University of Nevada, Reno

The Potential for Repurposing Disturbed Mining Properties in Nevada as Utility-Scale Solar Facilities

A Thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in Geography

by

Ezra J. Jones

Dr. Scott Bassett / Thesis Advisor

May, 2023

THE GRADUATE SCHOOL

We recommend that the thesis
prepared under our supervision by

EZRA JAMES JONES

entitled

The Potential for Repurposing Disturbed Mining Properties as Utility-Scale Solar Facilities

be accepted in partial fulfillment of the
requirements for the degree of

Master of Science

Scott D. Bassett, Ph.D.
Advisor

Kenneth E. Nussear, Ph.D.
Committee Member

Mohammed Ben-Idris, Ph.D.
Graduate School Representative

Markus Kemmelmeier, Ph.D., Dean
Graduate School

May, 2023

ABSTRACT

Stemming from the Paris agreement and an increased commitment to climate consciousness, calls for more sources of renewable energy to replace high emitting portions of our energy sector have become commonplace. Utility-scale solar has received increased attention as a potential solution to these problems, and is being encouraged in many parts of the desert west, including Nevada. However, questions remain about the best placement for these new energy production facilities. The relatively high incident solar radiation make Nevada's deserts ideal candidates for these solar facilities. However, these deserts serve as habitat for numerous animals, some of which are threatened or endangered, and the fences surrounding utility-scale solar facilities are impermeable to many animals, effectively blocking off those regions as habitat (Gray et al. 2019).

Figure 1 - Study areas of this analysis

Disturbed and relatively inactive mining properties are proposed as an alternative to undisturbed desert habitats where already disturbed lands will be repurposed to avoid the habitat loss and degradation

associated with new renewable energy installations and allow for the continued use of existing infrastructure like roads, powerlines and substations that are installed for the mining operations in alignment with the smart-from-the start approach to energy planning supported by Nevada's State Land Use Planning Advisory Council (SLUPAC) (Tibbitts, 2021). Similar proposals have also been championed by numerous agencies and organizations like The Nature Conservancy (Moan & Gower, 2022), the EPA (EPA, 2019) and most recently, the Biden Administration, which has allocated up to 450 million from the Bipartisan Infrastructure Law to advance similar projects on current and former mine lands (DOE, 2023). This thesis analyzes Nevada's solar potential and ranks disturbed mining sites on their potential for use as solar energy installations. A more detailed least cost path style analysis is also performed on mine sites within The Carlin Trend mining district in northeastern Nevada to estimate the potential return on investment from a subset of potential sites. Nuances to this proposal are also explored from a legislative and regulatory perspective which discover an encouraging trajectory of amendments and support for similar projects. This work identified promising groupings of disturbed mining properties in Nevada near Searchlight, Tonopah, and the Twin Creeks mine that may be ideal for utility-scale solar repurposing while also projecting a positive Return on Investment for 28 potential sites in the Carlin Trend mining region. This thesis intends to provide a useful perspective for potential solar developers regarding the repurposing of disturbed mine sites for solar power production.

Dedication

I dedicate this work to all those who have stood by my side and believed in me regardless of whether I am working in the spotlight behind a microphone or tucked away behind a computer in a basement. Your support has meant the world to me and I am grateful for each and every one of you. Thank you!

Acknowledgements

I would like to express my gratitude to my advisor Dr. Bassett, the rest of my committee and the UNR geography community as a whole for making my dream of becoming a Geographer a reality. Without their knowledge and feedback this project would have never come to fruition and without Dr. Bassett's encouragement to pursue a topic that I truly cared about I would have never been able to take pride in my work in the way that I am today.

I am also extremely grateful to the professionals that I have met and received assistance from throughout this project. Including Peter Gower, Tanya Anderson, Michael Clifford and Jaina Moan from the Nature Conservancy who allowed me to partner with their ongoing 'Mining the Sun Initiative' and will hopefully play a large role in getting this work to a place that it can truly make an impact. Also, a big thanks to Keith Hayes with the Nevada Dept. of Environmental Protection who was instrumental in the access of key information and was remarkably supportive of this work.

Lastly, I would like to express my deepest appreciation to my family and church community for believing in me and encouraging me throughout this process. Especially my wonderful wife Hunter who's continued prayer, emotional support and personal sacrifice made it all possible. Additionally, my immediate family who's combined 100+ years of experience in the mining industry and willingness to answer questions, proofread and correct my misunderstandings helped immensely.

Table of Contents

List of Tables

List of Figures

SECTION 1: INTRODUCTION

1.1 Similar Projects and Initiatives

The notion of utilizing mining properties as locations for new energy production facilities isn't entirely new. A 200-megawatt solar project is currently being completed at the old Martiki coal mine in eastern Kentucky (Graham, 2022). In southwest Virginia "six old mining sites owned by The Nature Conservancy will be some of the first utility-scale solar farms in the region" (Murphy, 2022) and a solar array on the former Sullivan Mine in Kimberly British Colombia known as SunMine has been operational since 2015 (Teck Resources Limited, 2023 & EcoSmart Foundation Inc., 2023). The SunMine solar farm has been championed by the International Council on Mining and Metals (ICCM) as a "pioneering sustainable transition to post-closure" that partnered with local communities and indigenous peoples to mitigate the impact of the eventual mine shutdown (Brock et al., 2019). While it may be slightly outside of the focus of this work, abandoned mine sites have also proven to be effective locations for wind farms in Tennessee and Pennsylvania (Nuclear Regulatory Commission, n.d.). Each of the above examples exist on abandoned mine properties not as a part of existing operations in support of their energy needs. However, projects such as these can still be seen as models for potential repurposing projects in Nevada.

In addition to the support from the ICCM, The Nature Conservancy's "Mining the Sun Initiative" (Moan & Gower, 2022) has been heavily promoting projects like those listed (Whealey & Moan, 2020) in Nevada and West Virginia. The EPA's RE-Powering

America's Land Initiative (EPA, 2019) has been tracking completed projects on contaminated lands, landfills and mine sites as a way to educate stakeholders and promote future site development. Additionally, the Department of Energy under the Biden Administration has allocated up to 450 million from the Bipartisan Infrastructure Bill to advance the development of clean energy projects, specifically on current and former mine lands (DOE, 2023). These organizations interest and recent investment show an increasing level of support behind similar projects and Nevada is poised to take advantage of this with more than a million acres of disturbed sites (Moan & Gower, 2022).

1.2 Legislative and Regulatory Background

Legislative and regulatory nuances exist for proposals for reclaimed post-mining land use. However, many of the hurdles are being dismantled due to support for these kinds of projects. Current mining operations in Nevada are regulated by multiple agencies, including the Bureau of Mining Regulation and Reclamation 'BMRR', a branch of the Nevada Division of Environmental Protection 'NDEP' that is responsible for ensuring compliance with the laws within chapter 519A of Nevada's revised statutes (Chapter 519A - Reclamation of Land Subject to Mining Operations or Exploration Projects, 2020). These regulations require a plan for reclamation to be submitted to the BMRR along with the federal bureau(s) responsible for land management on which the sites reside which are typically the United States Bureau of Land Management (BLM) or the United States Forest Service (USFS), for all operations active on or after Oct 1st -1990 (NAC 519A.100). Among other things this reclamation plan must include the type of disturbance(s) made to the land, the disturbance location and a proposed productive postmining land use (NAC 519A.270). As a way of assuring that reclamation will be completed, a surety which is also known as a reclamation bond must be filed with the appropriate agencies, be sufficient to conduct all required reclamation and undergo review “at least every 3 years” (NAC 519A.360, 370 & 380). It is important to recognize that a mining operation is not required to be reclaimed in its entirety prior to the release of surety funds. It is stated that “A portion of the surety covering the reclamation of a discrete part of a disturbance must be released when the requirements of the permit regarding the discrete part of the disturbance have been fulfilled” (NAC 519A.385). This statute opens the door for the partial reclamation of a mining operation and the return of a partial surety by repurposing a single dumping site or similar facility.

The release of surety funds is important to mine operators, and for many years renewable energy development did not guarantee the return of surety. Historically, mines have planned reclamation that prioritized livestock grazing or wildlife habitat as their postmining land use rather than renewable energy production (McNerney et al., 2017). However, on August 30th of 2018 “renewable energy development and storage” was explicitly added to the definition of potential “Productive postmining use of the land” (NAC 519A.070), which not only shows support for the projects explored in this thesis but also implies that it will be simpler for mine operators to regain their reclamation sureties if the land is transitioned into solar energy production.

While this research focuses on the state of Nevada, federal policy has had impacted minds of potential developers on contaminated lands. The Comprehensive

Environmental Response, Compensation, and Liability Act or CERCLA enables the EPA to assign liability onto potentially responsible parties or PRPs (US EPA, 2013). The implementation of CERCLA has been interpreted to be strict and severe and the act "imposes a disincentive for would-be landowners and developers that—whether because of perceived fears of federal enforcement or the cost of protecting against it—discourages development of contaminated lands" (McNerney et al., 2017). However, it is worth noting that many of these fears costly federal enforcement may be largely unfounded given that of the hundreds of NDEP sites across Nevada (BMRR, Most), only 3 have been elevated to this level of regulation (Sutton, 2023). While CERCLA regulation is worth consideration by potential energy developers, most sites fall under state regulation and state agencies provide support to prospective landowners and lessees (McNerney et al., 2017).

1.3 Thesis Objective and Outline

This thesis explores the potential for solar projects, similar to those listed above with a specific focus on solar PV projects in Nevada, but differs from those projects by looking into disturbed mining sites that are not necessarily abandoned. Many mining operations possess dumping grounds that represent a significant disturbance to the surface that may be repurposed or reclaimed without closing the entire mining operation, therefore taking advantage of the opportunity to recover partial reclamation sureties. To many people this proposal is a no brainer, energy production on disturbed land sounds ideal. However, projects that have actually completed this process show that there are more factors necessary for success than just locating the disturbed or abandoned lands.

The placement of infrastructure, solar resources, and protected lands can have a huge impact on whether a proposal of repurposement can effectively transition into a successful solar project. This work introduces a methodology for comparing disturbed sites against one another to prioritize projects with a high likelihood of success at both a statewide scale, and a more detailed scale focused on the Carlin Trend mining district. The statewide analysis will use GIS methods and Multi-Criteria Analysis to build a model that is tested against existing solar sites and used to rank potential sites by their location. The more detailed Carlin Trend region analysis uses a least cost path analysis to predict the placement of necessary transmission infrastructure and model the economic costs and benefits of the proposed sites using NREL software.

The purpose of this thesis is to identify the disturbed mining properties in Nevada that have the highest potential of being repurposed into utility-scale solar sites while simultaneously doing the same at the smaller scale of The Carlin Trend mining district. This work intends to provide perspective and information to be used by potential solar developers or mine operators who may be interested in offsetting their energy costs by repurposing portions of mine operations for solar power production. As proposals for the repurposment of mining lands for renewable energy production increase in popularity and gain notoriety, along with funding (DOE, 2023) this work hopes to serve as an analytical and pragmatic support in the academic literature. The Nature Conservancy and their “Mining the Sun Initiative” have been promoting ideas similar to this for years now and have partnered with this research through supporting data and consultation.

SECTION 2: METHODS

2.1 Statewide Solar Suitability

Different methods have been used to find suitable locations for utility-scale solar power plants throughout the United States (Brewer et al., 2015; Carlisle et al., 2016; Moore-O'Leary et al., 2017). A method combining Geographic Information Science (GIS) and Multi-Criteria Analysis (MCA) was conducted at ASU on the state of Arizona which concluded that between 3.9 and 8.2% of Arizona's land is considered Excellent or Very Good for solar PV development (Mujumdar and Pasqualetti, 2019). Their workflow was effective for ranking land across Arizona by its potential as a good site for utility-scale solar development and was used in this study as a framework for determining the same within the state of Nevada. The use of GIS technology and MCA allows for the overlapping and sometimes conflicting attributes of the land to be compared to one another, which can provide a nuanced understanding of the makeup of the state. Those determinations were then compared to the placement of sites disturbed by mining operations across Nevada. This portion of the Analysis was completed using ESRI ArcPro version 3.03.

2.1.1 Constraints

To determine suitable locations for utility-scale solar facilities defined by the BLM "as projects with capacities of 20 megawatts (MW) or greater that generate electricity that is delivered into the electricity transmission grid" (BLM, 2012), there are two major classifications of spatial data that need to be considered, constraints and ranking factors. Constraints eliminate portions of the landscape from consideration as potential utility-scale solar facilities whereas ranking factors serve to prioritize more affordable and effective sites over more expensive and inefficient sites.

Following constraint identification from ASU, the state of Nevada is constrained by the following; Developed areas, Areas for crop cultivation, Pasture, Forested areas, Wetlands, Military land, National wildlife refuge areas, USFS land, State parks, BLM designated Wilderness and conservation areas, BLM designated areas of critical habitat and environmental concern, BLM designated areas for Recreational activities, BLM designated areas of visual resource management, Places of historical and cultural importance, Areas of high wildfire risk, Areas of high seismic risk and Areas of high flood risk (Table 1). Rivers and a 0.5-mile buffer surrounding them were also considered constrained to avoid the potential for flooding of utility-scale solar facilities during times of high precipitation along with the intention of protecting the vulnerable river banks. The 200ft Wetlands buffer is considered constrained for the same reasons, the habitats are more likely to be vulnerable and wetlands represent an increased risk for potential flooding. A modification to the ASU methodology consisted of buffering and exclusion of land within 0.05 miles from roads, highways and railways. They elected to exclude these areas, however for this analysis they were left in due to the fact that many of the major road and rail features were already excluded from the analysis due to their classification as "Developed areas" within the National Land Cover Database (NLCD, 2019) which I used for their exclusion. Additionally, roads that were not excluded because of their classification as developed land were small and typically dirt which would be easier to move or shift if an area was selected for solar development. The data for each constraint were brought in from their respective sources and combined to ensure all land that should be restricted was covered. In many cases BLM data were joined with Forest Service data, or specific sites were digitized using documentation from sources lacking geospatial data. Each constrained layer was combined to form a comprehensive constraints layer reducing the scope of land considered for utility-scale solar placement. The constrained area covered 1,135,301.8 acres and covered roughly 48.94% of Nevada's total area leaving 1,135,301.8 acres for consideration (Figure 2).

Table 1 Indicates the Data source of each of the constrained areas of the Analysis

Constraint	**Data Source**
Developed Areas	2019 NLCD (CONUS) Land Cover: (Dewitz, 2019)
Areas for Cultivation	2019 NLCD (CONUS) Land Cover: (Dewitz, 2019)
Pastured Areas	2019 NLCD (CONUS) Land Cover: (Dewitz, 2019)
Forested Areas	2019 NLCD (CONUS) Land Cover: (Dewitz, 2019)
Wetlands and 200ft buffer	2019 NLCD (CONUS) Land Cover: (Dewitz, 2019)
Military Land	Data.gov: Military Installations, Ranges, and Training Areas: (DOD, 2021)
Areas for Wildlife	US Fish and Wildlife Service opendata.arcgis: (CDWG@fws.gov, 2022)
FS Land	USDA Forest Service Geodata Clearinghouse: (USFS Enterprise Content, 2015)
National and State Parks	NPS Open Data: (SvcNISCGISSQLtk@nps.doi.net, 2019), Extensive Digitization based off of esri Community Map Base map and NV Division of State Lands Web Map: (NV NDSL, n.d.)
BLM Wilderness and Conservation	BLM Solar Energy Program Resources: (blmsolarwebmaster@anl.gov, 2012) , USFS Enterprise Content National Wilderness Areas: (USFS Enterprise Content, 2015) , Misc shapefiles from Wilderness Connect: (Ronald, 2019)

BLM Critical Habitat and Environmental Concern	BLM Solar Energy Program Resources: (blmsolarwebmaster@anl.gov, 2012)
BLM Designated Recreation areas	BLM Solar Energy Program Resources: (blmsolarwebmaster@anl.gov, 2012), USDA Forest Service Geodata Clearinghouse - OtherNationalDesignatedArea layer: (data@fs.fed.us, 2023)
BLM areas of Visual Resource Management	BLM Solar Energy Program Resources: (blmsolarwebmaster@anl.gov, 2012), USDA Forest Service Geodata Clearinghouse OtherNationalDesignatedArea layer: (data@fs.fed.us, 2023)
Historical and Culturally Import areas	BLM Solar Energy Program Resources: (blmsolarwebmaster@anl.gov, 2012), National Register of Historic Places: (Stutts, 2014)
High Wildfire Risk	Forest Service Research Data Archive with the Top 20^{th} percentile excluded: (Scott et al., 2020)
High Seismic Risk	USGS Pubs Warehouse: (Petersen et al., 2011)
High Flood Risk	National Flood Hazard Layer (Classified as FLD_ZONE A)
Rivers and 0.5mile Buffer	Esri Data and Maps: (Esri Data and Maps, 2020)

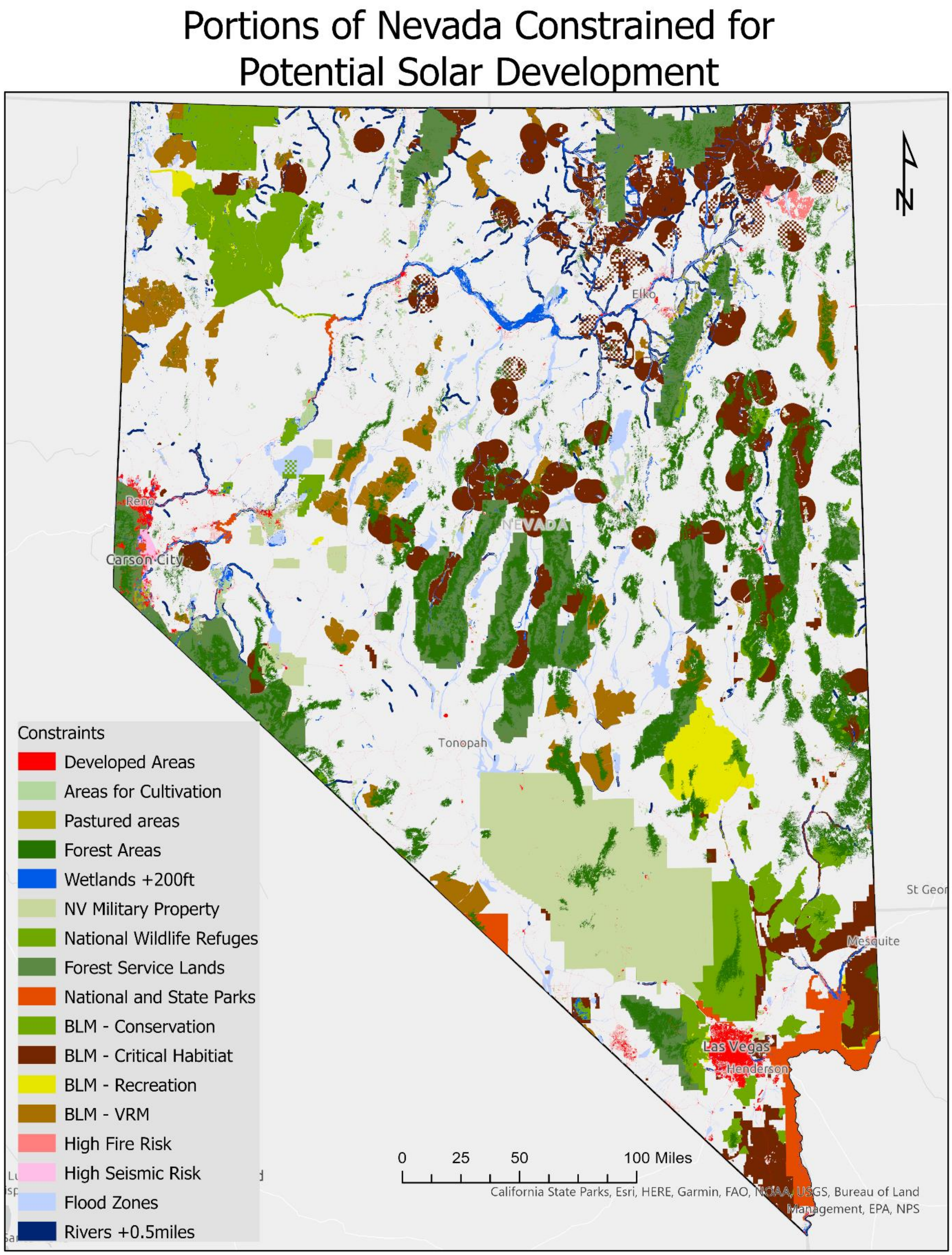

Figure 2 - Portions of Nevada Constrained for Potential Solar Development

2.1.2 Ranking Factors

The land still available for consideration after constraints were applied was ranked based on 5 variables; The slope and aspect of the land, Solar Irradiance, proximity to transportation infrastructure (Roads and Rail), proximity to Powerlines and proximity to Electrical Substations. Each variable was used to create a ranking surface with values ranging from 0 to 3 in alignment with the measurements used in the ASU analysis. Proximity to substations was an addition made to the ASU analysis which adopted the measurements used to classify land in proximity to transportation infrastructure and powerlines, assuming a similar relationship to its impact on viable utility scale solar development.

