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Dramatically increase wind farm output while protecting wildlife

Attached is a paper important to the future of low cost, renewable energy in CA. It explains the huge potential of vertical axis wind turbines and why they are only now ready to fill in the understories of wind farms. The first page, graphics and summary (below) outline the story, of which one of the core parts is the incredibly good, but unharvested near-ground wind resources in CAâ€™s wind farms. Â Â Please send me comments. Thank you. Kevin, kwolf@windharvest.com

Summary
* Approximately 20% of the worldâ€™s wind farms, including all in California, have good-to-excellent, but turbulent, near-ground wind resources that presently cannot be harvested by traditional horizontal axis wind turbines (HAWTs).

* Vertical axis wind turbines (VAWTs) can handle the turbulence, but it is only recently that VAWT designers have had available aeroelastic modeling similar to what HAWT engineers use to ensure 20-plus-year fatigue life in wind farm-strength winds.

* VAWTs also may now use the coupled vortex effect, occurring when VAWTs are placed very close together in arrays, bringing their efficiencies to the levels of modern HAWTs.

* In large-scale installations in existing wind farms, VAWT projects will eventually achieve a lower cost per MW and MWh than new HAWT projects can realize, primarily because they are able to use land and infrastructure that has already been paid for.

* Wind farm capacities and energy densities can be dramatically increased with layers of VAWTs.

* The theory that VAWTs can enhance the energy output of HAWTs when placed around and beneath them needs more field testing and modeling before layers of VAWTs can be safely and effectively installed in existing wind farms.

* Human field observation, along with motion-detection technology, must be done before the hypotheses can be proven that birds and bats will avoid the three-dimensional VAWTs better than they do the blades of the two-dimensional HAWTs.

* Government agencies need to become aware of the value of topographically enhanced near-ground wind resources and the potential contribution VAWTs can make to developing these valuable renewable resources.

Additional submitted attachment is included below.

Three Windstar 530G VAWTs among HAWTs in the San Gorgonio Wind Resource Area, California

Dramatically increase wind farm output while protecting wildlife

How to safely harvest high speed, near-ground wind in existing wind farms

This paper will be submitted for peer review to Renewable Energy Focus after receiving comments from the publication of excerpts in the April issue of Windpower Engineering. Send comments and suggestions to Kevin Wolf, Chief Operating Officer, Wind Harvest International, kwolf@windharvest.com

18 January 2018 (Draft)

Introduction

Wind farms in California and other regions of the world exist only in relatively small geographic regions.[1] Most of these resource areas have reached their physical or political[2] limits in their ability to install additional horizontal axis wind turbines (HAWTs).[3] However, many have topographies that create excellent near-ground wind speeds but also are home to or in the migrating paths of endangered bird and bats.

In order to profit from the energetic wind below their HAWTs, wind farm owners need cost-effective vertical axis wind turbines (VAWTs) that operate efficiently in high turbulence and that do so without the wake from the added rotors negatively impacting their existing turbines. They also need turbines that are wildlife friendly.

Harvesting excellent near-ground wind resources should eventually result in lower priced power than solar technologies, less land and habitat developed, and thousands of MWs of additional power produced well after the sun sets[4]

Near-Ground Turbulence

The good-to-excellent average annual wind speeds (6-9 m/s, 14–20 mph) found at 10–25m above ground level in wind farms in California[5] and other regions are well known to wind industry meteorologists.[6] Passes and ridgelines accelerate near-ground wind and cause wind shears to decrease, often dramatically. Meteorological data also document that thermal and obstacle-induced turbulence in the high-energy, near-ground wind is found in many wind farms, including in four of California's five Wind Resource Areas.

One reason near-ground wind resources haven't been developed is that HAWTs have increased failure rates when their blades pass through turbulence.[7] As a result, rows of HAWTs are hundreds of meters downwind of each other, and the bottom tips of their blades range between 20m and 50+m above ground level.

HAWT turbulence-loading problems arise primarily from their long blades connecting to the drive shaft at only one end and their large rotor having to operate in changing wind speeds and direction. The blades and bearings used in modern HAWTs would have to be substantially strengthened to withstand the high peak and cyclic loads from the near-ground layer of often extreme turbulence.[8]

Why VAWTs Now

VAWTs are intrinsically less sensitive to turbulence than HAWTs because their blades are attached to the rotating shaft at two or more locations. Their geometry also eliminates the need for VAWTs to yaw and turn into the changing wind direction.

At least one such wind turbine (i.e., Wind Harvest International's G168 VAWT[9]) is ready for certification and operation underneath HAWTs.[10] Other VAWTs could also soon be capable of achieving a 20+ year service life in high turbulence (e.g., Stanford/Dabiri's VAWTs), once they can comply with the IEC 61400 certification process, become UL listed and be ready for industry-scale sales.

