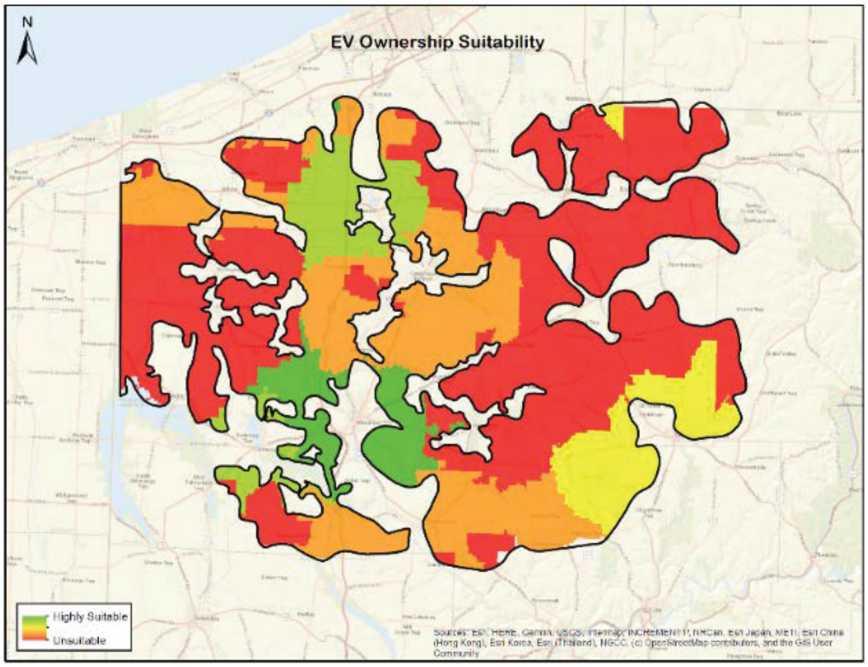

Figure 5: EV ownership suitability map

3.1.4. Existing power supplies

Identifying areas which would allow potential charging station locations to be placed closer to power supplies was undertaken in this study. Having a power supply within close proximity will help lower the installation cost of a charging system. If potential charging station locations were located further away from power lines, then the cost of running power to that area would need to be factored into the installation cost. A line shapefile of Northwestern REC's electric lines was used for this suitability factor. The Euclidean distance tool was used to create a raster image from the line shapefile. The raster was reclassified with classes ranging from 1 to 5, 1 being the furthest distance away from an existing three-phase power line and 5 being the closest distance. The areas closer to a power supply will be considered more suitable than those further away.

