Over 500 MW of Short Turbines Could be Added to the East San Diego Wind Resource Area[1]

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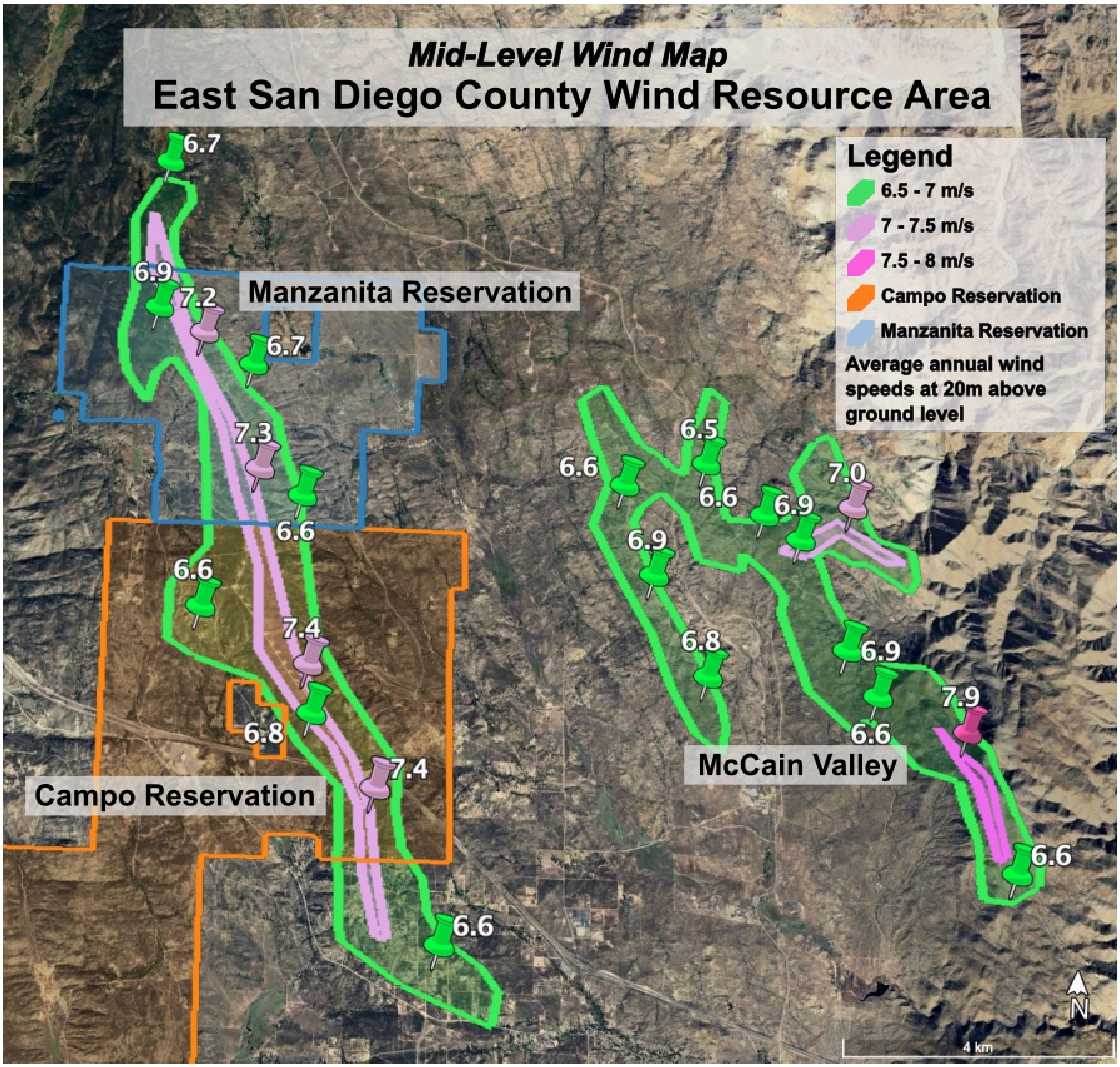


Image 1. Wind speed zones >6.5m/s (14.5mph)

[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. See Appendix for more information.

