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An Assessment of the Potential for Utility-Scale Solar Energy Development on the Navajo Nation

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ABSTRACT

The Navajo Nation covers about 27,000 square miles in the Southwestern United States with approximately 270 sunny days a year. Therefore, the Navajo Nation has the potential to develop utility-scale solar photovoltaic (PV) energy for the Navajo people and export electricity to major cities to generate revenues. In April 2019, the Navajo Nation issued a proclamation to increase residential and utility-scale renewable energy development on the Navajo Nation. In response, this research assesses the potential for utility-scale solar energy development on the Navajo Nation using criteria such as access to roads, transmission lines, slope/terrain data, aspect/direction, and culturally sensitive sites. These datasets are applied as layers using ArcGIS to identify regions that have good potential for utility-scale solar PV installations. Land availability on the Navajo Nation has been an issue for developing utility-scale solar PV, so this study proposes potential locations for solar PV and how much energy these potential sites could generate. Furthermore, two coal-fired power plants, the Navajo Generating Station and the San Juan Generating Station, will close soon and impact the Navajo Nation's energy supply and economy. This study seeks to answer two main questions: whether utility-scale solar energy could be used to replace the energy generated by both coal-fired powerplants, and what percentage of the Navajo Nation's energy demands can be met by utility-scale solar energy development? Economic development is a major concern; therefore, this study also examines what utility-scale solar development will mean for the Navajo Nation economy. The results of this study show that the Navajo Nation has a potential PV capacity of 45,729 MW to 91,459 MW. Even with the lowest calculated capacity, utility-scale solar PV has the potential to generate more than 11 times the power of the NGS and SJGS combined.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
APS	Arizona Public Services Company – large utility company in Arizona
DOE	Department of Energy
ESI	Energy Sovereignty Institute
KSP	Kayenta Solar Project – utility-scale solar PV
kW	Kilowatt = 1,000 Watts
kWh	Kilowatt hour
LEED	Leadership in Energy and Environmental Design
MOU	Memorandum of Understanding
MW	Megawatt = 1,000 kilowatts – used to specify capacity
MWh	Megawatt hour – used to specify generation
NGS	Navajo Generating Station – coal-fired power plant
NREL	National Renewable Energy Laboratories
NTUA	Navajo Tribal Utility Authority
PPA	Power-Purchase Agreement
PV	Photovoltaic
SEIA	Solar Energy Industries Association
SJGS	San Juan Generating Station – coal-fired power plant
SRP	Salt River Project – owner of NGS
TEP	Tucson Electric Power Company
USGS	United States Geological Survey
WAPA	Western Area Power Administration – large utility

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1. BACKGROUND

The Navajo Nation reservation, located in the Southwestern United States, is comprised of land mostly in Arizona and partially extending into New Mexico and Utah. The total land area is about 27,000 square miles (Begay). According to the 2010 Census, the population of enrolled Navajo members living on the Navajo Nation was approximately 157,000 people ("Navajo Population"). Furthermore, there are 110 Chapter Houses on the Navajo Nation, which function similar to municipalities. The Navajo people of this area are dispersed throughout the reservation, making it difficult to provide grid access to electricity to all, especially to those that live in very rural areas. For those that are not connected to the grid, residential solar is a potential solution to energy poverty on the Navajo Nation since it is estimated that between 18,000 and 34,000 Navajo people living on the Navajo Nation lack access to electricity (Begay, Tarasi). For those connected to the grid, utility-scale solar energy has been seen as a solution to mitigating the effects of closing the Navajo Generating Station and Kayenta Mine on the Navajo Nation by providing energy security and revenue. This study examines how utility-scale solar can be used to replace the energy generated by the Navajo Generating Station (NGS) and the San Juan Generating Station (SJGS) to benefit the Navajo people, and how much of the Navajo Nation's energy usage can be covered by solar energy. In addition, the cost and location for utility-scale solar will be examined to analyze the feasibility of such a project and suitable land for future projects. This study also examines the social aspect of solar development by assessing how utility-scale solar energy development will affect the lives of Navajo people.

The electricity distributed throughout the Navajo Nation by the Navajo Tribal Utility Authority (NTUA) comes from three main sources: Western Area Power Administration (WAPA), Tucson Electric Power Company (TEP), and Arizona Public Services Company (APS) (Terry). Between 2016-2018, the Navajo Nation used 874,582,788.00 kWh of electricity that NTUA purchased from these outside entities (Terry). APS and TEP are co-owners of the NGS located right outside the Navajo Nation which is supplied by the Kayenta Mine on Black Mesa ("Navajo Generating Station"). The NGS has a capacity of 2,250 MW with three 750 MW units in use, and the SJGS's capacity is 1,700 MW when all four units are in use (Cassella). In 2017, two units of SJGS's units were decommissioned, so only two units are in-use currently. The SJGS is scheduled to close in 2022 ("San Juan Generating Station"). The coal from the Navajo Nation generates electricity that is sent to APS and TEP, then NTUA buys electricity from both of those companies. Furthermore, TEP also owns a portion of the SJGS (Cassella).

In an effort to generate energy within its own boundaries, the Navajo Nation has been making progress developing utility-scale solar photovoltaic (PV) systems with the Kayenta Solar Project (KSP) Phase 1 and 2 located near Kayenta, AZ. As part of the Department of Energy's (DOE) Indian Energy Internship Program, researchers conducted a site visit to the KSP Phase 1 and 2, NTUA Headquarters in Fort Defiance, and NTUA branches in Chinle and Kayenta. The NTUA Headquarters in Fort Defiance and the Chinle branch—both Leadership in Energy and Environmental Design (LEED) certified buildings—have solar PV systems set up to produce electricity for those offices. The KSP Phase 1 is a 27.3 MW solar PV field, and the KSP Phase 2 is a 28 MW solar PV field adjacent to the KSP Phase 1 project (Garcia-Likens). Combined, the KSP Phase 1 and 2 utilizes 365 acres of land to produce approximately 55 MW of electricity (Terry). KSP Phase 1 costed about $64 million in total (Terry). The company that installed the solar panels for the KSP Phase 1 was Isolux Corsan, an international company operating in 35 countries ("Isolux Will Build"). For the KSP Phase 2, Swinerton Renewable Energy, an American company located in San Diego, installed the solar panels ("Kayenta Solar Project").

