5.7 GW of Short Turbines Could be Added to the Tehachapi Wind Resource Area[1]

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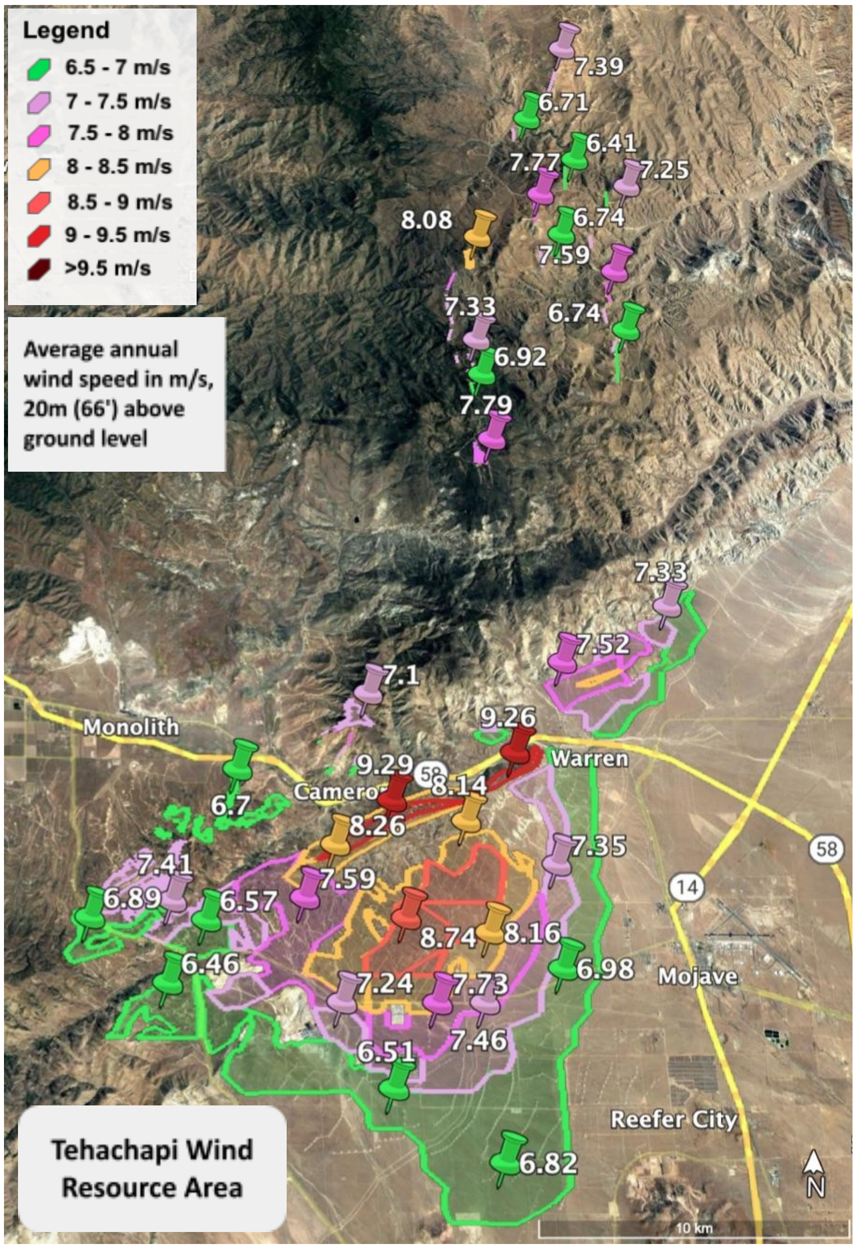

Image 1. Wind speed zones >6.5m/s (14.5mph)

[1] Land in and outside of wind farms where the average annual wind speed exceeds 6.5m/s (14.5 mph) at 66' (20m) above ground level. Estimated VAWT capacity does not include the two southernmost wind farms. See Appendix for more information.

Summary and Background

In the eastern half of Kern County California, topography and temperature differences create perfect conditions to generate a great deal of wind. From spring into fall, the sun heats up the Mojave desert creating a low pressure zone that intensifies up until sunset. By noon, the cooler air from the San Joaquin Valley is moving through the Tehachapi Pass and into Jawbone Canyon where it funnels and speeds up. Every hill and ridgeline accelerates it a second time.