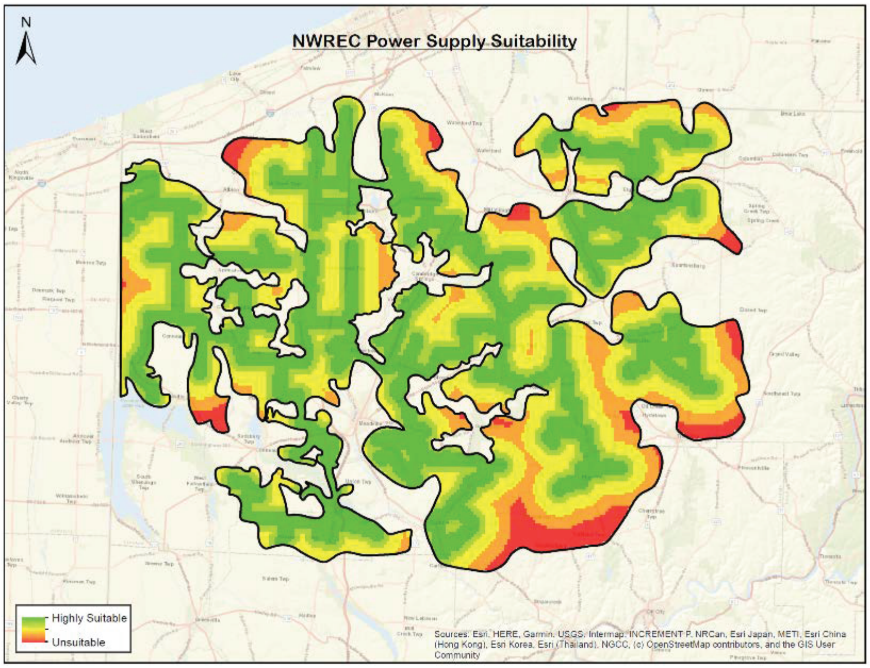

Figure 6: Power supply suitability map

3.1.5. Population density

Identifying areas with a greater population is another important factor when identifying suitable charging station locations. A shapefile of census tracts in the study area and 2020 decennial population data was downloaded from the United States Census Bureau's website. The population data was then joined to the census tract shapefile, and then the field calculator was used to calculate the population density of each census tract. The polygon to raster tool was used to create a raster based on population density, which was reclassified with classes ranging from 1 to 5. A class with a value of 1 represents areas with a lower population, and areas classified as a 5 have higher populations.

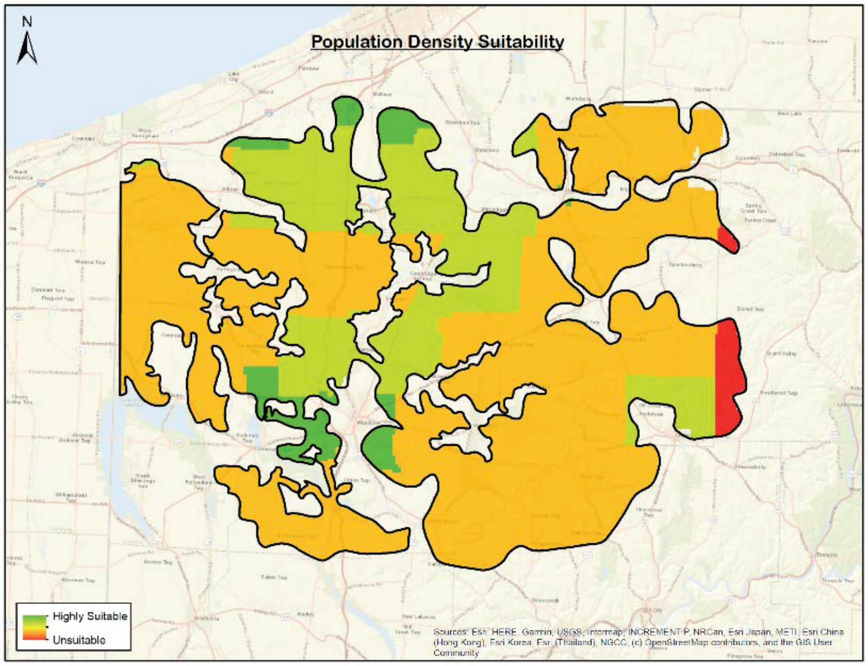

Figure 7: Population density suitability map

Table 2: Summary of factors and the corresponding reclassifications

	Reclassification				
Factors	1	2	3	4	5
Distance from existing three phase power (miles)	0-0.5	0.5-1	1-2	3-5	> 5
Distance to main roads (miles)	>5	2-5	1-2	0.5-1	0-0.5
Distance to existing EV charging stations (miles)	0-1	2-5	6-10	11-20	>21
EV ownership	0-1	2-4	5-6	7-12	12-28
Population density	0-30	31-63	64-127	128-280	>281

3.2. Multi-criteria decision making (MCDM)

Multi-criteria decision making is a comparison approach used when multiple factors are involved. MCDM provides a range of methods to evaluate the factors involved in the decision problem. To correctly determine the importance and weight of each criterion, the Analytical Hierarchy Process (AHP), proposed by Saaty in the 1970s, was used in this study. Geographic information system (GIS) offers a spatial approach to solving decision problems by storing, managing, and analyzing geospatial data. This project combines AHP and the weighted overlay tool in GIS to help identify the most suitable locations for an EV charging station within NWREC's service territory.

3.2.1. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process was used to help determine the importance and weights of the different criteria in this study. This method is a pairwise comparison, which means two factors are compared against each other to determine which one is more important and by how much. This process uses a 9-point rating scale for criteria preferences, 1 being an equal preference and 9 being extremely favored over another factor.