In April 2019, the President and Vice President of the Navajo Nation issued the Navajo Sunrise Proclamation which emphasizes the development of renewable energy built upon four fundamental principles: 1) diverse energy portfolio that favors job creation, 2) restoration of land and water, 3) rural electrification, and 4) utility-scale renewable energy development to support the Navajo Nation as well as the Western United States ("Office of President"). Examining the KSP Phase 1, approximately 300 people, 85% Navajo, were hired, for a few months, to install the solar PV panels, and the total Navajo workforce was paid $5.2 million along with specialized training in solar construction (Garcia-Likens). The KSP Phase 1 also generated more than $3 million in taxes for the Navajo Nation, and overall, the development on the KSP Phase 1 generated $15.6 million in economic activity in the communities surrounding the project (Garcia-Likens). On September 20, 2019, the Navajo Nation finished the construction of Phase 2 of the KSP, so the KSP Phase 1 and 2 generate 56 MW of electricity or enough electricity to power 36,000 homes (Hensius). The second phase of the KSP created about 150 temporary jobs for Navajo people, approximately half of the amount needed for Phase 1. Like KSP Phase 1, Phase 2 generated $15.5 million in economic impact (Hensius). From this 56 MW solar PV generation facility, the Navajo Nation has seen more than $30 million in economic activity in surrounding communities. The Salt River Project (SRP) has offered technical assistance to the tribe and has signed a Memorandum of Understanding (MOU) to develop up to 500 MW of renewable energy projects on the Navajo Nation (Garcia-Likens and Becenti). The Navajo Nation, along with the help of SRP, plan to expand to other sites, increasing generation and potential economic activity by 10 times.

NTUA currently has 200 residential solar PV systems and hybrid systems with small wind turbines deployed on the Navajo Nation; however, some of these systems can only power basic lighting while larger systems can also power refrigeration (Begay). Additionally, NTUA has also received assistance to extend powerlines to homes not connected to the grid through a project called "Light Up Navajo" ("Light Up the Navajo Nation"). These projects are important for connecting Navajo families to electricity sources, but there are still thousands living without electricity on the Navajo Nation. More research still needs to be done to determine how to bring electricity to them, whether that is through the further deployment of residential-scale solar PV systems, grid connection, or the creation of a microgrid using solar PV. The development of utility-scale solar PV could potentially bring electricity to families living near the solar field by extending transmission lines to their homes. The need for energy development and infrastructure on the Navajo Nation is critical.

There are various considerations when beginning the process of siting utility-scale solar PV. Such facilities can be susceptible to effects caused by technical, economic, environmental, and social factors (Brewer et al.). Solar PV systems are a type of solar energy technology that uses PV solar cells to capture energy from light (photons) to convert it into electricity (current) ("Solar PV Technology Basics"). There are typically two scales of solar PV development: distributed generation or residential solar and utility-scale ("Utility-Scale Solar Power"). Although the differentiation between the two scales are not exact there are two popular definitions of "utility-scale" solar:

1) Energy.gov focuses on electricity production scale, which is often 10 MW or more, and
2) SEIA's definition focuses on the sale of electricity to utility companies, not individual households ("Utility-Scale Solar Power" and "Renewable Energy").

To determine if an area is suitable for utility-scale solar PV development, Majumdar and Pasqualetti (2018) outline technical and environmental constraints like distance from transmission lines, roads, flat areas, solar PV resource potential, and land use. These factors also affect each other. For example, the economic cost for developing utility-scale solar is directly impacted by the distance from transmission lines and roads since the cost of installing transmission lines and roads is incorporated into the total cost of development (Brewer et al.). According to Brewer et al., there are generally two types of cost associated with solar PV development: "hard" costs and "soft" costs. The "hard" cost of developing solar is the price of the physical solar PV system while the "soft" costs are non-hardware costs like planning, permitting, and compliance (Brewer et al.). To reduce the cost of transmission lines and roads, this report focuses on areas within a mile on either side of the transmission lines and within two miles on either side of a road. Furthermore, utility-scale solar PV requires flat land for construction, and Majumdar and Pasqualetti (2018) emphasize areas of land with less than 3% slope. The solar PV resource potential as determined by National Renewable Energy Laboratory (NREL) examines the atmospheric conditions and solar irradiance availability to determine areas that are best suited for solar PV usage and displays that information using a map. According to the NREL tool, the Navajo Nation has an average solar PV potential of 5.6 $kWh/m^2/day$ to more than 6.6 $kWh/m^2/day$ ("Solar Maps").

Currently, there are several competing land-uses on the Navajo Nation: grazing land for livestock, homesite lease land, communities or towns, and culturally sensitive sites. One of the strongest perceived barriers to developing utility-scale solar energy is grazing permittees with or without livestock (Sneezer). On the Navajo Nation, 90% of the land is held in trust by the United States Government while the other 10% of land is fee-simple (Wagner and Harris). This means that only 10% of the land is privately-owned by the occupants while the other 90% of land is held in trust by the federal government. To distribute the land to Navajo people, a tribal member can apply for a homesite lease. This allows them to lease the land for 75 years for residential purposes ("Homesite Lease"). The process of obtaining a homesite lease is thorough and could take years. After a homesite lease is received, a person can choose to renew the homesite lease for another 75 years or transfer the lease into someone else's name which allows families to continue residing in a particular area. Like a homesite lease, a grazing permit allows Navajo people to graze their livestock in a certain area, and the size of the grazing land depends on the amount of livestock. A grazing permit does not give permittees the ownership of the land, but companies or developers must obtain permission from grazing permittees before building on or near grazing land ("Navajo Grazing Regulation"). There is no centralized database with all the grazing land on the Navajo Nation, so it is difficult to identify whether someone has a grazing permit for an area of land. Both land-uses significantly impact energy development on the Navajo Nation, which can make it difficult for the Navajo Nation to produce its own energy.

Energy independence or energy sovereignty is a complex concept. To understand what it means for tribal nations, the concept of sovereignty must be examined first. According to the National Conference of State Legislatures, "sovereignty refers to the right of American Indians and Alaska Natives to govern themselves," and they have the same rights as federal and state governments to "regulate internal affairs" ("An Issue of Sovereignty"). In the Worcester v. Georgia Supreme Court Case (1832), the Supreme Court upheld tribal sovereignty with the argument that tribal nations do not lose their sovereignty once they are subject to the United States, and only Congress has the power to take away their sovereignty ("An Issue of Sovereignty"). Energy sovereignty then becomes the idea of being able to take charge in making decisions about energy that reflects one's values. The Navajo Nation has the potential to become more energy sovereign (Breecker).

Currently, the Navajo Nation can decide where to purchase its electricity from or who to sell their coal to for electricity generation; however, the Navajo Nation is highly dependent on outside utility companies for its electricity or to process the coal. Energy production allows tribal nations to control energy distribution, so they can choose to keep the energy on tribal lands or to export the energy to outside entities. This allows tribal nations to address the needs of their people first before outside companies, and to use revenues to provide support services and programs to meet those needs. As mentioned previously, there are thousands of Navajo people living without electricity across the United States; by producing their own electricity they can directly address the needs of their people. Moreover, the choice remains with the communities, and they can determine what direction they would like to take to benefit themselves.