With these conditions, the Tehachapi Wind Resource Area is the most productive in the state. In its 90,000 acres[2] of wind farms, 3,263 gigawatts (GW)[3] horizontal axis wind turbines (HAWTs), the large wind turbines most people are familiar with, operate across 50 wind farms. These turbines should produce ~11,000 gigawatt hours (GWh)[4] of renewable electricity each year.

This report shows that at least an additional 5.7 GW and **18,364 GWh** can be produced in the wind resource area with vertical axis wind turbines (VAWTs), which capture the turbulent mid-level winds below where most turbines operate. **This is enough to power over 2.6 million California homes per year.**[5]

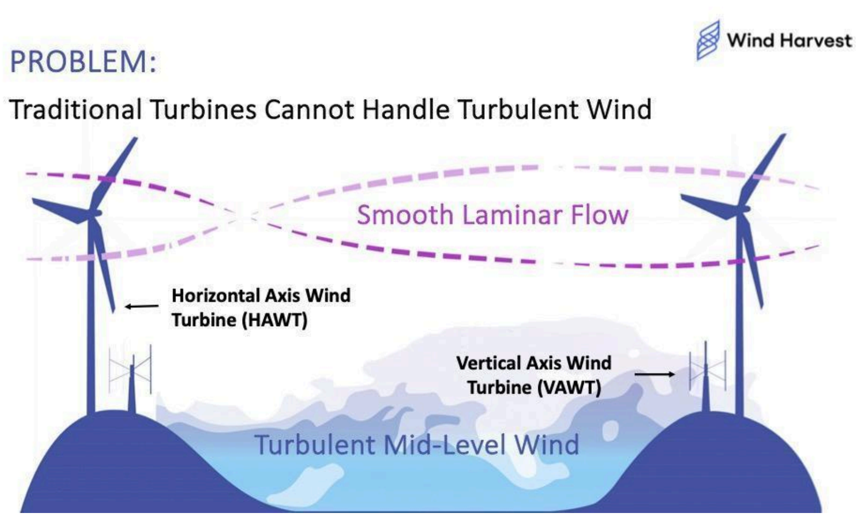

Image 2: Turbulence and Turbine Types[6]

The 3,263 megawatts (MWs) of wind farms in the Tehachapi Wind Resource Area, including Jawbone Canyon, cover roughly 90,000 acres of land. This equates to an energy density of HAWTs of 9 watts per square meter (W/m^2) or 0.036 MW per acre. This is a high energy density given that research shows small wind farms can achieve 10 W/m^2 and most large wind farms only achieve 1 W/m^2.

[2] See Appendix (3).
[3] US Wind Turbine Database
[4] See the Annual Energy Production table, Appendix (1).
[5] The average annual electric consumption per Californian household is ~7,000 kWh.
[6] How VAWTs like *Wind Harvesters* operate in turbulent wind

Table 1. Total Capacity and GWh with HAWTs and VAWTs in the TWRA

	Capacity (GW)	AEP (GWh/yr)
HAWT - existing	3.26	10,990
VAWT- potential	5.70	18,364
Combined Potential	**8.97**	**29,354**

Table 2. HAWT Annual Energy Production (AEP) by Wind Speed in the TWRA

Wind speed		HAWT Existing		VAWT Potential	
m/s	MPH	Capacity (GW)	AEP (GWh/yr)	Capacity (GW)	AEP (GWh/yr)
6.5 - 7	14.5 - 15.7	0.17	464	2.68	7,481
7 - 7.5	15.7 - 16.8	0.13	397	1.11	3532.8
7.5 - 8	16.8 - 17.9	0.63	2,238	0.78	2763.7
8 - 8.5	17.9 - 19	0.65	2,519	0.67	2614.6
8.5 - 9	19 - 20.1	0.99	4,215	0.40	1713.3
9 - 9.5	20.1 - 21.3	0.48	48	0.06	258.9
9.5 - 10	21.3 - 22.4	0.19	965	0	0
10 - 10.5	22.4 - 23.5	0.03	145	0	0
Total		**3.26**	**10,990**	**5.70**	**18,364**

On the same properties on which horizontal axis wind turbines (HAWTs) generate power, short vertical axis wind turbines (VAWTs) can be installed so that they don't cause turbulence that could harm the tall turbines under which they would operate. Because the HAWTs are spread far apart from one another to avoid the wake and gusts generated by their neighbors' blades and high above the ground to avoid the turbulence in the lower layers of wind, a great deal of open space is available below 100 feet above the ground.

