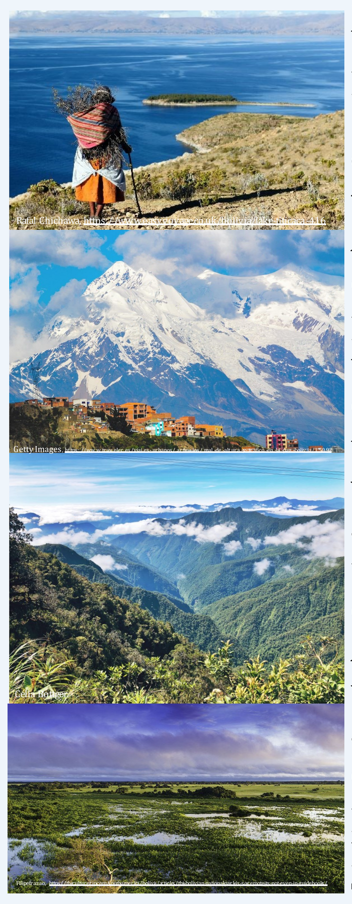
Em[power]ing Bolivia

Identifying Suitable Areas for Solar Development across Bolivian Geographies

Bolivia has one of the lowest rural electrification rates in Latin America, yet some of the highest solar radiation in the world. In 2007, rural access to electrification was estimated to be 50% while urban access was 98%. Under former President Morales, rural electrification expanded rapidly, jumping from 50 to 73% by 2016. However, much of this electrification was achieved by expanding natural gas and other fossil fuel sectors, to the detriment of Bolivia's natural environment and exacerbating the already acute impacts of climate change experienced by its mostly rural, indigenous poor. **Bolivia has enormous solar potential: the country's lowest solar radiation is equivalent to Europe's highest**, about 4 sun hours/m²/day. About a third of the country is an "altiplano," a completely flat and extremely dry high-altitude plain, the topography of which is very conducive to solar infrastructure. The rest of the country is categorized into two other topographic features: the Andes Mountain Range and its semi-tropical valleys, and the eastern tropical lowlands that are part of the Amazon rainforest. Bolivia's population is also very remote: population density is concentrated in its three main cities (La Paz/El Alto, Cochabamba, and Santa Cruz de la Sierra), while the rest of the population is dispersed among the rainforest, altiplano, and mountainous valleys. Bolivia is home to 37 indigenous peoples, many of whom reside in the Andean highlands and the rest in the tropical lowlands. The quite extreme topography and remote population of Bolivia presents difficulties for gas pipelines, which would need to cut through dense swaths of Amazon rainforest and reach the tops of some of the world's tallest mountains in order to supply electricity to every household.



Thus, the obvious solution to Bolivia's over-reliance on unsustainable fossil fuel extraction and tremendous solar potential is to use solar energy to electrify not only its rural population, but the population of the entire country. Solar energy not only alleviates logistical and infrastructural constraints of electricity supply in Bolivia, but it also provides an inexpensive, renewable, democratic, and empowering energy supply to Bolivia's inhabitants, especially its indigenous communities who have borne the brunt of the externalities of Bolivia's extractive industries, and who continue to be systemically oppressed by racism in the country. It is for these reasons that I decided to create a suitability analysis of solar energy in Bolivia, to not only see what locations were the best for solar infrastructure geographically, but to also use this data to see where marginalized indigenous communities could benefit from decentralized solar energy.

Data and Methodology

To complete my solar suitability analysis, I found data that could be spatially analyzed in raster form and then overlayed for my final suitability map. Both slope (2017) and land use (2001) raster and vector datasets were retrieved from the World Bank; a photovoltaic output raster dataset was downloaded from Global Solar Atlas (2018); both rainfall distribution (2017) and protected areas (2012) were found on ArcGIS Online as vector layers; and population density raster data was retrieved from LandScan data (2005) found in the Tufts GIS M: Drive.

First, land use, rainfall and protected areas vector data were converted into rasters. Then, the data from each raster layer was reclassified into five categories, with 1 representing the least suitable and 5 the most suitable, and symbolized accordingly. Suitability was measured in terms of possibility for solar development, e.g. low slope, high solar radiation, high population (to service Bolivia's highly concentrated urban populations), low rainfall, and favorable land use (these were reclassified manually). For the protected areas layer, an attribute query was used to locate indigenous territories.