2. RESEARCH APPROACH

To determine the locations best-suited for utility-scale solar development, ArcGIS Pro was utilized to apply a list of criteria to a map of the Navajo Nation. The criteria are summarized in Table 1-1. First, data was gathered from NREL, United States Geological Survey (USGS), ArcGIS, and other sources to create a map of the Navajo Nation with all the roads, transmission lines, solar resource potential, terrain, cities, parks, counties, states, and chapters. Sites were chosen if they were within two miles of a transmission line, within two miles of a road, and in a flat area. Using the Proximity Tool, buffers were created on either side of a transmission line and road to illustrate the distance constraints, and to find the areas where both buffers overlapped with the flat areas. Multiple Ring Buffers were drawn around cities or towns at one to three miles away to ensure that potential solar PV locations were not located too close to those communities. Using the Clip Tool, the Slope 2% layer—flat land—was first clipped by the Road Buffers layer to leave only the flat areas of land that fell within two miles of a road on either side. The new layer, created with only the flat lands that fell within a road buffer, was clipped again by the Transmission Line Buffers layer, resulting in flat areas of land that fell within two miles of both a road and transmission line. To filter out areas of land that were less than 300 acres, the Select By Attribute Tool was used to select lands that were less than 300 acres in size, and they were deleted. As a result, only the flat areas of land that fell within two miles of a road and transmission line and greater than 300 acres in size were left as potential sites for utility-scale solar PV development. Robust solar PV potential on the Navajo Nation was not a concern as resource potential ranges between 5.6 kWh/m^2/day to more than 6.6 kWh/m^2/day ("Solar Maps").

Table 1-1. Criteria for Utility-Scale Solar PV Development

Type	Criteria
Slope	≤2%
Roads	Within 2 miles
Transmission Lines	Within 2 miles
National and State Parks	Within 1.5 miles

One of the original goals of the research was to apply grazing land and culturally-sensitive sites as additional criteria to offer a more realistic analysis of the potential locations and amount of land available for utility-scale solar energy development; however, there is a lack of data on grazing and culturally sensitive sites for the entire Navajo Nation. There are estimated to be 10,000 grazing permittee holders ("Arizona Indigenous Rangelands") and further research needs to be conducted to determine grazing areas on the Navajo Nation. In addition, culturally-sensitive sites need to be catalogued and removed from potential development locations; however, not all sacred sites and culturally-sensitive sites have been shared or found. Unfortunately, these gaps in data make it difficult to accurately identify areas of land that would ultimately be suitable for utility-scale solar PV development. However, the strict criteria set by this study offers a conservative estimate of the available land for utility-scale solar PV development which may more closely resemble the actual amount of available land after considering grazing and culturally sensitive sites.

3. RESULTS AND DISCUSSION

This report seeks to answer two main questions about utility-scale solar PV development on the Navajo Nation: does the Navajo Nation have the land resource available to develop enough utility-scale solar PV to replace both the NGS and SJGS, and what percentage of electricity used on the Navajo Nation can be supplied by utility-scale solar PV?

The first question focuses on the area of land identified as suitable for utility-scale solar PV development when all the exclusions are applied to the Navajo Nation. To answer this question, the available solar resources on the Navajo Nation must be considered as well as the area of the suitable land. The importance of land in Navajo culture, and the different uses for land has made utility-scale solar PV development questionable for many Navajo communities. Furthermore, the use of coal on the Navajo Nation has been a major source of revenue for the tribe. The closure of both power plants presents a significant reduction in revenue. Additional utility-scale solar development could offset some of those economic losses through the sale of electricity.

The second question concentrates on the Navajo Nation's electricity use compared to the potential electricity generation from utility-scale solar PV based on suitable land areas. In addition, this question suggests the potential for economic development by examining the excess electricity that can be sold to utility companies off the Navajo Nation. Economic development is an important issue when discussing energy on the Navajo Nation. The coal industry has provided millions of dollars in revenue and thousands of employment opportunities to Navajo people while the Kayenta utility-scale solar PV development project employed hundreds of people, but only for a short period of time (Garcia-Likens).

Coal has been a major source of revenue and employment on the Navajo Nation, beginning in the early 1960s when the construction began on the Four Corners Power Plant (Baars). The NGS was constructed in the late 1960s and became operational in the 1970s ("Navajo Generating Station"). The coal industry on the Navajo Nation supplies thousands of employment opportunities; the NGS and Kayenta Mine has supplied approximately 700 jobs to Navajo people (Rainey). Furthermore, the Navajo Mine supplies approximately 300 jobs to Navajo people (Clay). Combined, the NGS and Four Corners Power Plant create more than $50 million in direct revenues annually to the Navajo Nation. This is approximately 25% of the Navajo Nation's budget (Office of Management and Budget). At the end of 2019, the NGS will close due to economic reasons; natural gas is a cheaper fuel source than coal ("Navajo Generating Station"). Then in 2022, the SJGS plans to shut down due to the new 2040 emissions-free goal set by New Mexico, as well as the new energy law which emphasizes the use of renewable energy ("New Mexico city aims to keep"). This is the trend across the United States as the price of natural gas continues to fall. Moreover, there has been a 40% decline in coal usage to generate power over the last decade (Gruenspecht). Compared to natural gas plants and renewable energy, coal-fired plants are becoming less economically viable. Renewable energy represents one way to recoup some of the revenue losses once the coal-fired power plants close (Gruenspecht). The Navajo Nation is located in a prime area for solar PV development since it is the largest Native reservation and has solar resources available.

The solar PV resource data used for this report was taken from NREL's Photovoltaics Resource Map of the United States that averaged solar resource between 1998 and 2009 ("Solar Maps"). Using ArcGIS and the data from this map, another map was created overlaying the boundaries of the Navajo Nation on top of the Photovoltaics Resource Map, which can be seen in Figure 1-1. Examining Figure 1-1, the average solar resource on the Navajo Nation ranges from 5.6 to more than 6.6 $kWh/m^2/day$. This map illustrates that the Navajo Nation has a significant solar resource

compared to other regions outside of the Southwest that do not receive as much solar resources. Since the Navajo Nation has significant solar resource, utility-scale solar PV systems would function efficiently. Utility-scale solar PV has a great potential on the Navajo Nation to become a major source of electricity generation that can be used to supply electricity to homes on the Navajo Nation or be sold as revenue to support the Navajo people. Furthermore, the revenues could also be used to support rural electrification projects such as transmission line extension or residential-scale solar PV system distribution to families living without electricity on the Navajo Nation. One possible employment opportunity for Navajo people would be to hire workers who helped install the utility-scale solar PV systems to also begin training to become troubleshooters or maintenance personnel for residential PV systems in their area. To streamline that process, NTUA could begin using the same solar PV systems for both utility-scale and residential-scale, depending on the economic feasibility. Since the Navajo Nation has the appropriate solar resources available, the amount of land available to utility-scale solar PV development now becomes a point of discussion and research.

