SOAKING IN THE RAYS

USING GIS AND MULTI-ATTRIBUTE UTILITY THEORY TO PRIORITIZE AREAS OF INVESTMENT FOR LARGE-SCALE SOLAR FARMS IN OREGON

Our current sources of energy are no longer a viable option. Climate change caused by pollution and other anthropocentric effects have proven the current energy paradigm to be both unsustainable and inefficient. The need to find renewable energy resources are a priority if we are to meet the requirement to combat climate change as mandated by the passage of one of the most aggressive renewable energy portfolios in the United States by the Oregon State Legislature. On March 1, 2016, the Oregon House and Senate passed Senate Bill 1547 requiring PacifiCorp and Portland General Electric (PGE) to obtain 50 percent of the electricity they supply from renewable sources by 2040. Solar generated electricity is one method that has extreme potential in the state of Oregon, and is a perceived better alternative to hydro-electric dams, that have been proven to be socially, environmentally, and ecologically detrimental in the Northwest, among many other areas in the world.

PURPOSE

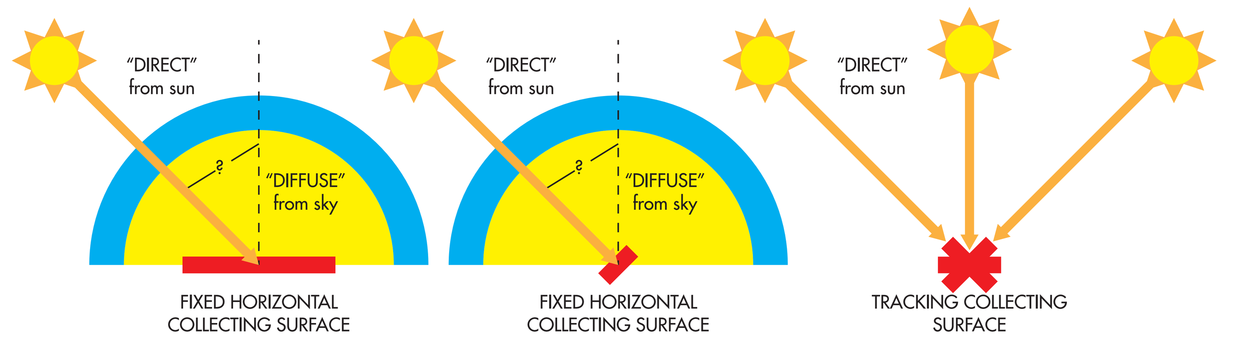
The goal of this analysis is to identify areas in the state of Oregon best suited to collect solar energy using multi-attribute utility theory, otherwise known as multi-criteria decision making. The assigned weights were determined using cited literature in the subject area of renewable solar resource generation in the field of GIS. Factors such as distance from city and power lines were used as cost factors, as these hinder the transmission of electricity due to their spatial dependency. Factors such as solar power generation capacity, slope, and land cover type will be used as benefits, as these are crucial to locating solar power generation sites.

RESEARCH QUESTIONS

Will the state of Oregon provide suitable locations for large scale solar farms based off of measured direct normal irradiance?

- Where will potential sites be located in the state of Oregon after applying various social, economic, and technological factors affecting the placement of solar farms?
- Which areas in the state will be best suited for investment in large scale solar farms?
- Does the model reflect current and proposed solar farm sites in the state of Oregon?
- Will the collection of solar energy be a viable option for the energy portfolio for Oregon and assist the state to meet its renewable energy needs mandated by OR Senate Bill 1547?

DNI GRAPHIC & EXPLANATION



DNI is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. Typically, you can maximize the amount of irradiance annually received by a surface by keeping it normal to incoming radiation. This metric is of particular interest when siting large solar collectors that concentrate the solar energy of the sun.

