Weather Driven Renewable Energy Analysis, Modeling New Technologies

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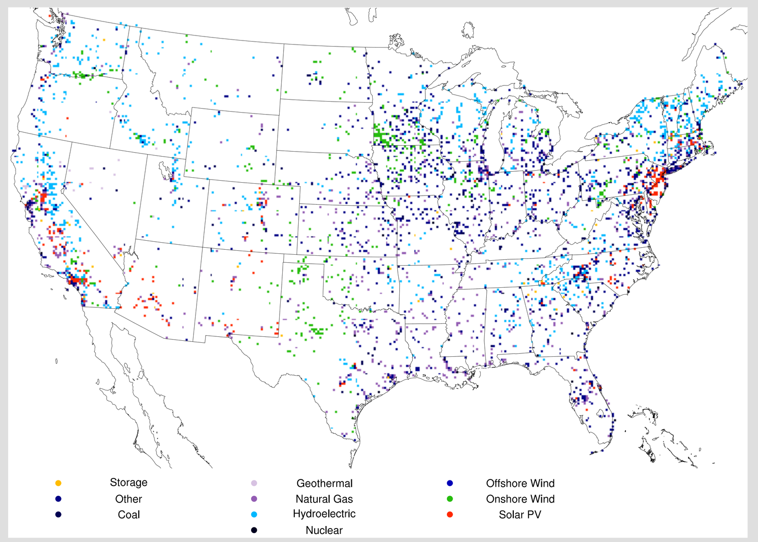
Introduction

Carbon emission reduction is essential to hampering anthropogenic climate change. While there are several methods to broach carbon reductions, this research focuses on limiting electrical generation emissions by using the NEWS model to create a national high-voltage direct-transmission structure that takes advantage of the strengths of different regions in terms of variable sources of energy. Here, concentrating solar power (CSP) acts as another source to contribute to the electric grid. Power tower solar fields are optimized taking into account high resolution, 13km, meteorological conditions gathered by NOAA from the years 2006-2008. It is important to realize that optimization of these power plants includes factors that decrease the optical efficiency of the heliostats reflecting solar irradiance. Cosine efficiency, atmospheric attenuation, and shadowing are included here, but are not the only limiting factors. Photovoltaic plants can be combined for similar efficiency to the power tower and at a lower cost, but they do not have a cost-effective capability to provide electricity when there are interruptions in solar irradiance. Power towers rely on a heat transfer fluid, which can be used for thermal storage changing the cost efficiency of this energy source. Thermal storage increases the electric stability that many other renewable energy sources lack, and thus, the ability to differentiate and choose electric pathways for direct electric conversion and thermal storage is discussed.

The NEWS model

The National Energy with Weather System model optimizes use of variable electricity generation. With the implement of high-voltage direct-current transmission lines, variable energy becomes much more likely as variability is combatted with the ability to transfer energy from areas in times where renewable energy generation is in excess to those where variable generation has been interrupted. The model currently incorporates onshore and offshore wind, solar photovoltaics (PV), hydroelectric, natural gas, and nuclear plants to minimize carbon emissions. The addition of concentrating solar power provides another source of energy to this electric grid.