Summary

544 MW of vertical axis wind turbines that can operate successfully in turbulent mid-level wind could be added to the East San Diego Wind Resource Area (ESDC WRA) once the technology becomes commercially available. This breakthrough would more than double the capacity and annual energy production (AEP) from the land, primarily in existing wind farms on the Kumeyaay Reservation and U.S. owned land.

Table 1. Potential in the ESDC WRA

Area	Existing Projects	Wind Speed (m/s)		Capacity (MW)		AEP (GWh/yr)	
		HAWTs	VAWTs	HAWTs	VAWTs	HAWTs	VAWTs
Campo Kumeyaay	Kumeyaay	8.19	6.93	52[2]	123	144[3]	362
McCain Valley	Tule	7.37	6.75	131	313	391	874
Imperial Valley	Ocotillo	6.10	5.35	223	0	505	0
Manzanita Kumeyaay	None	n/a	6.90	0	111	0	323
Total / Average		6.78	6.82	**406**	**547**	**1,069**	**1,559**

Image 2. Two rows of Vertical-Axis Wind Turbines (VAWTs) could be installed beneath existing Horizontal-Axis Wind Turbines (HAWTs) on wide ridgeline (*graphic not in the ESDC WRA*).

[2] Includes 50 MW Kumeyaay Wind Farm and single 2 MW turbine at Golden Acorn Casino
[3] Kumeyaay Wind annual output

Image 3. Kumeyaay Wind Farm[4]

Background

In southeastern San Diego County California, topography and temperature differences create conditions to generate a great deal of wind. From spring into fall, the sun heats up the Sonoran desert creating a low pressure zone that intensifies until temperatures drop in the desert at night. By noon on most days, cooler marine air from the Pacific Ocean moves up and accelerates over the lowest points in the Southern Laguna Mountains between the coast and the inland desert. The region's best wind farms are placed where the wind funnels and speeds up.

In this region there are three wind farms. One is on tribal land, while the other two are on a mix of public and private land.

Table 2. HAWT Wind Farms in the ESDC WRA

Project Name	Capacity (MW)	Hub Height (m)	Wind Speed (m/s)	AEP GWh/yr	Property Owner	Project Owner
Kumeyaay	50	67	8.19	144[5]	Campo Kumeyaay	Leeward Energy
Tule	131	80	7.37	391	USA Public Domain	Avangrid Renewables
Ocotillo Wind	223	80	6.10	505	Mostly BLM	Pattern Energy
Total / Average	**404**		6.77	**1,069**		

[4] Image of Kumeyaay Wind
[5] Gridinfo reports that the Kumeyaay Wind annual output is only 144GWh. Using UL predicted wind speeds and HAWTs achieving an expected 47% capacity factor, the AEP would be 174 GWh per year.

The 406 megawatts (MWs)[6] of horizontal axis wind turbines (HAWTs) that were originally installed in the East San Diego County Wind Resource Area (ESDC WRA). These turbines should produce ~1,000 gigawatt hours (GWh)[7] of renewable electricity each year with an energy density of 6 watts per square meter (W/m^2) or 0.02 MW per acre.

The Turbulence Problem and Opportunity

On the same land on which HAWTs generate power, short vertical axis wind turbines (VAWTs) can be placed in locations where they won't cause wake and turbulence that could harm the tall turbines under which they would operate.