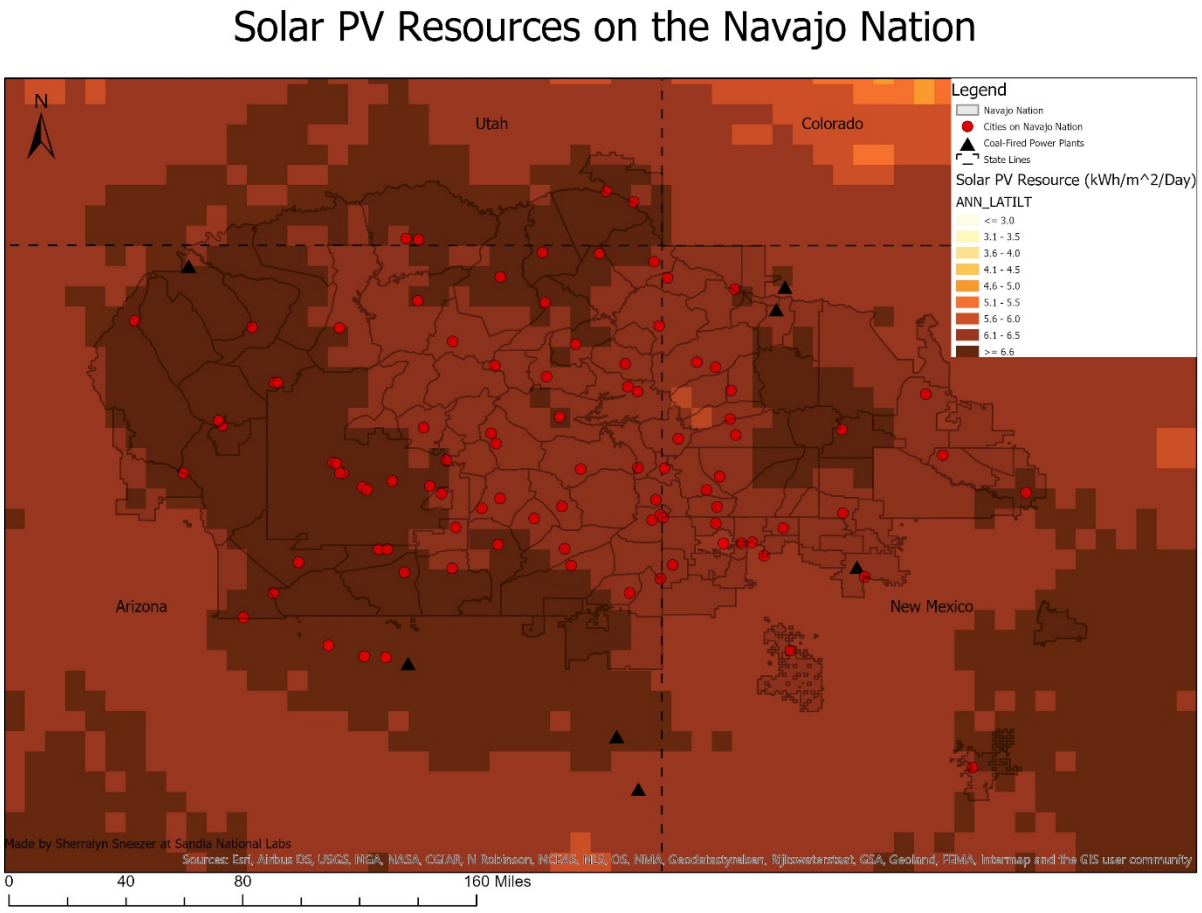

Figure 1-1. Map showing the average solar resource on the Navajo Nation and the Hopi Nation.

The total area of land suitable for utility-scale solar PV development is 457,294 acres. It is estimated that utility-scale solar power plants need a power density of 5 to 10 acres per megawatt (MW) which determines the potential capacity of an area of land. Capacity is the maximum power output, meaning the maximum amount of electricity that can be produced when a generator is functioning at its maximum (Mueller). The KSP Phase 1 and 2 combined utilized a total of 365 acres and has a

capacity of approximately 55 MW, which is 6.6 acres per MW (or 37.9 MW/km^2). Using this conversion, the suitable land for utility-scale solar PV development on the Navajo Nation has a potential capacity of 45,729 MW to 91,459 MW. Even with the lowest calculated capacity, utility-scale solar PV has the potential to generate more than 11 times the power of the NGS and SJGS combined. Doris et al. and Milbrandt et al. also assess the utility-scale solar PV potential, along with other renewable energy technologies, on the Navajo Nation as well as on other tribal lands. The methodology for determining the capacity assumes a power density of 48 MW/km^2 for Doris et al. and 32 MW/km^2 for Milbrandt et al. Using these power densities, the potential capacity for utility-scale solar PV development on the Navajo Nation is 88,848 MW (48 MW/km^2) and 59,232 (32 MW/km^2) which falls within the range of estimated capacities mentioned previously. The KSP Phase 1 and 2 outputs converted to a power density result in 37.9 MW/km^2, well within the range of power density estimates from Doris et al. and Milbrandt et al.

Converting the utility-scale solar PV capacity to generation used the same analysis methodology from Doris et al. (2013). This methodology assumes that the solar PV systems in use are single-axis tracking collectors aligned North to South at a 0 degree from the horizontal (Doris, 2013). Furthermore, Doris et al. (2013) assumes a power density of 48 MW/km^2 while Milbrandt et al. (2018) assumes a power density of 32 MW/km^2 with 14% system losses. Considering these assumptions, the estimated electricity generation would be 204,466,809.6 MWh for a power density of 48 MW/km^2 and 136,311,206.4 MWh for a power density of 32 MW/km^2. Comparing these estimates to both Milbrandt et al. and Doris et al., Milbrandt et al. estimates a generation of 1,829,623,629 MWh and Doris et al. estimates a generation of 2,494,474,583 MWh. The electricity generation results calculated in this study are approximately 93% less than the results calculated by Doris et al. Despite the reduced total, the estimate in this study is still significantly greater than the combined energy production of the NGS and SJGS.

The DOE Office of Indian Energy used Milbrandt et al. to develop the Tribal Energy Atlas, an interactive online tool designed to illustrate the potential renewable energy development on tribal lands ("Tribal Energy Atlas"). Moreover, the Milbrandt et al. study uses the same analytical methodology as the Doris et al. study, which also estimates the potential for renewable energy development on tribal lands. Both studies examine the Navajo Nation as a strong candidate for the development of utility-scale solar PV; however, their focus is on all tribal lands and renewable energy systems and is more general than the approach in this study. To determine the amount of available land for utility-scale solar PV development on tribal lands, both studies use the same list of exclusions: slope >5%; contiguous area <1 km^2; incompatible land-uses (urban areas, wetlands, forested areas, water, etc.); and protected areas (parks, wildlife refuges, wilderness) (Doris et al. and Milbrandt et al.). By excluding each of these factors, Doris et al., was left with a total land area of 22,678 km^2 while Milbrandt et al. had a total land area of 18,987 km^2 which is the suitable land for utility-scale solar PV development. This study had stricter criteria since the focus is only on the Navajo Nation. Results show an estimated 1,851 km^2 of total land area. The difference in the total amount of suitable land for solar PV development leads to the large difference in the estimated capacity and generation compared to the estimates of both Doris et al. and Milbrandt et al. Since their study is about the renewable energy potential on all tribal lands, they do not consider the different types of land-uses on the Navajo Nation or the method in which land is divided between grazing and homesite leases. They overlook the important role land plays on the Navajo Nation, and how different tribal land policies or practices may affect renewable energy development.

In addition, the range in generation and capacity for utility-scale solar PV development reflects the differences in the planning processes of developing utility-scale solar PV, which may be a result of

the different environmental or technological factors that constrain development. For example, available funding would determine the quality and quantity of the solar PV systems that are selected, which directly impacts the generation of electricity. Furthermore, power density or installation density is an estimate of how much energy a piece of land could potentially produce. This is also dependent on the solar PV systems that are chosen for energy production. Different solar PV contractors install panels with different yields. This can be seen when examining the KSP Phase 1 and 2 where two types of panels were used with different power densities.