	A - wrt AHP priorities - or B?		Equal	How much more?
1	◉ Distance to power supply	○ Distance to main road	○ 1	◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
2	◉ Distance to power supply	○ Distance to existing charging stations	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
3	◉ Distance to power supply	○ EV ownership	○ 1	○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
4	◉ Distance to power supply	○ Population density	○ 1	○ 2 ○ 3 ○ 4 ◉ 5 ○ 6 ○ 7 ○ 8 ○ 9
5	◉ Distance to main road	○ Distance to existing charging stations	○ 1	○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
6	◉ Distance to main road	○ EV ownership	○ 1	○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
7	◉ Distance to main road	○ Population density	○ 1	○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
8	◉ Distance to existing charging stations	○ EV ownership	○ 1	◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
9	◉ Distance to existing charging stations	○ Population density	○ 1	◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9
10	◉ EV ownership	○ Population density	○ 1	◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9

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AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Figure 8: AHP priorities, importance, and scale.

Cat		Priority	Rank	(+)	(-)
1	Distance to power supply	41.1%	1	10.3%	10.3%
2	Distance to main road	29.9%	2	7.6%	7.6%
3	Distance to existing charging stations	13.4%	3	2.9%	2.9%
4	EV ownership	9.1%	4	2.5%	2.5%
5	Population density	6.5%	5	1.3%	1.3%

Figure 9: Resulting weights based on the pairwise comparisons

A numerical weight estimate is calculated using the AHP calculator (Figure 9), which was then used within the weighted overlay tool to create the final suitability raster.

3.2.2 Weighted overlay analysis

The weighted overlay analysis tool in GIS is used for multi-criteria decisions, commonly site selection and suitability models. The reclassified rasters were added to the overlay analysis tool, and the assigned weights were entered into the weighted overlay analysis tool. The weights are expressed in percentages and must add up to 100 percent. Distance to power supplies is the most dominant factor, with a weight of 41 percent. The second preference is given to distance to main roads with a weight of 30 percent. The distance to existing EV charging stations is the third factor, with a weight of 13 percent. EV ownership becomes the fourth choice, with a weight of 9 percent. Population density is the least preferred factor, with a 7 percent influence on the final raster. After running this tool, a final output raster was created and then used to determine the most favorable areas for a level 3 charging station. The final suitability raster was grouped into categories ranging from 1 to 5, with values of 1 considered unsuitable and those with a value of 5 considered highly suitable.