The Wind Resource Area is already zoned for wind turbines. Access roads and security fences have already been installed. It should take less time and effort to secure a permit to install an understory of VAWTs into existing wind farms than it takes to develop new wind farms in the state. This is especially true for "capacity factor enhancement" projects which don't require additional substations and transmission lines.

Because the landscape is complex in the Resource Area, four different methods[7] were used for its four zones, and the two southernmost wind farms were left out of the analysis. The resulting analysis shows that 5.2 GWs of VAWTs could be added to the properties on which the HAWTs currently operate. An additional 525 MW could be added to adjacent properties that currently do not hold HAWTs. Thousands of acres with HAWTs had wind speeds less than 6.5m/s at 20m above ground level and were not considered.

By adding VAWTs in and around existing Tehachapi and Jawbone Canyon wind farms, the Tehachapi Wind Resource Area's **capacity could increase by 173% from 3.3 GW to 9 GW.** Total Annual Energy Production would increase by **18,364 GWh**.

Note: *Research[8] from Stanford, CalTech, and other universities predict that vertical mixing from understories of VAWTs will bring faster-moving wind into the rotors of the HAWTs in wind farms and increase their energy output by 10%. The additional expected output by HAWTs by adding VAWTs to wind farms was not included in this analysis.* This report does not include that additional energy production which could exceed 1,100 GWh, enough to sustain over 150,000 additional California households annually.

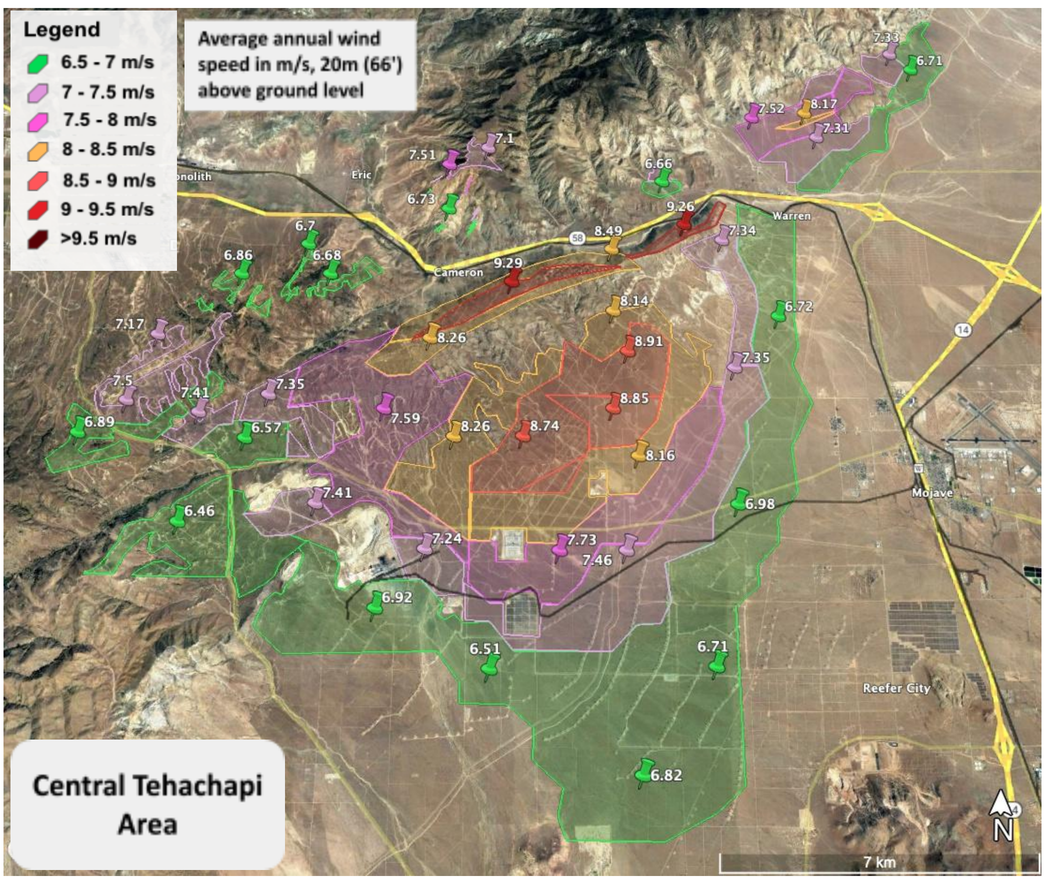

Image 2. Wind speed zones >6.5m/s (14.5mph)