DATA NEEDED WITH SOURCES

- Lower 48 and Hawaii DNI 10km Resolution 1998 to 2009 from the National Renewable Energy Laboratory
- Power Lines from Esri ArcGis
- Cities from the Oregon Spatial Data Clearinghouse from the National Atlas of the United States, Published on April, 20, 2002
- Highways from Oregon Spatial Data Clearinghouse from ODOT
- Land cover from Oregon Spatial Data Clearinghouse from USGS, Published on March 31, 2013
- Land management data from the Oregon Spatial Data Clearinghouse created by Oregon Department of Forestry, Published in 2010
- 30m DEM from Portland State University I drive
- Oregon Prime Farmland from Oregon Spatial Data Clearinghouse created by National Resource Conservation Service, Published in 2008
- Oregon Railways from Oregon Spatial Data Clearinghouse created by ODOT
- Oregon Native American Reservations from Oregon Spatial Data Clearinghouse created by Oregon Department of Forestry
- Oregon Wetlands from Oregon Spatial Data Clearinghouse created by Oregon Natural Heritage Center & The Wetlands Conservancy, Published on October 30, 2009

PREPROCESSING & METHODS

- Set extent of study area to the state of Oregon outline shapefile from the Oregon Spatial Data Clearinghouse and cell size to 5500.
- Reproject all initial data into the projected coordinate system, NAD_1983_2011_Oregon_Statewide_Lambert_ft_intl, using batch reproject tool or define projection tool in data management toolbox.
- Create binary raster of prime farmland, Native American reservations, and wetlands in the state of Oregon by creating a new field in shapefile attribute table, converting shapefile to raster in the conversions tools toolbox, mosaicing raster site data with study area data using the mosaic to new raster tool in the data management toolbox, and using reclassify tool in spatial analyst toolbox to finalize the creation of the binary rasters, site locations given a value of 0 and the rest of the study area given a value of 1.
- Create euclidean distance raster of the powerlines, cities, and railroads in the state of Oregon using euclidean distance tool in spatial analyst toolbox. Results were converted into an integer type raster due to weighted overlay analysis tool only using integer numbers, the conversion was done using the int tool in the spatial analyst toolbox. The distance rasters were then reclassified using the reclassify tool in the spatial analyst toolbox.
- The direct normal irradiation shapefile was converted to a raster with a cell size of 5500 feet with the shapefile to raster tool in the conversions tool box. The conversion was based on the field that held the average dni values for the study area from 1998-2008.
- 30-meter digital elevation model from the Oregon Spatial Data Clearinghouse was obtained and used to derive a slope raster using slope tool in the spatial analyst toolbox. The slope raster was converted to an integer type raster for the weighted overlay analysis with the int tool in the spatial analyst toolbox.
- The Oregon land cover file was converted into a raster using the shapefile to raster tool in spatial analyst based off of the land manger field.
- Land ownership data was converted into a raster using the polygon to raster tool in the conversion toolbox. The polygon was converted to raster based off of the land manger field.

