California's Massive Mid-Level Wind Resources Rediscovered

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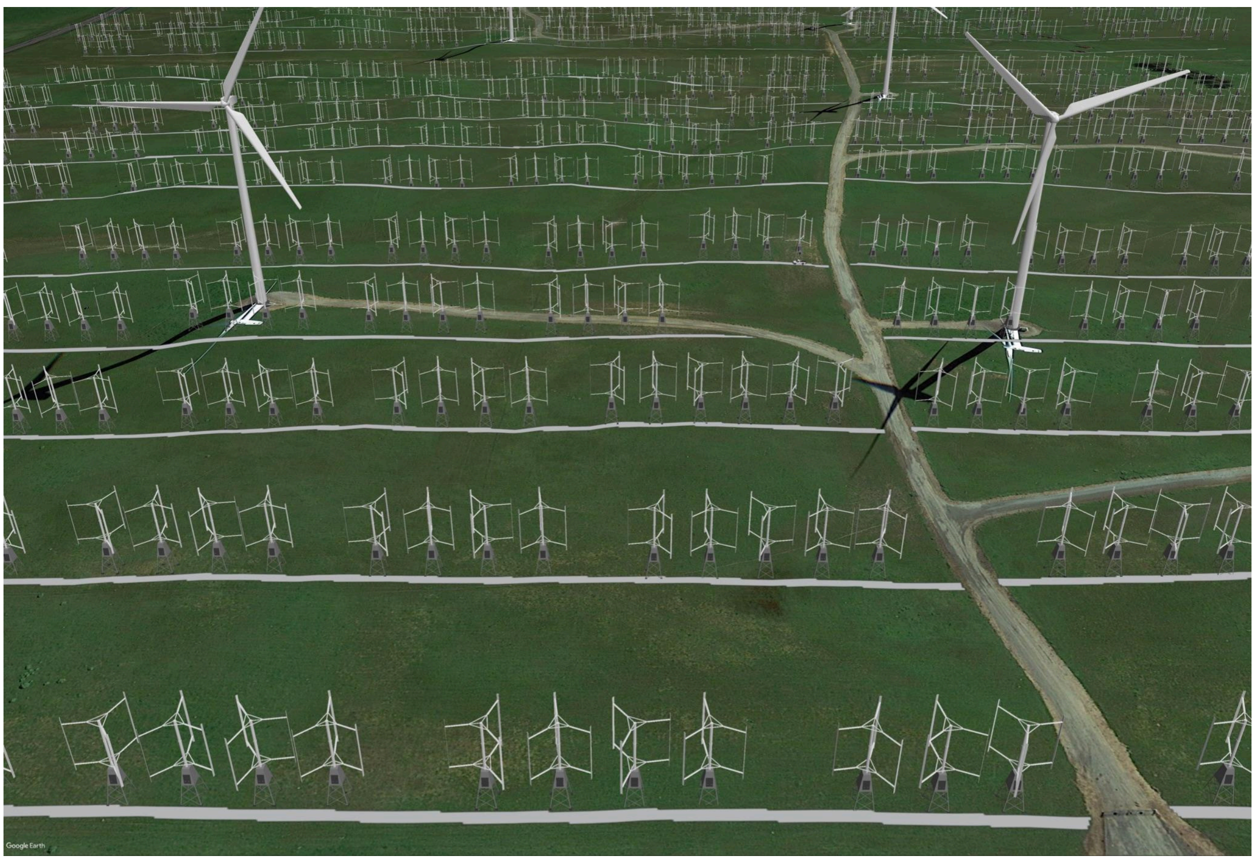
Image 1: Graphic of full understory buildout of the Shiloh II Wind Farm in the Solano WRA



Terms

AEP	Annual Energy Production
AGL	Above Ground Level
CEC	California Energy Commission
GWh	Gigawatt hour (1000 MWh)
H-type	A VAWT with straight blades that can be placed three feet away from a neighboring turbine
HAWT	Horizontal-Axis Wind Turbine
Met mast	Meteorological Mast with wind speed and directional sensors
Mid-level wind	Wind from 5-30m agl (<100’). Usually turbulent.
m/s	Meters per second (multiply by 2.4 for mph)
MWh	Megawatt hour (1000 kWh)
UL	Underwriters Laboratories
VAWT	Vertical-Axis Wind Turbine
Wind shear	Wind shear is calculated using the following formula: (anemometer wind speed) x [(“hub” height/anemometer height)^roughness factor]
Wind Harvester	An H-type VAWT made by Wind Harvest with 169m2 (1,819 sq ft.) of rotor swept area that has completed Technology Readiness Level 7 - a full scale prototype tested in industrial conditions of highly turbulent wind.
Wm2	Watts per square meter
WRA	Wind Resource Area

Executive Summary

All of California's Wind Resource Areas and almost all of its wind farms have "good to excellent" average annual "mid-level" wind speeds at 15-20 meters (50-66') above ground level. Using estimates from UL's Windnavigator, considered one of the best wind resource prediction tools available, Wind Harvest calculated that approximately 100,000 acres of land in and around the Altamont Pass, East San Diego County, Solano, San Gorgonio and Tehachapi Wind Resource Areas have wind speeds averaging **above 6.5m/s** (14.5mph) at 20m above ground level. Over 8,500 acres have wind speeds averaging over 8m/s at this height above ground.

All of California's wind farms are on land already zoned for wind energy production. Roads and infrastructure are already in place and paid for. In 2021, 6000+ megawatts (MW)[1] of horizontal axis wind turbines (HAWTs) in California wind projects generated **~15,200 gigawatt-hours** (GWh) of electricity — ~8% of all power generated within California[2].

To reach its goal of carbon neutrality, California would need to produce an additional 135,000 GWh of energy from renewable sources by 2045. Wind Harvest estimates that, if fully built out in the wind resource areas, H-type vertical axis wind turbines (VAWTs) could add 15 GW of capacity and about 45,000 GWh of energy per year to California's grid, or about 33% of that goal. Alternatively, if these VAWTs were only added to existing wind farms, California could add ~10 GW and 31,500 GWh of energy to the grid, or about 23% of what the state needs to reach carbon neutrality.