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[7] See VAWT Capacity Calculation, Appendix (2) and Theoretical Capacity Density, Appendix (5).
[8] Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms

The existing capacity of HAWTs in Jawbone Canyon is 360 MWs. This report estimates ~98 MW of VAWTs could also be added to Jawbone Canyon wind farms, increasing capacity of the area by 27%. The key assumption made about placing VAWTs in the canyon was that they would be installed almost exclusively along existing roads where erosion would not be a problem.

Jawbone Canyon is a prime condor country. Before this resource is built out with a lower layer of turbines, the US Fish and Wildlife Service will need solid information that rows of VAWTs can operate without harming condors. This will likely entail field research on turkey vultures and condors in Chile. Adding high-definition camera motion detection technology that shuts down the turbines when a condor is near the ground could also be used. This technology is widely used in Europe's wind farms to protect their rare vultures and eagles.

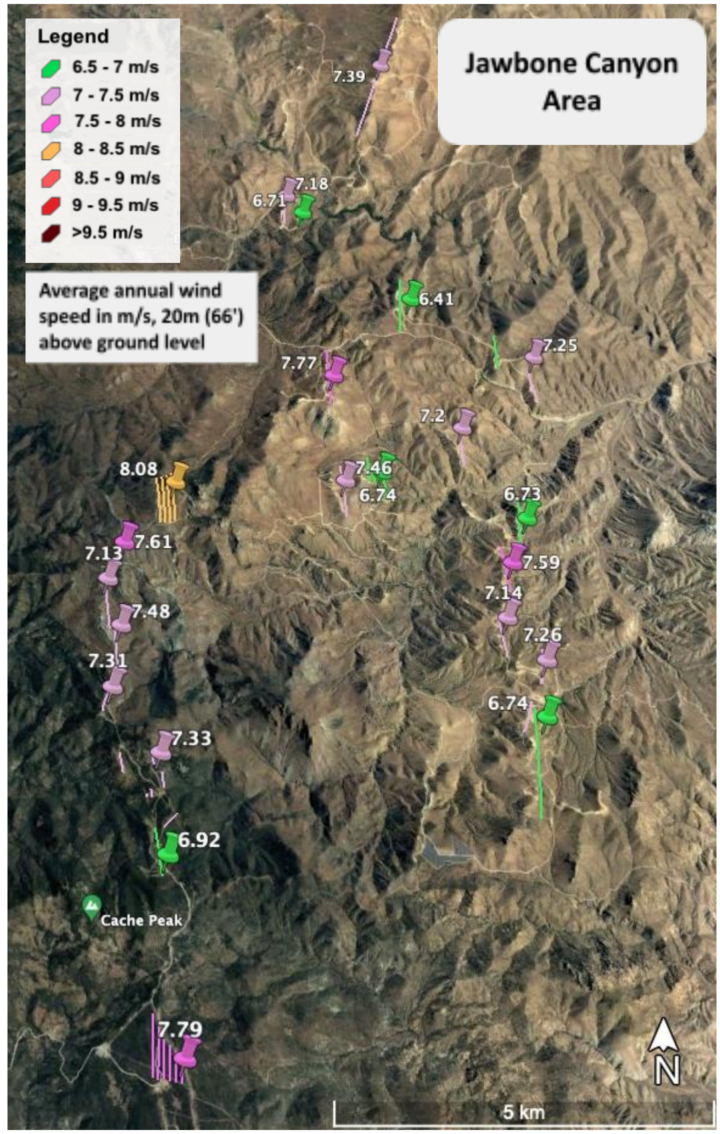


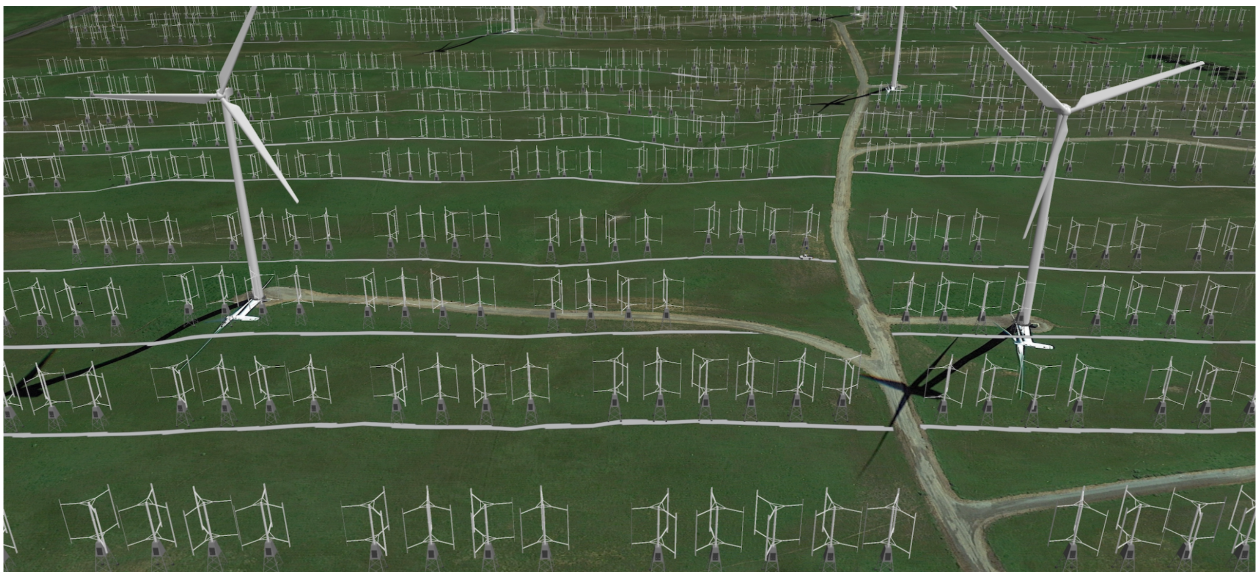
Image 4. Land Available for VAWTs with Wind Speeds >6.5m/s (14.5 mph

Recommendations

1. The California Energy Commission should fund meteorologists who have wind speed data in the Resource ARa to analyze and estimate how much acreage in the wind resource area exceeds 6.5m/s at 66' (20m) above ground level.