RECLASSIFICATION SCHEMA

- Euclidean distances from Oregon cities was classified into three distance groups. The first being within 5 miles of a city and given a weighting of nine in the weighted overlay, the second area was distances between five and fifteen miles and given a ranking of 6, and all areas with a distance greater than fifteen miles from a city were given a rank of one in the weighted overlay analysis. The classification goal is to place the solar farm closer to cities where the power will be used.
- Euclidean distance raster of the Oregon railway system was classified into 2 different groups. Areas within two miles of a railway were given a restricted value and all other areas were given a value of nine. The goal of this reclassification is to avoid particulate matter and other disturbances created by rail transportation from interfering with solar collecting equipment.
- Euclidean distance from Oregon highways was reclassified into three classes. Areas with a distance less than fifteen miles from an Oregon highway were given a value of nine, areas between fifteen and thirty miles were given a value of six, and areas greater than thirty miles from a highway were given a value of one. The goal of this classification is to allow accessibility to areas where solar collection sites will be located.
- Binary rasters derived for Oregon wetlands, Native American reservations, and prime farmland were given a value of nine in areas where these sites are not located. If one of these sites were located in the study area, they received a restricted value. The goal of these reclassifications was to avoid placing any solar collection sites on an existing wetland, Native American reservation, or prime farmland in the state of Oregon in an attempt to avoid social conflict.
- The slope raster was reclassified into two classes. Slope values less than five percent were given a value of nine and values greater than five percent were restricted in the weighted analysis. This is due to the cited literature stating that solar collection sites cannot be placed on areas with a slope greater than five percent.
- Land cover types were reclassified into four classes. The first class included the land types: open water, perennial snow and ice, highly developed, woody wetlands, and emergent wetlands, and these were assigned restricted values. The second class included the land types: medium intensity development, deciduous forest, evergreen forests, mixed forests, and cultivated crops, these areas were assigned a value of one in the weighting criteria. The third class included the areas unclassified land, low intensity development, shrub/ scrub, herbaceous, and hay and pasture, these areas were assigned a value of six in the weighting criteria. The fourth class includes the lands types barren and open development, and these were assigned a value of 9 in the weighting analysis overlay. The goal of this reclassification is to place solar collection sites on land cover types most suitable for them.
- The land management data was reclassified according to the land manager of the area and into four different groups. The first class included U.S. Bureau of Indian Affairs, U.S. Bureau of Land Management, U.S. Department of Agriculture, U.S. Coast Guard, U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Fish and Wildlife, Federal Aviation Administration, U.S. Department of Energy, U.S. General Services Administration, and U.S. Department of Defense, and was assigned a weighting criteria of six. The second class consisted of Oregon State University, land held under the general title of the state of Oregon, the Oregon University system, the Oregon Department of State Lands, Oregon Department of Transportation, and Oregon Department of Forestry, these areas were assigned a rank of nine in the criteria. The third class consisted of areas in the field land manager such as the Bonneville Power Administration, and Private (PVI & PV), these were given a weighting of six in the weighted overlay. The fourth class consisted of the area held by the U.S. National Park Service, Oregon Parks & Recreation Department, Oregon Department of Fish & Wildlife, tribal areas, and areas covered in water, and these areas were assigned restricted values. The goal of this reclassification is to avoid social conflict, as well as place sites with land managers more suitable for consideration of solar collection sites.
- The measured direct normal irradiance raster was reclassified into five classes each according to the measurement of direct normal irradiance in watts per meter squared. The goal of this reclassification is to optimize the amount of solar energy that can be harvested from the area annually.
- The above mentioned reclassification were combined into a weighted overlay analysis using the weighted overlay tool in the spatial analyst toolbox according to the weighting schema in the table.
- The weighted analysis raster was combined with the Oregon counties shapefile using the zonal statistics tool in the spatial analyst toolbox to create a choropleth map of counties most suitable for investment for solar farms.
- Test sites were obtained from the Renewable Energy Project to test viability of analysis and used to validate model.