Image 2: Graphic of VAWT buildout of a ridgeline in the Tehachapi WRA

[1] US Wind Turbine Database
[2] California Energy Commission 2021 Electric Generation

Using one meter (~3') distances between rotating blades of H-type VAWTs and 5X a VAWT rotor's height between rows of VAWTs to calculate density, this report shows that almost 15,000 MWs or 15 GWs **of short VAWTs** can be added to these relatively small but intense wind resource areas. [3]

Given the assumptions underlying this report, an additional **45,000 GWh** of energy could be produced in the existing wind farms and in the surrounding windy parts of the resource areas where tall turbines aren't allowed. Assuming households in California use 10 MWhs of electricity per year, harvesting the full mid-level wind potential in these areas would supply enough electricity annually for 4,500,000 homes in the state.

Table 1: Mid-Level Wind Resources in California's Wind Resource Areas

Wind Resource Area	Acres Available > 6.5m/s (14.5mph)	GW of VAWTs possible	GWh/year potential
Tehachapi	33,807	5.61	18,049
San Gorgonio	13,745	3.14	10,040
Solano	24,950	4.99	13,528
East San Diego County	4,391	0.80	2,296
Altamont Pass	2,458	0.45	1,265
Total	**79,351**	**15**	**45,178**

Background

During the late 70s and early 80s, the California Energy Commission (CEC) conducted large-scale assessments of wind as a resource. Using data collected primarily from anemometers on 10m meteorological masts, the CEC published regional reports that were summarized in 1983 in Wind Resource Assessment of California: a summary of CEC-sponsored studies[4].

These reports proved that relatively small areas in passes between the State's cooler coastal and hotter inland areas have abundant and strong wind resources which was the foundation of the world's first large-scale projects to harness wind energy.

By the time the CEC compiled and published the 1985 Wind Atlas[5] over 10,000 wind turbines averaging 250 kW each had been installed in four of the State's five Wind Resource Areas. California's pioneering leadership stimulated the rise of three of the world's largest wind turbine "original equipment manufacturers" - Vestas, GE (originally Zonds, then Enron) and Siemens

[3] Note that the height and diameter of the VAWTs will not affect the density. Taller rotors require more distance between rows of VAWTs. Wider diameter rotors only save 1m distance between pairs of VAWTs.
[4] 1983 Wind Resource Assessment of California
[5] CEC 1985 Wind Atlas

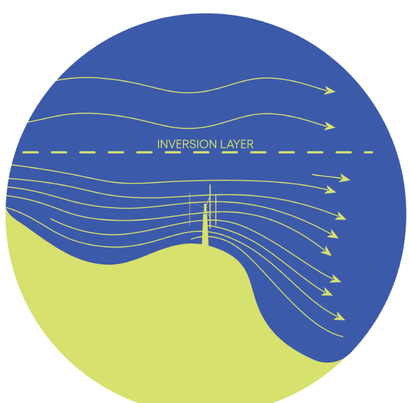
(originally Bonus Energy) as they had the opportunity to bring their manufacturing to scale with the sales they made in the state. The turbines installed in the early 1980s were relatively short[6]. The small HAWTs usually had hub heights (the middle of their rotors) at 30m above the ground. The only VAWTs installed in the state (500 Flowinds) had the center of their rotors between 10-20m above the ground.

By the end of 2002, the CEC had updated its 1985 Wind Atlas in the “New Wind Energy Resource Maps of California – final report”[7]. 10m above ground wind speed data from the 1980s were extrapolated to 50m using the 0.05 to 0.12 wind shear exponents that had been with the data in computer discs that were in the back of the 1985 Wind Atlas.

Later, the National Renewable Energy Laboratory (NREL) used the CEC’s 50m maps to produce their 30m California wind speed maps. By then, the computer discs with associated raw data had been lost and no wind shear information was readily available. Without knowing the wind shears, NREL used more standard wind shears of 0.2 to back extrapolate from 50m to their 30m maps[8]. As a result, NREL’s 30m maps of California underestimated mid-level wind speeds. Since no wind shear data was available from the CEC and wind farm owners do not share their wind data, CEC staff and NREL did not have the information to identify and correct the resulting mapping errors. **The knowledge of the enormity of the state’s mid-level wind resource was subsequently underestimated and mostly forgotten.**

Wind Harvest learned of this underestimation problem during its debriefing process with CEC staff during the company’s unsuccessful EPIC grant application in 2017. “The proposal suggests that VAWTs might be used as an understory below HAWTs and suggests that the primary driver for the height of HAWTs is that mid-level wind is too turbulent. Wind resources are much greater at height and this calls into question the resource potential for VAWTs deployed in this fashion.”[9]

Image 3[10]: Airflow over an idealized ridge located in a high wind region



[6] Flowind: The World’s Most Successful VAWTs
[7] https://windharvest.com/wp-content/uploads/2018/07/CEC-500-01-009.pdf
[8] As told by meteorologist Rich Simon who had helped collect the data and research for the regional reports, 1985 Wind Atlas and 2002 update.
[9] Jocelyn Brown-Saracino comments.
[10] This graphic was adapted from the graphic on page 12 of the CEC 1985 Wind Atlas

It took a while to learn why, in 2017, the DO and the CEC did not seem to know how good mid-level wind speeds were in California's wind farms. The breakthrough in solving this problem occurred when Wind Harvest received permission from UL's Windnavigator to use its wind speed predictions to publish new mid-level wind maps. UL bought leading wind farm meteorological enterprise AWS Truepower[11] to help create its Windnavigator business. AWS was the company that had provided wind data collection and mapping services to the CEC in the 1980s. One reason why UL's estimates are so accurate for the San Gorgonio Pass is Windnavigator's access to AWS's early data sets of the region.

The hills and ridgelines in the San Gorgonio and Tehachapi Passes in Southern California have near-ideal conditions for exceptional mid-level wind speeds. The regional reports (linked in the sections below) show how many sections exceed 8m/s (14.5mph) at 20m (66') above ground level.