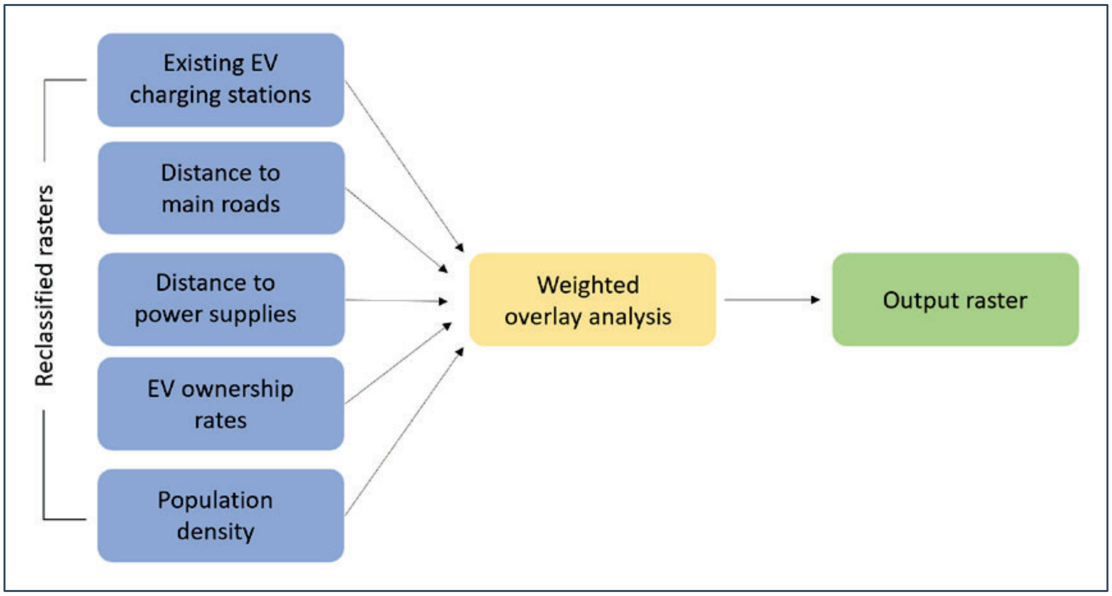

Figure 10: Weighted overlay model

4. Results

After running the analysis, the final output raster identified several areas (Figure 11) within NWREC's service territory that would be optimal for an electric vehicle charging station. Once these areas were identified on the final output raster, they were digitized in GIS to create a polygon shapefile of those areas. Once the suitable areas were identified, it was necessary to narrow down the potential locations further. To accomplish this, county parcel data was obtained, and the parcels that interest the suitable areas were selected. Since the cost of installing an EV charging station is high, it was determined beneficial to partner with a business where the paved facilities could be used to help lower installation costs. Also, in the study that Guler and Yomralioglu (2020) conducted, the authors used proximity to shopping centers, park areas, and gas stations as important factors when identifying locations for charging stations. This criterion was used to reduce the number of parcels that would be optimal locations for a charging station. The next step was selecting parcels with land-use codes for gas stations, hotels, restaurants, retail, and recreation with existing paved areas. The results identified 20 parcels that offer existing pavement and recreation, lodging, retail, or food service.