The importance of land to Navajo people and culture must not be overlooked when discussing the potential for any type of development that consumes large amounts of land on the Navajo Nation. Navajo people develop attachments to the land, both grazing and homesite lease land, especially if it has been in their family for generations. This attachment could be spiritual and subsistent in nature since Navajo families depend on their land for both themselves and their livestock which also function as a form of income and food (Kelley and Francis). For example, Kelley and Francis summarize this connection by stating, "the Holy People put us here and the people considered all things sacred, the land, plants, and animals – we are their children. When it is cold, we burn the wood, which keeps us warm." Thus, by reducing the area of land or relocating Navajo families, they may not be able to live off the land as they have been doing for previous generations. Many people on the Navajo Nation have grazing permits. This poses a significant threat to the development of utility-scale solar PV development as any development requires the approval of all land-holders (Sneezer 2019). Furthermore, the land may already be occupied by families with homesite leases, and they would be forced to relocate if utility-scale solar PV is implemented nearby. However, utility-scale solar PV development does not result in the destruction or degradation of land, so it is possible to allow livestock to graze beneath the panels if the solar PV field was designed to accommodate livestock.

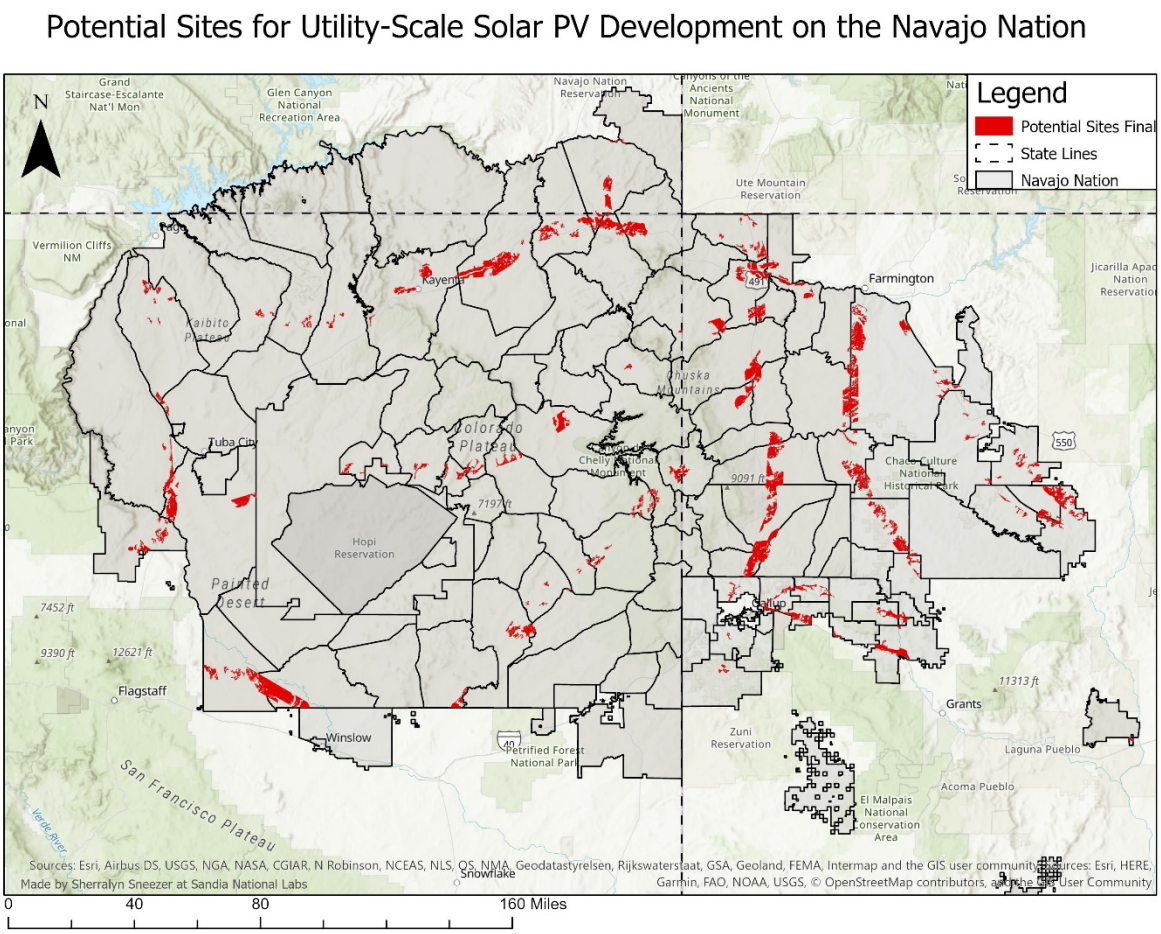

Figure 1-2. 213 Potential Sites for Utility-Scale Solar PV Development

The second question this report seeks to answer is how much of the Navajo Nation's electricity need could be covered by utility-scale solar PV. As mentioned previously, the Navajo Nation uses an average of 874,583 MWh/year (Terry). Using the methodology provided by Lopez et al., this study calculates the potential estimated annual generation is between 136,311,206 MWh and 204,466,809 MWh. The potential electricity generation far exceeds the Navajo Nation's energy demands. Utility-scale solar PV development has the potential to produce 15,586% to 23,379% of the annual total used electricity on the Navajo Nation which exceeds the amount of electricity needed; therefore, the surplus energy could be sold to utility companies off the Navajo Nation. It is important to note that unless energy storage is integrated into the system, the utility-scale solar PV fields will be unable to provide any electricity at night or on cloudy days. This is an important consideration as there is also electricity demand at night when the solar PV panels are not producing electricity. The KSP Phase 1 and 2 do not have any energy storage, and energy storage for a utility-scale system would be an additional costly step. Furthermore, these estimates are dependent upon the assumption that all the lands highlighted in red as potential sites in Figure 1-1 are developed with utility-scale solar PV. Even though utility-scale solar development would not be able to cover the Navajo Nation's 24-hour energy demands 100% of the time, it presents the Navajo Nation with the opportunity to be more energy independent by producing its own electricity.

The KSP Phase 1 and 2 can be used a model for future utility-scale solar PV installations on the Navajo Nation. Focusing on economic development and job creation, hundreds of employees were hired for both Phase 1 and 2, but most of the people hired were only employed for a short period of time. The contractor and NTUA work on the planning stages together to determine the location and configuration of the solar field. Although NTUA funded this first project, NTUA does not have the financial capacity to fund multiple utility-scale solar projects, so the Navajo Nation would have to find additional sources of funding from different organizations or companies. The Navajo Sunrise Proclamation does not set aside funding for the expansion of utility-scale solar PV on the Navajo Nation, so it is unclear where the source of funding will come from. One potential option would be for SRP and the Navajo Nation to enter into a power-purchase agreement (PPA) since they already have an MOU, which would result in the NTUA selling the electricity generated by a utility-scale solar PV project to SRP. This plan may already be in the works as SRP and NTUA have decided to develop up to 500 MW of renewable energy capacity on the Navajo Nation (Garcia-Likens and Becenti). Through the sale of electricity, the NTUA will be able to continue developing projects which also results in job creation for Navajo people.