Methodology

Using UL's Windnavigator, Wind Harvest compiled thousands of estimates of mid-level wind speeds at different locations in all of California's wind farms. To confirm the accuracy of the Windnavigator estimated wind speeds, Wind Harvest hired renowned meteorological consultant Rich Simon, a contributor to the data and analysis that was compiled into the 1985 Wind Atlas. Using the extensive set of wind speed data his company had collected for wind farm owners and developers, Simon confirmed the overall accuracy of the Windnavigator information for San Gorgonio WR. In the windiest section of the Pass, Windnavigator underestimated the wind speed by 0.1m/s. In the other areas, UL's model overestimated the wind speed by 0.59m/s. In this report, Wind Harvest adjusted the San Gorgonio Pass data to account for Simon's more accurate assessments, but has left the mid-level wind speeds in other resource areas as they are estimated by Windnavigator.

Simon also noted that putting rows of VAWTs downwind of widely separated rows of HAWTs (e.g many ridgelines) should not create harm for the upwind HAWTs because winds in California's wind resource areas are unidirectional. Research[12] out of Stanford and CalTech on VAWTs in wind farms predicts that vertical mixing from understories of VAWTs will actually bring faster-moving wind into the rotors of the HAWTs and could increase their energy output by 10%.

Assumptions

1. Windnavigator's wind speed estimates are reasonably accurate. If it was on the low end of the average margin of error, the tables below would be reduced by 0.5m/s.
2. Adding mid-level VAWTs in the understories of existing and new wind farms is cost-effective and can compete with alternative sources of renewable energy, especially when they are manufactured at scale. (e.g 500+ MWs per year).

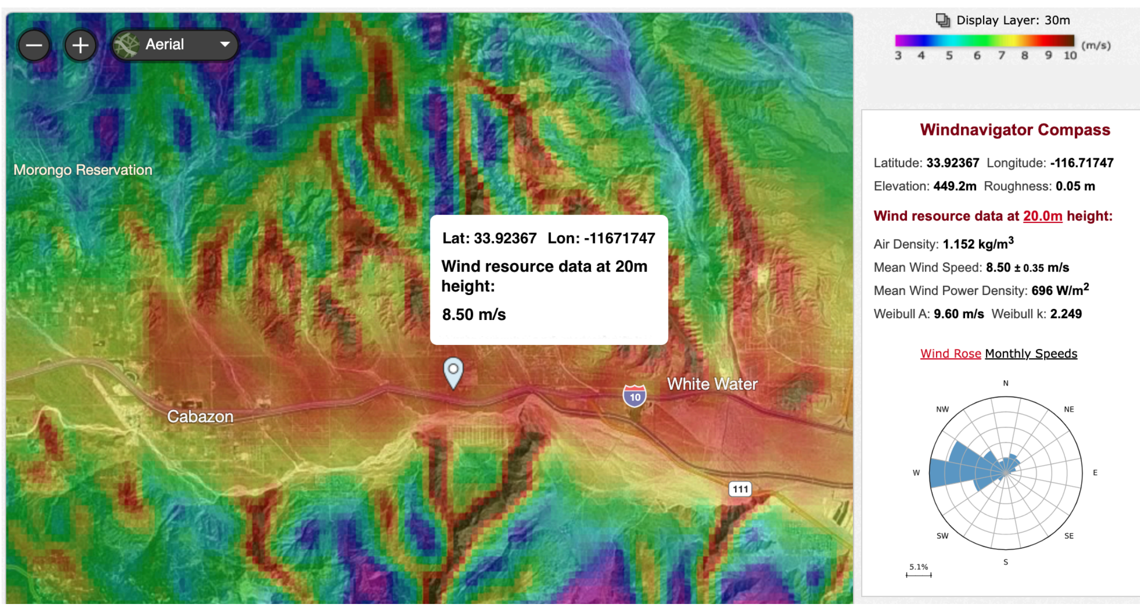
[11] UL Acquisition of AWS Truepower
[12] Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms

3. Mid-level VAWTs can produce 3000 MWh per MW in 7m/s (15.7mph) average annual wind speeds.
4. Mid-level H-type VAWTs can be placed one meter apart from one another, utilizing the coupled vortex effect[13]. As modeled by a CEC grant[14], when placed this close together, these VAWTs can then achieve the 45-50% efficiencies that modern HAWTs attain.

The Evaluation Process

Using UL's Windnavigator, Wind Harvest found data points for wind speeds at 15 and 20 meters (49-66') above ground level in a grid pattern covering the windy area in each zone. The space between the data points in the grid varied based on the wind speed and area analyzed, but they were generally between 100 and 500 meters (328-656') apart. Once Windnavigator's estimate of 20m (66') above ground level wind speed dropped below 6.5m/s (14.5mph), Wind Harvest stopped finding additional data points. To estimate the size of the different wind speed areas, Wind Harvest used Google Earth's polygon area estimate tools.

Image 4: Wind Map of San Gorgonio area as available on UL Windnavigator



The outermost polygon (usually that of the wind speed range 6.5-7m/s or 14.5-15.7mph) was used to determine the "Total Land Area" in the Wind Resource Area.

Within each wind speedzone, Wind Harvest estimated the area that could be used by H-type turbines. This was done by making polygons that would go around existing structures, roads, and slopes that are too steep for the turbines. The main method for estimating the potential for VAWTs in the WRAs was to put the total acreage through the VAWT Theoretical Density Calculator to determine the MWs that could be installed within that area of land. The Tehachapi and San Gorgonio Wind Resource Areas used this method in the flat land but used different methods for calculating the VAWT potential on hills and ridgelines (see the regional reports).

[13] The Coupled Vortex Effect occurs when two H-type VAWTs are placed close together. Blockage by the blades forces wind into neighboring rotors and into the gap where the wind speeds up.
[14] Modeling Blade Pitch and Solidities in Straight Bladed VAWTs

Table 2: VAWT Theoretical Density Assumptions

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
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	Space between arrays is assumed to be needed for bird passage. The gap between arrays is 2 turbines wide.
Distance between rows	70	meters	230	feet	Rows can be installed as close as 5X the rotor height and realize the same wind speed as the upwind row.

The area available for H-type turbines is organized by wind speed. Using the calculations in Table 2, the MWs per wind speed area is calculated. Annual Energy Production is by assuming VAWTs will have the power performance of *Wind Harvesters.*

Each of the regional areas used a different method to calculate capacity density. For details, see the methodology section in the three regional reports which are linked in their respective sections below. The Altamont Pass and East San Diego Wind Resource Areas used a simplified method with an estimated capacity density of 57 W per square meter or 0.23 MW per acre.