According to the BLM's Approved Resource Management Plan Amendments/Record of Decision (ROD) for Solar Energy Development in Six Southwestern States "Most solar generating technologies must be sited on relatively flat ground to ensure that the solar collectors can use the solar resource effectively." Depending on the technology, the ideal slope can vary, although lower slopes are generally better for siting solar energy generation (BLM, 2012). However, the slope itself is not the only impact to solar energy production. "Developers generally prefer south facing slopes, or those within 20-30 degrees of due south to provide sufficient exposure to the sun over the course of the year. Slope orientations outside of the 20-30-degree range of due south will typically result in lower annual energy production from the PV system, and may necessitate additional design work and system layout modifications to address row-to-row shading issues" (Kiatreungwattana et al. 2013). Both slope factors

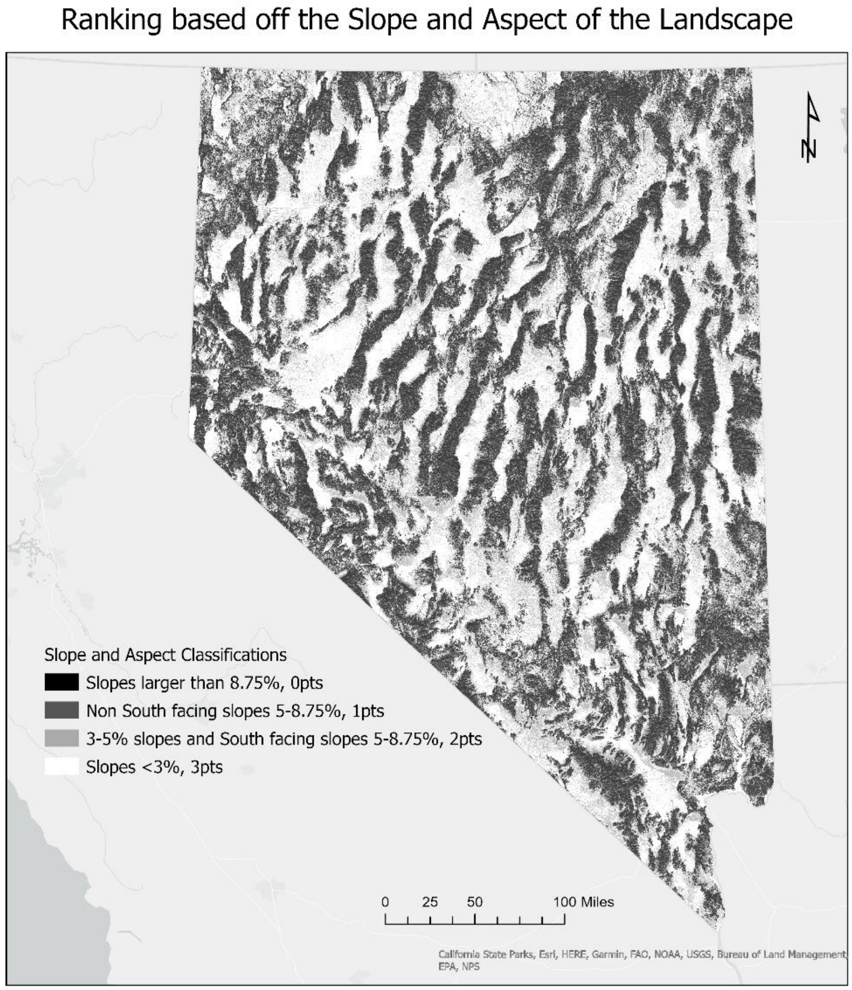

Figure 3 - Rankings associated with the Slope and Aspect of Nevada's Landscape

taken into consideration, Nevada's land area was ranked (Figure 3) according to the following; land with a slope less than 3% or 0.1719 degrees was given a top ranking of 3 points. Land with a slope between 3-5% or 0.1719 and 2.86 degrees and south facing slopes between 5-8.75% or 2.86 and 5 degrees were awarded 2 points. All other non-south facing slopes between 5-8.75% or 2.86 and 5 degrees were awarded a single point whereas everything with a larger slope was given no points. These determinations were made by creating slope and aspect layers for the state of Nevada based off the 30-meter dem published by the US Geologic Survey (custserv@edcmail.cr.usgs.gov, 1999) and reclassifying them in accordance with the values listed above. The slope classifications resulted in 38.6% of Nevada's land given a 3-point ranking for a total of 885,745.75 acres. 21.5% or 492,614.4 acres a 2-point ranking, 10.2% or 233,875.18 acres a single point and 32.5% or 745,382.19 acres received no points. Solely using slope factors prioritized valley floors while deprioritizing mountain ranges.

The second rating factor, solar radiation, was rated using a similar numerical scheme. NREL notes "the factors that are most important in evaluating whether a particular site is a good candidate for a PV system is whether the site receives abundant sun most of the day. To be economically viable, PV systems generally require a minimum solar radiation of 3.5 kWh/m2/day" (Kiatreungwattana et al., 2013). Annual average global solar irradiance data were downloaded from the National Solar Radiation Database (NSRDB) (Sengupta et al., 2018) which makes use of the meteorological and cloud cover observations at National Weather Service Stations around the country as inputs to models to simulate the solar resource at those sites (Renne et al., 2008). The data indicate that the entirety of the state of

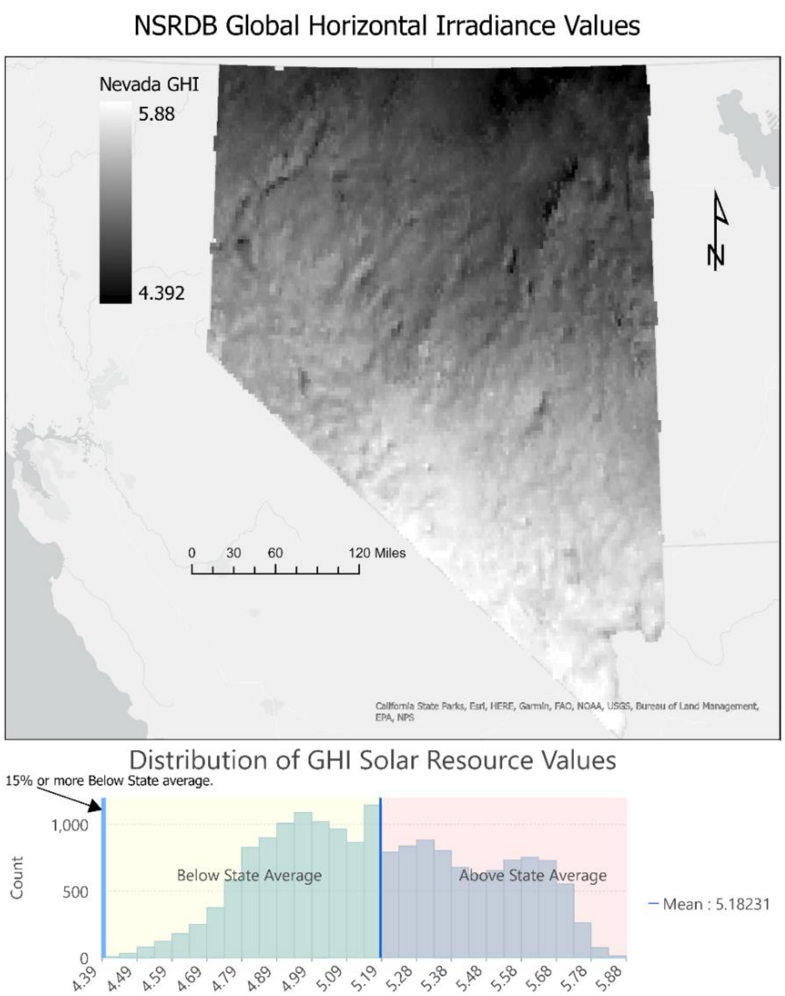

Figure 4 - Representation of the Distribution of Solar Irradiance across Nevada (Sengupta et al., 2018).

Nevada falls above the 3.5 kWh/m2/day threshold, and would be economically viable for PV systems. However, while the whole state may be viable, sites with higher GHI values are preferable because of the greater potential to produce energy. Rankings were assigned based on the pixels GHI value in relation to the State average (Figure 5). Nevada's average GHI value of 5.17935 kWh/m2/day was calculated using the NSRDB data constrained to Nevada. Values greater than the State average were given 3 points, below average were given 2 points and those values 15 or more percent less than the State average were given a single point. Slightly more than half of Nevada accounting for 50.12% of the state fell above the average and into the 3-point category for a total of 1,182,736.47 acres. 49.86% or 1,176,528.64 acres of the state fell below the average GHI and was awarded 2 points. Finally, slightly more than a single percent

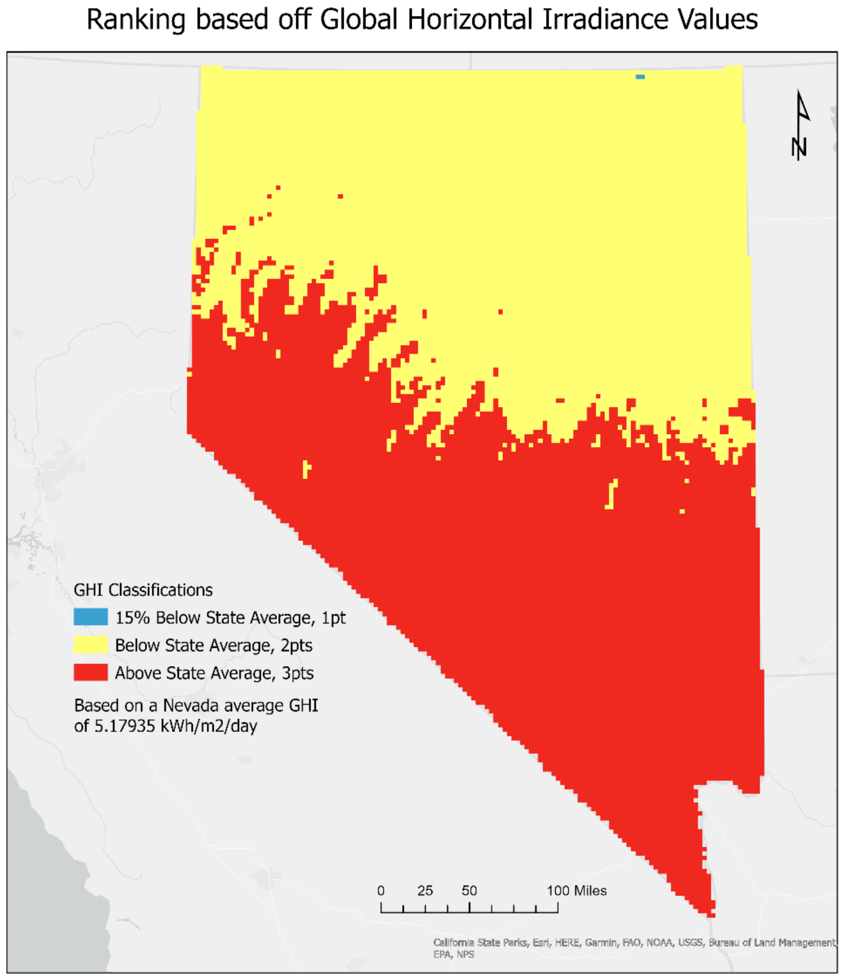

Figure 5 - Rankings based on Solar Irradiance

representing 267.21 acres fell 15% below the state average and was given a single point. The distributions of these rankings followed a predictable pattern of higher rankings in southern Nevada and most of the northern half of the state falling below the state average but not low enough to place land areas in the lowest ranking category. The lowest ranking section falling 15% below the state average was clustered near the Idaho border northeast of the Jarbridge Wilderness.

Proximity to existing transportation and electric infrastructure has been prioritized as a part of this analysis due to its critical nature "for renewable project construction and regular maintenance of projects" (ICF Inc). An NREL publication exploring the best practices for siting solar PV on Landfills lists several benefits to locating solar projects near the existing transportation infrastructure. NREL states: "Landfills can leverage existing infrastructure of graded roads and transmission lines for equipment transport during construction and tie-in to the grid", and that "Existing roads may be sufficient to transport materials required for construction of the solar system as they are likely designed to accommodate the large trucks typically used to haul waste to the landfill" (Kiatreungwattana et al.). While this study focused specifically on the benefits of infrastructure supporting Landfills, the same is true for mining sites. Many mine sites especially the modern ones are supported by large wide roads that would prove beneficial for Solar development. "Utility-scale solar projects run the risk of delay because of the time needed to acquire appropriate sites for development and to ensure transmission and other supporting infrastructure are in place. Siting large solar projects on former mine lands can help alleviate both of these concerns" (McNerney and Jaffe).

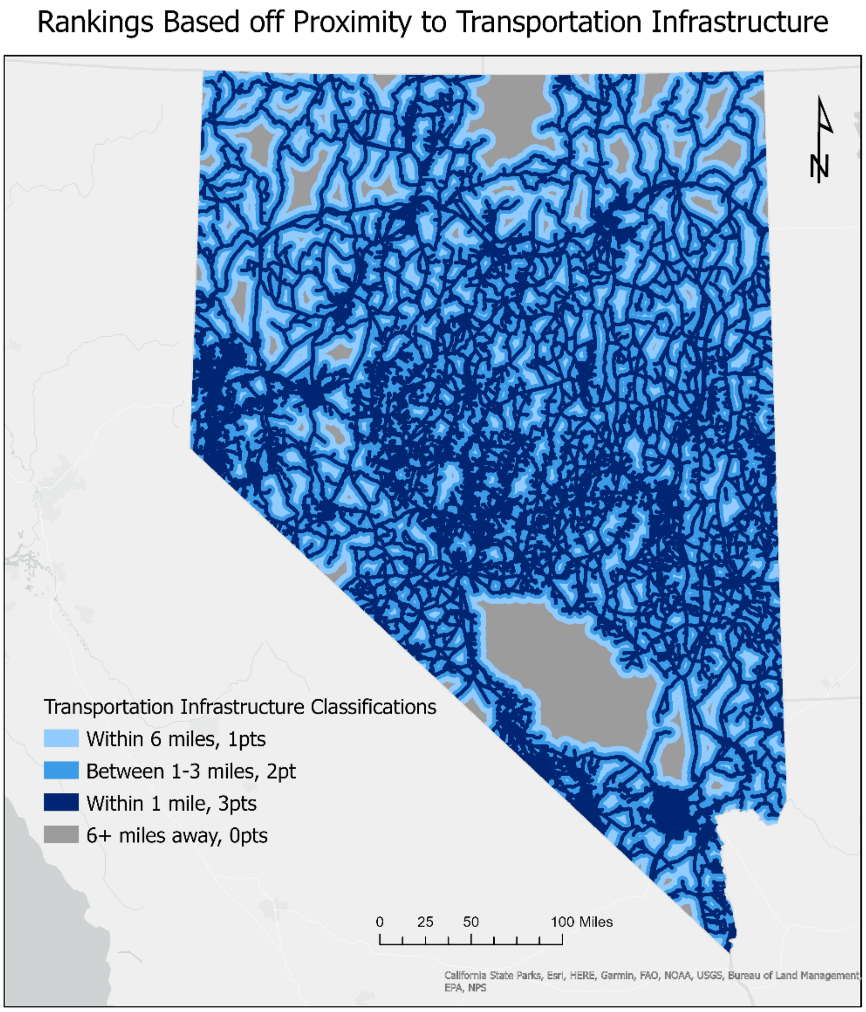

Figure 6 - Rankings associated with proximity to road and rail Infrastructure

Proximity to existing roads and railroads were clumped together under the term of transportation infrastructure. Road data were acquired from the Nevada Dept of Transportation (NDOT Open Data) and railroad data were acquired from a federal archive (US Rails Tiger Lines). These datasets were joined together to create a representation of Nevada's transportation infrastructure and rankings were determined by the land's proximity to it (Figure 6). Land within a mile of these features was considered highly suitable and given a ranking of 3, lands within 1-3 miles were given a ranking of 2, areas within 6 miles were given a single point and all areas farther than 6 miles away were considered undesirable and given 0 points. These rankings resulted in 1,036,245.99 acres or 43.43% of the state being given a 3-point ranking, 845,149.09 acres or 35.42% was given a 2-point ranking and 13.69% or 326,567.95 acres were awarded a single point, leaving 178,115.36 acres or 7.46% of the state given no additional points in the ranking. The distribution of these areas visually appeared to be linked to several characteristics. The location of Nevada's population centers, major population center connecting highways, and valley locations where transportation infrastructure tends to be located. Subsequently, the rankings influenced by transportation infrastructure likely follows a similar pattern to rankings produced by the slope factors and should be noted. One observation worth consideration is the apparent lack of completeness in transportation infrastructure within federal military instillations. Noticeable gaps in the suitable rankings occur based off roads and rail northwest of Las Vegas in land administered by the Department of Defense and the Department of Energy along with other Military bases in Nevada. An acceptable attribute given these lands are already eliminated from consideration due to their DOD or DOE classifications.