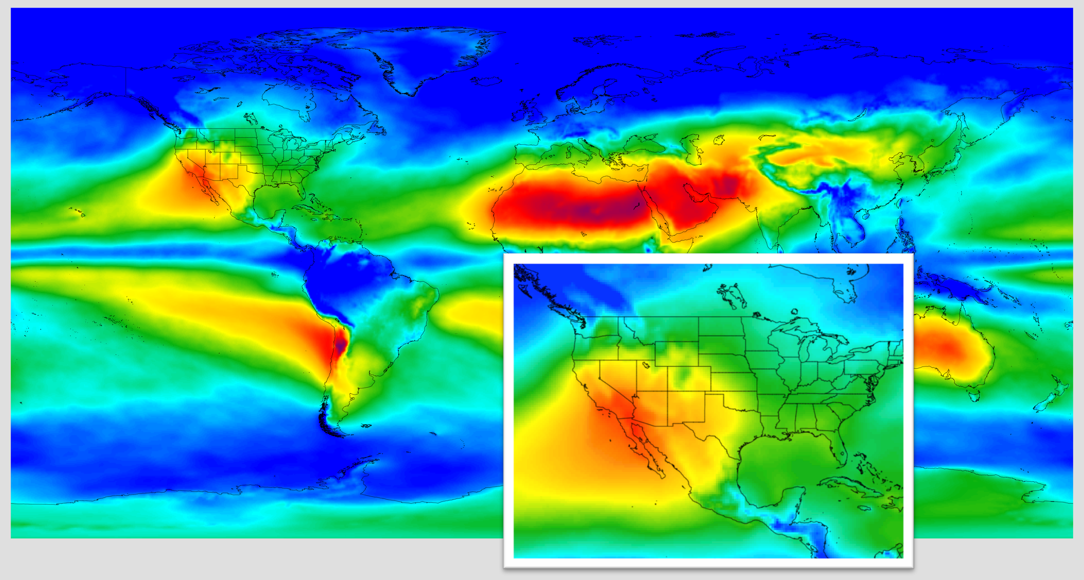


Concentrating Solar Power Towers

Concentrating Solar Power (CSP) comes in different forms though this research focuses solely on power towers. This is due to its potential for greater efficiency with the high concentration of heat in the heat transfer fluids as opposed to troughs or sterling engine systems. To incorporate such a system, the power tower plant requires optimization of the heliostat field and location to offset the costs of maintenance that otherwise hinders the choice of this plant over solar photovoltaics in the NEWS model.

Methodology

DIRECT NORMAL IRRADIANCE

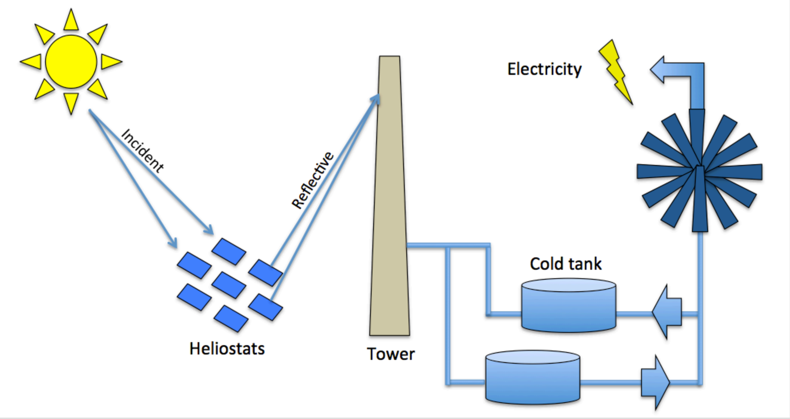


The conversion of the sun's energy to electricity for the power grid begins with the incorporation of the direct normal irradiance (DNI), uninterrupted radiation from the sun upon arrival to the Earth's surface, at a pre-determined location into the model. Factors contributing to the DNI include aerosols, pollution or cloud coverage, which inhibit the radiation from reaching the surface of the Earth. With regards to the United States, the highest DNI consistently lies in the southwest. The southern-most border between Nevada and California currently shows the highest potential for concentrating solar power and has already been the site of power towers.

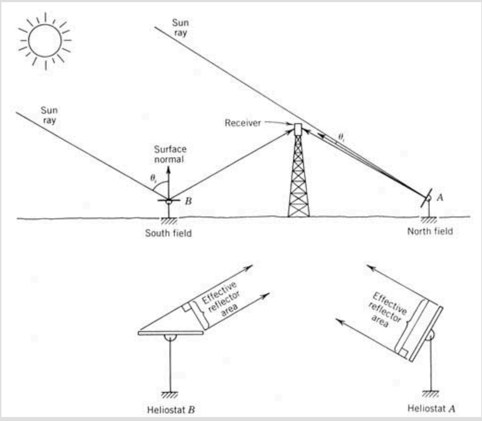
COMPONENTS TO THE OPTICAL EFFICIENCY OF A POWER TOWER PLANT

Direct conversion from DNI is not possible due to other factors diminishing the efficiency of the power tower plant. These include cosine efficiency, atmospheric attenuation, spillage, and shadowing and blocking. Cosine efficiency is dependent on the incident vector of solar irradiance. The smaller the angle between this vector and that of the reflective vector, the greater the efficiency of the reflective radiation. This is best seen at different latitudes. At the equator, cosine efficiency is high throughout the field of heliostats, but at higher latitudes, such as 60°N, the southern portion of the field drastically decreases in efficiency. This is due to the much higher angle between the incident and reflective rays of radiation. So, in the northern hemisphere, power tower fields will either have a greater proportion of, or only, heliostats in the north.