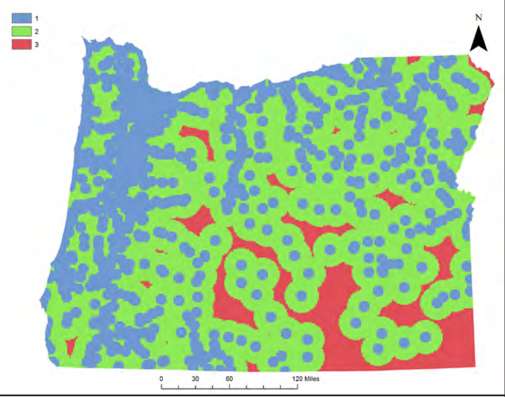
GIS CRITERIA DEVELOPED TO IDENTIFY SOLAR FARM LOCATIONS IN OREGON

VARIABLE	IDEAL SOLAR COLLECTION CONDITIONS	ORIGINAL DATA TYPE	ORIGINAL DATA FORMAT	FINAL DATA TYPE	RANGE OF ASSIGNED VALUES	WEIGHT ASSIGNED TO VARIABLE	REASONING FOR INCLUSION
Solar Potential of Area	Maximize watts per meter squared annually	Discrete	Polygon	Categorical Raster	9,8,7,6,5	30%	Janke, Cerabi, Sanchez-Lazano
Distance to Transmission Lines	Locate close to powerlines due to loss of the collected resource over distance	Discrete	Polyline	Categorical Raster	1, 6, 9	15%	Janke, Chao-Rong Chen, Cherabi, Sanchez-Lazano
Distance to Highway	Locate close to highway to provide accessibility to location	Discrete	Polyline	Categorical Raster	1, 6, 9	10%	Cerabi, Sanchez-Lazano, Janke
Land Cover Type	Locate areas within land covers that are supportive of solar farms	Continuous	Polygon	Categorical Raster	Restricted,1,6, 9	10%	Cherabi, Janke, Sanchez-Lazano
Slope of Area	Areas must be located on slopes of less than 5%	Continuous	Raster	Categorical Raster	Restricted, 9	5%	Cherabi, Choa-Rong Chen, Janke
Land Ownership of Area	Locate land owned by entities that would avoid social conflict	Discrete	Polygon	Categorical Raster	Restricted, 6,9	5%	Little/Swiahrt, Cherabi, Janke, Sanchez-Lazano
Prime Farmland	Do not locate areas classified as prime farmland	Discrete	Polygon	Categorical Raster	Restricted, 9	5%	Little/Swihart
Railroads	Do not locate a solar farm near an existing railroad	Discrete	Polyline	Categorical Raster	Restricted, 9	5%	Little/Swihart
Wetlands	Do not locate a solar farm on a designated tribal area	Discrete	Polygon	Categorical Raster	Restricted, 9	5%	Swihart/ Little,
Cities	Ideally located near areas where power is needed	Discrete	Point	Categorical Raster	1, 6, 9	5%	Janke

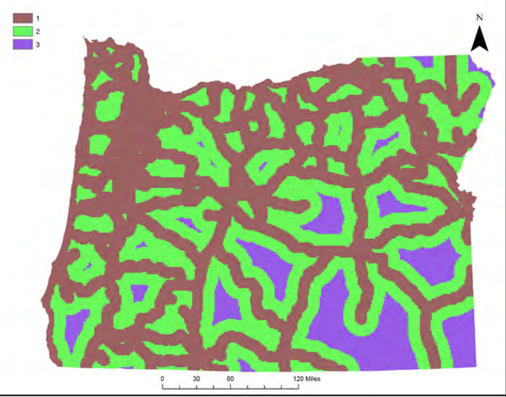
INDIVIDUAL MAPS USED FOR ANALYSIS

CITIES

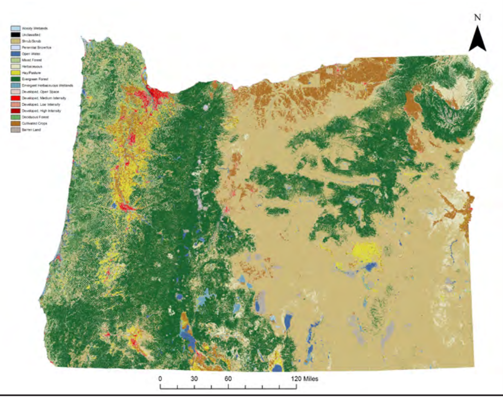
RECLASSIFIED EUCLIDIAN DISTANCE FROM CITIES