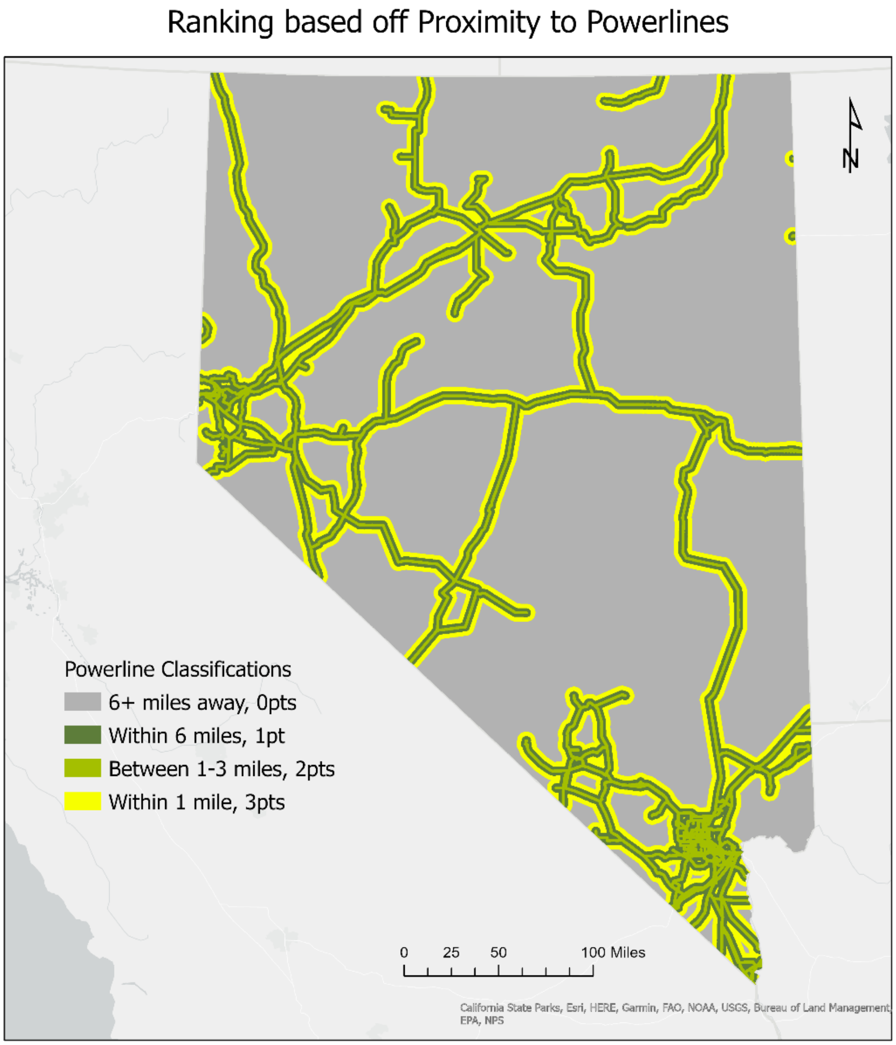

Figure 7 - Rankings associated with the distribution of Powerlines

Electric Infrastructure was taken into consideration in two different ways, the location of electrical transmission lines was considered in the same way that Arizona's land was ranked in the methodology modeled by ASU. In addition to transmission lines the locations of electrical substations were included in the rankings, assuming a desire to connect proposed new power production facilities into the electric grid, an important cost associated with such a utility-scale solar production. Developers are typically responsible for all costs incurred, including new transmission lines and upgrades required to physically connect the generator to the grid. These costs depend on the utility's requirements, however according to and EPA report California's ISO's cost guide "The estimated interconnection costs range from $0.9 million to $2.5 million per mile to ‘reconductor’ a typical 69-kV single circuit line to upgrade its carrying capability” (ICF Inc). The exact costs depend on the line’s voltage and the length of the line. For example, a NREL publication analyzing the protentional for Renewable Energy Development on DOE lands states that, “costs for a 100-MW capacity, can range from $50,000 to $180,000 per mile” (Dahle et al.). Regardless of the voltage level of new power lines the incurred costs of their construction make it imperative that new utility-scale solar facilities be placed within a reasonable proximity to remain economically feasible. Using powerline data, (ORNL et al., 2022) Areas within 1 mile of a Transmission line were given a 3-point ranking, those with in a 1-3 mile radius were given a 2-point ranking and those within 3 to 6 miles were given a single point while the remaining land area received no additional points. Roughly 73.62% of Nevada totaling 2,912,665.80 acres was not given any additional points from this classification. The rest of Nevada followed with 225,561.91 acres or 5.7% receiving 3 points, 364,799.30 acres or 9.22% receiving 2 points and 453,072.51 acres or 11.45% receiving a single point (Figure 7).

On top of the cost of new transmission lines, substations where the varying voltages of the electricity from power generators are stepped up or down to a level suitable for the flow of the electrical grid (National, 2023) can increase cost. New substation equipment can range from $12.5 to $15 million for a 69-kV to a 230-kV substation for a single existing transmission line” (ICF Inc). In an attempt to reduce additional costs proximity to substations was included as a factor in the analysis (Figure 8). Areas within a single mile of a substation were given a 3-point ranking, those with in a 1-3 mile radius were given a 2-point ranking and those within 3 to 6 miles were awarded a single point with no additional points given to the remaining lands. This resulted in 13,043.95 acres or 0.55% receiving 3 points, 57,920.69 acres or 2.46% receiving 2 points and 123,008.99 acres or 5.23% receiving a single

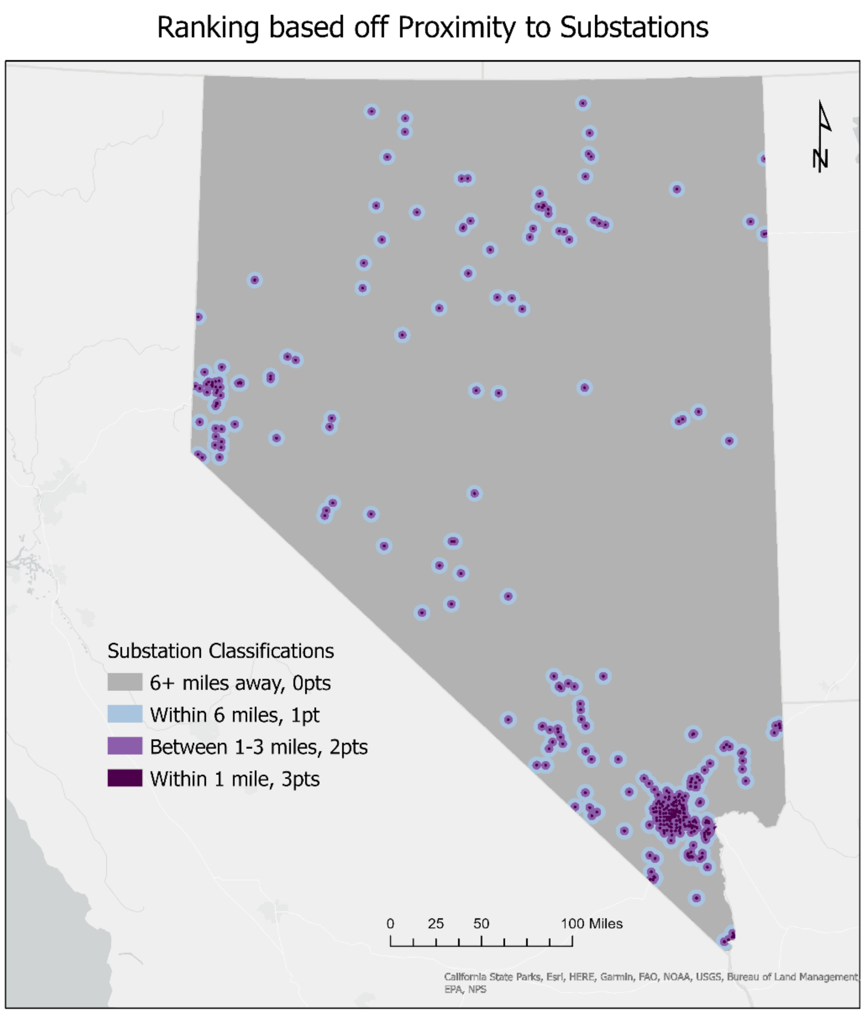

Figure 8 - Rankings associated with the distribution of electric substations

point. The remaining land is 91.79% of Nevada at 2,164,113.49 acres without any additional points.

The ASU solar analysis found no change in the resulting number of solar PV power plants within each land classification when the weights of each factor were varied and found negative results when the weight of incoming solar radiation was doubled. Therefore, each ranking factor was given equal weight in the creation of the model. The spatial data layers created to represent all the individual rankings were summed and locations within the constrained areas eliminated from siting consideration.

(Slope and Aspect Rankings + Solar Irradiance Rankings + Distance from Transportation Infrastructure Rankings + Distance from Powerlines Rankings + Distance from Substations Rankings)

Values of the output raster were used to determine 8 degrees of suitability. Land receiving a score of 0 correlated with the areas considered ‘Constrained’ and were classified as such. Any land receiving 90% or more the full score was classified as ‘Excellent’ land for PV development. Likewise, land receiving 80% or more of the full score was classified as ‘Very Good’, 70% or more was ‘Good’, 60% or more was ‘Average’, 50% or more was ‘Below Average’, 50% or less was ‘Poor’ and land receiving less than 25% of the full score was classified as ‘Bottom 25 Percent’ to differentiate between the two lowest performing classifications. Lands awarded 0 points on any of the 5 ranking surfaces were not considered constrained as was done in the ASU analysis. This decision to include 0 ranked land was made to minimize lands restricted by a single category in such a way that a site with many good characteristics for solar development would not be eliminated solely because it is far from an existing substation or powerline, it would simple rank less favorably.

To validate the resulting ranking surface a dataset of 47 existing solar sites within Nevada was pieced together by combining a dataset from a previous analysis (Wright, 2021) and digitizing additional sites based on satellite imagery corresponding to the point location within a US Energy Information Administration Power Plants database (US EIA, 2021). The dataset of existing sites was then compared to the ranking surface by recording the highest ranked portion of the landscape intersecting the footprint of the solar sites. This was then repeated with the urban solar farms within the Las Vegas metropolitan area removed from the dataset. Lastly, the ranking surface was compared to the locations of the existing Solar Energy Zones (BLM, 2012) within Nevada.

2.1.3 Analyzed Mining Properties

Spatial point data representing the locations of known reclamation projects (265), tailings piles (216) and waste rock dumps (872) within the state (Figure 9) were acquired from the BMRR a branch of the NDEP (BMRR, Most).

Potential Nevada Mining Sites for Solar Repurposing

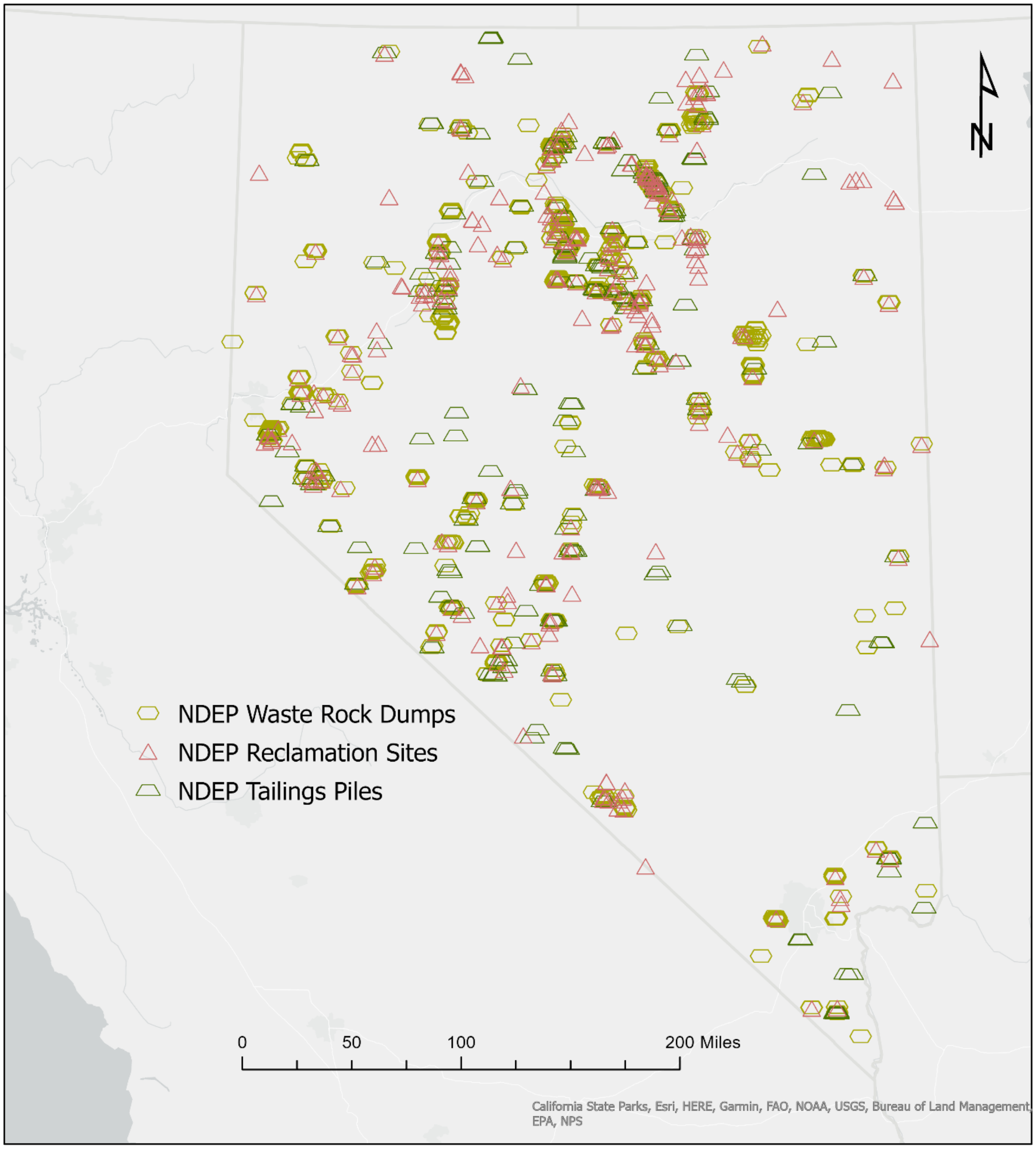

Figure 9 - Disturbed Mining sites across Nevada selected to be analyzed

Tailings piles were selected because they are made of material already processed to extract precious metals. Tailings piles typically contain chemicals that can create undesirable conditions for wildlife habitat (Keenan and Holcombe). Waste rock dumps were also considered to be potential locations for solar PV development. These sites contain material deemed uneconomic for processing by mining operations and are typically removed to access more desirable ore bodies. Waste rock dumps are likely less desirable than Tailings piles due to possible economic shifts making waste material more palatable for reprocessing, however they still may have viability as locations with little activity. The Reclamation sites, “dataset includes both active mines and active exploration projects” (BMRR, Most), that will eventually need to be reclaimed and be converting to a post-mining use (Nev. Admin. Code 519A.070 (2020) and may have the potential to be converted to solar PV. The inclusion of reclamation sites caused some redundancy because active mining sites containing tailings piles and waste rock dumps would be included twice, once as the overarching projects and again as its individual parts. However, this was considered acceptable because it allowed for mine properties without documented waste rock piles or tailings piles along with exploration projects to be included in the analysis. Each of these sites were selected because they are representative of a disturbance to the surface, but a relatively inactive one. Infrastructure supporting the mining operation (buildings, processing facilities, parking lots etc.) is typically not located on these sites and if the dumping of either tailings of waste rock was to cease these would be ideal locations to be repurposed as PV sites due to the requirement that they are stable (Nev. Admin. Code 519A.230-7 (2020), the high likelihood that they are near the infrastructure related to the mining operation, the potentially high energy demand associated with the mining operation and the fact that a solar field sited on one of these locations won’t be contributing to further habitat degradation that a solar field sited elsewhere is likely to (Lovich & Ennen, 2011). Many of these benefits remain regardless of whether the mining operation remains active or shuts down. However, grid interconnection can link utility-scale solar facilities to the high energy demand of population centers which can provide consumers for the long term.

The values determined by the summed ranking surface were extracted at each of these locations and classified using the same system that was used to classify the land itself. This was done to allow for the prioritization of high-ranking sites over others for further attention and exploration as potential locations for being repurposed as viable utility-scale solar facilities. Sites ranking as “Good”, “Very Good” or “Excellent” were kept for the map representing “High Ranking Mine Sites for Potential Solar Repurposing.” Lower ranking sites were considered “less than ideal”.

2.2 Carlin Trend Least Cost Path Analysis

2.2.1 Site Selection and Digitization

The Carlin Trend Mining District East of Elko was selected for a more detailed analysis in accordance with a recommendation from The Nature Conservancy’s Michael Clifford along with a visual inspection of the electrical infrastructure in the region. The area already contained 12 substations in addition to preexisting powerlines suggesting a comparatively simple connection to the broader electric grid. Reclamation permits for 15 distinct mining operations in the area were acquired from BMRR, from which waste rock dumps and tailings piles with a footprint larger than roughly 100 acres were selected to be Study Sites. This resulted in 28 sites (Figure 10 & Table 2) ranging from 97.3 to 2,272 acres with 8 tailings piles and 20 waste rock dumps with 2 categorized as reclaimed and 1 categorized as proposed.