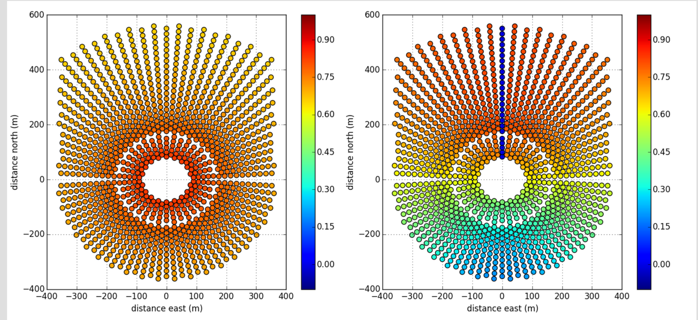
Optical efficiency
$\eta = \cos\theta \int_{at} \int_{sp} \int_{sb}$

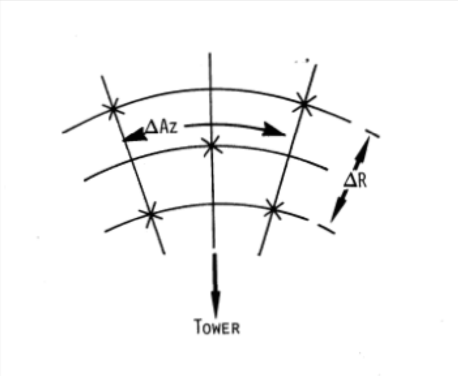


To minimize decrease in efficiency due to shadowing and blocking, a radial staggered formation was chosen for this power tower model. The number of heliostats in the field is variable with the change in subsequent rows. Remaining components of optical efficiency are dependent upon heliostat distance from the tower and were based upon DELSOL3 model calculations.