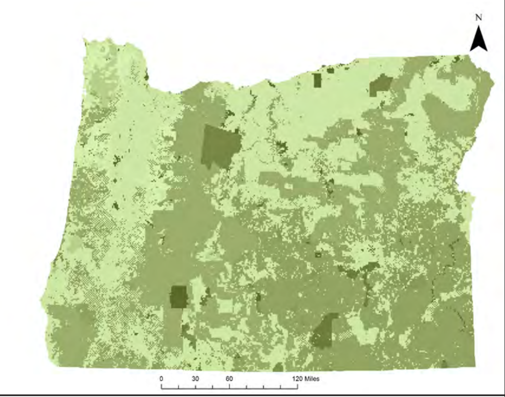
RECLASSIFIED EUCLIDIAN DISTANCE FROM OREGON HIGHWAYS



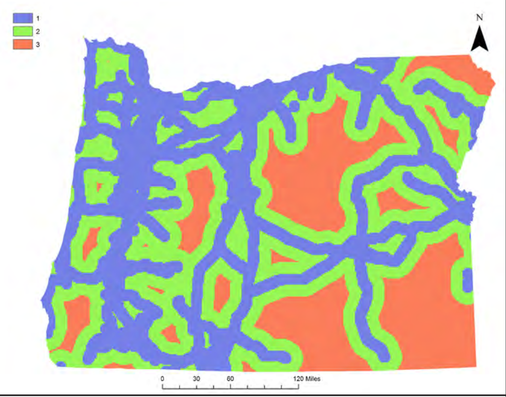
NATIONAL LAND COVER RASTER CONVERSION



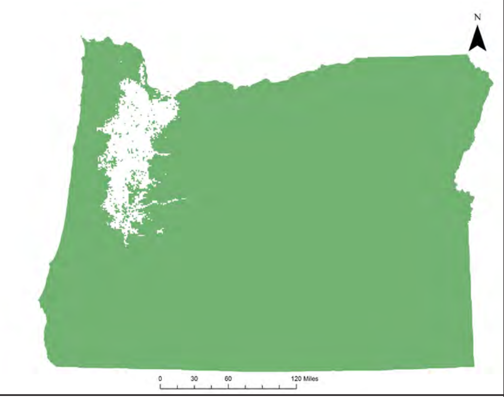
LAND MANAGEMENT RASTER CONVERSION



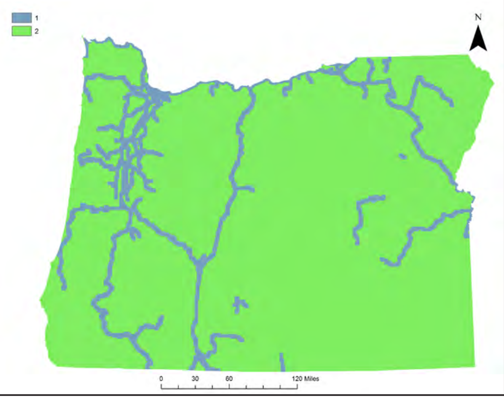
EUCLIDEAN DISTANCE FROM POWER TRANSMISSION LINES IN STATE OF OREGON



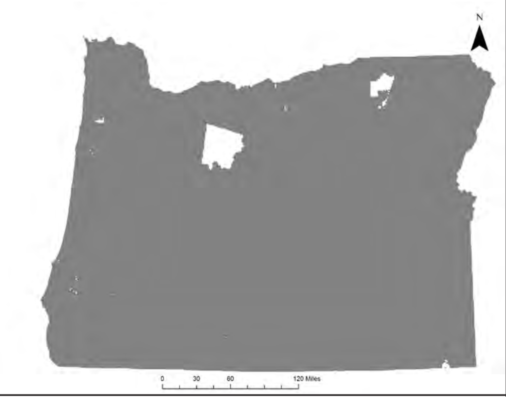