Carlin Trend Mining District Study Sites

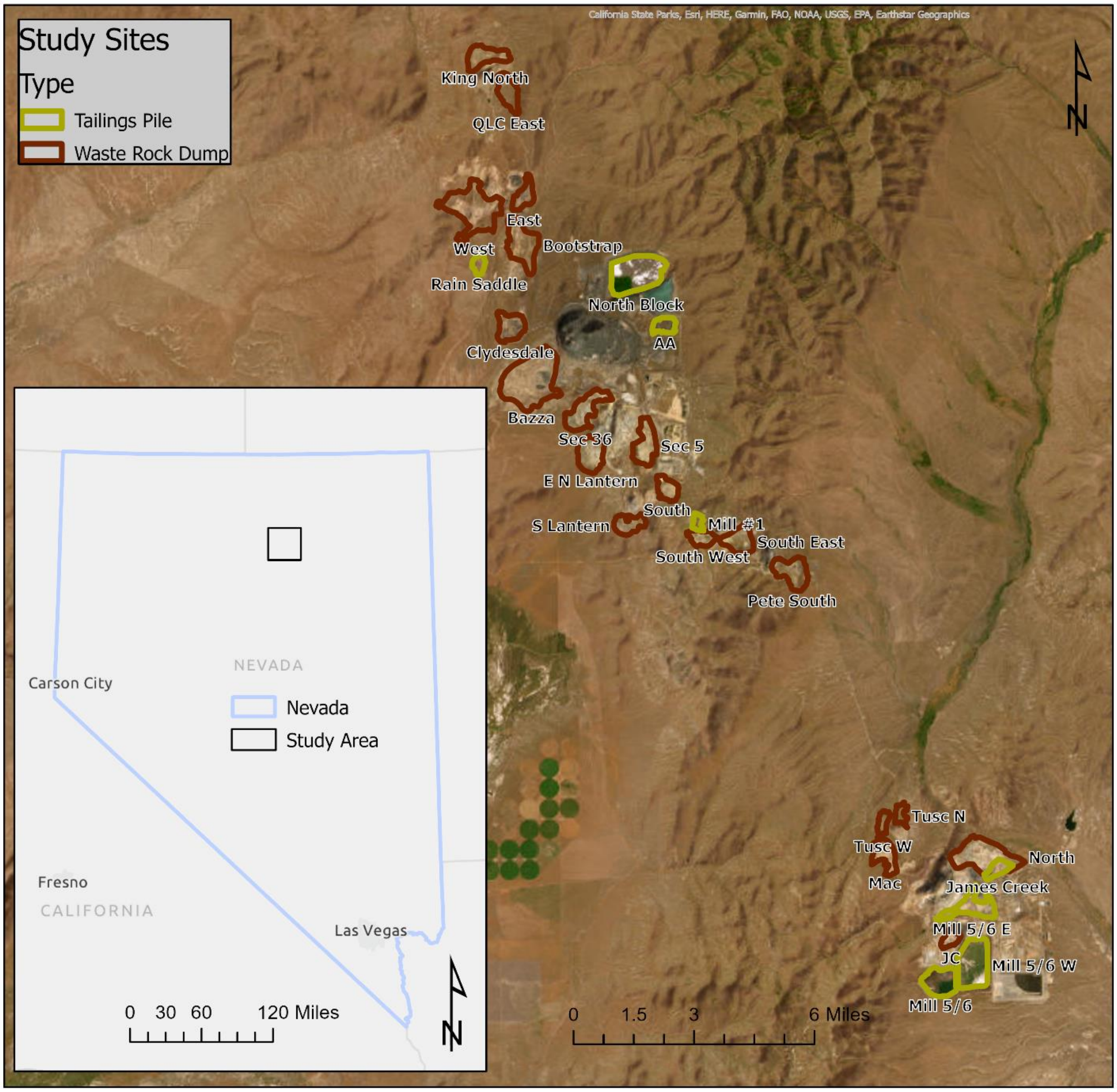

Figure 10 - The 28 study sites within the Carlin Trend Mining District

Table 2 - The 28 study sites within the Carlin Trend Mining District, their type, acreages, permit number and status

Site Name	Type	Documented Size (Acres)	Permit Number	Proposed
Bazza Waste Dump	Waste Rock Dump	2271.9	26	Present
Clydesdale Waste Rock Dump	Waste Rock Dump	535	26	Present
North Block Tails	Tailings Pile	1266.8	26	Present
AA Tails	Tailings Pile	206.4	26	Present
King North WRDF	Waste Rock Dump	286.3	257	Present
QLC East WRDF	Waste Rock Dump	236.9	257	Proposed
South East WRSF	Waste Rock Dump	225	175	Present
South West WRDF	Waste Rock Dump	154	175	Present
Pete South WRDF	Waste Rock Dump	436	175	Present
Mill #1 Tailings	Tailings Pile	149	175	Present
East WRDF	Waste Rock Dump	186	355	Present
West WRDF	Waste Rock Dump	1348	355	Present
East North Lantern	Waste Rock Dump	278	96	Present
Section 36	Waste Rock Dump	361	96	Present
Section 5	Waste Rock Dump	342	96	Present
South	Waste Rock Dump	203	96	Present
South Lantern	Waste Rock Dump	199	96	Present
North WRDF	Waste Rock Dump	862	56	Present
James Creek	Tailings Pile	125	56	Present
Mac WRDF	Waste Rock Dump	504	56	Present
Tusc-West WRDF	Waste Rock Dump	121	56	Reclaimed
Tusc-North WRDF	Waste Rock Dump	121	56	Reclaimed
Mill 5/6	Tailings Pile	798	56	Present
Mill 5/6 West	Tailings Pile	399	56	Present
Mill 5/6 East	Tailings Pile	758	56	Present
JC WRDF	Waste Rock Dump	213	56	Present
Bootstrap WRDF	Waste Rock Dump	526	101	Present
Rain_Saddle Tailings	Tailings Pile	97.3	14	Present

Each site was located using the NDEP BMRR point database (BMRR, Most) and digitized into a polygon by referring to satellite imagery native to ArcPro. It is recognized that the precision of digitized polygon area is entirely dependent on the accuracy of the digitization and it is worth noting that the sizes of the sites used in all calculations were pulled directly form the reclamation permits and did not rely on the area of these polygons.

2.2.2 Production and Cost Estimates of Sites

According to a 2013 NREL publication "the total-area capacity-weighted average is 8.9 acres/MWac, with 22% of power plants within 8 and 10 acres/MWac" (Ong et al., 2013). This value of 8.9 acres/MWac was used to estimate the potential nameplate capacity of the Study sites by dividing the documented acreages by 8.9 which resulted in a nameplate capacity in MW and could be converted to kW by multiplying by 1,000. These potential nameplate capacities were utilized in the renewable energy industry software application produced by NREL and referred to as the System Advisor Model or SAM (NREL, 2017). Each site was estimated using a single owner power purchase agreement financial model and a Photovoltaic PVWatts performance model (Blair et al. 2017). Individual solar irradiation data were downloaded from the National Solar Radiation Database (NREL, 2021) at the centroid of every study site to be used as an input in the model.

The SAM software was generally run with the default settings, but a few adjustments were made to better align with the methods of this analysis. The land area per system capacity input was adjusted to align with the 8.9 acres/MWac value (Ong et al., 2013) and cost estimates for *'permitting and environmental studies'* were removed because it is likely those costs would be greatly affected by these sites being located on existing mine sites which are already required to have Environmental Impact Assessments (Environmental Law Alliance Worldwide (ELAW, 2010). Cost estimates within SAM for *'grid interconnection'* were removed and calculated using a methodology that considered the length, voltage and proximity to substations of the necessary transmission lines. The default value for the Power Purchase Agreement (PPA) of 0.04$ per kWh was used, which was affected by time of day delivery factors from 2016 Pacific Gas and Electric (PG&E), a major electric supplier in California, to better align with nearby market shifts throughout the days opposed to a standard sale price across day and night.

2.2.3 Least Cost Path Analysis, Spur Transmission Line placement

Approaches to effectively route Transmission lines attempt to minimize length, the need to pass through areas with complex terrain and passage through land which may be characterized as sensitive or cost prohibitive. To predict ideal transmission line routes from the study sites to nearby substations, where the power can be stepped up or down to the voltage of the grid, a Least Cost Path (LCP) analysis was adopted based upon approaches used in (Monteiro et al., 2005) and (Lima et al., 2016). To effectively calculate least cost path routes for transmission lines two main inputs were necessary; First - a cost surface representing the terrain, land usage that may raise cost or cause significant damage to the environment and obstacles like rivers or railroads. The cost surface takes the form of a raster in which more difficult areas to pass through or areas with characteristics that make them undesirable to pass through will be represented by higher values while comparatively simple areas to pass through will have lower values. Second - Origin and destination points for each of the potential routes are necessary. The inputs used within a LCP function will calculate the cheapest route between the origin and destination points, using the raster values as a temporary cost values. Unless otherwise noted, all the work done in the transmission line portion of this analysis was conducted in R/RStudio version 4.2.2 statistical computing environment. (R Core Team, 2022) and used the leastcostpath package (Lewis, 2022).

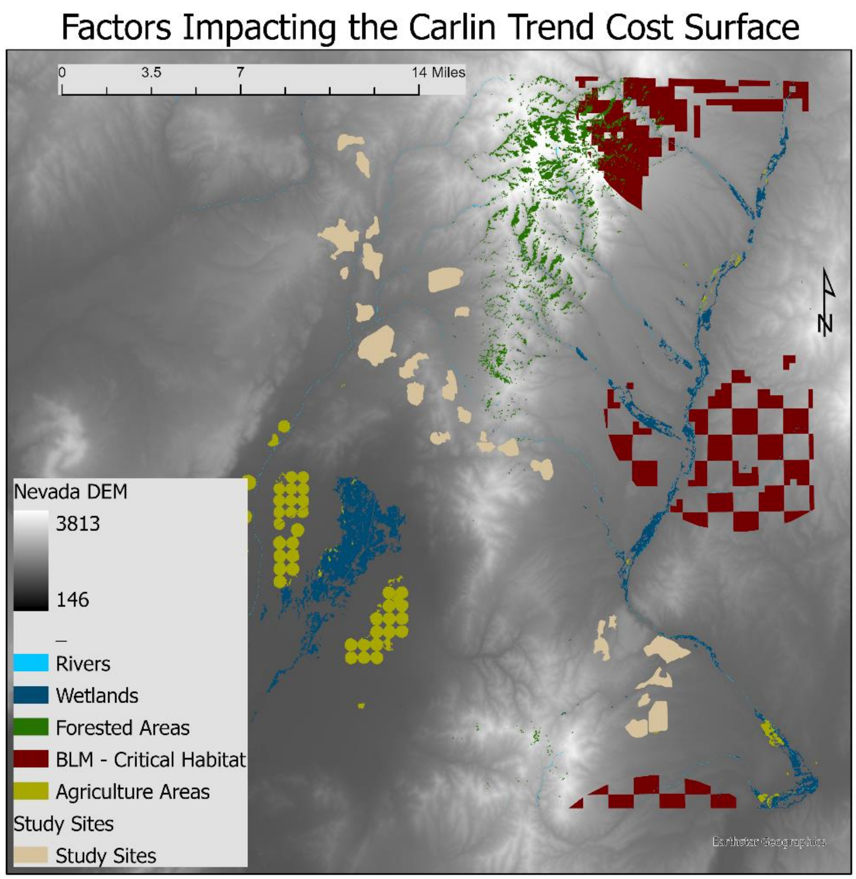

Figure 11 -Factors given additional weighting in the creation of the Carlin Trend cost surface raster

To create a cost surface to use in least cost path calculations 3 USGS DEM's (*1sec USGS DEM*, 2018) were imported and appended to cover the study area. The DEM's were used to create a cost surface in R and ArcPro was utilized to increase the cost values associated with various land uses which serve as impediments to transmission line routing. (Figure 11). Land classified as pasture or areas for crop cultivation (Dewitz, 2019) were given an increased cost because it was assumed that the routing of Transmission lines through these areas would lead to an increased cost due to the displacement of economic production. Forested areas and wetlands (Dewitz,

2019) were given an increased cost due to the likelihood that installation and maintenance costs will increase with the need to cut down forest or reinforce against water. Land classified as Critical Habitat or Environmental Concern by the BLM (Renne et al., 2008) which in this study area represents critical sage grouse habitat was also given and increased cost to avoid degradation to these sensitive areas. In addition to the areas included based on their land use classification, rivers (Esri Data and Maps, 2020) were also given an increased cost because they can act as a partial barrier for transmission line installation. It was assumed that each of these portions of identified land would serve as a comparable impediment to transmission line routing and no variability was introduced to differentiate the amount costs were increased based on the land use. Each of the raster cells within lands identified as impediments was given a roughly 50% cost increase. The original values of the cost surface ranged from 5.5 to 164.5 indicating that a 50% cost increase would require 79.5

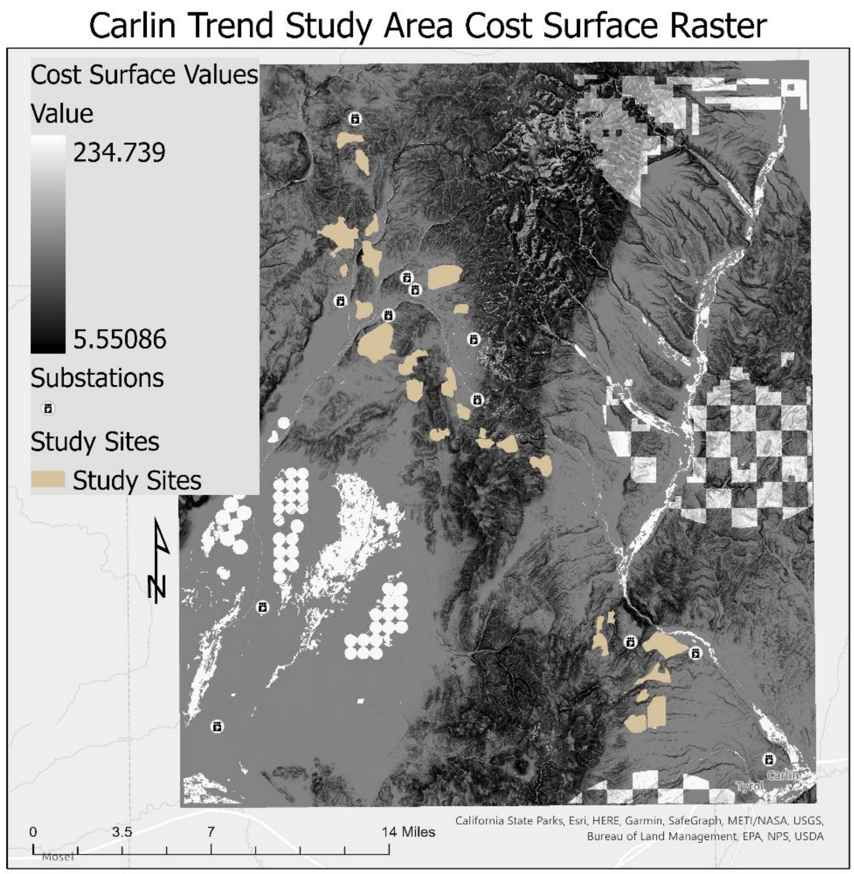

Figure 12 - The Cost surface raster used in the calculation of least cost path predictions of spur transmission lines

additional points. This was rounded to 80 and each of the identified land uses were given an 80pt increase to their raster value which effectively made it highly preferable that the transmission lines would be routed away from them (Figure 12). It is worth noting that the land classifications that received an increased cost were selected because they were the constraining factors included in the Statewide Solar Analysis that were present in the Carlin Trend study area. The 200ft buffer around wetlands was also present in the study area but it was excluded from the LCP analysis due to it being abundantly cautious. After these cost increasing factors were added to the cost surface raster is was imported back into R for further analysis.

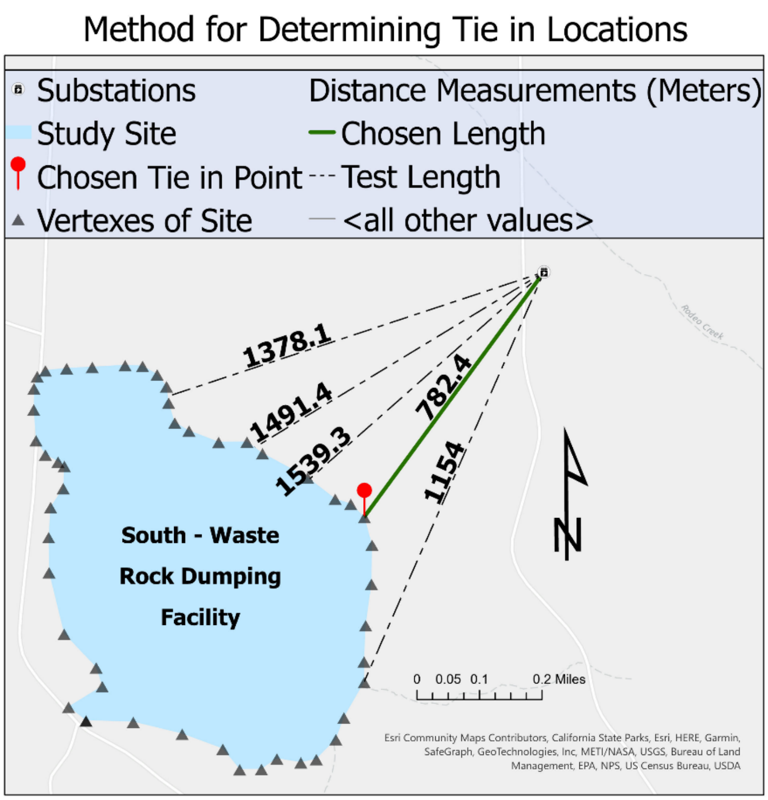

Figure 13 - Method used to determine the ideal tie in location and the nearest substations

To determine appropriate LCP origin and destinations points, the best potential tie in location for transmission lines was identified to be a point along the outline of the study site that was nearest to the closest substation. This would allow new solar sites to have a comparatively easily connection to the grid. These points were predicted to be used as origin points and the nearest substations were to be used as destination points. Study site polygons were converted to point locations with multiple points representing a single site based on vertex locations of lines comprising each polygon (Wickham et al., 2022). Substations were assigned unique identifiers corresponding with their listed names (Substations, 2019). The distances between each vertex and each of the 12 potential substations was calculated (Figure 13) (Etten and Sousa, 2017). The shortest distance was selected and resulting associated vertex from the initial polygon became origin point while the associated substation became the destination point. The process was repeated for all 28 study sites resulting in 28 pairs of points. Following the creation of the cost surface accounting for barriers/land use and the set of origin and destination points, least cost paths were able to be created. Cost values for each least cost path could then be compared.