2. The CEC in conjunction with the wind industry should determine which wind farms would be best to install pilot projects. Topography matters. To accurately determine the best locations of VAWTs in the TWRA will require the use of LiDAR to collect wake data from strategically placed VAWT pilot projects and sophisticated modeling.

3. The DOE and CEC should fund the evaluation of how harvesting mid-level wind in the resource area could:
    a. Increase capacity factors from wind farms with and without new transmission lines.
    b. Extend the life of HAWTs under which the VAWTs are installed.
    c. Be done without harming birds and bats.
    d. Increase the energy output of the HAWTs by drawing faster moving wind from higher altitudes toward the ground.



Conclusion

California, its citizens, and businesses would benefit greatly from the buildout of even a small fraction of the 5.7 GWs of mid-level wind energy in the Tehachapi Wind Resource Area. New short VAWTs will soon be available to handle the turbulent, high-energy winds. When turbines are installed to tap the Wind Resource Area's excellent mid-level wind speeds, more jobs, property and other taxes, and lower cost energy would benefit the region and the state.

Appendix

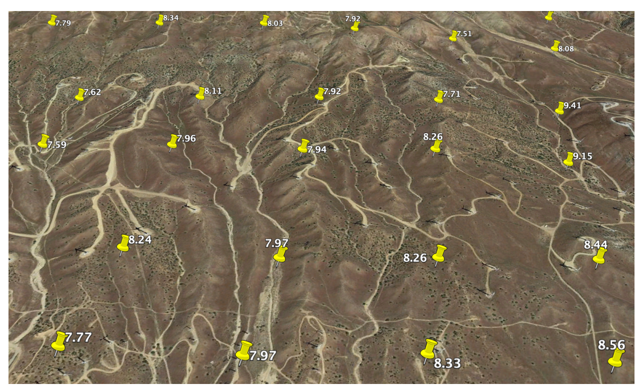
1. H-type VAWT Annual Energy Production (AEP)

This table uses power performance data from the *Wind Harvester* Model 3.1 prototype at the UL Advanced Wind Turbine Testing Facility in Texas. It assumes a 15% increase in AEP because pairs of H-type VAWTs placed close together gain the benefit of the coupled vortex effect. All H-type VAWTs of this size when installed 3 feet apart should realize the same power performance and annual energy production.