Finally, once each raster layer was reclassified, a weighted suitability analysis was performed using raster calculator to overlay the five different layers. The result was a final map with a suitability scale that combined all five factors, giving a suitability measurement for every location in the country.

Results & Discussion

The areas most suitable for solar development in Bolivia are located in the Oruro and Potosí departments, but high solar potential encompasses essentially the entire southwestern third of the country. Because this part of the country is composed of a sparsely populated, high-altitude desert plain, these results are fitting. More significantly, the entire country has relatively high solar potential, with the lowest potential located in the steep, snowy Andes Mountain range that separates the Amazonian lowlands from the altiplano.

The universally high solar potential in Bolivia indicates that opportunities for solar development abound across the country. Bolivia is well-suited for both larger-scale solar fields servicing its populous cities, as well as small-scale rooftop panels that can provide electricity to indigenous settlements in the Amazon and Andes alike.

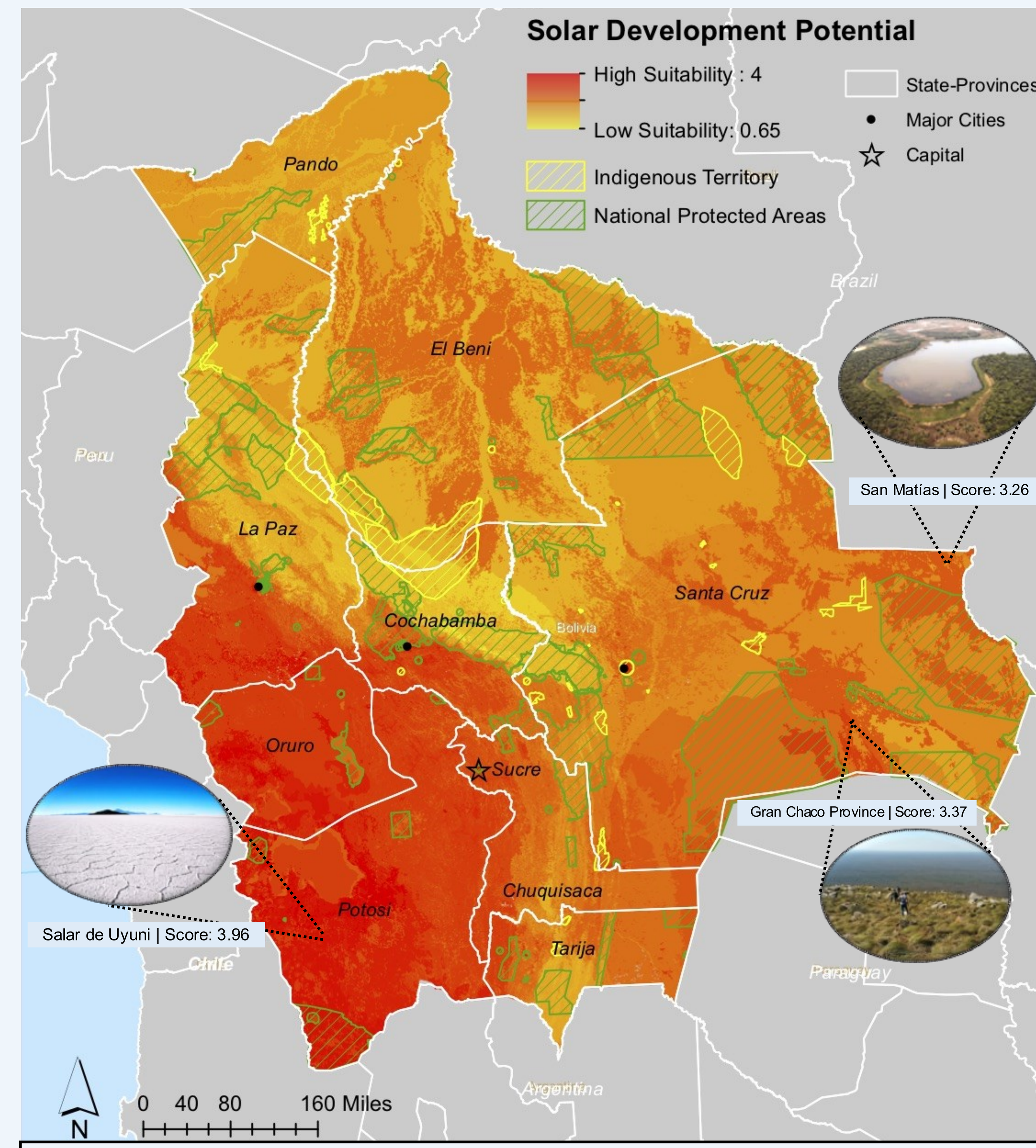
World Bank, https://olc.worldbank.org/content/solar-power-lights-rural-bolivia