BINARY RASTER OF PRIME FARMLAND IN THE STATE OF OREGON



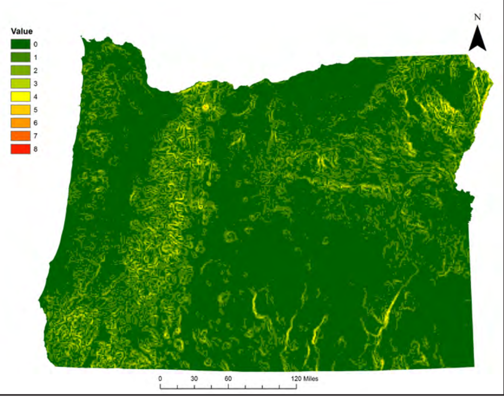
RECLASSIFIED EUCLIDEAN DISTANCE FROM RAIL LINES IN OREGON



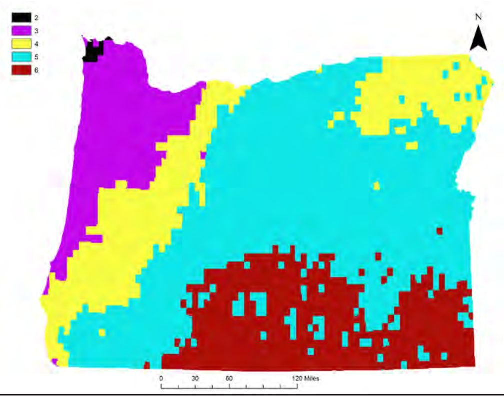
BINARY RASTER OF TRIBAL AREAS IN THE STATE OF OREGON



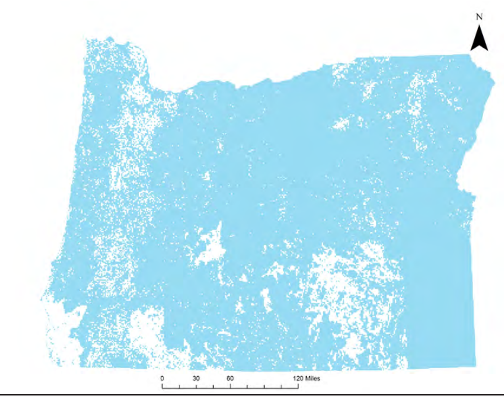
SLOPE RASTER FROM 30M DEM OF STATE OF OREGON



RECLASSIFIED SOLAR POTENTIAL OF STATE OF OREGON (ANNUAL W/M²)