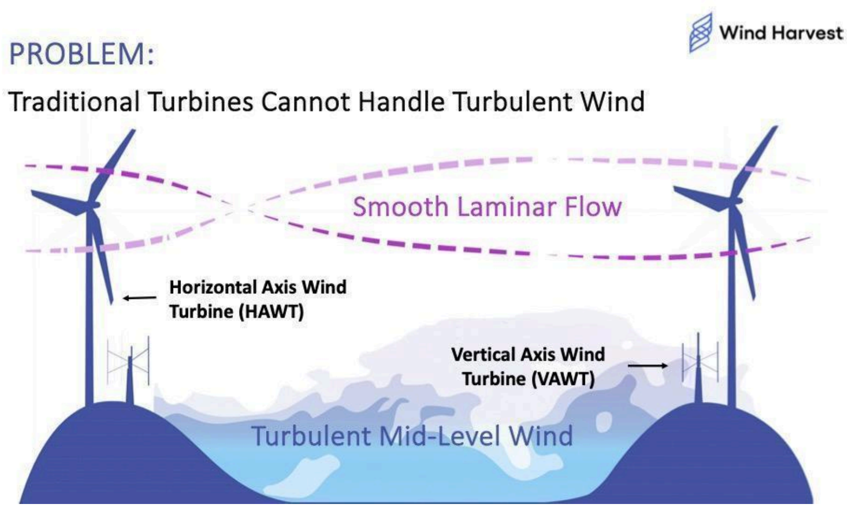


Image 3: Turbulence and Turbine Types[8]

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[9] which don't require additional substations and transmission lines.

[6] US Wind Turbine Database
[7] See the Annual Energy Production table, Appendix (1).
[8] How VAWTs like *Wind Harvesters* operate in turbulent wind
[9] Capacity factor enhancement projects

Research[10] from Stanford, CalTech, and other universities predict that vertical mixing from understories of VAWTs will draw faster-moving wind from higher altitudes down to the rotors of the HAWTs in wind farms and increase their energy output by 10%.

VAWT Potential

The areas considered for VAWTs within existing wind farms are the Kumeyaay Wind Farm on the Campo Band of Kumeyaay Indians[11] Reservation and the Tule Wind Farm in McCain Valley. Using UL Windnavigator predictions for wind speeds, the **Campo Kumeyaay Reservation** should have wind speeds averaging 6.9 m/s at 20m above ground level. This ~900 acres has the potential for over 120 MW of VAWTs[12]. There is also a 2 MW turbine on Campo Kumeyaay land outside the wind farm at the Golden Acorn Casino. **Tule Wind Farm** wind speeds average 6.75 m/s at 20m agl across ~2,000 acres with a potential for 300+ MW of VAWTs.