Left: Rooftop solar installation in El Choro, Oruro, Bolivia

Right: The Oruro Photovoltaic Power Station, Bolivia's largest solar plant (produces 100 MW)

Bolivian Chamber of https://www.pv-tech.org/news/bolivian-government-approves-breakthrough-50mw-solar-project

BOLIVIA'S SOLAR POTENTIAL



Final Suitability Analysis

The following weights were assigned to each factor:

30% Photovoltaic Output	20% Slope	10% Population Density
25% Land Use	15% Rainfall	(Protected Areas not included in analysis)

Cartographer: Celia Bottger
UEP-232, Introduction to GIS, Tufts University
December 15, 2019
Projection: WGS 1984 Margen UTM Zone 21S

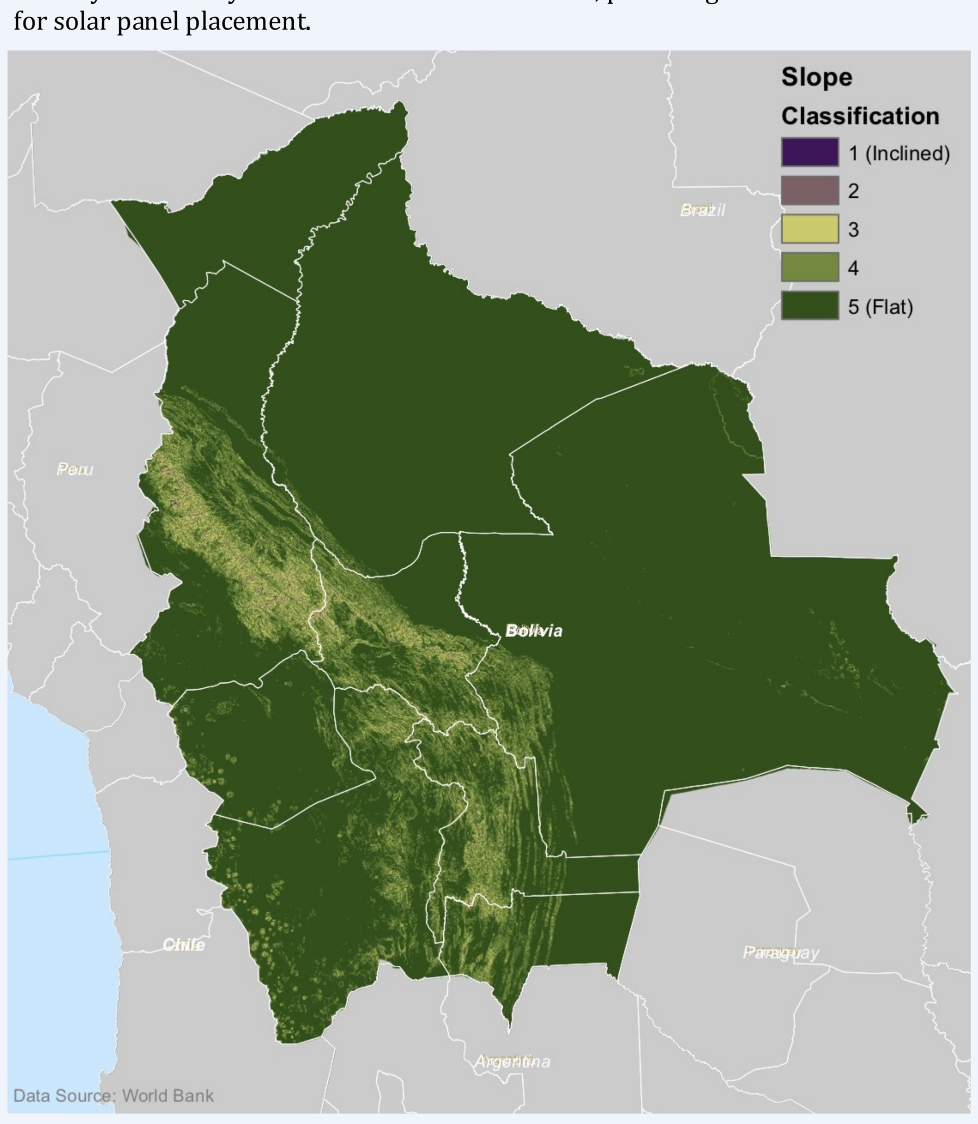
Data Sources: World Bank, Global Solar Atlas, ArcGIS Online, LandScan, Tufts GIS M: Drive

