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The Rush to Renewables: A Solar and Wind Energy Suitability Analysis for Colorado

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Class: UEP 232 Intro to GIS
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Background: Climate change is currently one of the greatest issues facing the world. One of the major factors leading to it is the burning of fossil fuels for energy which emit high levels of Carbon Dioxide (CO_2). However, one excellent step towards mitigating these CO_2 emissions is through the use of Renewable Energy. Two of the most predominant types are Solar power through large-scale photovoltaic panel projects, and Wind Power through large wind turbine fields. Colorado has been a very progressive state in terms of its implementation of Renewable Energy, producing nearly 20% of its power through Renewables, with 80% of it coming from wind, but just 5% of that coming from solar. As one the fastest growing states in the United States in terms of population, there will likely be a need for increasing levels of energy to be produced. Additionally, Colorado is a very diverse state, with desert areas, plains, and the Rocky Mountains running through it. Thus, given this diversity and need, it is important to determine which areas are feasible and likely fruitful for Solar or Wind Power, and which type is better in specific areas.

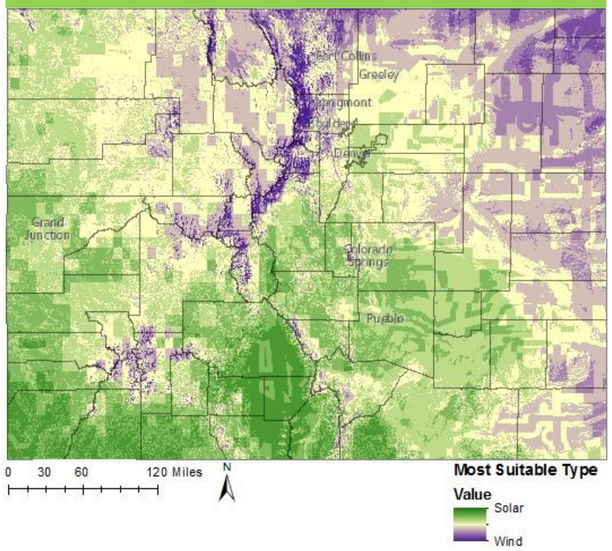
Objectives: To produce maps showing the weighted suitability for Solar Power or Wind Power throughout Colorado based on the consideration of multiple factors.
To produce a map showing which specific areas throughout Colorado are relatively more suitable for Solar versus Wind.

Methods and Data Analysis: The first phase of the analysis is to take all of the factors that are being analyzed, which have been inspired by previous scholarly projects and student projects on similar topics, and convert them to Raster layers. In each layer, various levels of that factor are given a different score based on their suitability, with the higher score the better. Wind Power was given a Suitability score ranked from 1-5, based on Wind Turbine Capacity, a ranking based off wind speed. Solar Energy in Colorado averages between 3.5 to 5.5 kWh/m2/Day, so it was divided into 5 even increments with the score ranging from 1-5. For Slope, using data about elevation features, I used the Slope spatial analyst function to create a slope raster, which was then reclassified into 5 categories with breaks at 4, 10, 18.5, 29, and 75 degrees. The Scoring of these factors ranked 1-5, with the lower the slope the better, because high slope negatively impacts the ability to construct and the effectiveness of Solar and Wind projects. Population density was determined by dividing the population of a census block by its area. The levels were evenly divided into 5 breaks, scored 1-5 with 1 being the highest density, and 5 being the lowest. Critical and Endangered Species and National Parks were analyzed similarly. Because an area is either a Habitat/Park or not, and being within a park boundary or endangered species habitat area is a negative for potential because of the regulatory difficulties of construction, a positive score of 1 was given for areas that are not, and a negative score was given for those that are. Areas in a national park were given a –4, and areas in Endangered/Critical species habitats were given a –5. For Distance to Roads and Distance to Electrical Transmission Lines, I was able to use Euclidean Distance to create 5 even intervals for distance. There are 5 mile intervals for roads, and 15 mile intervals for transmission lines. These interval differences are because distance from roads are more of a negative to development because building roads often poses more difficulty. For both, the score ranged 1-5, with 1 being the furthest distance and 5 being the closest.

Then using the Raster Calculator I was able to create a map for both overall Solar suitability and Wind suitability. This was done using a weighting system, based on concepts of previous literature, which divided all of the factors considered into 4 different tiers. Table 1 shows how factors were weighted and divided for Wind, and Table 2 does the same for Solar. Overall, as every factor influences suitability for wind and solar in the same way, just not necessarily the same magnitude, the two weighting systems are very similar. For both, energy potential was the highest weighted. Of the notable differences, slope was weighted slightly higher for solar because it is more difficult to install panels on a high slope, and distance to roads was slightly higher for wind because transporting turbines requires larger vehicles and thus better roads.