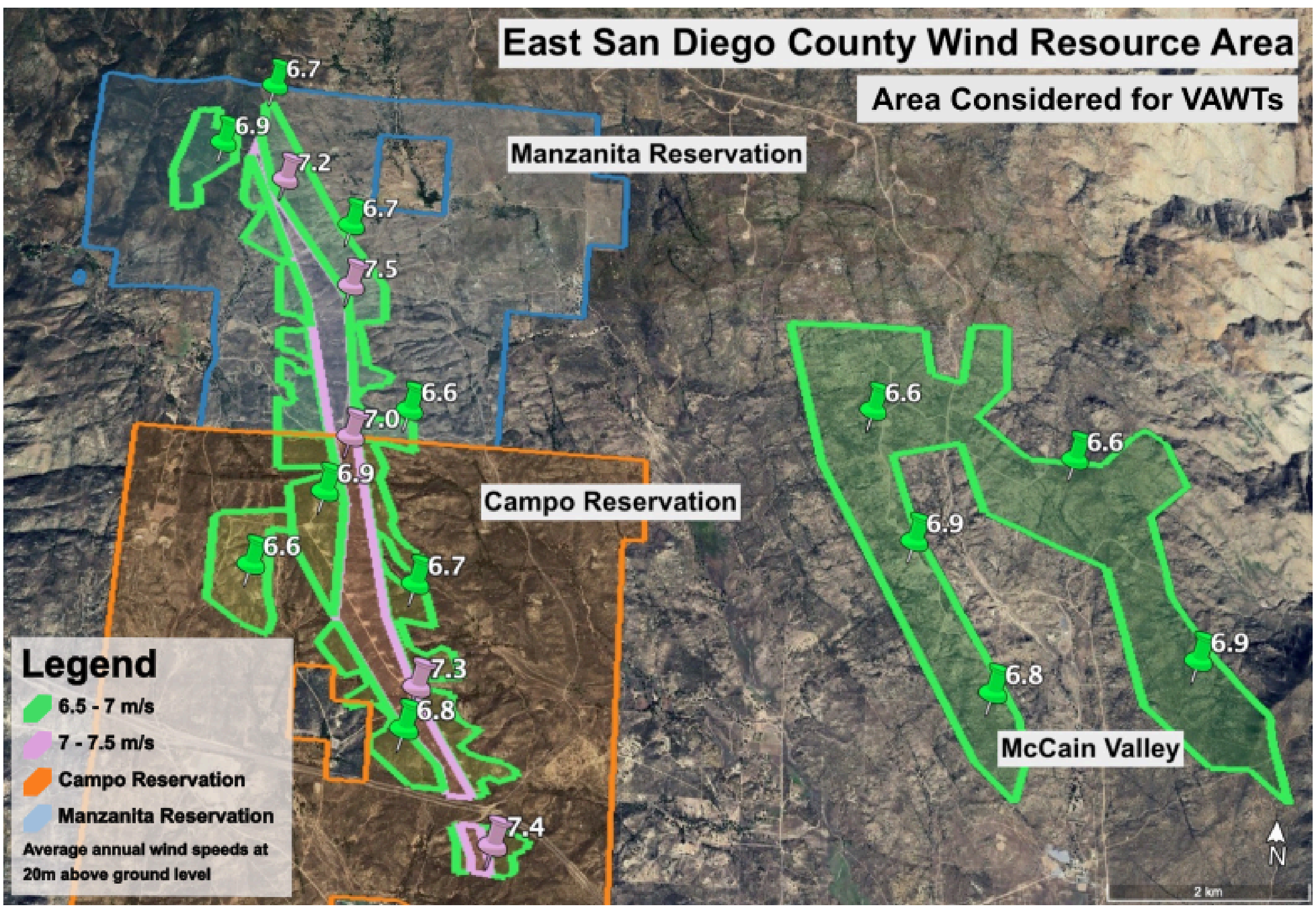


Image 4. Area Available for VAWTs

[10] Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms
[11] Campo Band of Kumeyaay Indians
[12] See Appendix - Capacity Density Calculations

Outside of existing wind farm areas, the **Reservation Land of the Manzanita Band of the Kumeyaay Nation**[13] has good mid-level wind speeds. About 800 acres of the land have average annual wind speeds of over 6.5 m/s at 20m above ground level. 235 acres should have wind speeds between 7.0 and 7.5 m/s at 20m agl. On these parts of the ridgeline, 110+ MWs of VAWTs could be added. Based on these predicted wind speeds and the assumptions explained in the appendix, these new turbines could produce >320 GWh per year.

Ocotillo's Imperial Valley, currently home to the 223 MW **Ocotillo Wind Project**[14], was left out of the VAWT potential analysis due to low wind speeds at 20m above the ground.

In total, 544 MWs of VAWTs could be added to land around and near where HAWTs currently operate. By adding VAWTs in and around existing Campo and McCain Valley wind farms, the East San Diego County Wind Resource Area's **capacity could more than double from 406 MW to 991 MW.** Total Annual Energy Production would increase by **1,550 GWh**. This is enough electricity to meet the needs of 222,000 California homes per year.[15]

Table 3. Total Capacity and GWh with HAWTs and VAWTs in the ESDC WRA

Wind speed @ rotor height		HAWT Existing		VAWT Potential	
m/s	MPH	Capacity (MW)	AEP (GWh/yr)	Capacity (MW)	AEP (GWh/yr)
6.5 - 7	14.5 - 15.7	211	617	469	1,311
7 - 7.5	15.7 - 16.8	124	429	75	238
7.5 - 8	16.8 - 17.9	26	127	-	-
8 - 8.5	17.9 - 19	14	55	-	-
8.5 - 9	19 - 20.1	31	174	-	-
Total		**406**	**1,046**	**544**	**1,550**

Note: The sloped terrain in the Resource Area changes the calculation for determining potential VAWT capacity from that if the land had been primarily flat and open. Using the density of 35 W/m^2 or 0.14 MW per acre assumes that VAWTs would be installed where extensive excavation work to level the land is not needed, avoiding gullies and steeper slopes.

[13] Manzanita Band of the Kumeyaay Nation
[14] Ocotillo Wind Project
[15] The average annual electric consumption per Californian household is ~7,000 kWh.