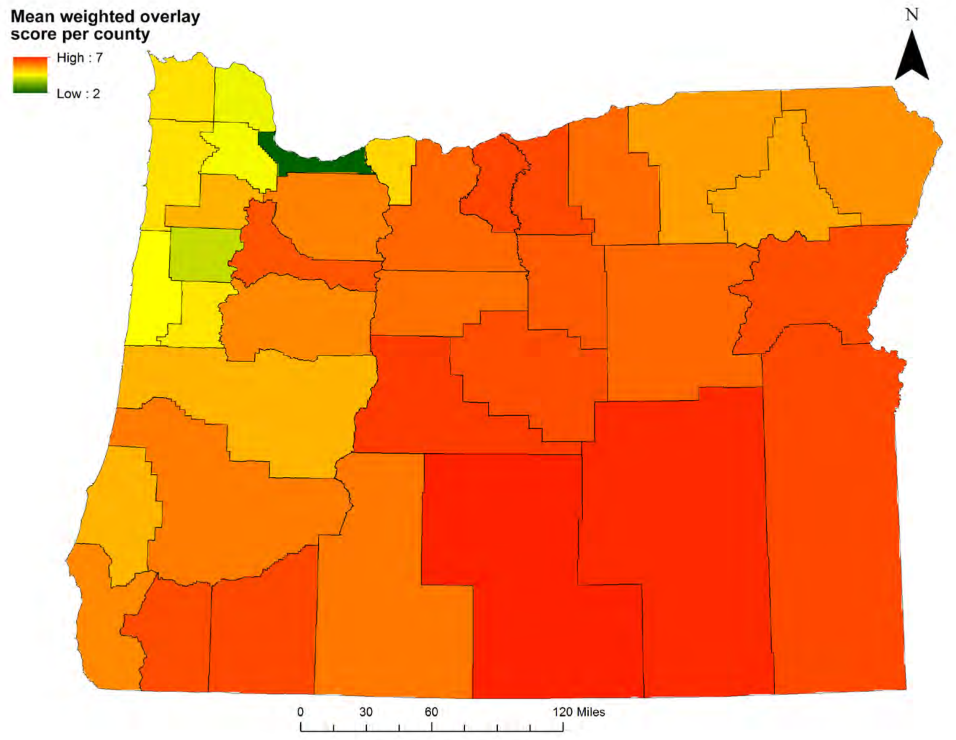
BINARY RASTER OF OREGON WETLANDS



ANALYSIS OUTCOME

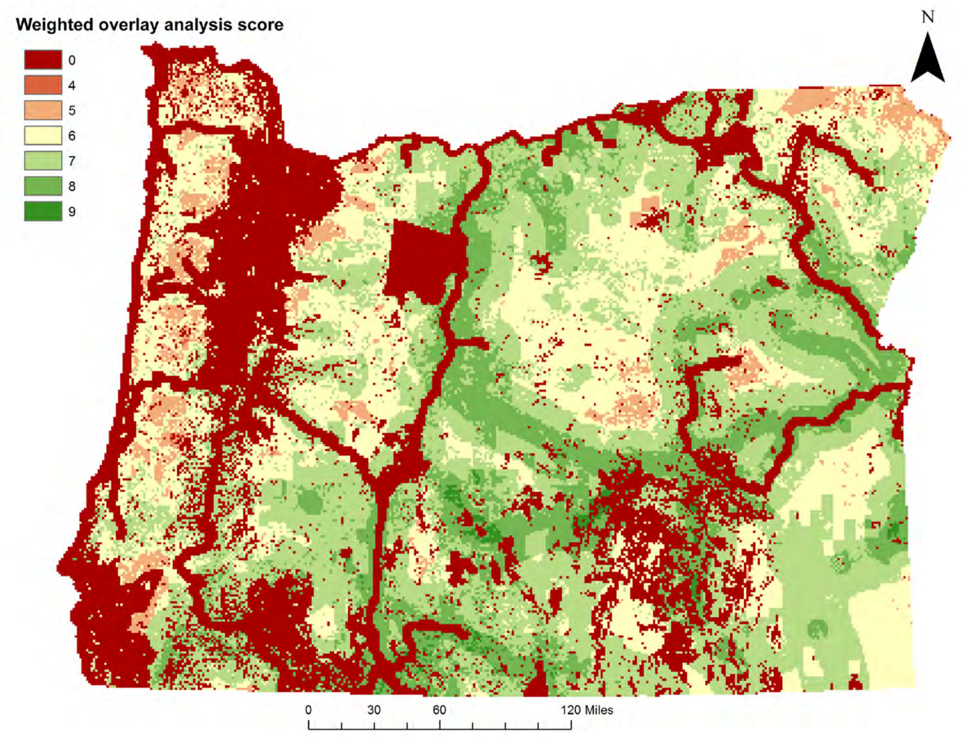
CHOROPLETH OF MEAN WEIGHTED ANALYSIS SCORE FOR LARGE SCALE POWER GENERATION IN THE STATE OF OREGON

This map shows the solar power generation capability of each county in the state of Oregon based off of the mean weighted overlay score derived from the analysis.



WEIGHTED OVERLAY ANALYSIS FOR SOLAR POWER GENERATION IN THE STATE OF OREGON

This weighted overlay shows the solar potential for the state of Oregon based on various social, technological, and environmental factors such as direct normal irradiance, slope, and land management agency for the area.



RESULTS

The research and analysis rendered informative locations for potential large scale solar collection sites. While many small-scale solar collection sites are located near high-demand urban sites, such as the Intel partnerships in Hillsboro, the Oregon State University 35th street solar field, or the Clackamas ProLogic warehouse project, the analysis was weighted to locate large scale sites, based off of direct normal irradiance, which is better suited for sites of large scale solar collection versus photovoltaic measures. After applying social, technological, and environmental variables valued by Oregonians, to avoid social conflict in the placement of these sites, a weighted overlay analysis was produced that displays potential suitable sites for large scale solar generation in the state of Oregon. This weighted overlay analysis was then used to produce a choropleth map showing counties in the state of Oregon most suitable for investment for large scale solar power generation. We found that counties in the southeastern and southcentral part of the state, such as Harney, Lake and Klamath counties, had many sites which proved to have exceptional large scale solar power generation potential according to the weighted criteria used in the analysis.