2.2.4 Interconnection Estimations

A spur transmission line is defined as "the relatively short length of line connecting the generator to the bulk transmission grid" (Andrade & Baldick, 2017) To estimate the spur transmission line costs, each of the 28 sites were grouped into a voltage classification appropriate to the nameplate capacity of the potential solar facility following values in Table 3, and sites with a capacity less than 110MW being estimated to need 69kV lines, less than 230MW needing 138kV lines and sites less than 1,500MW needing 345kV lies. The length of the lines resulting from the LCP process were used to calculate the estimated cost for each potential spur transmission line (Table 3). Each length was multiplied by a per mile constant according to the necessary voltage.

$1,114,000 per mile of 345kV line, $823,000 per mile of 138kV line and $847,000 per mile of 69kV line in accordance with the estimation in (Andrade and Baldick, 2017).

Table 3 - Spur Line costs per mile at varying capacities and voltages. Adapted from (Andrade and Baldick, 2017)

Voltage (kV)	**Capacity (MW)**	**Cost** USD/mile
345	1,500	1,114,000
138	230	823,000
69	110	847,000

The Point of Interconnection Costs or POI were also estimated according to the nameplate capacity of the potential sites. POI refers to the infrastructure that allows the connection between a new spur line and the grid, costs are typically associated with necessary upgrades to existing substations (Andrade & Baldick, 2017). These costs can be contrasted to the potential cost of constructing entirely new substations which can rise into the tens of millions of dollars (ICF Inc). Because each of the chosen sites are in proximity to the existing substations, the POI costs are based on the standard value of $114 per kW (Andrade and Baldick, 2017). The nameplate capacity in kW was used to calculate these cost estimates.

SECTION 3: RESULTS

3.1 Statewide Analysis Ranking Surface and Model Validation

The ranking surface created to classify mining properties resulted in 48.94% of Nevada accounting for 1,135,301.8 acres being classified as 'Constrained'. Leaving 1.7% or 39,482.15 acres to be classified under the 'Bottom 25 Percent' category, 25.47% or 590,894.3 acres as 'Poor', 10.66% or 247,372.89 acres as 'Below average', 9.71% or 225,291.4 acres as 'Average', 1.8% or 41,791.88 acres as 'Good', 1.42% or 32,978.12 acres as 'Very Good' and only 0.28% or 6,531.22 acres as 'Excellent'. The overall summed rankings produced do not directly compare to the data produced in the ASU solar suitability analysis from which the ranking procedure were due to the inclusion of the proximity to substations being included in the calculations and that lands awarded 0 points as part of the ranking layers for slope and aspect, proximity to transportation Infrastructure and proximity to energy infrastructure (powerlines and substations) were not added to the land considered as constrained. Overall, the lands where "High Ranking Mine Sites for Potential Solar Repurposing" could existed were considered to be the 3.5% of Nevada's land was classified as Good or better (Figure 14). As expected, the distribution of High-ranking areas was largely driven by the placement of energy infrastructure with factors such as slope/aspect and the location of transportation infrastructure being more evenly distributed across Nevada.

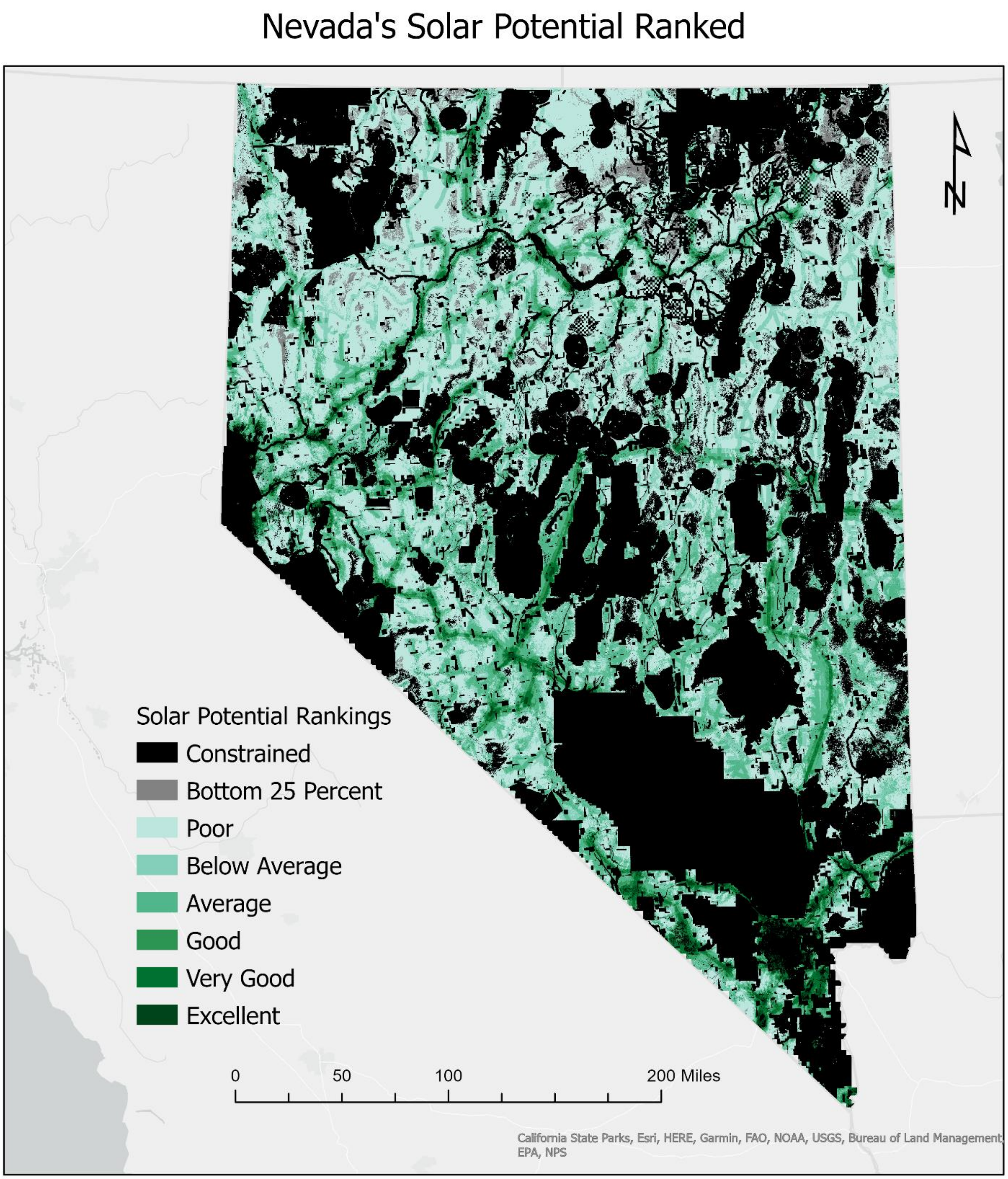

Figure 14 - The Ranking surface created to represent Utility-scale Solar potential across Nevada

When testing the ranking surface against the existing solar sites, 81% of sites intersected land ranked as” Good” or better with 60% intersecting “Excellent” land.

These results were slightly skewed by Utility-scale Solar Sites existing within Urban environments, a majority of which were large rooftop solar installations in Las Vegas. These sites would appear 100% surrounded by constrained territory because of the lands classification as developed according to the NLCD (Dewitz, 2019). When these urban solar farms are removed from the dataset the pool of validating solar sites is reduced to 39 and 87% of the existing sites intersected land ranked “Good” or better with 61% intersecting “Excellent land.

Additionally, when compared against Nevada’s 5 solar energy zones (BLM, 2012) each site intersected land identified as Average or better by the model. Dry Lake and Millers ranked as ‘Excellent’, Amargosa and Dry Lake Valley North ranked as ‘Very Good’ and Gold Point ranked as ‘Average’ (Figure 15).

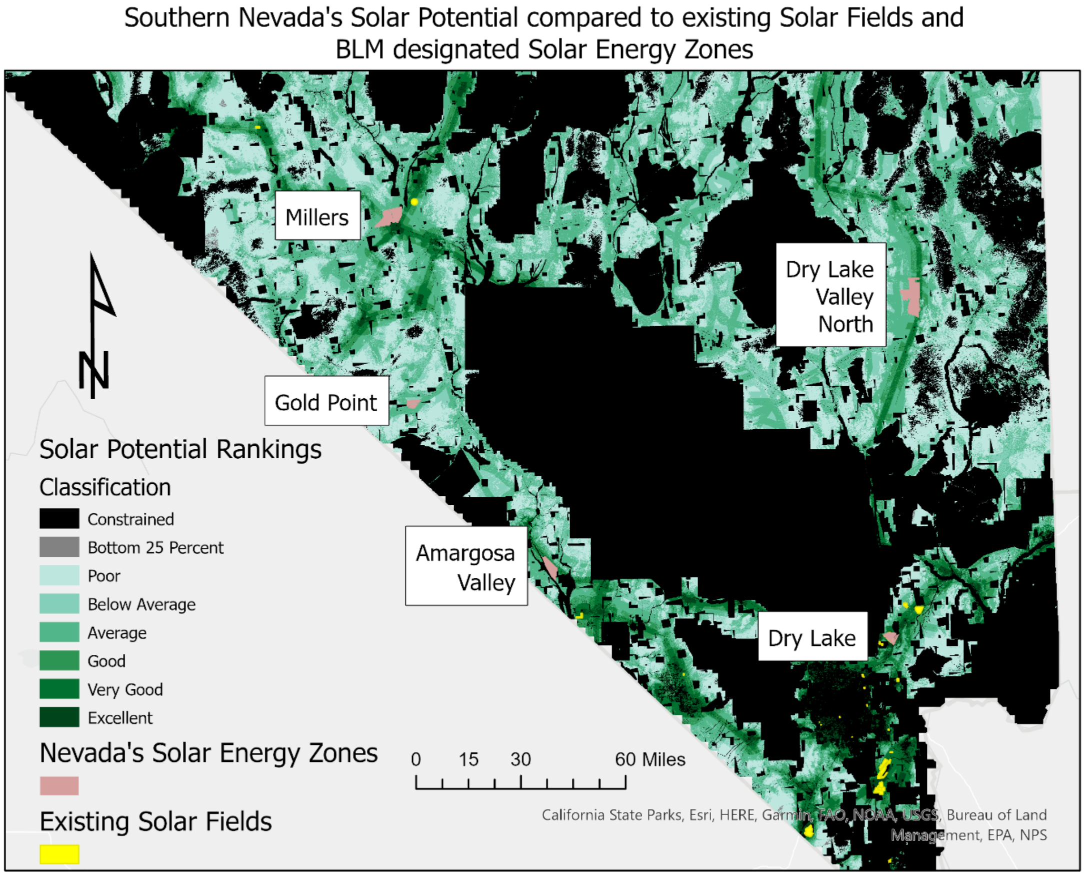

Figure 15 - A representation of the validation comparison done between the ranking surface, existing Solar Fields and the BLM designated Solar Energy Zones

3.2 High Ranked Mine Properties

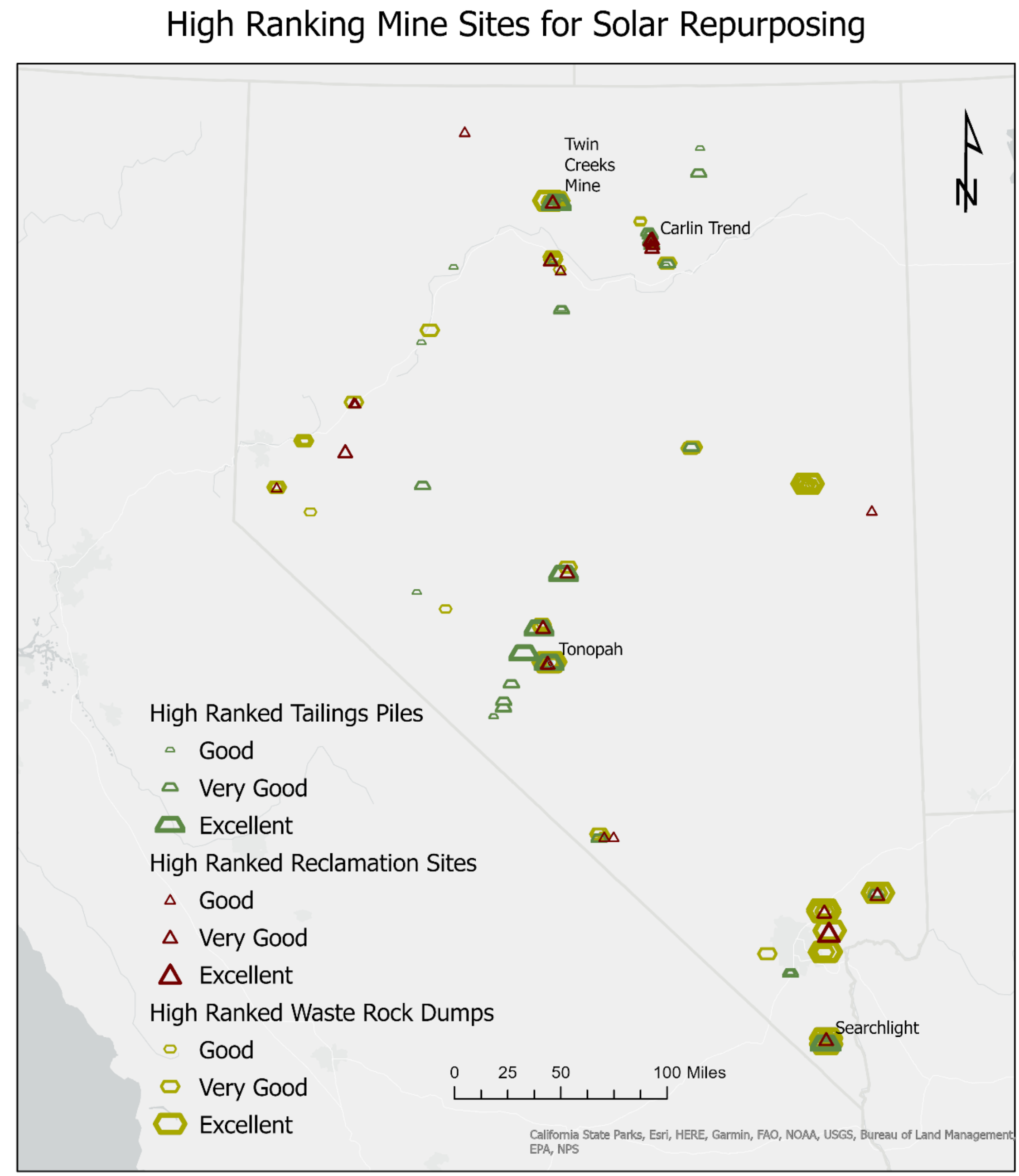

Figure 16 - The resulting High-Ranking disturbed mining sites from the NDEP BMRR dataset (BMRR, Most)

When comparing the sites from the tailings pile, waster rock dump and reclamation site NDEP BMRR databases (Most, 2022) to the ranking surface raster, 170 of the initial 1,353 (7.96%) sites ranked "Good" or better with 21 "Excellent", 75 "Very Good" and 64 "Good" sites (Table 4 and Table 5), the remaining 1,182 sites ranked Average or lower. The high-ranking sites formed a few clusters near Searchlight, Tonopah, the Twin Creeks mine north of Winnemucca and the Carlin Trend mining region (Figure 16).