Recommendations

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

2. 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.

3. Develop a pilot project to test the potential of a VAWT buildout.

Conclusion

The exceptionally windy areas in California are small. The land is mostly maxed out in its capacity to add tall turbines. No additional capacity has been added to these locations in years. Yet the mid-level wind blowing beneath the blades of the HAWTs is commercially viable once a turbine is made that can withstand the turbulence in this layer of energetic air.

California, its citizens, and organizations would benefit from using even a fraction of the 500+ MWs of mid-level wind energy in the East San Diego County Wind Resource Area. The wind blows at night during spring and summer reducing the need for solar energy storage. Small projects of VAWTs could be added to the land without needing new transmission lines. When VAWTS are installed to tap the Wind Resource Area’s excellent mid-level wind speeds, more renewable energy, jobs, property taxes, lease income, and lower long-term energy costs would benefit the tribes, 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. HAWT Annual Energy Production (AEP)

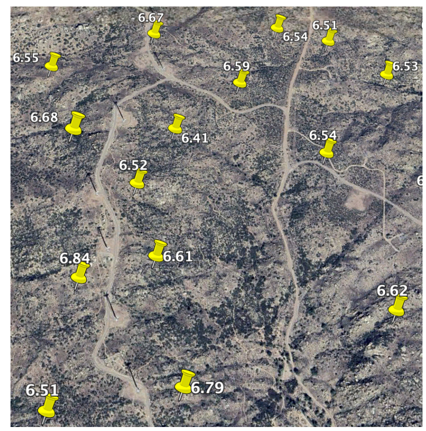
Wind speed		Per MW	Capacity
m/s	MPH	MWh/yr	Factor
5	11.2	1005	10.90%
5.5	12.3	1830	19.90%
6	13.4	2265	24.60%
6.5	14.5	2715	29.50%
7	15.7	3150	34.20%
7.5	16.8	3525	38.30%
8	17.9	3900	42.40%
8.5	19	4275	46.50%
9	20.1	4650	50.60%

HAWT AEP was calculated by taking the MWh/yr, based on the average wind speed at hub height across the site, and multiplying by the MW of HAWTs at the site. Note that despite a high MW capacity at Ocotillo Wind, low wind speeds across the site are cause for low AEP. This in turn drags down the entire AEP per MW of HAWTs installed in the ESDC WRA.

3. Capacity Density Calculations

	Capacity Density	
	W/m^2	MW/acre
Existing HAWTs	6	0.02
Potential VAWTs	35	0.2
Potential Combined	42	0.22

A. VAWT Capacity Density



1. Wind Harvest analyzed **66 feet** (20 meters) above ground wind speeds in the East San Diego County Wind Resource Area using publicly available location information and predictions for average annual wind speeds from UL Solution's Windnavigator. The image to the right shows a subset[16] 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 the
   a. The distance between rows of VAWTs is set at 7.5 X their rotor height.
   b. Capacity density is 35 W/m2 or .14 MW/acre.
   c. Imperial Valley, Ocotillo Wind Farm: The area around the 223 MWs of HAWTs in Ocotillo's Imperial Valley, currently home to the Ocotillo Wind Project, was left out of the VAWT potential analysis due to low near-ground wind speeds but was included in the HAWT calculations throughout this report.

3. The potential VAWT buildout was calculated as follows
   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.

VAWT capacity density is lower than in the primarily flat San Gorgonio Pass Wind Resource Area for example, due to the rugged and sloped terrain in the ESDC WRA.

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

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 40 W/m^2 or 0.16 MW per acre.

B. HAWT Capacity Density

Density for HAWTs is determined by dividing the 406 MW of capacity by the 20,000 acres of existing Wind Farms. Some wind farms are denser and others less so. Density for VAWTs at 35 W/m^2 is determined by dividing the 544 MWs of capacity by 3,892 acres where winds exceed 6.5m/s.

4. *Wind Harvester* Sized VAWT - Theoretical Density Assumptions[17]

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.
Theoretical density assumption	35	W/m2	0.14	MW/acre	Estimated average VAWT capacity by surface area, which may vary ± 25% based on terrain.

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