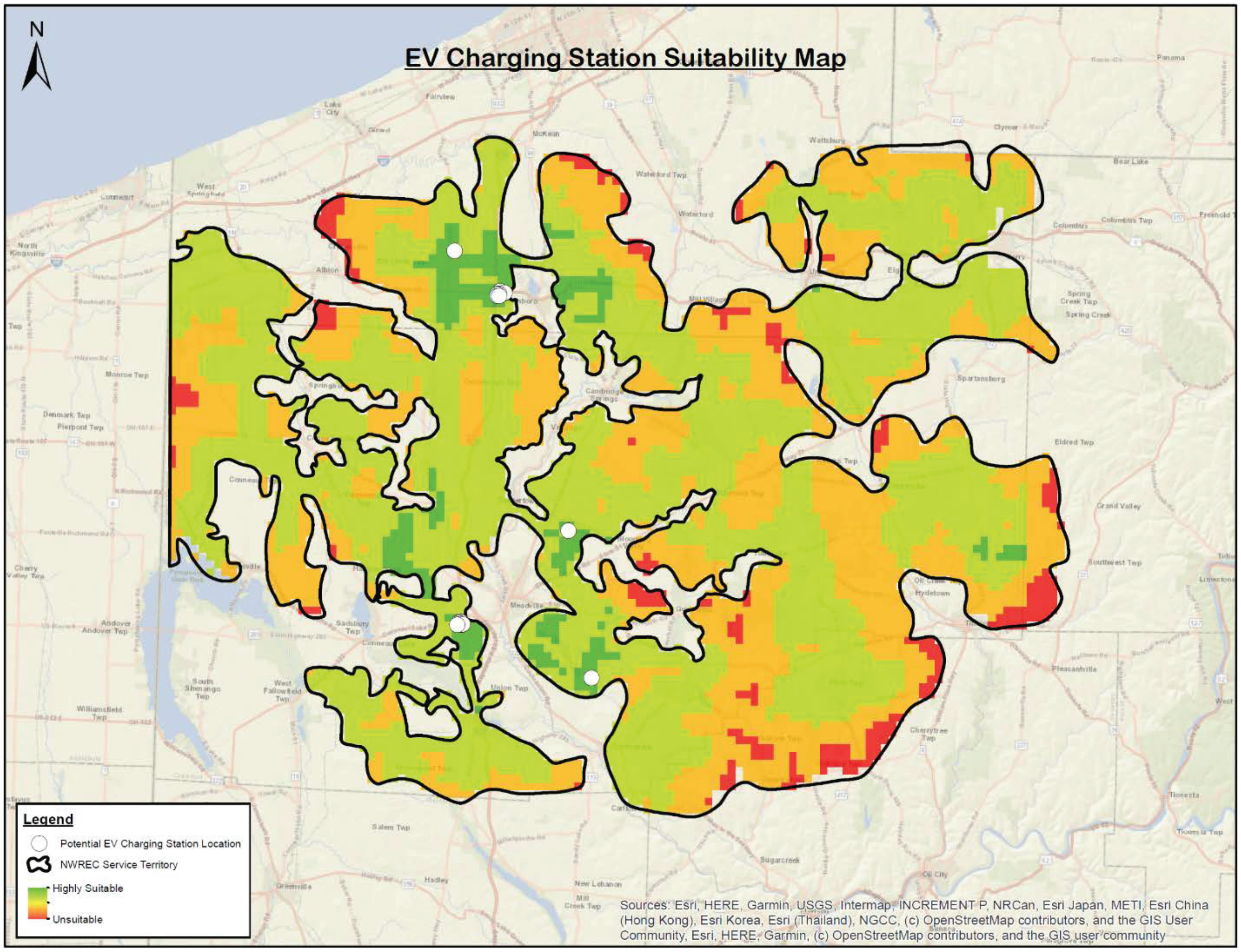

Figure 11: Site suitability map showing optimal areas for a charging station in NWREC service territory

To identify an optimal EV charging station location, narrowing down the results was required. In the study conducted by Csiszár et al. (2020), traffic information was one of the factors used to help identify potential charging station locations along roadways that would help support long-distance trips. The next factor analyzed was the annual average daily traffic information from the Pennsylvania Department of Transportation. The areas with higher annual average daily traffic are considered more desirable, assuming that greater traffic volume correlates with a better probability of a driver utilizing an EV charging station. The table below shows the final 20 locations with their corresponding land-use code, average annual daily traffic counts, and suitability level.

Table 3: Suitable EV charging stations

Location	Name	Land Use Code	Average Annual Daily Traffic	Suitability
1	Walmart	Restaurants, Stores	11029	High
2	Washington Towne Center	Restaurants, Stores	11029	High
3	Wendy's	Restaurants, Stores	11029	High
4	Country Fair	Gas Station	11029	High
5	Camboro Veterinary	Restaurants, Stores	11029	High
6	Dunkin'	Restaurants, Stores	11029	High
7	Comfort Suites	Hotel	11029	High
8	Tractor Supply	Restaurants, Stores	11029	High
9	O'Reilly Auto Parts	Restaurants, Stores	11029	High
10	Meadville Cinema	Recreation	3638	Moderate
11	Timber Creek Tap & Table	Commercial Retail	3638	Moderate
12	Fat Eddy's	Commercial Retail	3638	Moderate
13	Gianna's Pizzeria	Commercial Retail	3638	Moderate
14	Valenza Restaurant	Commercial Retail	3638	Moderate
15	Dollar General	Commercial Retail	3638	Moderate
16	Griffin Motors	Commercial Retail	3638	Moderate
17	CrossFit XBA	Commercial Retail	3638	Moderate
18	Edinboro McKean VFW Post 740	Restaurants, Stores	2113	Low
19	Smith's Hardware & Supply	Commercial Retail	818	Low
20	Woodcock Creek Reservoir	Recreation	178	Low

The potential EV charging station locations (Figure 12) will go through a field checking process before determining where the level 3 charging station should be placed. This potential location will help close the charging station infrastructure gap and help electric vehicle ownership in rural areas become a realistic option.