Table 3: HAWTs Across California WRAs[15]

Wind Resource Area	**HAWT Area**		**Capacity**	**Density**		**Annual Energy Production**[16]
	Hectares	**Acres**	**GW**	**W/m2**	**MW/Acre**	**GWh/year**
Tehachapi	36,422	90,000	3.26	9	0.04	10990
San Gorgonio	3,237	8,000	0.62	19	0.08	2402
Solano	11,331	28,000	1.07	9	0.04	3724
East San Diego County	8,094	20,000	0.45	6	0.02	1316
Altamont Pass	4,047	10,000	0.34	8	0.03	1034
Total / Average	**63,131**	**156,000**	**6**	9	0.04	**19,465**

[15] US Wind Turbine Database
[16] The **19,465** GWh in Table 3 is more than the **15,200** the CEC stated was generated in 2021. Either many turbines were offline in 2021, or we overestimated their efficiencies.

Data Presentation

The following tables show the potential for VAWTs across the state's wind resource areas.

Table 4: Average wind speed across all regions

Average wind speed at 20m (66') agl	6.96m/s | 15.7mph
Average wind speed at 80m (262') agl	7.78m/s | 17.4mph
Average wind shear	0.09

Table 5: Potential VAWT buildout in across all regions

Wind Speed		VAWT Potential			
m/s	**MPH**		**Existing wind farms**	**Beyond existing wind farms**	**Total**
> 6.5	**> 14.5**	Buildout (GW)	10.28	4.70	**14.98**
		AEP (GWh/year)	31,513	13,665	**45,178**
		Acres	56,270	23,082	**79,352**
6.5 - 7	**14.5 - 15.7**	Buildout (GW)	6.41	3.22	9.62
		AEP (GWh/year)	17,743	8,682	26,425
		Acres	32,800	16,261	49,061
7 - 7.5	**15.7 - 16.8**	Buildout (GW)	1.71	0.76	2.46
		AEP (GWh/year)	5,390	2,400	7,790
		Acres	9,386	3,534	12,920
7.5 - 8	**16.8 - 17.9**	Buildout (GW)	0.88	0.72	1.61
		AEP (GWh/year)	3,124.0	2,553.0	5,677.0
		Acres	5,511.0	3,247.0	8,758.0
> 8	**> 17.9**	Buildout (GW)	1.3	0.0	1.3
		AEP (GWh/year)	5,256	30	5,286
		Acres	8,573	40	8,613

This same data can also be broken down by regions: The Altamont Pass, East San Diego County, San Gorgonio, Solano and Tehachapi WRAs. The tables in the regional sections below break down the current wind resource area buildout in the area with estimates of:

- how much energy is produced currently
- how much could be added by VAWTs if adding only to the understory of existing wind farms
- how much potential there is if VAWTs were built out in the entire windy area.

Tehachapi Wind Resource Area

Kern County, California

For more detailed information, see the [Tehachapi Regional Report here.]

The Tehachapi WRA has excellent mid-level wind speeds because the Pass funnels cool air blowing from the Pacific Ocean into the hot Mojave Desert to the east. The area is home to dozens of wind farms including one of the largest wind energy projects in the country, Alta Wind Energy Center. Adding VAWTs to this wind resource area, both as an understory to and on land outside of existing wind farms, could increase capacity from the current 3.5 GW[17] to 9.1 GW. Energy production could more than triple from the current 13.3 to 31 GW per year.

Table 6: Wind shears and average wind speeds in Tehachapi WRA

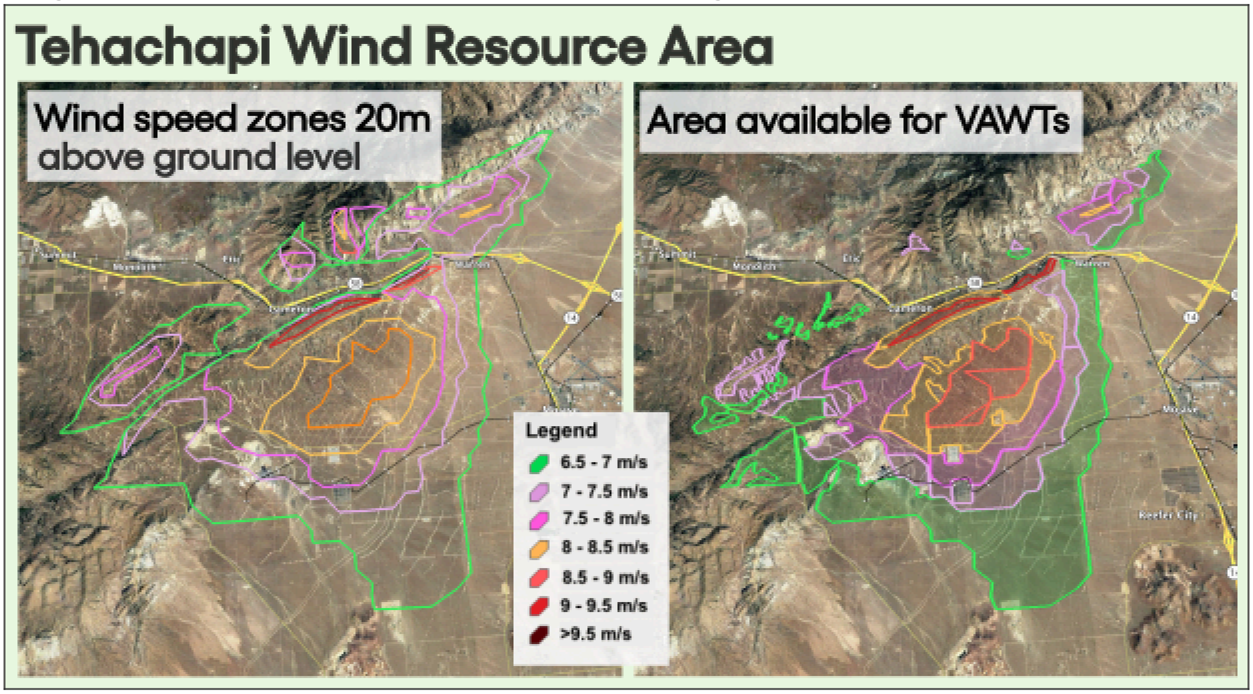
Average wind speed at 20m (66') agl	7.36m/s | 16.5mph
Average wind speed at 80m (262') agl	8.88m/s | 19.9mph
Average wind shear	0.08