Wind speed		Turbine	Per MW	Capacity
m/s	MPH	MWh/yr	MWh/yr	Factor
6.5	14.5	181	2,586	29.5%
7.0	15.7	210	3,000	34.2%
7.5	16.8	235	3,357	38.3%
8.0	17.9	260	3,714	42.4%
8.5	19.0	285	4,071	46.5%
9.0	20.1	310	4,429	50.6%

2. VAWT Capacity Calculation

1. Wind Harvest analyzed **66 feet** (20 meters) above ground wind speeds in the Tehachapi Wind Resource Area using publicly available location information and predictions for average annual wind speeds from UL Solution's Windnavigator. This image shows a subset[9] of the wind speed predictions at the proposed hub height of VAWTs.



2. The topography and existing infrastructure were analyzed using Google Earth Areas available for H-type turbines were then categorized into four densities.
    a. High VAWT density potential: Relatively flat areas without hills
        i. The distance between rows of VAWTs is set at 5X their rotor height.
        ii. Capacity density is 48 W/m2 or .20 MW/acre

[9] For all the wind speeds included in this report, please contact us for the kmz file with all the wind speed pins.

b. Medium VAWT density potential: Areas with some hills and sloped terrain
   i. The distance between rows of VAWTs is set at 7.5 X their rotor height.
   ii. Capacity density is 35 W/m2 or .14 MW/acre
c. Light VAWT density potential: Hills with steeper slopes
   i. The distance between rows of VAWTs is set at 10 X their rotor height.
   ii. Capacity density is 24 W/m2 or .10 MW/acre
d. Jawbone Canyon: VAWTs can only be placed along existing roads and ridgelines.
   i. Capacity is estimated based on kilometers of road available for VAWTs with 3.5 MW per kilometer of road.
e. Southern wind farms: The area around the 333 MWs of HAWTs comprising the Manzana and Pacific Wind Farms was not included in this report. Only the hilly area in the eastern portion exceeds 6.4m/s. VAWTs could be placed along the roads and across other places but not enough information is known to determine VAWT densities so this small area was left out.

3. The potential VAWT buildout was calculated individually for each of the four types of terrain mentioned above.
   a. For this analysis, 43’ (13m) tall rotors were used. This scales so if the rotors were 66’ (20m) tall, the rotor swept area of VAWTs per acre would be roughly the same.

   b. In a row of VAWTs, it is assumed that neighboring turbines are installed 3.3’ (1m) apart from each other. Arrays of four VAWTs in a row are separated by an 85’ (26m) gap to allow for bird passage if needed.