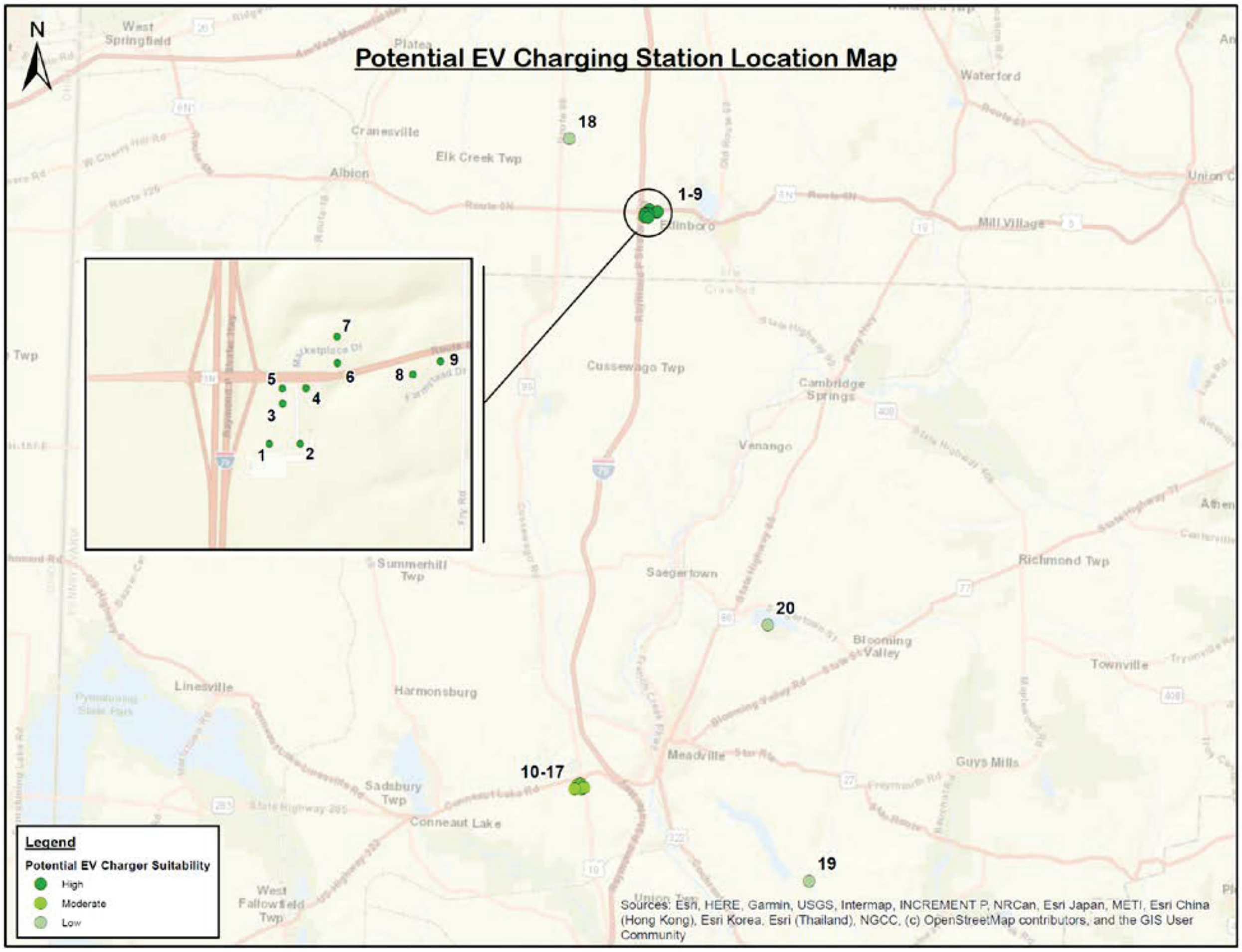

Figure 12: Map showing potential locations for an EV charging station

5. Next Steps

Once the optimal location has been identified, the results will be shared with Northwestern REC's management team. After the results have been shared with management, it will be necessary to contact the parcel owner of the candidate location to discuss a potential partnership with NWREC in placing the EV charging station. Once the location is finalized, it would be beneficial to share this information with Northwestern REC's members. The main reason to share this information with the members is to show them that Northwestern REC is pioneering the way for electric charging infrastructure in rural areas. It will also help educate the members on the benefits of electric vehicles, which could increase electric vehicle adoption rates in the rural area that NWREC serves. Additionally, sharing the methods used in this project with other rural electric cooperatives would be beneficial in helping identify more EV charging stations in rural areas.

6. Conclusions

The lack of rural EV charging station infrastructure is an obstacle that must be surmounted in order to facilitate widespread electric vehicle adoption. Determining the most suitable EV charging locations requires research and planning. This paper aims to develop a methodology to identify suitable locations for the deployment of EV charging stations in rural environments. This study used the Analytical Hierarchy Process combined with GIS methods to identify rural EV charging stations best located in proximity to power supplies, main roads, existing EV charging station infrastructure, EV ownership rates, and population density. Using these methods resulted in 20 suitable locations within NWREC's service territory. The results and methods used in this paper aim for repeatability that can be applied in other rural areas. As such, rural areas must be a primary focus of EV charging station development in order to overcome the obstacles hindering electric vehicle adoption.

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