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4. CONCLUSION

This report examines the potential for utility-scale solar PV development on the Navajo Nation by applying multiple criteria to eliminate the areas of land not suitable for utility-scale solar PV. The criteria were within two miles of a road and a transmission line, flat land (< 2% slope), and outside any state or national parks. Applying these criteria using ArcGIS Pro to the Navajo Nation, the total estimated area of land suitable for the Navajo Nation is 457,294 acres which has the potential to generate between 136,311,206.4 MWh and 204,466,809.6 MWh of electricity. Even with the stringent criteria (distance), the Navajo Nation has the potential to generate more than enough electricity to power the Navajo Nation and sell the excess for revenue. Moreover, while planning for utility-scale solar PV development, it is important to consider the social impacts and land use rights that are in place on the Navajo Nation to develop utility-scale solar PV in a manner consistent with Navajo cultural beliefs. This study was not able to fully assess the potential for utility-scale solar PV development since grazing land, homesite lease land, and culturally-sensitive sites were not included in the criteria because the data associated with these land-uses is lacking for the entire Navajo Nation. Utility-scale solar PV development can be used to benefit the Navajo Nation through the generation of their own electricity, or energy sovereignty, and economic development once a portion of the Navajo Nation revenue is lost after the closure of NGS.

Going forward, social impacts and land-uses on the Navajo Nation are important factors in making development decisions and future studies need to be considered, so there needs to be more work done to identify the lands on the Navajo Nation with their different uses like homesites, grazing, or culturally-sensitive sites. However, data on culturally-sensitive sites would have to be protected to keep the locations of these sites hidden to prevent potential looting or destruction. Once data are collected, it is important to keep the data updated since people are constantly obtaining more or losing grazing land and homesite leases while new culturally-sensitive sites are being found. Furthermore, the community perceptions of solar development must be understood since the community plays an important role in determining whether utility-scale solar PV is built in that community (Terry). Determining the communities on the Navajo Nation that are more accepting of utility-scale solar PV development will also help in deciding the potential locations of future projects. In addition, utility-scale solar PV development is an expensive project with most of the cost being upfront, so determining potential sources of funding is crucial for further development. Organizations like the Energy Sovereignty Institute (ESI) are instrumental in determining potential funding sources, and they plan to create an online repository with potential funding sources ("ESI Workshop"). Once the upfront investment is made, the electricity sales will pay off any loans or the cost of installation, generating revenue for the Navajo Nation which will help sustain these types of projects and continue to provide jobs for Navajo people.

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APPENDIX A. Additional Maps of Navajo Nation

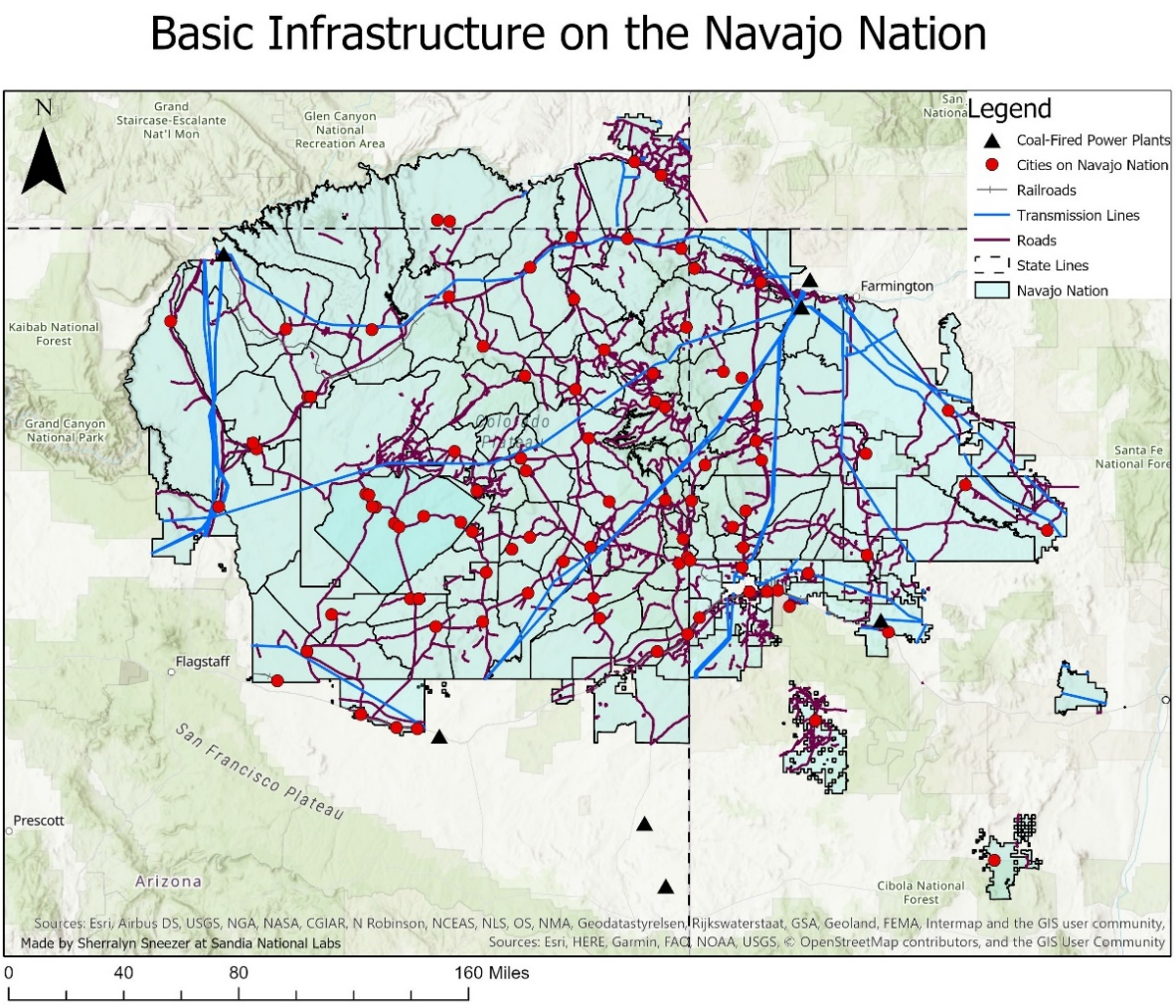

Figure A-1. Infrastructure on Navajo Nation

The infrastructure on the Navajo Nation is important in determining a location for utility-scale solar PV, and this report uses this map of basic infrastructure to indicate most suitable locations for utility-scale solar PV development.