Sources for images above: (1) Beautiful World, https://www.beautifulworld.com/south-america/bolivia/salar-de-uyuni/ (2) Robert Reimer, https://www.amborotours.com/kaa-iya.html (3) Página Siete Archive https://www.paginasiete.bo/gente/2016/4/21/pantanal-boliviano-alto-riesgo-93929.html

SUITABILITY FACTORS

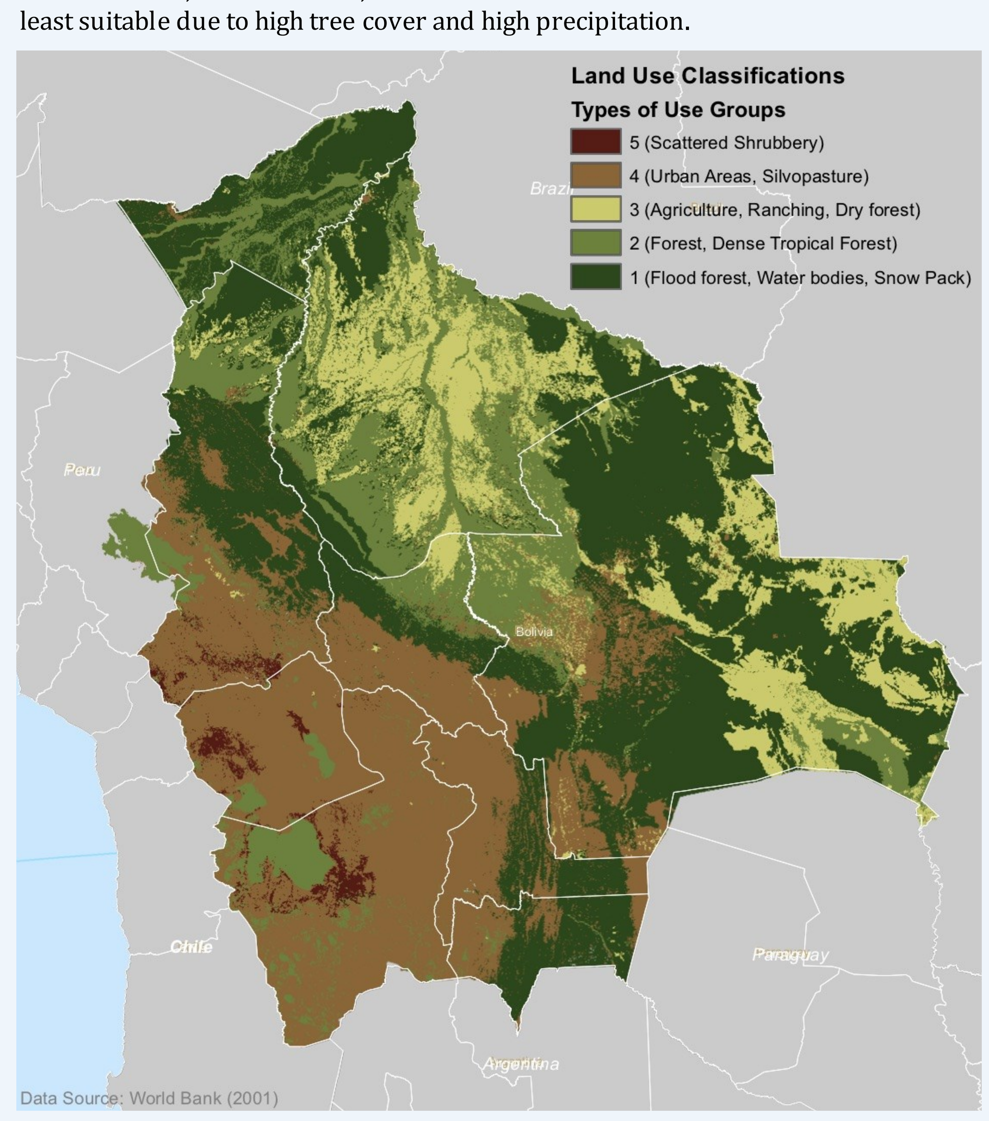
Slope

Solar radiation is maximized on flatter terrain where panels can adjust to the position of the sun's rays. Slope raster data was reclassified