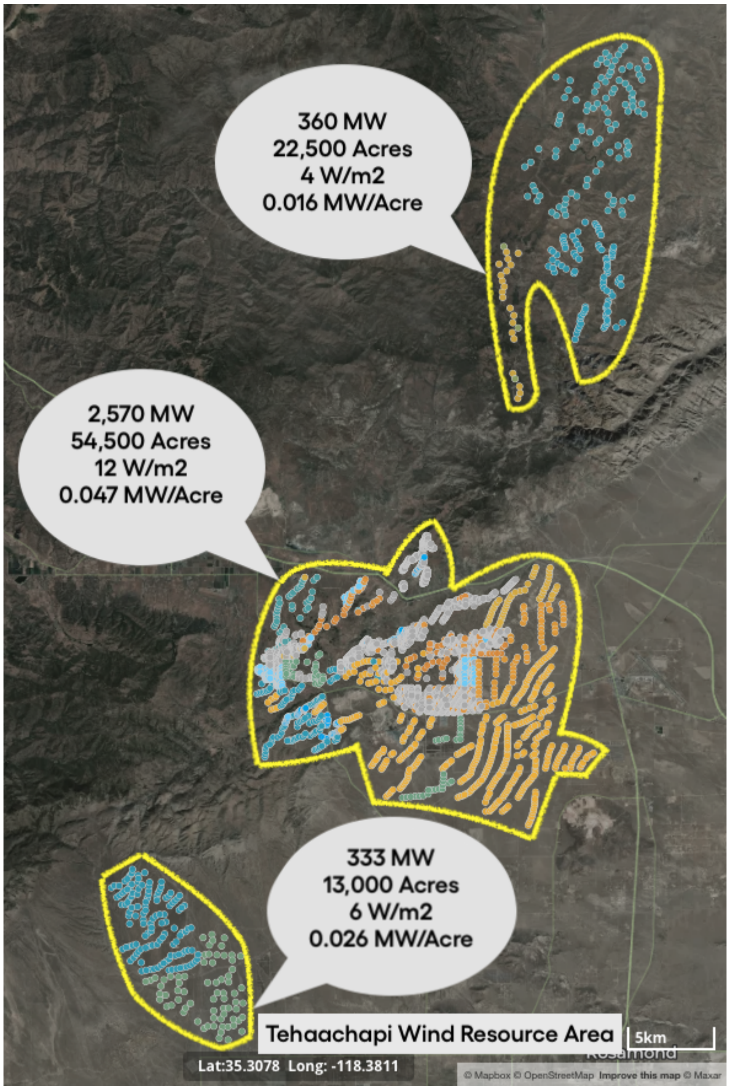
	Capacity Density	
	W/m^2	MW/acre
Existing HAWTs	9	0.03
Potential VAWTs	23	0.1
Potential Combined	32	0.13

Density for HAWTs is determined by dividing the 3,260 MW of capacity by the 90,000 acre. Some wind farms are denser and others less so. At 9 W/m2, the overall density of HAWTs is high compared to wind farms in other parts of the country. This is the same density as the Solano Wind Resource Area and half that of the 20 W/m2 in the San Gorgonio Pass.

Density for VAWTs at 23 W/m2 is determined by dividing the 5700 MWs of capacity by 60,000 acres where winds exceed 6.5m/s VAWT capacity is as high as 48 W/m2 in the flatter land where many rows can be installed. Capacity density falls in the hiller land where the valleys and gullies and steeper slopes preclude VAWT installations.

Note: For this analysis, we assumed VAWTs would be arranged in arrays of four to allow for bird and bat passage between each set of four. If seven turbine arrays were used in the calculation, high density areas could increase to 57 W/m^2 or 0.23MW per acre.

3. How was HAWT capacity density calculated?



The existing wind farms in the Tehachapi Wind Resource Area cover about 90,000 acres of land (pictured to the left, areas outlined in yellow).

The 3,263 MW of turbines in the area divided by the 90,000 acres produces a capacity density of 9 W/m^2 or 0.036 MW per acre.

4. *Wind Harvester* Sized VAWT - Theoretical Density Assumptions[10]

Generator size	0.07	MW	70	kW	
Rotor diameter	13	meters	43	feet	
Rotor height	13	meters	43	feet	
Rotor Swept Area	169	m2	554	ft2	0.41 kW per m2 or 0.13 kW per ft2
Center of Rotor	20	meters	66	feet	Above ground level
Distance between turbines in array	1	meter	3.28	feet	
Length of array	55	meters	180	feet	4 H-type VAWTs each 43’ (13m) wide with 3’ (1m) between turbines
Distance between arrays in row	26	meters	85	feet	The space between arrays assumes that it is needed for bird passage. The gap between arrays is 2 turbines wide.
Distance between rows	70	meters	230	feet	Rows of VAWTs can be installed as close as 5X the rotor height and realize the same wind speed as the upwind row.

5. *Wind Harvester* Sized VAWT - Theoretical Capacity Density

Theoretical density - high density	48	W/m2	0.20	MW/acre	Estimated average VAWT capacity by surface area, which may vary ± 25% based on terrain.
Theoretical density - medium density	35	W/m2	0.14	MW/acre	
Theoretical density - light density	24	W/m2	0.10	MW/acre	
Theoretical density - by length of roads	49.4	MW/km	5.56	MW/mi	

[10] Density of VAWTs scales. For example, a VAWT with a 2x rotor height would have half the number of rows.