Potential Sites for Utility-Scale Solar PV Development on the Navajo Nation

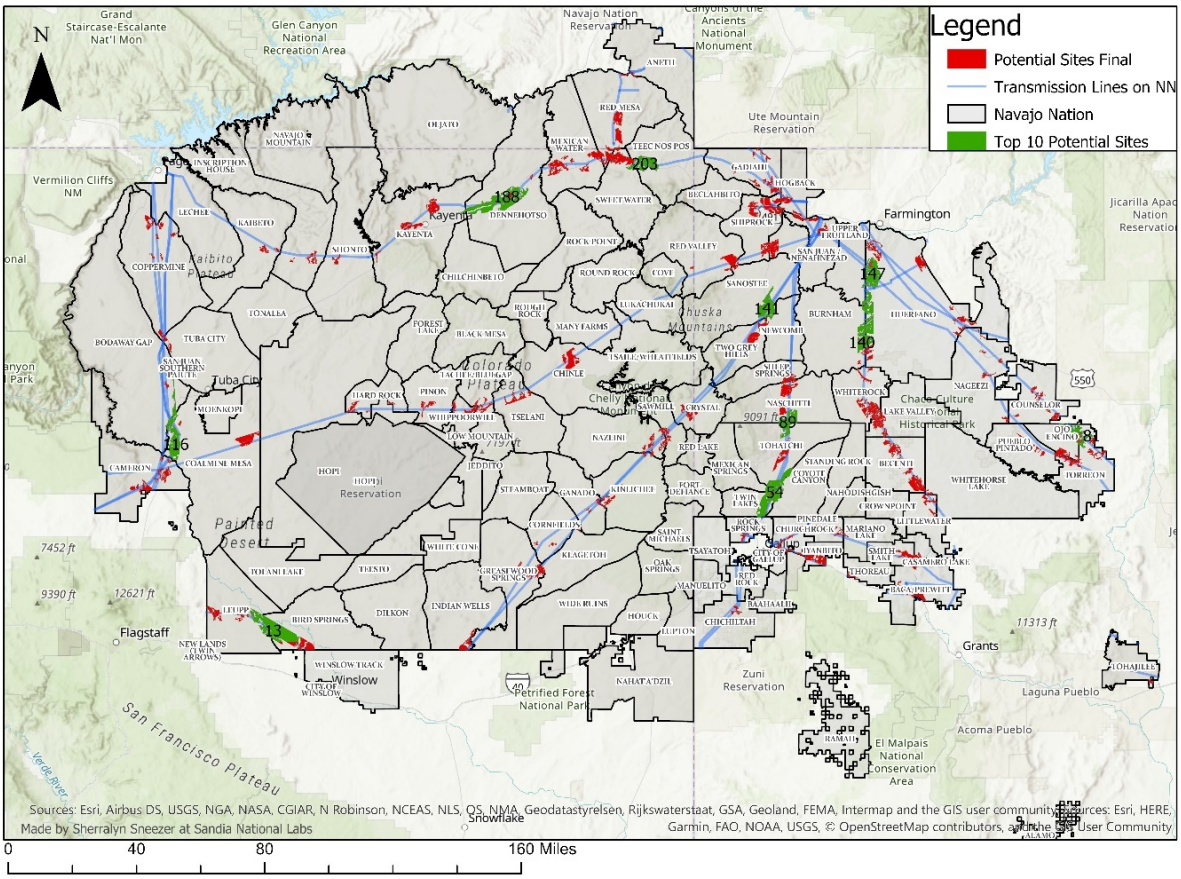

Figure A-2. Potential Sites for Utility-Scale Solar PV Development with Top 10 sites selected