according to incline. The country is relatively flat on either side of the Andes, providing favorable conditions for solar panel placement.



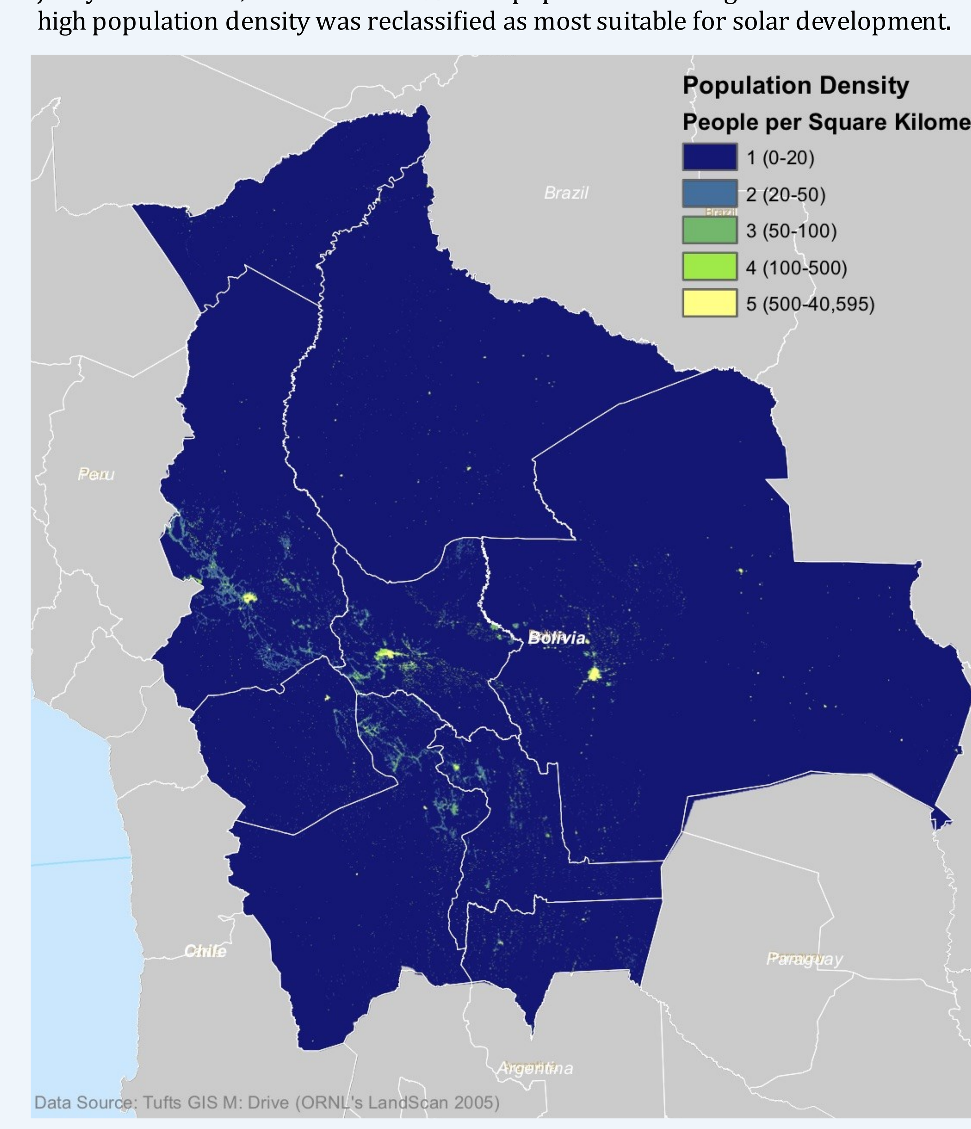
Land Use

Land use data was reclassified manually according to use group descriptions. For instance, the use group "scattered shrubbery" was identified as highly suitable due to lack of trees, infrastructure, or residences. "Flood forests" were identified as least suitable due to high tree cover and high precipitation.