NAME	EXISTING OR PROPOSED	POWER GENERATION CAPABILITIES	LONGITUDE	LATITUDE	SCORE FROM ANALYSIS
OIT Solar	Existing	2000 KW	121° 47' 8.6964" W	42° 15' 35.9172" N	8
OIT Campus - phase 2	Existing	1.8 MW	121° 47' 19.986" W	42° 15' 16.074" N	8
Outback Solar	Existing	4950.0 KW	120° 29' 17.3328" W	43° 14' 5.568" N	6
Tumbleweed Solar	Proposed	9900 KW	121° 14' 8.6172" W	44° 11' 17.1924" N	6
Industrial Finishes	Existing	450.0 KW	123° 9' 4.0716" W	44° 3' 34.8084" N	5
OSU 35th St Solar Field	Existing	1435 KW	123° 17' 41.1504" W	44° 33' 57.1608" N	Restricted
Black Cap solar	Existing	2000 KW	120° 21' 46.0692" W	42° 10' 30.0936" N	8
OR Solar 7 (Jacksonville)	Proposed	10000 KW	122° 54' 37.2528" W	42° 20' 20.7636" N	Restricted
OR Solar 2 (Agate Bay)	Proposed	10000 KW	122° 49' 38.712" W	42° 31' 21.6156" N	Restricted
Poplar's Ranch	Proposed	12000 KW	120° 55' 34.1184" W	43° 17' 26.2716" N	7
Adams Solar Center	Proposed	10000 KW	121° 7' 20.8596" W	44° 40' 37.5708" N	7
Vale Air Solar Center	Proposed	10000 KW	117° 15' 28.8" W	43° 57' 46.8" N	9
Grove Solar Center	Proposed	10000 KW	117° 23' 2.4" W	43° 56' 6" N	9
Open Range Solar Center	Proposed	10000 KW	117° 3' 39.6" W	43° 47' 49.2" N	9

CONCLUSION

In 2015, the population of Yamhill, Multnomah, Clackamas, and Columbia counties increased by two percent and is expected to continue this growth in the coming years. The increasing population, coupled with the rising number of technology and manufacturing jobs will create demand for considerable power resources, at a time in which the state is phasing-out climate change inducing and ecologically destructive power generation methods such as coal and hydro-electric dams. These circumstances point to solar energy as a potential major contributor to Oregon's power grid, but it must be implemented correctly. Most importantly, solar power collection and transmission cannot contribute to the loss of some of the nation's best agricultural land such as the Willamette Valley. The weighted analysis and maps created propose a solution that will allow Oregon to meet the goals outlined in Senate Bill 1547 without having a deleterious effect on farms outside the Portland metropolitan area, among many other factors that could induce social conflict. Not only are logistical and economic concerns such as distance to cities, proximity to power transmission lines and direct normal irradiance addressed, NLCD land cover data was utilized to determine areas in which solar farms will not encroach on land needed for agriculture.

While this may have led to overly restricting some areas, the analysis concludes that the best potential sites for the location of large scale solar generation are on the southern border of Grant County, the northern border of Harney county, the eastern border of Klamath County, the western border of Lake County, as well as the areas surrounding Ontario, Oregon on the eastern border of Malheur county near the Idaho border. Upon inspection of proposed and active solar power generation sites in the state of Oregon from the Renewable Energy Project, it was found that the sites align with the proposed areas from the weighted overlay analysis. The test of the model against these proposed and active sites resulted in three out of fifteen of the test sites from the Renewable Energy Project being restricted from the analysis, the remaining twelve sites tested resulted in an average weighted analysis score of 7.55. This shows relative accuracy in the model. The restricted values were due to the limiting of prime farmland in the Willamette Valley, which is not something to be sacrificed, when there are other more viable options for the placement of solar farms. If the proposed sites with an average score of 7.55 from the weighted overlay analysis were made a reality, 60,000 KW of power would be available from renewable resources. A sum that will not wholly replace the total energy needed to meet Oregon Senate bill 1547, but will begin the shift to a diverse renewable portfolio necessary to combat climate change.

SOURCES

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Map scales- 1:2,500,000
Spatial reference-NAD_1983_2011_Oregon_Statewide_Lambert_ft_intl
Cell size- 5500 feet
GIS Data Sources

- Oregon Spatial Data Clearinghouse
- http://www.nrel.gov/gis/data_solar.html-Lower 48 and Hawaii DNI 10km Resolution 1998 to 2009 from National Renewable Energy Labratory