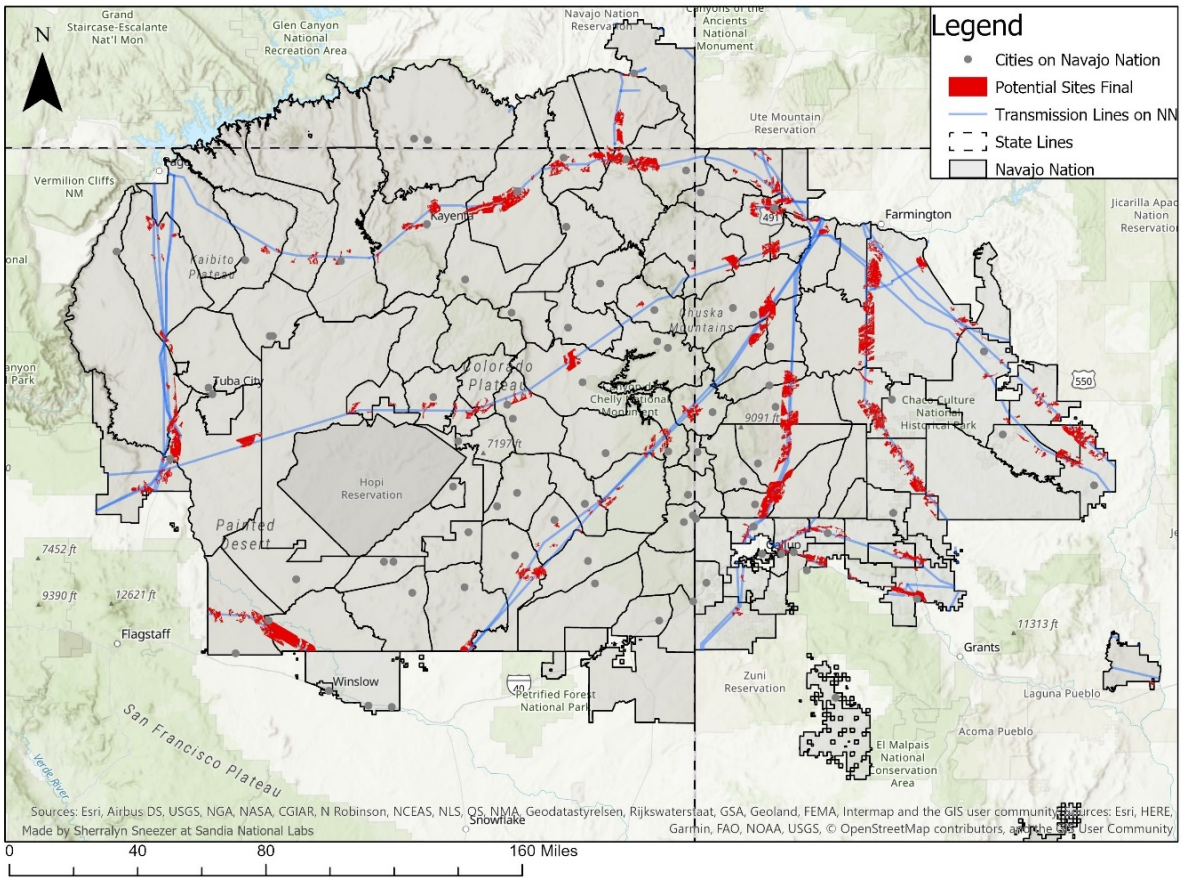

Figure A-3. Potential Sites and Where They Fall Along a Transmission Line

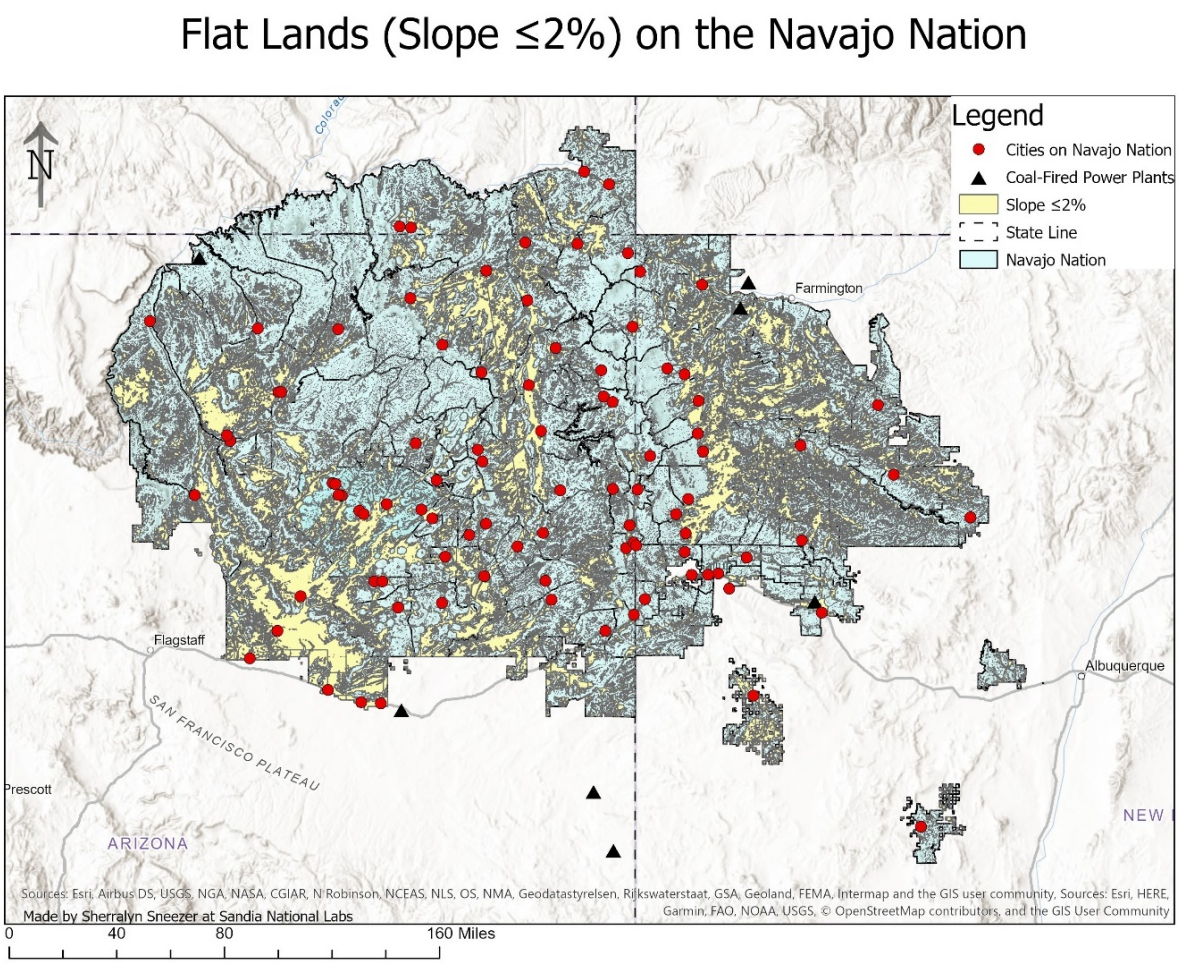

Figure A-4. The suitable flat areas of land for utility-scale solar PV development

Potential Sites for Utility-Scale Solar PV Development on the Navajo Nation

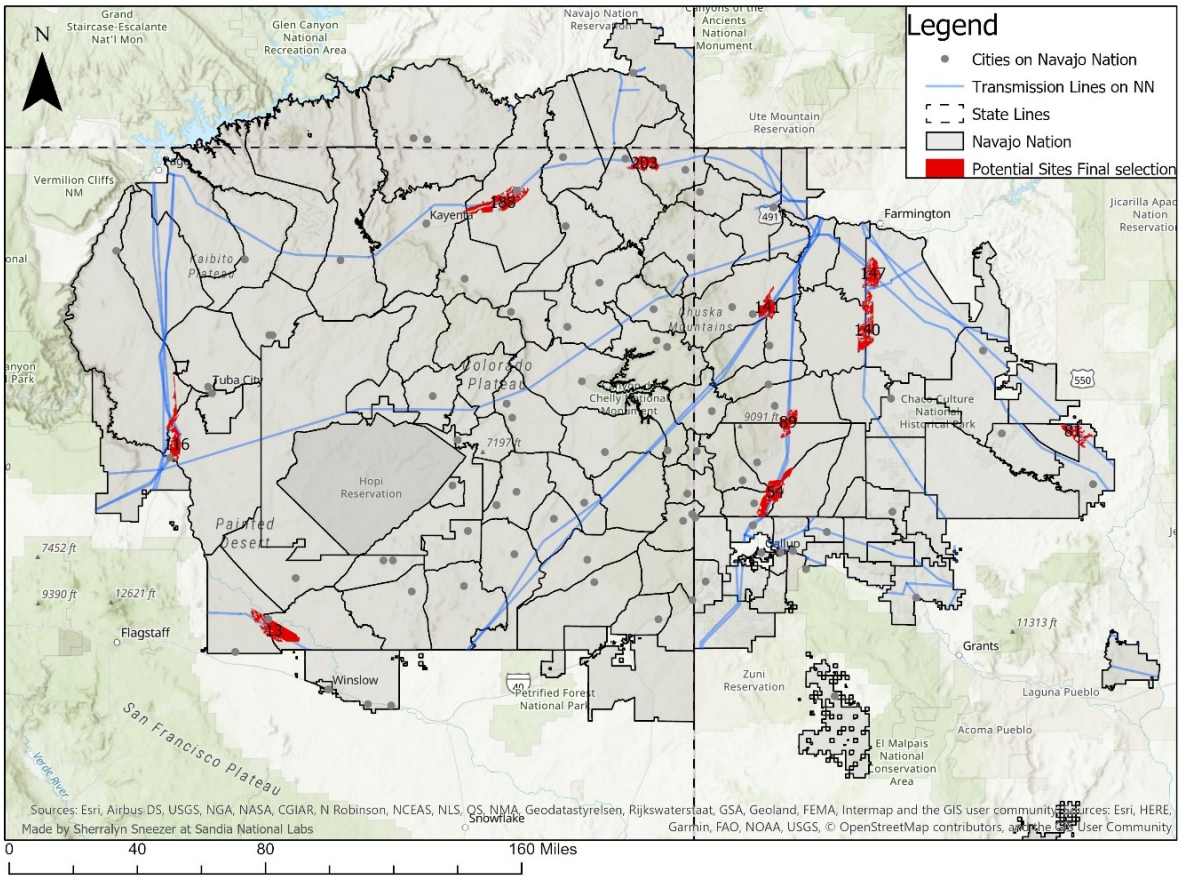

Figure A-5. Top 10 Potential Sites

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