Table 7: Potential VAWT buildout in Tehachapi WRA

Wind Speed		**VAWT Potential**			
m/s	**MPH**		**Existing wind farms**	**Outside of wind farms**	**Total**
> 6.5	**> 14.5**	Buildout (GW)	5.08	0.53	**5.61**
		AEP (GWh/year)	16,405	1,644	**18,049**
		Acres	31,128	2,679	**33,807**
6.5 - 7	**14.5 - 15.7**	Buildout (GW)	2.44	0.21	3
		AEP (GWh/year)	6,822	577	7,399
		Acres	13,345	1,055	14,400
7 - 7.5	**15.7 - 16.8**	Buildout (GW)	0.91	0.17	1
		AEP (GWh/year)	2,879	535	3,414
		Acres	5,710	859	6,569
7.5 - 8	**16.8 - 17.9**	Buildout (GW)	0.62	0.14	1
		AEP (GWh/year)	2,188	502	2,690
		Acres	4,360	725	5,085
> 8	**> 17.9**	Buildout (GW)	1.11	0.01	1
		AEP (GWh/year)	4,516	30	4,546
		Acres	7,713	40	7,753

17 US Wind Turbine Database

Image 5: Tehachapi WRA wind speed map at 20m agl and area available for VAWTs



San Gorgonio Pass Wind Resource Area

Riverside County, California

For more detailed information, see [SGP Regional Report here](#).

One of the most legendary wind resource areas in California is the San Gorgonio Pass. Some of the first wind turbines were installed here in the early 1980s. It quickly grew to hold over 600 MW[18] of wind turbines but has had no significant increases in capacity in decades. Yet under and around the existing turbines blows one of the world's best wind resources. A short vertical axis wind turbine (VAWT) that doesn't create turbulence problems for existing turbines is needed to exploit this resource.

The entire windy area in the San Gorgonio pass assumes VAWTs are only installed:

- 30m (98') away from roads
- 150m (492') away from residences
- 100m (348') away from facilities and freeways
- 800m (0.5 miles) away from the Pacific Crest Trail
- In areas with wind speeds greater than 6.5m/s (14.5mph) at 20m (66') above ground level.

[18] US Wind Turbine Database

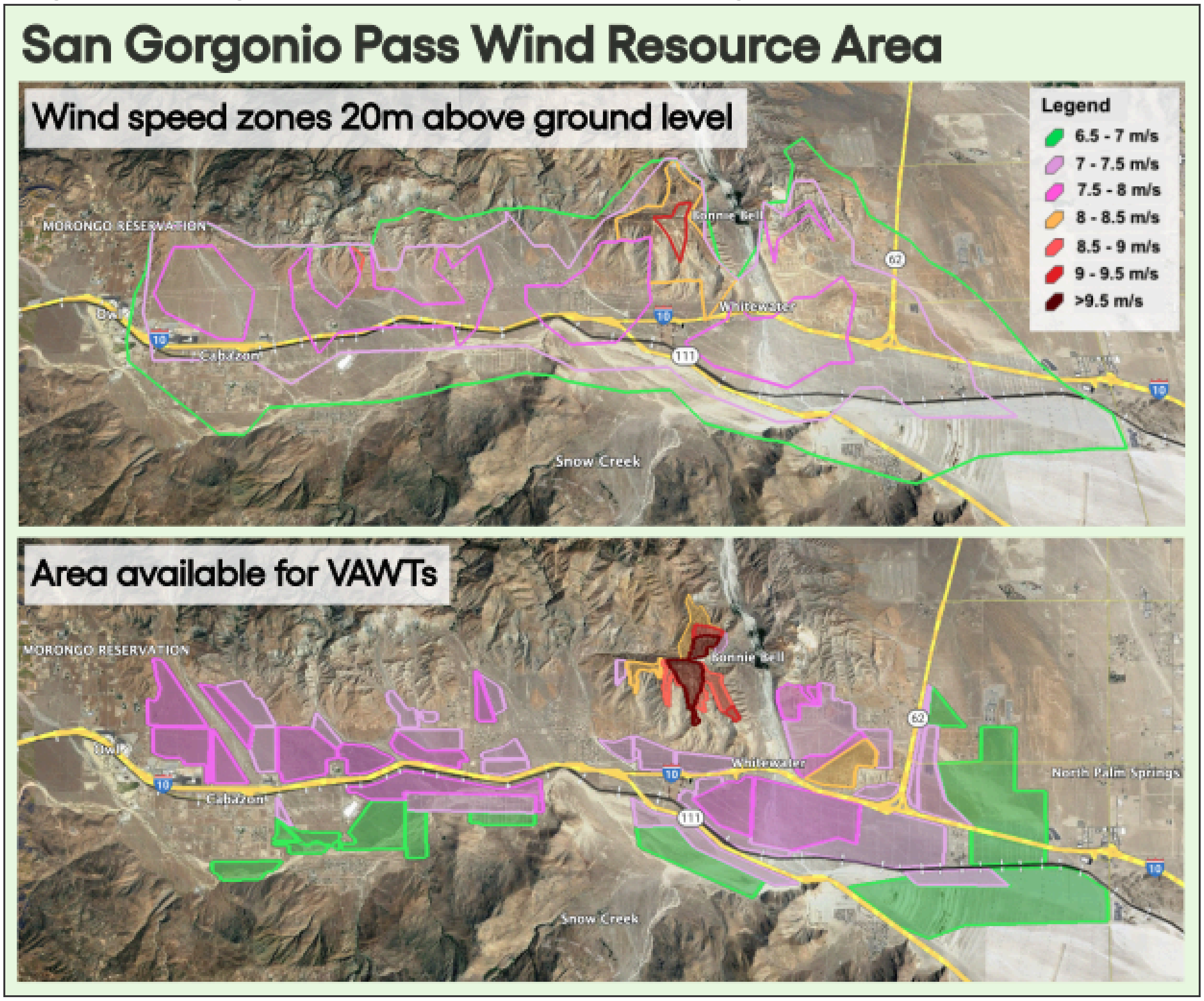
Table 8: Wind shears and average wind speeds in San Gorgonio WRA