These two maps are then combined into a final map that gives the viewer the ability to look at the map and know whether that specific part of Colorado would be better suited either for the development of Solar or Wind. To do this, I reclassified the Solar Suitability index into 10 different rankings, scored 1 through 10, with 1 being the least suitable, and 10 being the most suitable, and these rankings were divided into 10 percentile increments. The same thing was done for wind suitability, except this time ranked -1 through -10, with the least suitable ranked -1, and the most suitable ranked -10. Then I used the raster calculator, and added these two variables together to create a map where the more positive the value, the better it is suited for Solar, and the more negative the value, the better it is be suited for wind.

Comparative Suitability of Wind versus Solar throughout Colorado



Wind Suitability throughout Colorado

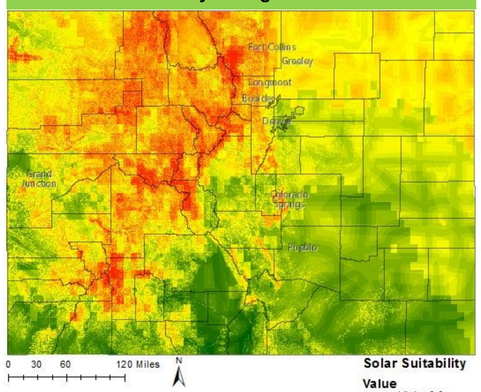


Table 1: Wind Suitability Tiers

Tier #	Feature (s)	Weight
Tier 1	Wind Energy Potential	35%
Tier 2	Distance to Roads, Slope	15 %
Tier 3	Distance to electrical transmission lines, population density	10%
Tier 4	Endangered/Critical Habitats, National Parks	7.5%

Solar Suitability throughout Colorado

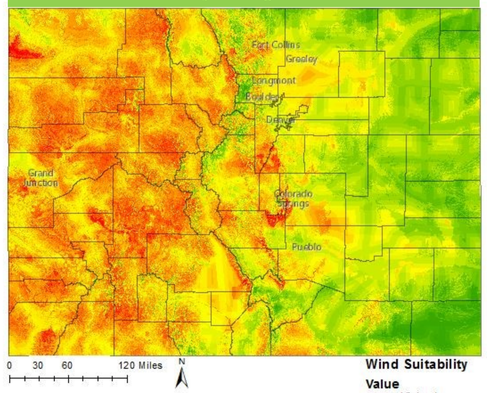


Table 2 : Solar Suitability Tiers

Tier #	Feature (s)	Weight
Tier 1	Solar Energy Potential	35%
Tier 2	Slope	20%
Tier 3	Distance to roads, distance to electrical transmission lines, population density	10%
Tier 4	Endangered/Critical Habitats, National Parks	7.5%

Conclusions and Discussion: Colorado is certainly a diverse state, and this diversity proves itself to be present in the levels of suitability of solar energy or wind energy across the state, as well as among the difference between the suitability of each in different places. Looking at Solar suitability, the best areas are the central southern areas which have low slope and are non-densely populated areas of the Southern Rocky Mountains. Most of the Colorado Plateau area in the western corner is well suited, as well as a majority of the eastern part of the state which is mostly made up of a low slope shortgrass prairie area. Potential was particularly low in the central and northern areas of the state which is also a part of the Southern Rocky mountains, where the slope was particularly high and there was relatively less solar energy potential. Looking at Wind suitability, which is currently the more developed of the two in Colorado, overall the Western part of the state was much less suitable which is as to be expected considering the WTC score for most of the West is a just a 1. However, considering the other factors that make wind energy suitable, there are some places that appear yellow and green on the map indicating there a wind project would still be worth considering. Again, following expectations of WTC scores, areas further east in the relatively low slope areas of the shortgrass prairies have the greatest potential, which is also consistent with the fact that all of Colorado's current wind farms are located in the Eastern Part of the state. Finally, looking at the comparison map, the far east of the state is certainly best for Wind, which is inline with what has be developed so far. However, with so much of the state appearing green on the map, it means that there is certainly tremendous potential throughout the state to look into solar projects. Also, although nothing has be constructed for wind in the west, it may still be worth a second look.