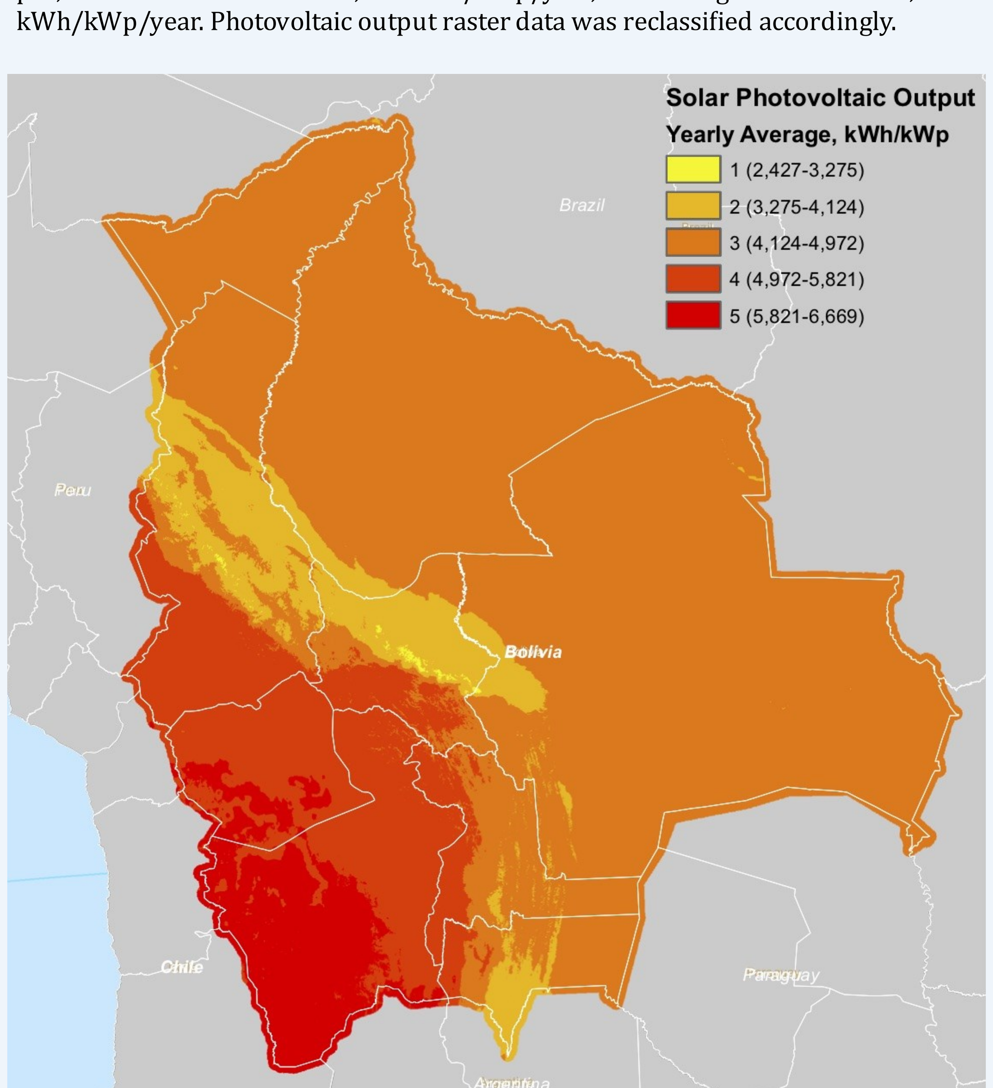
Population Density

Higher solar electricity demand lies in areas with the highest population. Bolivia is an extremely remote country, with less than 20 people per km² occupying the majority of land area, and around 70% of its population residing in urban areas. Thus, high population density was reclassified as most suitable for solar development.