Stine and Geyer 2001

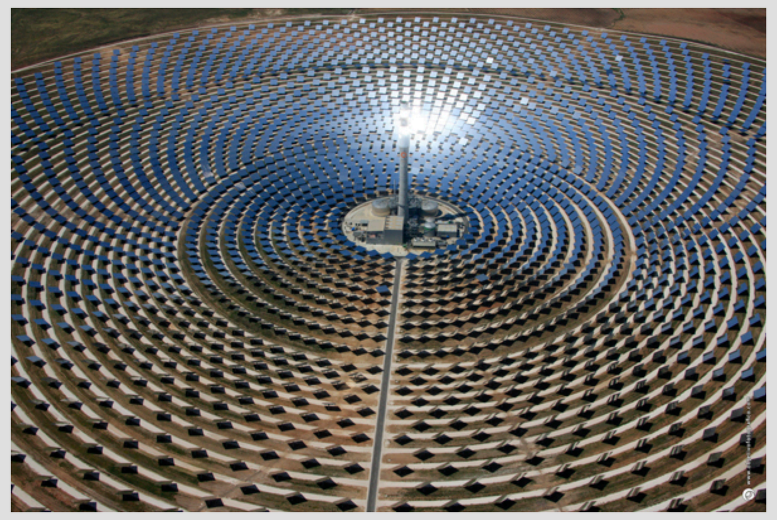


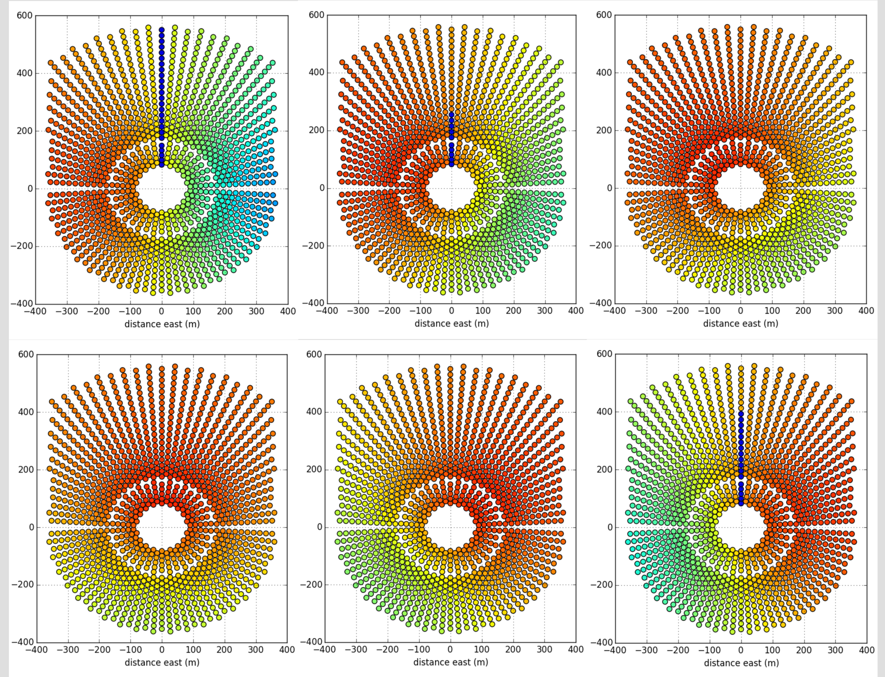


Kistler 1986

Power Generation

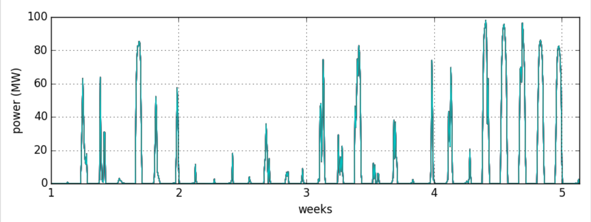
With an input of latitude and longitude, the model of the field proceeds to utilize hourly DNI data for that location to show the diurnal cycle of cosine efficiency. The height of the tower is adjustable and its shadow is taken into account rendering those heliostats under the shadow to decrease the tower's efficiency. As the sun rises, the greatest efficiency is on the west side of the field, rotating clockwise until the the greatest efficiency is on the east as the sun sets.



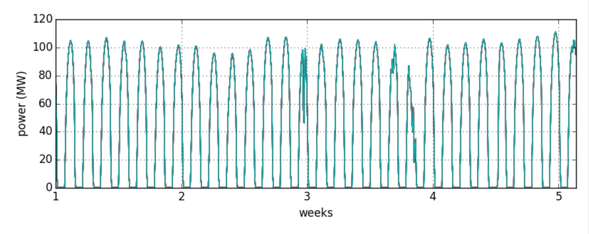


Impact of Concentrating Solar Power

At the moment, photovoltaic plants can match the energy output of CSP when spanning the same time frame. However, the benefit to concentrating solar power is the potential of time variability. Heat transfer fluids capture energy while PV depends on storage if energy without sunlight is desired. The capture of solar radiation into a heat transfer fluid greatly increases the flexibility of usage, and in turn, transmission. Previously, the NEWS model did not choose CSP for optimizations because the plant itself gives an equivalent amount of energy for higher costs than PV plants. But rather than using this stored energy to match the electric load into the night – reaching a minimum allowing natural gas to assume load requirements – the model sends excess energy to areas in the US where variable energy cannot meet the load. In this case, those months with large excess in CSP, such as June in southern California, can be most efficiently used.



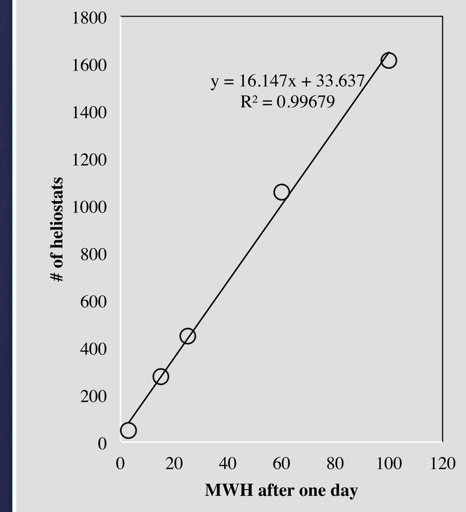
December

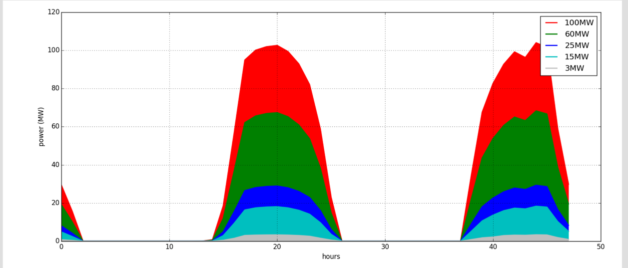


June

Alternate fields

Separating the power received directly from the solar field and the power transferred to the power block from thermal storage is required to make CSP preferable for optimization. However, it is as important to create a model that is robust in its ability to change the power tower model. Both the size and type of field can be adjusted for optimization of an individual plant. A field resembling *Gemasolar*, a functioning power tower in Sevilla, Spain, will first be incorporated directly into the NEWS model. Continued analysis in plant capacity will attempt to find the most efficient plant size for the national transmission line.





MW capacity	# heliostats	Type	MWH
3	33	NORTH	50
15	186	NORTH	277
25	301	SURROUND	449
60	733	SURROUND	1056
100	1254	SURROUND	1614

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