Table 4 – Distribution of High-Ranking sites across type

Site Type	Excellent	Very Good	Good
Tailings Piles	7	20	14
Waste Rock Dumps	23	43	39
Reclamation Sites	1	12	11

Table 5 – High-Ranking sites from the NDEP BMRR database

Type	Site Name	Ranking
Tailings Pile	16-1 Mill	Good
Tailings Pile	4/2 Tails	Very Good
Tailings Pile	AA Block	Very Good
Reclamation Site	Apex Quarry	Very Good
Waste Rock Dump	Apex Quarry 1	Excellent
Waste Rock Dump	Apex Quarry 2	Excellent
Waste Rock Dump	Apex Quarry 3	Good
Waste Rock Dump	Apex Quarry 4	Excellent
Waste Rock Dump	Apex Quarry 5	Excellent
Waste Rock Dump	Apex Quarry 6	Very Good
Tailings Pile	Battle Mountain Gold	Good
Tailings Pile	Big Springs	Good
Tailings Pile	Blair 2	Very Good
Waste Rock Dump	Blue Diamond Mine RO2 South	Very Good
Waste Rock Dump	Brady's Project	Very Good
Reclamation Site	Brady's Project	Good
Tailings Pile	Bullfrog	Very Good
Waste Rock Dump	Bullfrog North Dump	Very Good
Waste Rock Dump	Bullfrog Montgomery South	Good
Waste Rock Dump	Bullion Monarch	Good
Reclamation Site	Carlin-Pete Operations	Very Good
Waste Rock Dump	Cash Boy Mine Dump	Excellent
Waste Rock Dump	Clark Mine Dump JL	Good
Waste Rock Dump	Clark Mine Dump N	Good
Waste Rock Dump	Clark Mine Dump P1	Good
Waste Rock Dump	Clark Mine Dump P2	Very Good
Waste Rock Dump	Clark Mine Dump P3	Very Good
Waste Rock Dump	Clark Mine Dump P4	Good
Waste Rock Dump	Clark Mine Dump P5	Very Good
Waste Rock Dump	Clark Mine Dump R	Good
Waste Rock Dump	Clark Mine Dump S	Good
Waste Rock Dump	Clark Mine Dump U	Good
Waste Rock Dump	Clark Mine Dump V	Good
Waste Rock Dump	Clark Mine Dump XE	Good
Tailings Pile	Colado Mine and Mill	Good
Tailings Pile	Copper Canyon	Very Good
Waste Rock Dump	Coyote Mine 1	Good
Waste Rock Dump	Coyote Mine 2	Very Good
Waste Rock Dump	Coyote Mine 3	Excellent
Waste Rock Dump	Coyote Mine 4	Excellent
Reclamation Site	Coyote-Blossom Mine	Very Good
Reclamation Site	Crown Exploration	Good
Tailings Pile	Cyrus Noble	Excellent
Tailings Pile	Dan Tucker Summit King Mine	Very Good
Tailings Pile	Duplex Mine	Excellent
Reclamation Site	Fernley Mine	Good
Reclamation Site	GBAR Mine	Good
Waste Rock Dump	Getchell Main Pit Dump	Very Good
Tailings Pile	Getchell Mine	Very Good
Tailings Pile	Getchell Mine	Excellent
Tailings Pile	Getchell Mine	Very Good
Waste Rock Dump	Getchell North Pit Dump	Good
Waste Rock Dump	Getchell North Pit Dump East	Good
Waste Rock Dump	Getchell Townsite Dump	Excellent
Waste Rock Dump	Getchell Turquoise Ridge Pit Backfill	Good
Waste Rock Dump	Getchell Turquoise Ridge Pit Dump	Good
Waste Rock Dump	Getchell Turquoise Ridge Valmy Pit Backfill	Good
Tailings Pile	Gold Quarry North TSF	Good
Waste Rock Dump	Golden Anchor Mine Dump	Excellent
Waste Rock Dump	Great Western Mine Dump	Excellent

Reclamation Site	Hazen Project	Very Good
Reclamation Site	High Desert Exploration	Good
Tailings Pile	James Creek	Very Good
Tailings Pile	Jerritt Canyon TSF 1	Very Good
Tailings Pile	Kinkead Mill	Good
Reclamation Site	Leeville Underground Mine	Good
Reclamation Site	Liberty Mine	Very Good
Tailings Pile	Lone Tree	Good
Reclamation Site	Lone Tree	Very Good
Waste Rock Dump	Lone Tree S11 WRDF	Very Good
Waste Rock Dump	Lone Tree S13 Pit Backfill	Good
Waste Rock Dump	Lone Tree S13 WRDF	Good
Waste Rock Dump	Lone Tree S14 WRDF	Very Good
Waste Rock Dump	Lone Tree S24 WRDF	Good
Waste Rock Dump	Marigold 8 North WRSF	Good
Reclamation Site	Marigold Mine	Good
Waste Rock Dump	McKane Mine Dump	Excellent
Waste Rock Dump	Midway Mine Dump	Very Good
Tailings Pile	Mill 1	Very Good
Waste Rock Dump	Mill 5/6 North WRSF	Very Good
Tailings Pile	Miller's Mill	Excellent
Waste Rock Dump	Minnesota Mine 1	Good
Waste Rock Dump	Mizpah Mine North	Very Good
Waste Rock Dump	Mizpah Mine South	Very Good
Waste Rock Dump	New Boston 1	Good
Waste Rock Dump	New Boston 2	Good
Waste Rock Dump	New Boston 3	Good
Waste Rock Dump	New Boston Stockpile	Good
Waste Rock Dump	New Discovery Mine	Good
Reclamation Site	New Discovery Mine/Mill	Good
Reclamation Site	North Area Leach	Very Good
Tailings Pile	North Block Tails	Very Good
Tailings Pile	North Block Tails 3	Good
Waste Rock Dump	Oreana Mill South	Very Good
Waste Rock Dump	Pabco Gypsum Mine	Excellent
Reclamation Site	Pabco Gypsum Mine	Excellent
Reclamation Site	Pearl Exploration	Very Good
Tailings Pile	Quartette Mine	Very Good
Waste Rock Dump	Quartette Mine 1	Excellent
Waste Rock Dump	Quartette Mine 2	Excellent
Waste Rock Dump	Quartette Mine 3	Excellent
Waste Rock Dump	Quartette Mine 4	Excellent
Waste Rock Dump	Quartette Mine 5	Excellent
Waste Rock Dump	Rescue Eula Mine Dump	Very Good
Waste Rock Dump	Robinson Banjo Dump	Very Good
Waste Rock Dump	Robinson Keystone Dump	Excellent

Waste Rock Dump	Robinson Lane City Dump	Good
Waste Rock Dump	Robinson Libery Dump	Very Good
Waste Rock Dump	Robinson Ruth Dump	Good
Waste Rock Dump	Robinson Star Pointer Dump	Good
Waste Rock Dump	Robinson Stillwater Dump	Good
Waste Rock Dump	Robinson White Hills Dump	Good
Waste Rock Dump	Rossi Barite North	Good
Waste Rock Dump	Rossi Barite West	Good
Reclamation Site	Round Mountain Mine	Very Good
Waste Rock Dump	Round Mountain North WRD	Very Good
Tailings Pile	Ruby Hill	Very Good
Waste Rock Dump	Ruby Hill East Dump	Very Good
Waste Rock Dump	Ruby Hill West Dump	Very Good
Tailings Pile	Silver Peak historic	Very Good
Tailings Pile	Silver Peak Homestead	Good
Waste Rock Dump	Silver Top Mine Dump	Very Good
Waste Rock Dump	Simplot Silica 1	Very Good
Waste Rock Dump	Simplot Silica 2	Very Good
Tailings Pile	Simplot Silica 3	Very Good
Waste Rock Dump	Simplot Silica 3	Very Good
Waste Rock Dump	Simplot Silica 4	Excellent
Waste Rock Dump	Simplot Silica 5	Very Good
Reclamation Site	Simplot Silica Products	Very Good
Tailings Pile	Slime Gulch	Excellent
Tailings Pile	Sloan Quarry 1	Good
Tailings Pile	Sloan Quarry 2	Very Good
Tailings Pile	Sloan Quarry 3	Very Good
Tailings Pile	Sloan Quarry 4	Very Good
Tailings Pile	Sloan Quarry 5	Good
Tailings Pile	Sloan Quarry 6	Good
Tailings Pile	Smoky Valley Common	Excellent
Waste Rock Dump	Spring Valley 1	Good
Waste Rock Dump	Spring Valley 2	Very Good
Waste Rock Dump	Spring Valley 3	Very Good
Waste Rock Dump	Spring Valley 4	Very Good
Waste Rock Dump	Spring Valley 6	Very Good
Reclamation Site	Spring Valley Mine	Good
Tailings Pile	Springer	Good
Reclamation Site	Thacker North - South Exploration	Good
Reclamation Site	Three Hills Mine	Good
Waste Rock Dump	Three Kids 1	Very Good
Waste Rock Dump	Three Kids 2	Very Good
Waste Rock Dump	Three Kids 3	Excellent
Waste Rock Dump	Three Kids 4	Very Good
Waste Rock Dump	Three Kids 5	Excellent
Waste Rock Dump	Three Kids 6	Excellent

Waste Rock Dump	Tonopah Belmont Mine Dump 2	Good
Waste Rock Dump	Tonopah Belmont Mine Dump 3	Very Good
Waste Rock Dump	Tonopah Extension Mine Dump N	Very Good
Waste Rock Dump	Tonopah Mine Copper Dump	Very Good
Tailings Pile	Tonopah Mine Equitorial	Excellent
Waste Rock Dump	Tonopah Mine Moly Dump 1	Very Good
Waste Rock Dump	Tonopah Mine Moly Dump 2	Good
Waste Rock Dump	Tonopah Mine Moly Dump 3	Very Good
Reclamation Site	Tonopah West Exploration Projecct	Very Good
Reclamation Site	Turquoise Ridge Mine	Very Good
Waste Rock Dump	Twin Creeks Mega Pit Backfill	Very Good
Tailings Pile	Twin Creeks Pinon TSF	Good
Waste Rock Dump	Twin Creeks Waste Dump G	Very Good
Waste Rock Dump	Twin Creeks Waste Dump H	Good
Waste Rock Dump	Twin Creeks Waste Dump I	Very Good
Waste Rock Dump	Undentified Tonopah 1	Excellent
Waste Rock Dump	Unidentified Tonopah 2	Very Good
Tailings Pile	Weepah	Very Good

3.3 Carlin Trend Region Cost estimation analysis

After calculating the cost estimates for potential solar installations on each of the 28 study sites, the cost estimates for their necessary spur transmission lines (Figure 18) and Point of Interconnection costs along with the estimated revenue over a period of 25 years it was possible to estimate the sites return on investment. Some of the analyzed sites did not reach the threshold of 20 megawatts (MW) or greater (BLM, 2012) set to be classified as utility-scale solar facilities. However, every site had a positive return on investment indicating that they would all be economically viable locations for solar development. The “Bazza Waste Dump” had the highest potential revenue while the “Rain Saddle Tailings” pile had the lowest potential revenue. Those values were heavily determined by the acreage of the sites because the solar irradiation data didn’t vary drastically across the study region. “North WRDF” returned the highest ROI while “Tusc-West WRDF” returned the lowest ROI (Figure 17). ROI was impacted by the acreages of the sites which would lead to higher revenues paired with higher installation costs, however the spur line transmission cost, which was heavily driven by the length of the proposed spur lines had the ability to impact ROI in such a way that smaller sites would perform better than larger sites (Table 6). “North WRDF” also possessed one of the shortest and absolute cheapest spur transmission line which lead it to have a larger ROI than larger sites like the “Bazza Waste Dump” and “West WRDF” which have larger 25-year kWh outputs and projected 25-year revenue. The “Pete South WRDF” had the longest and most expensive spur transmission line at 3.67 miles and $3,110,993.72 which caused it to drop to 6th worst ROI ranking. In contrast the “North WRDF” spur transmission line was only .32 miles in length and estimated to cost $270,983.21. These results showed the value in siting new utility-scale solar facilities near existing substations to reduce the necessary length of spur transmission line.

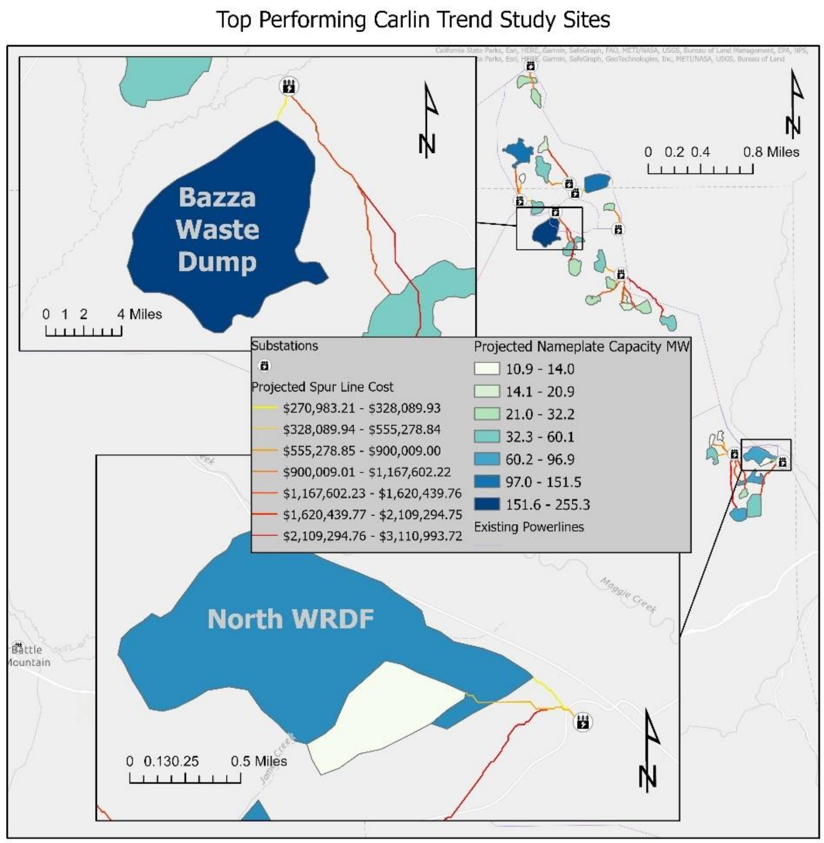

Figure 17 - Representation of the Top performing Sites in the Carlin Trend Mining District

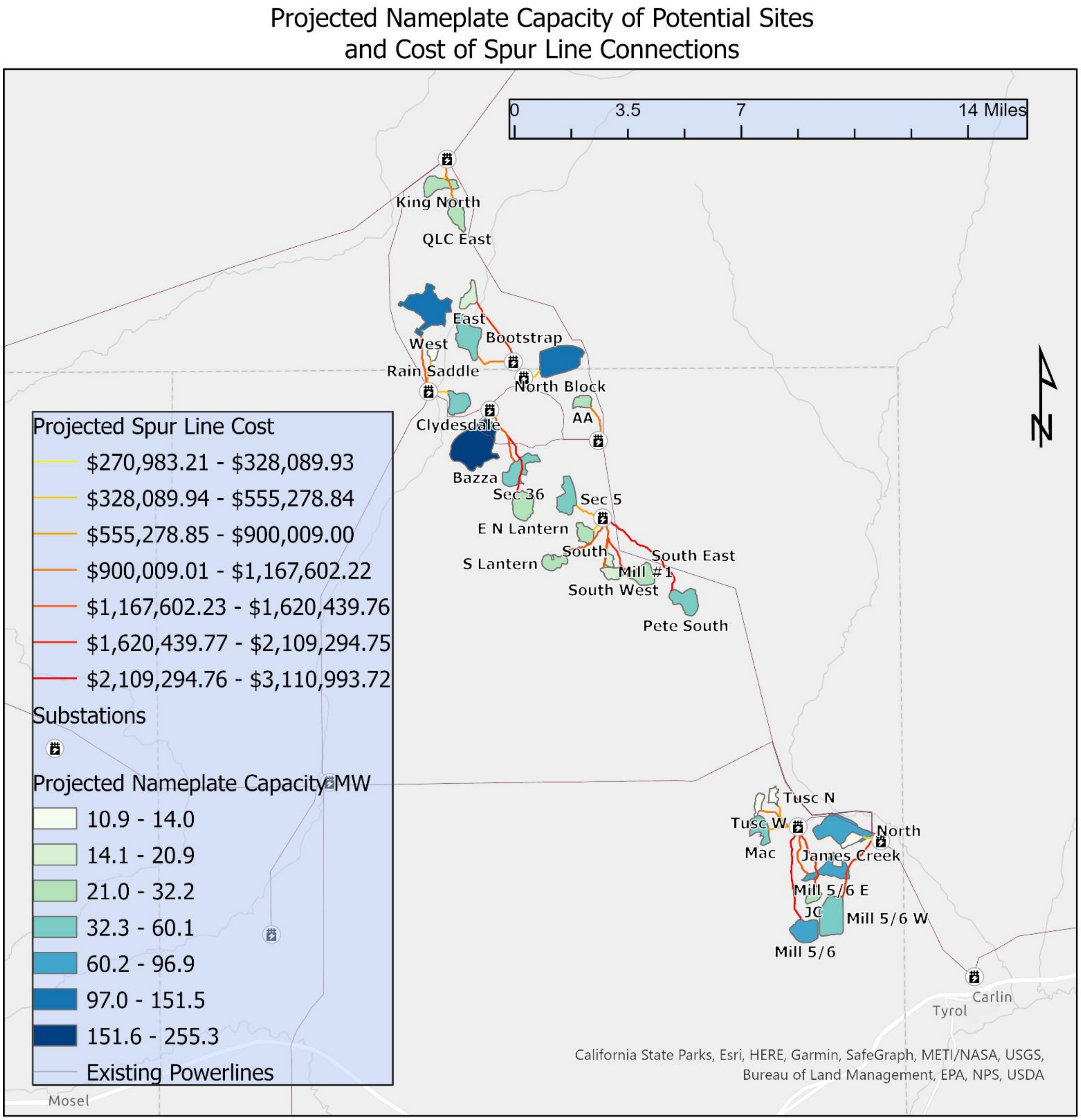

Figure 18 - Map showing the projected nameplate capacity and the projected spur line cost of the 28 analyzed sites in the Carlin Trend Mining District

Table 6 - Projected Energy and Revenue outputs

Legend

Nameplate Capacity	25 Year Revenue
Lowest Projected Capacity	Lowest Projected Revenue
Highest Projected Capacity	Highest Projected Revenue

Site Name	Nameplate Capacity	1Yr kWh output	25Yr kWh output	1Yr Revenue	25Yr Revenue	Voltage Need kV
North WRDF	96.9	190,770,144	4,493,772,112	$6,705,444	$177,982,069	69
James Creek	14	27,562,654	649,264,540	$968,810	$25,715,043	69
South	22.8	43,915,480	1,034,470,892	$1,548,908	$41,112,557	69
Bootstrap WRDF	59.1	113,257,288	2,667,883,176	$3,994,051	$106,013,779	69
Bazza Waste Dump	255.3	483,343,765	11,385,622,208	$16,875,176	$447,916,510	345
North Block Tails	142.3	268,920,640	6,334,681,760	$9,393,343	$249,326,764	138
QLC East WRDF	26.6	51,328,896	1,209,100,940	$1,810,164	$48,047,058	69
Clydesdale Waste Rock Dump	60.1	113,784,182	2,680,294,664	$3,972,594	$105,444,261	69
West WRDF	151.5	286,306,880	6,744,230,784	$10,000,640	$265,446,199	138
Mac WRDF	56.6	107,157,848	2,524,205,032	$3,741,246	$99,303,614	69
Mill 5/6 East	85.2	161,304,448	3,799,679,888	$5,631,689	$149,481,478	69
King North WRDF	32.2	60,852,600	1,433,440,924	$2,125,570	$56,418,834	69
Tusc-North WRDF	13.6	26,559,866	625,642,900	$935,360	$24,827,175	69
Section 5	38.4	72,700,880	1,712,538,448	$2,538,236	$67,372,209	69
South East WRSF	25.3	49,144,356	1,157,642,088	$1,733,224	$46,004,827	69
Mill #1 Tailings	16.7	32,166,264	757,706,956	$1,134,511	$30,113,246	69
Mill 5/6	89.7	169,824,016	4,000,366,400	$5,929,136	$157,376,592	69
Section 36	40.6	76,866,008	1,810,652,024	$2,683,655	$71,232,052	69
AA Tails	23.2	43,923,596	1,034,662,112	$1,533,523	$40,704,187	69
Mill 5/6 West	44.8	84,817,624	1,997,959,760	$2,961,273	$78,600,834	69
Rain Saddle Tailings	10.9	20,888,670	492,052,486	$736,645	$19,552,719	69
East WRDF	20.9	40,329,928	950,009,788	$1,422,275	$37,751,341	69
Pete South WRDF	49	92,769,224	2,185,267,400	$3,238,891	$85,969,622	69
South Lantern	22.4	42,409,000	998,984,384	$1,480,644	$39,300,607	69
JC WRDF	23.9	45,248,868	1,065,880,128	$1,579,793	$41,932,322	69
South West WRDF	17.3	32,753,450	771,538,678	$1,143,535	$30,352,766	69
East North Lantern	31.2	59,069,544	1,391,439,280	$2,062,320	$54,739,995	69
Tusc-West WRDF	13.6	25,748,436	606,528,922	$898,966	$23,861,192	69