Average wind speed at 20m (66') agl	7.2m/s | 16.1mph
Average wind speed at 80m (262') agl	8.12m/s | 18.2mph
Average wind shear	0.11

Table 9: Potential VAWT buildout in the San Gorgonio WRA

Wind Speed		**VAWT Potential**			
m/s	**MPH**		**Existing wind farms**	**Beyond existing wind farms**	**Total**
> 6.5	**> 14.5**	Buildout (GW)	1.81	1.33	**3.14**
		AEP (GWh/year)	5,713	4,327	**10,040**
		Acres	7,966	5,779	**13,745**
6.5 - 7	**14.5 - 15.7**	Buildout (GW)	0.82	0.27	1
		AEP (GWh/year)	2,296	763	3,059
		Acres	3,575	1,188	4,763
7 - 7.5	**15.7 - 16.8**	Buildout (GW)	0.55	0.48	1
		AEP (GWh/year)	1,741	1,513	3,254
		Acres	2,380	2,069	4,449
7.5 - 8	**16.8 - 17.9**	Buildout (GW)	0.26	0.58	1
		AEP (GWh/year)	936	2,051	2,987
		Acres	1,151	2,522	3,673
> 8	**> 17.9**	Buildout (GW)	0.17	0	0
		AEP (GWh/year)	740	0	740
		Acres	860	0	860

Image 6: San Gorgonio WRA wind speed map at 20m agl and area available for VAWTs



Solano Wind Resource Area

Solano County, California

For more detailed information, see the [Solano Regional Report here.]

The Solano Wind Resource Area is the second biggest in the state with over 1 GW of horizontal axis wind turbines (HAWTs) operating in its 13 wind farms[19]. These turbines produce over 3000 GWh of renewable electricity each year but no more can be installed without changes in Solano County's zoning laws. An **additional 5 GW and 13,500 GWh** can be produced in the windy parts of Solano County with short vertical axis wind turbines (VAWTs) and meet zoning laws.

In the winter, storms bring high-speed wind into the Wind Resource Area. But it is the temperature difference between the Pacific Ocean outside the Golden Gate Bridge and the heat in the Sacramento Valley in spring through fall that drive most of the wind that makes this area renowned for its excellent average annual wind speeds.

[19] US Wind Turbine Database

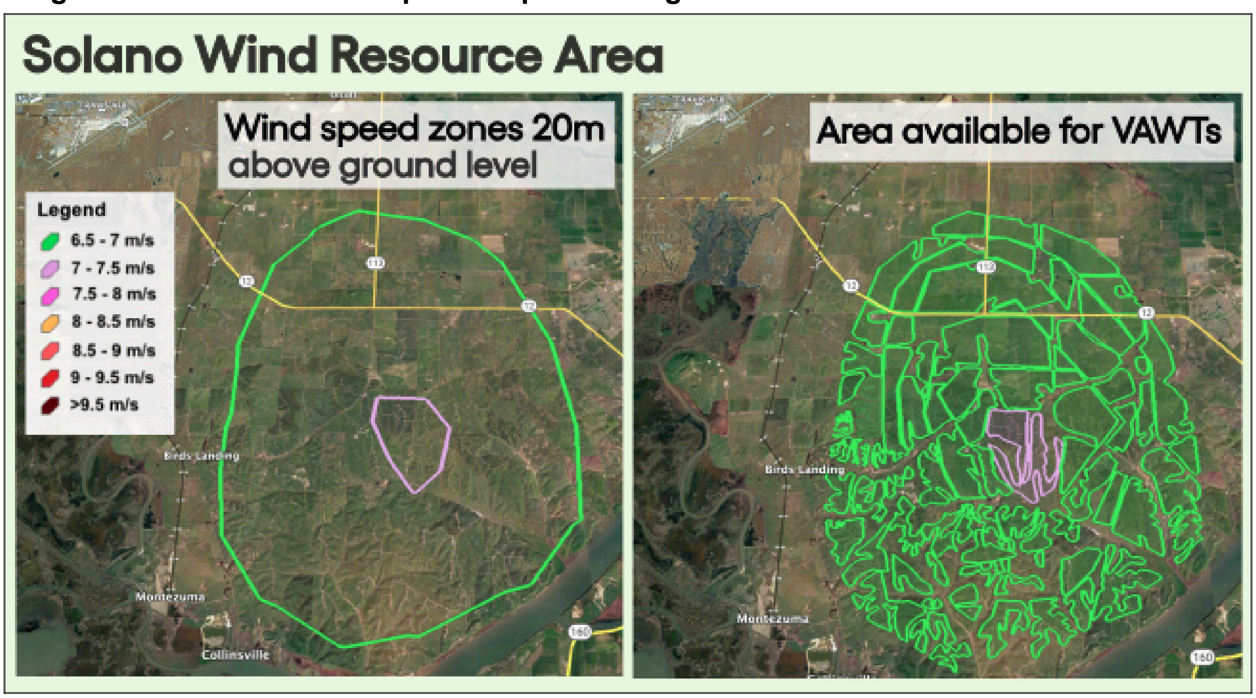
Table 10: Wind shear and average wind speeds in Solano WRA

Average wind speed at 20m (66’) agl	6.72m/s | 15mph
Average wind speed at 80m (262’) agl	7.8m/s | 17.4mph
Average wind shear	0.11

Table 11: Potential VAWT buildout in Solano WRA

Wind Speed		VAWT Potential			
m/s	**MPH**		**Existing wind farms**	**Beyond existing wind farms**	**Total**
> 6.5	**> 14.5**	Buildout (GW)	2.95	2.04	**4.99**
		AEP (GWh/year)	8,130	5,398	**13,528**
		Acres	14,747	10,203	**24,950**
6.5 - 7	**14.5 - 15.7**	Buildout (GW)	2.77	2.04	4.81
		AEP (GWh/year)	7,583	5,398	12,981
		Acres	13,836	10,203	24,039
7 - 7.5	**15.7 - 16.8**	Buildout (GW)	0.18	0	0
		AEP (GWh/year)	547	0	547
		Acres	911	0	911