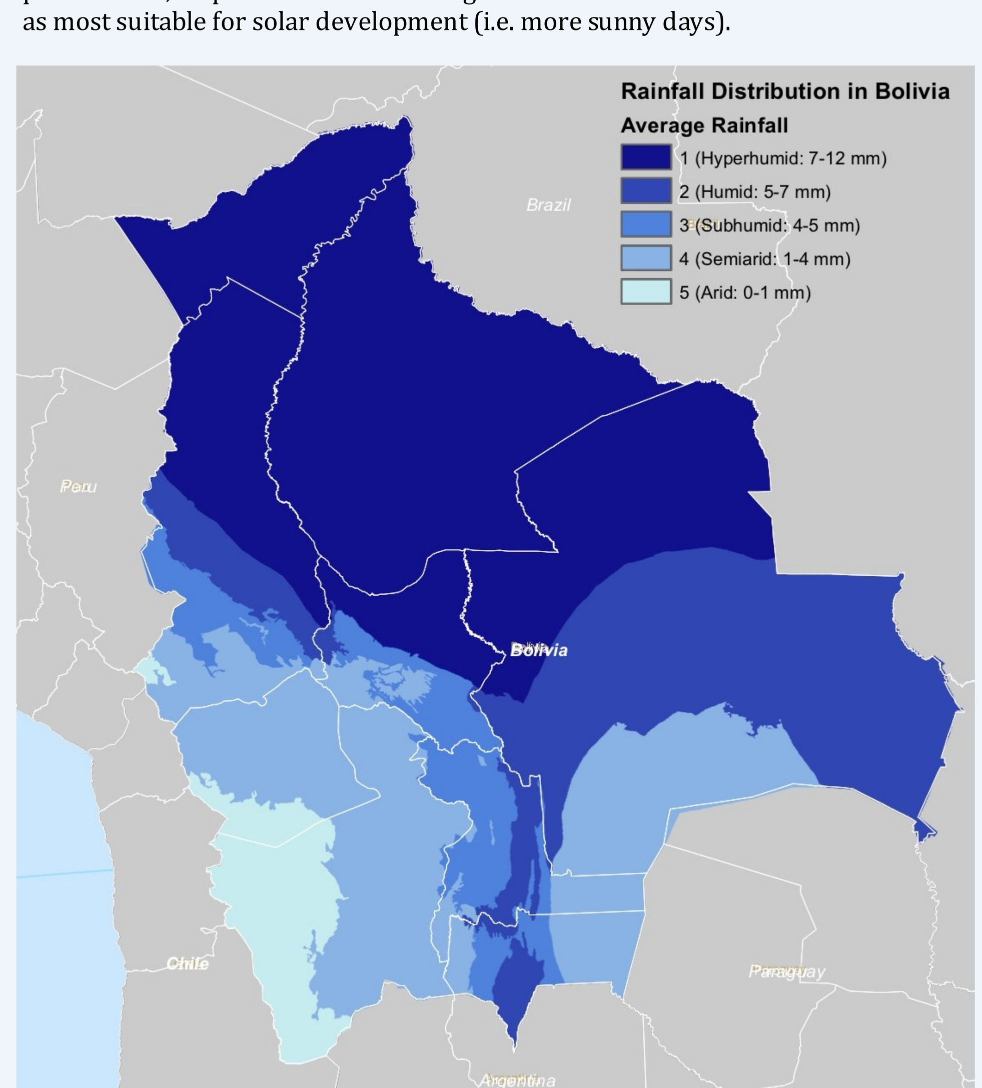
Photovoltaic Output

Average solar photovoltaic output is perhaps the most important factor when identifying suitable areas for solar development. Bolivia has very high photovoltaic output, with the lowest around 2,427 kWh/kWp/year, and the highest at almost 6,700 kWh/kWp/year. Photovoltaic output raster data was reclassified accordingly.



Rainfall

Rainfall data was used as a proxy for cloudy climate, i.e. low solar radiation. Bolivia's climate features many extremes, from arid, desert-like conditions on the altiplano to wet, tropical rainforest. Average rainfall was reclassified with low rainfall as most suitable for solar development (i.e. more sunny days).



Protected Areas

Bolivia's protected areas and indigenous territories were not included in the weighted suitability analysis, but are important nonetheless when identifying locations for solar development. Large-scale solar plants could be disruptive to fragile ecosystems, and could displace indigenous communities in their territories.