Table 6 Continued - Projected economic outputs

Legend

Spur Line Length 'Miles'	Total Cost	Net Revenue Gain	Return on Investment % (ROI)
Bottom 5%, Shortest Lengths	Lowest Projected Total Cost	Lowest Projected Net Revenue	Best Projected ROI%
All other values			
Top 15%, Longest Lengths	Highest Projected Total Cost	Highest Projected Net Revenue	Worst Projected ROI%

Site Name	Spur Line Length	Spur Line Cost	POI Cost	PV System Cost	Total Cost	Net Revenue Gain	ROI %
North WRDF	0.32	$270,983.21	$11,046,600	$100,289,562	$111,607,145.21	$66,374,923.79	59.47%
James Creek	0.60	$508,634.82	$1,596,000	$14,489,720	$16,594,354.82	$9,120,688.18	54.96%
South	0.49	$415,662.76	$2,599,200	$23,597,544	$26,612,406.76	$14,500,150.24	54.49%
Bootstrap WRDF	1.27	$1,073,206.44	$6,737,400	$61,167,318	$68,977,924.44	$37,035,854.56	53.69%
Bazza Waste Dump	0.29	$328,089.93	$29,104,200	$264,230,394	$293,662,683.93	$154,253,826.07	52.53%
North Block Tails	0.59	$486,011.83	$16,222,200	$147,277,654	$163,985,865.83	$85,340,898.17	52.04%
QLC East WRDF	1.32	$1,120,417.52	$3,032,400	$27,530,468	$31,683,285.52	$16,363,772.48	51.65%
Clydesdale Waste Rock Dump	0.60	$512,312.04	$6,851,400	$62,202,298	$69,566,010.04	$35,878,250.96	51.57%
West WRDF	1.78	$1,463,015.32	$17,271,000	$156,799,470	$175,533,485.32	$89,912,713.68	51.22%
Mac WRDF	0.94	$799,870.54	$6,452,400	$58,579,868	$65,832,138.54	$33,471,475.46	50.84%
Mill 5/6 East	1.71	$1,447,838.77	$9,712,800	$88,180,296	$99,340,934.77	$50,140,543.23	50.47%
King North WRDF	0.66	$555,278.84	$3,670,800	$33,326,356	$37,552,434.84	$18,866,399.16	50.24%
Tusc-North WRDF	1.06	$900,009.00	$1,550,400	$14,075,728	$16,526,137.00	$8,301,038.00	50.23%
Section 5	1.00	$843,959.11	$4,377,600	$39,743,232	$44,964,791.11	$22,407,417.89	49.83%
South East WRSF	2.06	$1,744,830.64	$2,884,200	$26,184,994	$30,814,024.64	$15,190,802.36	49.30%
Mill #1 Tailings	1.17	$989,020.53	$1,903,800	$17,284,166	$20,176,986.53	$9,936,259.47	49.25%
Mill 5/6	3.10	$2,629,427.89	$10,225,800	$92,837,706	$105,692,933.89	$51,683,658.11	48.90%
Section 36	1.91	$1,617,228.90	$4,628,400	$42,020,188	$48,265,816.90	$22,966,235.10	47.58%
AA Tails	1.18	$1,000,748.19	$2,644,800	$24,011,536	$27,657,084.19	$13,047,102.81	47.17%
Mill 5/6 West	2.49	$2,109,294.75	$5,107,200	$46,367,104	$53,583,598.75	$25,017,235.25	46.69%
Rain Saddle Tailings	1.00	$843,662.09	$1,242,600	$11,281,282	$13,367,544.09	$6,185,174.91	46.27%
East WRDF	2.24	$1,898,419.16	$2,382,600	$21,631,082	$25,912,101.16	$11,839,239.84	45.69%
Pete South WRDF	3.67	$3,110,993.72	$5,586,000	$50,714,020	$59,411,013.72	$26,558,608.28	44.70%
South Lantern	1.91	$1,620,439.76	$2,553,600	$23,183,552	$27,357,591.76	$11,943,015.24	43.66%
JC WRDF	2.13	$1,803,417.12	$2,724,600	$24,736,022	$29,264,039.12	$12,668,282.88	43.29%
South West WRDF	1.67	$1,412,031.56	$1,972,200	$17,905,154	$21,289,385.56	$9,063,380.44	42.57%
East North Lantern	3.03	$2,565,233.37	$3,556,800	$32,291,376	$38,413,409.37	$16,326,585.63	42.50%
Tusc-West WRDF	1.38	$1,167,602.22	$1,550,400	$14,075,728	$16,793,730.22	$7,067,461.78	42.08%

SECTION 4: DISCUSSION

4.1 Insights and Takeaways

The major takeaway from this work is that Nevada has many disturbed mining sites that could be potentially repurposed into utility-scale solar facilities as a part of a low impact energy transition. With 41 high ranking tailing piles and 105 high ranking waste rock dumps energy across Nevada (Figure 15) developers are likely to find a location suitable for the size of project that they have envisioned that is within reasonable proximity to energy and transportation infrastructure and has suitable solar resources. These potential sites could also contribute to the resiliency of the electrical grid by further distributing electrical generation across the landscape and allowing mine operations increased energy independence from centralized power production. The model created also proved to be a useful tool for siting solar development with 87% of existing, non-urban solar faculties intersecting land ranked “Good” or better showing that other types of disturbed lands including superfund sites and brownfields have potential to be ranked using it. The statewide analysis also showed an even distribution of high-ranking sites between southern and northern Nevada with 85 above the 39th parallel and 85 below it showing potential for utility-scale solar development in the northern portion of the state regardless of the current state of solar development showing only 9 of the 47-existing utility-scale solar fields above the 39th parallel. The distribution of sites also confirmed the recommendation of Michael Clifford (TNC) in showing that The Carin Trend Mining region has a high potential for utility-scale solar development.

Importantly, the LCP analysis of the Carlin Trend region resulted in every analyzed site projecting a positive return on investment (Table 7). This is key because, even if internal information from within a mining operation disqualifies any given site from a potential conversion into a utility-scale solar facility every other site has also been projected to be viable. This would make it simple to shift personal, funding and resources from the development of one project to another depending on the viability of shutting down any given tailings pile or waste rock dump due to how it plays into the mine's current operations. It could also be significant if the mining operation is interested in investing in solar production infrastructure that could be moved from one area to another periodically potentially utilizing a Ballast system (Mohapatra et al., 2012). Another key takeaway from the Carlin Trend LCP analysis was the major impact that the length of spur transmission line played into the overall cost and resulting return on investment (ROI) of each site with each of the 6 shortest spur transmission lines having ROI values ranking them in the top 10. This indicates the importance of siting new utility-scale solar developments near existing substations and supports their inclusion in the statewide analysis as an addition to the ASU model along with showing their value in future work. Overall the results of this analysis are supportive to the proposal of siting utility-scale solar facilities on disturbed mining sites across Nevada and specifically in the Carlin Trend mining district.

4.2 Limitations of Data and Analysis

This analysis began with the intention to explore the possibility of installing utility-scale solar facilities on both disturbed sites and abandoned mine properties across the state of Nevada. However, this idea was limited in a few key ways by data availability and accessibly. The data for abandoned mine lands across the state were difficult to access and this analysis wasn't able to find a reliable source to use. The Nevada Division of Minerals has an Abandoned Mine Lands program (NDOM & Derby, 2021) which is known to possess a database of the abandoned mines across the state however this data is not publicized due to the hazardous nature of these sites and the potential for people to use the data to locate and explore them. If these data were accessible it may have been possible to compare these locations to the ranking surface and determine which abandoned mine site may have potential as solar facilities. However, it is worth noting that many of these are quite small, typically with a small amount surface material disturbed and would not be suitable for utility-scale solar development. Additionally, the acreages of the sites were not included in the BMRR dataset (BMRR, Most). I was able to access these values when I acquired the reclamation permits for each of the sites individually but their exclusion from the larger databases did not allow for the size of each site to be used as a constraining factor. Due to this, my resulting High Ranked sites table (Table 6) undoubtedly includes some sites that would not be large enough for solar facilities with a 20MW capacity.

The impact of heat and its impact on the efficiency of solar PV systems was also not included in this analysis. It is known that an increase in surface temperature reduces the efficiency of PV modules by 0.5% for every 1℃-temperature rise (Siecker et al., 2017). Various cooling technologies have been implemented to combat this reduction in efficiency. However, without their implementation a reduction in the efficiency of solar PV arrays can be seen when comparing those in hotter climates to those in cooler climates. This would undoubtedly impact the production of solar sites in southern Nevada compared to those in northern Nevada but it was not accounted for in the PVWatts model used within SAM for this analysis.

Data indicating the available carrying capacity of nearby transmission lines were also inaccessible which didn’t allow for that factor to be accounted for when predicting the potential cost of tying new energy production facilities into the existing grid infrastructure. It is known that this factor can play a large role in determining the final cost incurred because, if necessary the cost of upgrading the grids capacity typically falls to the developer (ICF Inc) and could be prohibitively large. However, projects may be able to take advantage of energy storage solutions like batteries or pumped hydro energy storage (Rehman et al., 2015) making it viable to deliver power to the grid when demand is high and the transmission lines have available carrying capacity. Or artificially increase electrical demand in the area by installing electrical vehicle charging stations near the solar sites. Solutions like these were considered outside the scope of this research but may provide potential for future work.

4.3 Key stakeholders and potential for legislative streamlining

While information related to proposals of siting utility-scale solar facilities on disturbed mining properties may be interesting to any number of readers there are a few key groups that can really make a difference in making projects like these a reality. Prospective solar developers and veterans in the solar development sector are an obvious target for this work due to their ability to explore areas like these when determining where to site their next projects. This may allow them to take advantage of some of the funding allotted by the Biden administration in the Bipartisan Infrastructure Law (DOE, 2023) or simply capitalize on the increasing demand for green energy. Mine operators would also be wise to consider proposals related to converting portions of their property to solar generation. Not only is it now considered a *'Productive post-mining land use'* and the confidence in the return of surety on the rise, it could help to offset the cost of power for the mining operation regardless of whether the solar facility reaches the 20MW threshold of *'utility-scale solar'* or if interconnection with the wider grid is feasible at all. It would be wise to reclaim a dumping site that is considered full and repurpose it as a utility-scale solar facility for the remaining lifespan of the mining operation.

Legislators can also play a major role in encouraging these projects across the state. Liability protection for those concerned with their involvement with contaminated areas could be enacted to protect prospective developers from financial liability associated with necessary cleanup that may be required after the redevelopment of a site but is linked to damage imposed by a previous use of the land. Costs and time associated with *permitting and environmental studies'* like those typically modeled using the System Advisor Model (NREL, 2017) could also be reduced through an expedited permitting process for those attempting to site utility-scale solar facilities on contaminated mine lands. This could be justified due to the pre-established understanding of these mine lands being poor habitat for wildlife (Gray et al. 2019) and the shift from one wildlife impediment to another could be considered negligible.

Other key stakeholders in proposals such as these are habitat conservationists, consumers concerned with sourcing their energy need from environmentally friendly, non-invasive production sources and the animals themselves who may benefit from utility-scale solar facilities being located in non-habitat. As renewable energy production increases across Nevada it is important to be asking, 'Where are these production facilities being placed?' And 'Could there be a better location?' Disturbed mining properties deserve to be considered in this conversation as potentially better locations than open desert territory.

SECTION 5: CONCLUSION

5.1 Future Work

Future work into this topic in Nevada could include an analysis of abandoned mining sites along with active disturbed sites. Many of Nevada's abandoned mining operations are small and may not contain enough acreage to develop economically feasible utility-scale solar facilities. However, those sites that are large enough would have all the benefits or more of siting solar on disturbed sites that exist as a part of active operations. Work could also be done to expand upon the work done in the Carlin Trend Mining District analysis portion of this project to include spur transmission line estimates and acreage based economic predictions for other mine sites with high potential to be repurposed as utility-scale solar facilities like those near Searchlight, Tonopah, and the Twin Creeks mine identified in the statewide analysis.

Future work could also explore the ability for PV solar sites to be daisy chained together reducing the total length of necessary spur transmission line and in turn, the overall cost per MW of energy produced in the area. There are many opportunities for this within the Carlin Trend study area which would lead to and increased return on investment and may allow for some of the sites which don't reach the 20 MW threshold to be combined together and considered utility scale.

The potential for energy storage solutions paired with utility scale solar projects on disturbed mining properties could also be explored by looking into their ability to alleviate the need for carrying capacity upgrades to the grid and provide benefits related to peak load sharing. The intermittent nature of solar energy has led to many solar energy plants to supplement their production with another type of energy (OSRTI Abandoned Minelands Team, 2011). This may not be necessary in areas like the Carlin Trend because the area is already wired to consume energy from the grid. However, energy storage has the potential to convert solar energy production on disturbed mining sites from a resource only available during daylight hours to an on-demand energy solution that can be by a mining operation overnight or sent to high demand centers.

The potential sites considered as a part of this analysis could also be modeled at a more detailed level which would result in more accurate predictions for energy and economic output. The PVWatts model within SAM used in this analysis models PV systems based off a few basic inputs, making internal assumptions about the specific characteristics of the system and is intended to be used for preliminary analysis. However, the Detailed Photovoltaic model within

SAM provides an opportunity for more detailed estimates by requiring specifications for the modules and inverters included in the system (NREL, 2017). This also allows for predictions that estimate losses due to temperature and provides a more in-depth method for calculating shading losses. The Detailed Photovoltaic model may be to specific for a set of sites, but could potentially represent a pragmatic next step for analysis related to a site that is receiving specific interest from a solar developer.

Adjacent but related work could provide an analysis similar to this one for the wind energy potential across the state related to the locations of disturbed and/or abandoned mining properties. The environmental impacts of wind energy production differ from those of solar production but are similar enough that this work could potentially serve as a model framework for the analysis.

5.2 Relevance of Work

The importance of this work in exploring the potential for utility-scale solar on disturbed mining properties across Nevada is key to understanding the validity of proposals that promote these types of projects. As we attempt to undergo an energy transition from fossil fuels and high carbon emitting carbon sources to renewables it is imperative that we identify and prioritize low impact areas in a smart-from-the-start approach to energy planning (Tibbitts, 2021) that balances clean energy goals with their impacts to our natural landscapes, wildlife, and places of recreation. Disturbed mining properties present an opportunity to do just that, but not every tailings pile, waste rock dump, or abandoned operation is the next 100+ MW generation facility. This work allows for a greater understanding of which sites have the greatest potential for these projects across the state.

REFERENCES

Andrade, J., & Baldick, R. (2017). *Estimation of Transmission Costs for New Generation* (The Full Cost of Electricity (FCe-), pp. 1–27) [White Paper]. University of Texas at Austin. https://energy.utexas.edu/sites/default/files/UTAustin_FCe_TransmissionCosts_2017.pdf

BLM. (n.d.). *Areas Identified in the 2012 Solar PEIS Record of Decision (ROD)* [Govenment]. 2012 Solar PEIS ROD. Retrieved April 6, 2023, from https://blmsolar.anl.gov/solar-peis/

BLM. (2012). *Approved Resource Management Plan Amendments/Record of Decision (ROD) for Solar Energy Development in Six Southwestern States*. 197.

blmsolarwebmaster@anl.gov. (2012). *Maps of Solar Land Use Allocations and Exclusions from the 2012 Solar Programmatic Environmental Impact Statement ROD*. Bureau of Land Management Solar Energy Permitting and Program Resources. https://blmsolar.anl.gov/maps/solar-peis/

Brewer, J., Ames, D. P., Solan, D., Lee, R., & Carlisle, J. (2015). Using GIS analytics and social preference data to evaluate utility-scale solar power site suitability. Renewable Energy, 81, 825–836. https://doi.org/10.1016/j.renene.2015.04.017

Brock, D., Black, N., Clayton, H., Cleland, R., Davy, A., Roberts, D., Williams, H., Ashenbrenner, K., Foster, S., & Weeks, B. (2019). *Integrated Mine Closure: Good Practice Guide (2nd edition)* (Good Practice Guide No. 2; Mining with Principals). ICCM- International Council on Mining and Metals. https://www.icmm.com/en-gb/guidance/environmental-stewardship/2019/integrated-mine-closure

Carlisle, J. E., Solan, D., Kane, S. L., & Joe, J. (2016). Utility-scale solar and public attitudes toward siting: A critical examination of proximity. Land Use Policy, 58, 491–501. https://doi.org/10.1016/j.landusepol.2016.08.006

CDWG@fws.gov. (2022). *FWS National Realty Tracts*. U.S. Fish & Wildlife Service. https://gis-fws.opendata.arcgis.com/datasets/fws::fws-national-realty-tracts/about

Chapter 519A - Reclamation of Land Subject to Mining Operations or Exploration Projects, (2020). https://www.leg.state.nv.us/nrs/nrs-519a.html

custserv@edcmail.cr.usgs.gov. (1999). *nv_dem.img*. U.S. Geological Survey (USGS), EROS Data Center. https://archive.epa.gov/esd/archive-nerl-esd1/web/html/nvgeo_gis3_dem_md.html

Dahle, D., Elliott, D., Heimiller, D., Mehos, M., Robichaud, R., Schwartz, M., & Walker, A. (2008). *Assessing the Potential for Renewable Energy Development on DOE Legacy Management Lands* (DOE/GO-102008-2435). National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy08osti/41673.pdf

data@fs.fed.us. (2022). *FSTopo Boundary Ownership Polygon*. United States Department of Agriculture: Forest Service. https://data.fs.usda.gov/geodata/edw/datasets.php?xmlKeyword=FSTopo

data@fs.fed.us. (2023). *National Forest Lands with Nationally Designated Management or Use Limitations*. US Forest Service Automated Lands Program. https://data.fs.usda.gov/geodata/edw/datasets.php?xmlKeyword=Other

Dave. (2018, January 16). How Does a Solar Farm Connect to the Grid? *SolarLandLease*. https://www.solarlandlease.com/solar-farm-connect-grid