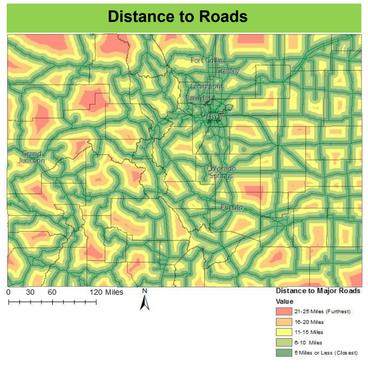
Overall, this project can serve as a guide to policy makers and solar or wind companies on where to start looking to find a suitable place for a new, large scale renewable energy project. The weighting system I used could easily be altered to give different weights to the various factors if someone wanted to repeat this analysis in a way that their research and knowledge deemed to be more appropriate. Additionally, if others factors were determined to be important for an analysis, they could be added using this method as well. Error most likely could stem from the not a perfect weighting system, the fact I had to convert the projection system of some of the layers to WGS, and that the wind data was collected in the 1980s which has possibly changed because of climate change.

Data Sources:
Wind Energy Potential: National Renewable Energy Laboratory
Solar Energy Potential: National Renewable Energy Laboratory
Population: US Census TIGER Data
Electrical Transmission Lines: United States Geological Survey
Major Roads: US Census TIGER Data
Critical/Endangered Habitats: US Fish and Wildlife Environmental Conservation
National Park Boundaries: Earth Data Analysis Center, University of New Mexico
Terrain: ESRI ArcGIS

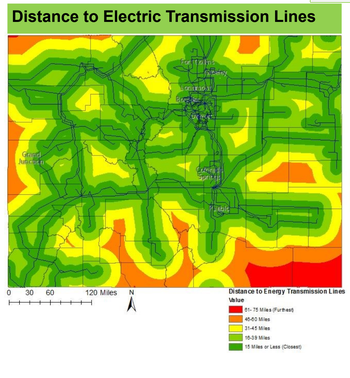
Literature Cited:

Al-Yahyai, Sultan, Yassine Charabi, Adel Gastli, and Ab dullah Al-Badi. "Wind farm land suitability index ing using multi-criteria analysis." *Renewable Energ gy 44 (August 2012): 80-87. doi:10.1016/ j.renene.2012.01.004.*
Baban, Serwan M.j, and Tim Parry. "Developing and ap plying a GIS-assisted approach to locating wind farms in the UK." *Renewable Energy 24, no. 1 (September 2001): 59-71. doi:10.1016/s0960-1481 (00)00169-5.*
Castillo, Carolina Perpiña, Filipe Batista E Silva, and Carlo Lavalle. "An assessment of the regional po tential for solar power generation in EU-28." *Ener gy Policy 88 (January 2016): 86-99. doi:10.1016/ j.enpol.2015.10.004.*
Charabi, Yassine, and Adel Gastli. "PV site suitability analysis using GIS-based spatial fuzzy multi- criteria evaluation." *Renewable Energy 36, no. 9 (September 2011): 2554-561. doi:10.1016/*

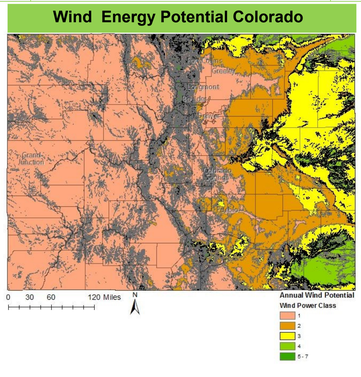
Distance to Roads



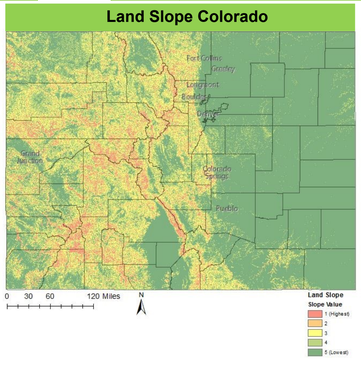
Distance to Electric Transmission Lines



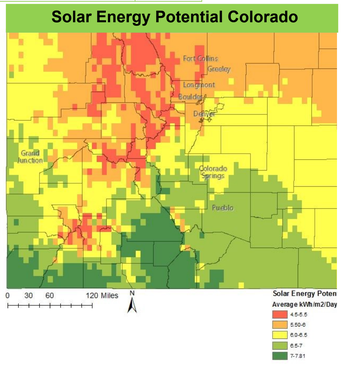
Wind Energy Potential Colorado



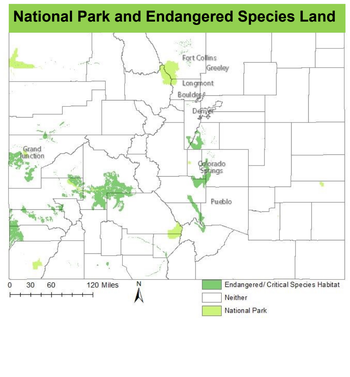
Land Slope Colorado



Solar Energy Potential Colorado



National Park and Endangered Species Land



Population Density Colorado