Image 7: Solano WRA wind speed map at 20m agl and area available for VAWTs



East San Diego County Wind Resource Area

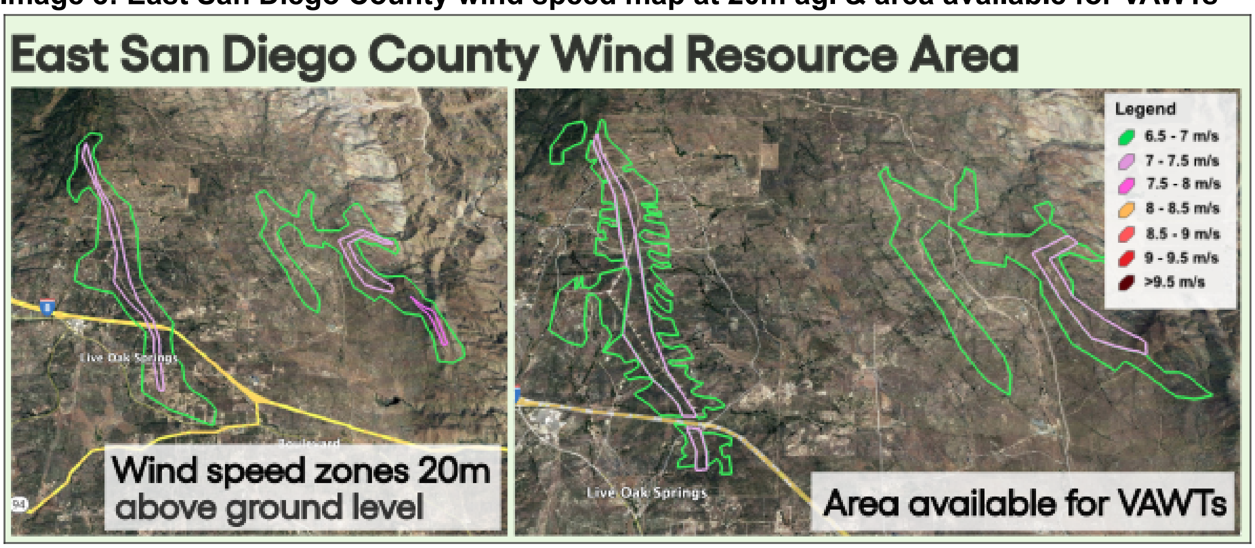
Table 12: Average wind speeds in East San Diego County

Average wind speed at 20m (66') agl	6.79m/s | 15.8mph
Average wind speed at 80m (262') agl	7.64m/s | 17.1mph
Average wind shear	0.12

Table 13: Potential VAWT buildout in East San Diego County

Wind Speed		VAWT Potential			
m/s	**MPH**		**Existing wind farms**	**Outside wind farms**	**Total**
> 6.5	> 14.5	Buildout (GW)	0.19	0.61	**0.80**
		AEP (GWh/year)	548	1,748	**2,296**
		Acres	1,038	3,353	**4,391**
6.5 - 7	14.5 - 15.7	Buildout (GW)	0.14	0.51	0.65
		AEP (GWh/year)	389	1,428	1,818
		Acres	764	2,802	3,566
7 - 7.5	15.7 - 16.8	Buildout (GW)	0.05	0	0
		AEP (GWh/year)	159	320	479
		Acres	274	551	825

Image 8: East San Diego County wind speed map at 20m agl & area available for VAWTs



Altamont Pass Wind Resource Area

Alameda County, California

The Altamont Pass is an underused wind resource area because of the impacts that wind turbines have had on birds, especially raptors. Because H-type VAWTs are three bladed, they are more likely to be seen and avoided[20] than the two bladed Flowind VAWTs[21] that were there in the 1980s. If some bird and bat species can't consistently avoid the rotating blades of VAWTs, modern motion detection technology[22] can identify species from hundreds of meters away and slow down or stop the turbines in arrays as those birds and bats come closer. When they have gone, the turbines can motor up again and begin producing power.

Given the consistent summer evening and night winds that blow through the Altamont Pass plus the area's proximity to high energy demand, it should be worth the state's investment into researching if VAWTs could be added to the area without harming wildlife.

Image 9: Flowind VAWTs in Tehachapi WRA

[20] [Biological Effects of Repowering a Portion of a the Altamont Pass WRA: The Diablo Wind Energy Project]

[21] [A retrospective of VAWT Technology]

[22] E.g. [DT Bird] and [nvisionist]