Dewitz, J. (2019). *National Land Cover Database 2019 - Landcover & Imperviousness (NLCD2019)*. US Geological Survey. https://www.mrlc.gov/data?f%5B0%5D=category%3ALand%20Cover

DOE, N. (2023, April 3). *Biden-Harris Administration Announces $450 Million To Deploy Clean Energy Projects on Mine Lands*. Energy.Gov. https://www.energy.gov/articles/biden-harris-administration-announces-450-million-deploy-clean-energy-projects-mine-lands

EcoSmart Foundation Inc. (2023). SunMine – EcoSmart Sun [EcoSmart]. *Mining the Sun*. https://www.ecosmartsun.com/sunmine/

Electric Power Transmission Lines. (2022). Homeland Infrastructure Foundation Level Database (HIFLD). Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Idaho National Laboratory (INL), National Geospatial-Intelligence Agency (NGA) Homeland Security Infrastructure Program (HSIP) Team. https://hifld-geoplatform.opendata.arcgis.com/datasets/geoplatform::electric-power-transmission-lines/about

Electric Substations. (2019). Homeland Infrastructure Foundation-Level Data (HIFLD). Oak Ridge National Laboratory (ORNL), Los Alamos National Laboratory (LANL), Idaho National Laboratory (INL), National Geospatial-Intelligence Agency (NGA) Homeland Security Infrastructure Program (HSIP) Team https://hifld-geoplatform.opendata.arcgis.com/datasets/substations/explore?location=40.864007%2C-116.286381%2C11.24

Environmental Law Alliance Worldwide (ELAW). (2010). *Guidebook for Evaluating Mining Project EIAs* (1st ed.). Environmental Law Alliance Worldwide. https://elaw.org/mining-eia-guidebook

EPA. (2019). *RE-Powering America's Land Initiative: Tracking Completed Projects on Contaminated Lands, Landfills and Mine Sites*. Office of Communications, Partnerships and Analysis ; Office of Land and Emergency Management.

https://www.epa.gov/sites/default/files/2019-10/documents/re_tracking_matrix_final_508_100219.pdf

Esri Data and Maps. (2020). *USA Rivers and Streams*. Environmental Systems Research Institute. https://hub.arcgis.com/datasets/esri::usa-rivers-and-streams/about

Etten, J. van, & Sousa, K. (2017). *R Package gdistance: Distances and Routes on Geographical Grids* (1.6) [R CRAN]. Foundation for Open Access Statistics; Journal of Statistical Software. https://cran.r-project.org/web/packages/gdistance/index.html

Gray, M. E., Dickson, B. G., Nussear, K. E., Esque, T. C., & Chang, T. (2019). A range-wide model of contemporary, omnidirectional connectivity for the threatened Mojave desert tortoise. Ecosphere, 10(9). https://doi.org/10.1002/ecs2.2847

Graham, K. (2022, January 2). *Former Kentucky coal mine to be turned into state's largest solar farm* [News]. Digital Journal. https://www.digitaljournal.com/tech-science/former-kentucky-coal-mine-to-be-turned-into-states-largest-solar-farm/article

ICF Inc, L. (2019). Interconnection: Plugging RE-powering Sites Into the Electric Grid. *US EPA RE-Powering America's Land Initiative*, 18.

installations_ranges. (2021). Department of Defense. https://catalog.data.gov/dataset/military-installations-ranges-and-training-areas

Keenan, J., & Holcombe, S. (2021). Mining as a temporary land use: A global stocktake of post-mining transitions and repurposing. *The Extractive Industries and Society*, *8*(3), 100924. https://doi.org/10.1016/j.exis.2021.100924

Kiatreungwattana, K., Mosey, G., Jones-Johnson, S., Dufficy, C., Bourg, J., Conroy, A., Keenan, M., Michaud, W., & Brown, K. (2013). *Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills. A Study Prepared in Partnership with the Environmental*

Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites (NREL/TP-7A30-52615). National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/1076646

Lewis, J. (2022). *leastcostpath* (1.8.7) [Computer software]. https://www.rdocumentation.org/packages/leastcostpath/versions/1.8.7

Lima, R. M., Osis, R., Queiroz, A. R., & Santos, A. H. M. (2016). Least-cost path analysis and multi-criteria assessment for routing electricity transmission lines. *IET Generation, Transmission & Distribution*, *10*(16), 4222–4230. https://doi.org/10.1049/iet-gtd.2016.1119

Lovich, J., & Ennen, J. (2011). Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. BioScience, 61(12), 982–992. https://doi.org/10.1525/bio.2011.61.12.8

Majumdar, D., & Pasqualetti, M. J. (2019). Analysis of land availability for utility-scale power plants and assessment of solar photovoltaic development in the state of Arizona, USA. *Renewable Energy*, *134*, 1213–1231. https://doi.org/10.1016/j.renene.2018.08.064

McNerney, M., & Jaffe, C. (2017). *Barriers and Opportunities for Siting Solar Energy Projects on Contaminated Mine Lands in Nevada* (p. 35) [Prepared for The Nature Conservancy By the Environmental and Regulatory Law Clinic at the University of Virginia School of Law]. University of Virginia School of Law.

McNerney, M., Jaffe, C., & The Environmental and Regulatory Law Clinic at the University of Virginia School of Law. (2017). *Barriers and Opportunities for Siting Solar Energy Projects on Contaminated Mine Lands in Nevada*. The Nature Conservancy.

Miranda, H., Geusebroek, P., & Scholey, B. (2018). *Technical Report on the South Arturo Mine, Elko County, State of Nevada, USA* (Technical Report Project #2955). Roscoe Postle Associates Inc. https://www.miningdataonline.com/reports/SouthArturo_Technical_Report_03262018.pdf

Moan, J., & Gower. (2022, July 21). *Mining the Sun in Nevada*. The Nature Conservancy. https://www.nature.org/en-us/about-us/where-we-work/united-states/nevada/stories-in-nevada/solar-energy-at-former-mines/

Mohapatra, P., Ali, S., Mishra, S. P., & Pradhan, A. (2012). FUTURE ASPECTS SOLAR PANEL INSTALLATION ON CLOSED LANDFILLS. International Journal of Advances in Engineering & Technology. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=20a3368496391a0f646135dc7836a1cfd987e345

Monteiro, C., Ramirez-Rosado, I. J., Miranda, V., Zorzano-Santamaria, P. J., Garcia-Garrido, E., & Fernandez-Jimenez, L. A. (2005). GIS spatial analysis applied to electric line routing optimization. *IEEE Transactions on Power Delivery*, *20*(2), 934–942. https://doi.org/10.1109/TPWRD.2004.839724

Moore, C., Bergen, D., Valliant, W., Collins, S., & Altman, K. (2012). *Technical Report on the Goldstrike Mine, Eureka and Elko Counties, Nevada, USA* (Technical Report Project #1663). Roscoe Postle Associates Inc. https://www.miningnewsfeed.com/reports/Goldstrike_Technical_Report_03222019.pdf

Moore-O'Leary, K. A., Hernandez, R. R., Johnston, D. S., Abella, S. R., Tanner, K. E., Swanson, A. C., Kreitler, J., & Lovich, J. E. (2017). Sustainability of utility-scale solar energy – critical ecological concepts. Frontiers in Ecology and the Environment, 15(7), 385–394. https://doi.org/10.1002/fee.1517

Most, M. (2022a). *BMRR Reclamation Sites*. NDEP BMRR. https://data-ndep-gis.opendata.arcgis.com/datasets/2ed19015fd724797b85450026a97d466_0/about

Most, M. (2022b). *BMRR Tailings*. NDEP BMRR. https://data-ndep-gis.opendata.arcgis.com/datasets/30d969940a1e401cbeb6dbdd2f1cbca7_1/about

Most, M. (2022c). *BMRR WasteRockDumps*. NDEP BMRR. https://data-ndep-gis.opendata.arcgis.com/datasets/b15264fae25742e880a1a9c38f5a5162_0/about

Murphy, Z. (2022, March 3). *In Virginia, abandoned coal mines are transformed into solar farms* [News]. Washington Post. https://www.washingtonpost.com/climate-solutions/2022/03/03/coal-mines-solar-farms-climate-change-video/

National Flood Hazard Layer. (2021). US Department of Homeland Security, Federal Emergency Management Agency. https://www.fema.gov/flood-maps/national-flood-hazard-layer

National, G. (2023). What is an electricity substation? | National Grid Group. What Is a Substation? https://www.nationalgrid.com/stories/energy-explained/what-is-a-substation

NDOT Open Data. (2020). *Feature Service of FSystem layer*. Nevada Department of Transportation. https://geohub-ndot.hub.arcgis.com/datasets/NDOT::fsystem/about

Nevada Bureau of Mining Regulation and Reclamation. Goldstrike Mine Reclamation Permit, Permit No. 0026, 23 July 2019, Print.

Nevada Bureau of Mining Regulation and Reclamation. Arturo Mine Reclamation Permit, Permit No. 0355, 28 February 2020, Print.

Nevada Bureau of Mining Regulation and Reclamation. Storm Underground Mine Reclamation Permit, Permit No. 0243, 18 July 2019, Print.

Nevada Bureau of Mining Regulation and Reclamation. Dee Gold Mine Reclamation Permit, Permit No. 0118, 18 July 2019, Print.

Nevada Bureau of Mining Regulation and Reclamation. Rossi Mine Reclamation Permit, Permit No. 0257, 6 June 2019, Print.

Nevada Bureau of Mining Regulation and Reclamation. Bootstrap Project Reclamation Permit, Permit No. 0101, 29 July 2021, Print.

Nevada Bureau of Mining Regulation and Reclamation. Carlin Pete Operations Area Reclamation Permit, Permit No. 0175, 18 July 2019, Print.

Nevada Bureau of Mining Regulation and Reclamation. North Area Leach Reclamation Permit, Permit No. 0176, 31 January 2020, Print.

Nevada Bureau of Mining Regulation and Reclamation. Leeville Underground Mine Reclamation Permit, Permit No. 0208, 12 July 2021, Print.

Nevada Bureau of Mining Regulation and Reclamation. Meikle Mine Reclamation Permit, Permit No. 0030, 17 November 2020, Print.

Nevada Bureau of Mining Regulation and Reclamation. Rain-Saddle Mine Reclamation Permit, Permit No. 0014, 23 February 2021, Print.

Nevada Bureau of Mining Regulation and Reclamation. Emigrant Mine Reclamation Permit, Permit No. 0312, 23 February 2021, Print.

Nevada Bureau of Mining Regulation and Reclamation. Gold Quarry/South Operations Area Reclamation Permit, Permit No. 0056, 27 May 2020, Print.

Nevada Bureau of Mining Regulation and Reclamation. Ivanhoe-Hollister Reclamation Permit, Permit No. 0154, 18 June 2021, Print.

Nevada Bureau of Mining Regulation and Reclamation. Genesis-Bluestar Mine Reclamation Permit, Permit No. 0096, 23 July 2019, Print.

Nevada Division of State Lands. (n.d.). *State Managed Lands Web Map* [Earthstar Geographics Web Map]. State Managed Lands Web Map. Retrieved February 22, 2022, from http://webgis.lands.nv.gov/Html5Viewer/Index.html?configBase=http://webgis.lands.nv.gov/Ge ocortex/Essentials/REST/sites/StateLands/viewers/HTML5/virtualdirectory/Resources/Config/Default

NREL. (2021). *NSRDB* [Database Host]. NSRDB: National Solar Radiation Database. https://nsrdb.nrel.gov/

NREL, D. (2017). *System Advisor Model - SAM*. https://sam.nrel.gov/

Nuclear Regulatory Commission. (n.d.). *A Breath of Fresh Air for America's Abandoned Mine Lands: Alternative Energy Provides a Second Wind*.

NV Energy. (2023). NV Energy. NV Energy-Owned Generating Resources. https://www.nvenergy.com/

Ong, S., Campbell, C., Denholm, P., Margolis, R., & Heath, G. (2013). *Land-Use Requirements for Solar Power Plants in the United States* (NREL/TP-6A20-56290, 1086349; p. NREL/TP-6A20-56290, 1086349). https://doi.org/10.2172/1086349

Optimal design and routing of power lines; ecological, technical and economic perspectives (OPTIPOL). Progress Report 2010. (n.d.). SINTEF. Retrieved March 15, 2023, from https://www.sintef.no/en/publications/publication/1238198/

OSRTI Abandoned Minelands Team. (2011). *Shining Light on a Bright Opportunity - Developing Solar Energy on abandoned mine lands*. United States Environmental Protection Agency. https://semspub.epa.gov/work/11/176032.pdf

Petersen, M., Frankel, A., Harmsen, S., Mueller, C., Haller, K., Wheeler, R., Wesson, R., Zeng, Y., Boyd, O., Perkins, D., Luco, N., Field, E., Wills, C., & Rukstales, K. (2011). *Seismic-Hazard Maps for the Conterminous United States, 2008*. US Geological Survey. https://pubs.usgs.gov/sim/3195/

Piirisaar, I. (2019). A multi-criteria GIS analysis for siting of utility-scale photovoltaic solar plants in county Kilkenny, Ireland [Lund University]. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8989290&fileOId=8989294

R Core Team. (2022). *R: A Language and environment for statistical computing.* R Foundation for Statistical Computing. https://www.R-project.org/.

Rehman, S., Al-Hadhrami, L. M., & Alam, Md. M. (2015). Pumped hydro energy storage system: A technological review. Renewable and Sustainable Energy Reviews, 44, 586–598. https://doi.org/10.1016/j.rser.2014.12.040

Renne, D., George, R., Wilcox, S., Stoffel, T., Myers, D., & Heimiller, D. (2008). *Solar Resource Assessment* (NREL/TP-581-42301). National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/924643

Rocky Mountain Institute. (2019). *Mining the Sun: Phase 1 Data Roadmap* (No. 1; pp. 1–28). The Nature Conservancy. Print

Ronald, L. (2019). *East_Fork_High_Rock_Canyon, Little_High_Rock_Canyon, High_Rock_Canyon*. Wilderness Connect: Wilderness Institute, University of Montana. https://wilderness.net/visit-wilderness/gis-gps.php#e

Scott, J., Gilbertson-Day, J., Moran, C., Dillon, G., Short, K., & Vogler, K. (2020). *Wildfire Risk to Communities: Spatial datasets of landscape-wide wildfire risk components for the United States Data publication contains GIS data*. Forest Service Research Data Archive. https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016

Sengupta, M., Xie, Y., Lopez, A., Habte, A., Maclaurin, G., & Shelby, J. (2018). The National Solar Radiation Data Base (NSRDB). *Renewable and Sustainable Energy Reviews*, *89*, 51–60. https://doi.org/10.1016/j.rser.2018.03.003

Siecker, J., Kusakana, K., & Numbi, B. P. (2017). A review of solar photovoltaic systems cooling technologies. *Renewable and Sustainable Energy Reviews*, *79*, 192–203. https://doi.org/10.1016/j.rser.2017.05.053

Stutts, M. (2014). *National Register of Historic Places*. National Parks Service DataStore. https://irma.nps.gov/DataStore/Reference/Profile/2210280

Sutton, J. (2023). *FAC - Superfund Site Boundaries (EPA)*. US Environmental Protection Agency. https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7BFC07D75C-8596-434B-B1A6-0688C9CD45B5%7D

SvcNISCGISSQLtk@nps.doi.net. (2019). *NPS - Land Resources Division Boundary and Tract Data Service*. National Park Service Land Resources Division. https://public-nps.opendata.arcgis.com/maps/c8d60ffcbf5c4030a17762fe10e81c6a/about

Teck Resources Limited. (2023). *Teck About the Sullivan Mine* [Company Webpage]. Teck Resources Limited. http://www.teck.com/operations/canada/legacy/sullivan-mine/sullivan-mine-legacy/current-activity

The Nature Conservancy, W. V., & Brolis, E. (2019). *Roadmap for Solar on Mine Lands*. The Nature Conservancy. https://www.nature.org/content/dam/tnc/nature/en/documents/west-virginia-solar-road-map-exec-summary.pdf

Tibbitts, J. (2021, June 9). State Land Use Planning Advisory Council [Government Planning Council]. 2023-04-12. https://lands.nv.gov/uploads/documents/SLUPAC_Endorsement_of_Concept_Smart-From-the-Start_Letter_(As_Approved).pdf

TIGER/Line Shapefile, 2019, nation, U.S., Rails National Shapefile. (2019). US Census Bureau, Department of Commerce. https://catalog.data.gov/dataset/tiger-line-shapefile-2019-nation-u-s-rails-national-shapefile

US EIA. (2021). *PowerPlants_US_EIA*. U.S. Energy Information Administration. https://www.eia.gov/maps/layer_info-m.php

US EPA, O. (2013, February 22). *Summary of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)* [Overviews and Factsheets]. https://www.epa.gov/laws-regulations/summary-comprehensive-environmental-response-compensation-and-liability-act

USFS Enterprise Content. (2015). *US Forest Service National Wilderness Areas*. US Forest Service Automated Lands Program. https://hub.arcgis.com/datasets/usfs::national-wilderness-areas/about

USGS 1 arc-second n41w116 1 x 1 degree. (2018a). US Geological Survey. https://www.sciencebase.gov/catalog/item/5df04efee4b02caea0f4fb07

USGS 1 arc-second n41w117 1 x 1 degree. (2018b). US Geological Survey. https://www.sciencebase.gov/catalog/item/5df04efee4b02caea0f4fb09

USGS 1 arc-second n42w117 1 x 1 degree. (2018c). US Geological Survey. https://www.sciencebase.gov/catalog/item/5df04f0fe4b02caea0f4fb79

Utility_Scale_Solar_Electric_(.pdf. (n.d.).

Wheatley, B., & Moan, J. (2020, September 4). Mining the Sun: How Nevada and West Virginia are Reclaiming Former Mine Lands with Solar Panels. The Nature Conservancy. https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/nevada-west-virginia-solar-energy-former-mines/

Wickham, H., Francoia, R., Henry, L., Muller, K., & Vaughan, D. (2023). *dplyr: A Grammar of Data Manipulation* (1.1.0) [R]. https://cran.r-project.org/web/packages/dplyr/index.html

Wright. Scott. Utility Scale Solar Electric (UTILITY SCALE SOLAR FACILITIES) and land use implications of meeting 2030 Renewable Energy Goals for California and Nevada in the Mojave Desert (28499283) \[Master's Thesis, University of Nevada, Reno\]