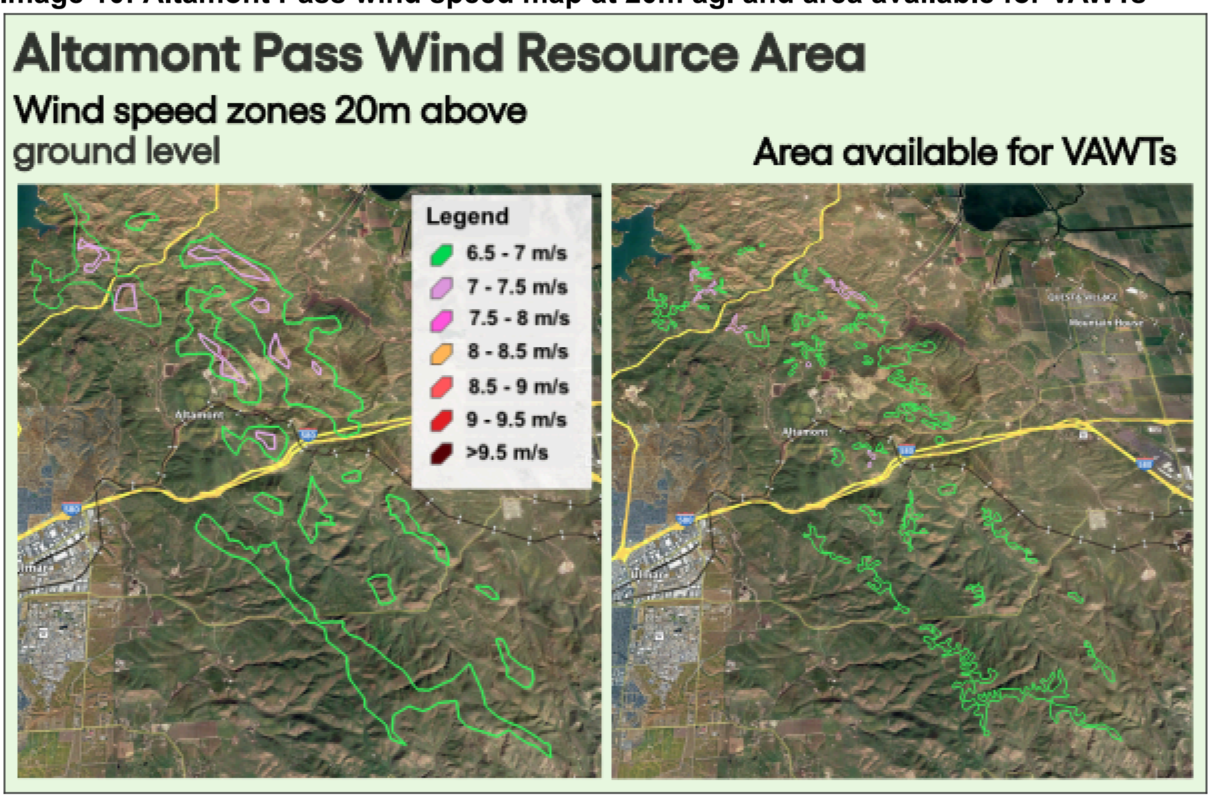
Table 14: Wind shear and average wind speeds in Altamont Pass WRA

Average wind speed at 20m (66’) agl	6.73m/s | 15.1mph
Average wind speed at 80m (262’) agl	7.23m/s | 17.5mph
Average wind shear	0.06

Table 15: Potential VAWT buildout in Altamont Pass WRA

Wind Speed		VAWT Potential			
m/s	**MPH**		**Existing wind farms**	**Outside of wind farms**	**Total**
> 6.5	> 14.5	Buildout (GW)	0.25	0.20	**0.45**
		AEP (GWh/year)	717	548	**1,265**
		Acres	1,391	1,067	**2,458**
6.5 - 7	14.5 - 15.7	Buildout (GW)	0.23	0.18	0.42
		AEP (GWh/year)	652	516	1,169
		Acres	1,280	1,013	2,293
7 - 7.5	15.7 - 16.8	Buildout (GW)	0.02	0	0
		AEP (GWh/year)	64	32	96
		Acres	111	55	166

Image 10: Altamont Pass wind speed map at 20m agl and area available for VAWTs



Conclusions

Summary

California has relatively small areas where commercially harvestable wind exists. This is shown first in the California Energy Commission's seminal research on wind speeds throughout the state in the early 1980s.

Now, UL Windnavigator's wind shears and estimated wind speeds show that the CEC's research was correct. All of the state's Wind Resource Areas and the wind farms in Shasta, Merced and Santa Barbara counties have good to excellent "mid-level" wind speeds from 5-30 m above ground level.

Excellent mid-level winds are also available to the distributed wind markets on properties in places like the Anza Hills, Mount Vaca and southern Solano County. Wind in all of these resource areas blows at night during spring and summer months.

When there are wind turbines certified to handle mid-level wind turbulence, the windiest properties will be developed first. As turbine prices drop with scale, lower wind speed properties would be built out. Initially projects that increase the capacity factors of wind farms by 10-30% and don't require new transmission lines will most likely be developed. Where new transmission lines are too difficult to develop, understory projects in existing and new wind farms will likely be used to produce green hydrogen gas.

Recommendations

1. The CEC should confirm that UL Windnavigator's assessment, as compiled in this report, of the mid-level wind speeds in CA's Wind Resource Areas is accurate. An inexpensive way to do this would be to hire the meteorologists who have the most data on CA wind farms (e.g. Rich Simon, Ron Nierenberg) to validate this analysis and produce their own report on mid-level wind speeds.

2. The CEC and DOE should fund research and analysis of how mid-level wind turbines can be installed in wind farms to not harm HAWTs while at the same time increasing the wind speeds that enter HAWT rotors.

3. The CEC and DOE should fund research and analysis on the economics of increasing wind farm capacity factors by adding capacity with mid-level wind turbines. Included in this analysis should be how this could allow HAWTs to pitch their blades earlier as wind speeds reach rated capacity, how much this would extend the life of the HAWTs, and how this could benefit ratepayers.

4. Before the state's relatively small resource areas can be tapped for additional energy production from their mid-level wind layers, short VAWTs or other types of turbines that

can operate well in turbulent mid-level wind will need to be commercialized. The state could help support the companies developing turbines for turbulent wind.

5. Before large scale installations are made in bird sensitive wind resource areas such as Tehachapi (e.g. condors), Solano (e.g. Swainson hawks), Altamont (e.g. golden eagles), studies will need to be done to test the hypothesis that birds (and bats) will be able to more easily avoid collision with three dimensional VAWTs than with two dimensional HAWTs. Research can use 24/7 bird detection technology to more rapidly collect the data and adjust VAWT operations to reduce or eliminate harm they might cause to wildlife. This research will be needed to satisfy permitting requirements that potential environmental impacts be known and mitigated. The CEC should help fund this research.

6. Once it has been determined that there are mid-level wind turbines available to infill California's wind farms, the CEC should support planning for how their components can be manufactured in the state and assembled close to the wind resource areas.

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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.[23]

Wind speed		Turbine	Per MW	Capacity
m/s	MPH	MWh/yr	MWh/yr	Factor
5	11.2	67	957	10.90%
5.5	12.3	122	1,743	19.90%
6	13.4	151	2,157	24.60%
6.5	14.5	181	2,586	29.50%
7	15.7	210	3,000	34.20%
7.5	16.8	235	3,357	38.30%
8	17.9	260	3,714	42.40%
8.5	19	285	4,071	46.50%
9	20.1	310	4,429	50.60%

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%

[23] The Coupled Vortex Effect

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