Historically, VAWTs have had trouble with mechanical design and durability because they lacked the field-validated, aeroelastic modeling that HAWT engineers use. That has recently been resolved by WHI[11] and the Technical University of Denmark - DTU. Both now have a suite of prototype-validated frequency response, aerodynamic, fatigue and finite element analysis models that together function as an aeroelastic model.[12]

The aerodynamic modeling funded by a 2010 California Energy Commission (CEC) EISG grant[13] to WHI proved that modern VAWTs, placed close together would also create the "coupled vortex effect" and produce 20–30% more energy from a pair of 11% solidity rotors operating a meter apart than from two single VAWTs operating separately. This countered the problem VAWTs face that HAWTs don't: their blades create drag as they return into the wind. Historically, this increase in drag prevented them from realizing much more than a 40% efficiency,[14] whereas HAWTs can achieve 50%. With the coupled vortex effect, VAWTs in arrays can theoretically realize the efficiencies of HAWTs.

Another problem hindering VAWT development is that smaller VAWTs like WHI's G168 use more steel and material per rotor-swept area and MW of installed capacity than do large HAWTs. Now however, with large-scale use possible in wind farms:

- The mass manufacture of the smaller VAWTs offer significant savings.[15] For example, VAWTs with straight blades can be extruded or pultruded and avoid the expensive hand work involved in making the blades of large HAWTs.

- Their shorter towers use less material and are easier to make and install. WHI's G168 VAWTs' foundations are one-half meter deep, and their rebar cages can be mass manufactured.
- They make dual use of valuable land and infrastructure[16] when installed in existing or new wind farms with HAWTs.

One additional benefit modern VAWTs have for repowering wind farms is that they can help solve the grid harmonics and reactive power problems that are caused by older HAWTs using "induction generators". These problems harm the efficiency and quality of energy transmission. A MW of VAWTs like WHI's G168 with inverters similar to the ones in Northern Power Systems' 100kW HAWTs can instantaneously source or sink 450 KVARs[17] of the problematic reactive power, independently of wind speed, and thus make a significant difference in improving the power quality of older wind farms.

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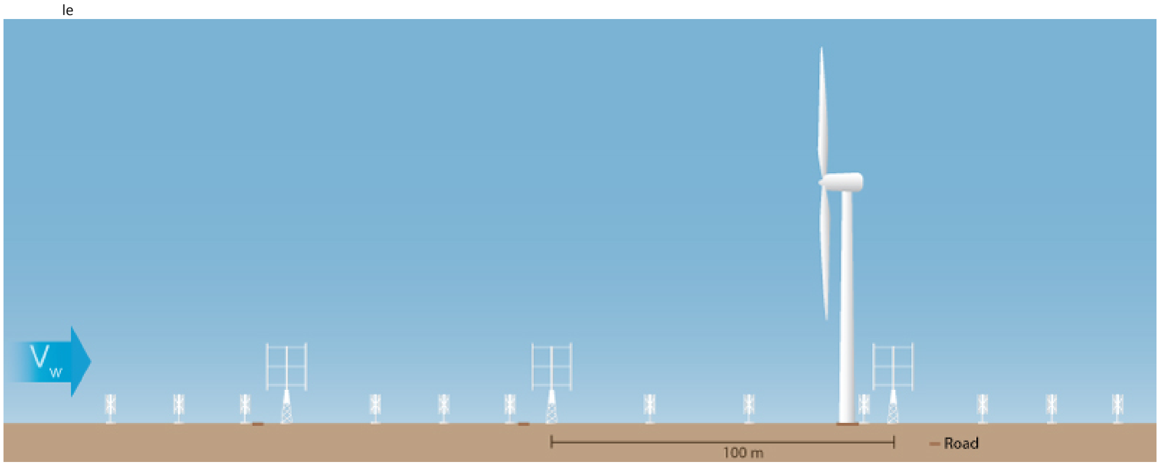

***Figure 1**. This graphic shows a vertical and horizontal staggering of VAWTs upwind and downwind of a 2MW HAWT. The distances between VAWTs and their heights are described in Table 1 with the exception that the G168 VAWT distance immediately upwind of the HAWT is 100m and not 70m. The faster-moving wind that is upwind and above the HAWT will be drawn down toward the ground by the vertical mixing and energy extraction of the VAWTs below.*

VAWT Impacts on HAWTs

Aerodynamics predict that the wake from VAWTs won't harm HAWTs, and may in fact help them. The wake and vortices shed from an array of tightly spaced VAWTs should stay in the same wind layer that passes through their vertically spinning rotors. Modeling shows that downwind by five rotor heights[18] or ~eight rotor diameters[19] , the wake of VAWTs is gone, their vortices have disintegrated, and the wind speed has recharged, in part due to the vertical mixing that their spun-off vortices create.

VAWT placements are theorized to increase the wind speeds entering the rotors of the HAWTs above them in two major ways.

Lowering the wind shear

A growing body of field data and research, led in large part by Dr. John O. Dabiri, has demonstrated how the vertical mixing created by counter-rotating VAWTs lowers wind shears by bringing higher, faster-moving wind toward the ground and replenish the wind speeds lost to the energy and turbulence the VAWTs produce.[20] As a result, faster moving wind from above will drop down into HAWT rotors and increase their energy output.[21].

Stanford University doctoral candidate Anna Craig led a study that modeled various VAWT arrangements. Their results[22] indicate that VAWTs can interact positively when placed in close proximity to one another. Craig noted that "We think that the VAWTs can have blockage effects causing speedup around the turbines that helps downstream turbines. They can also have vertical wind mixing in the turbine's wake region, which assists in the wind velocity recovery."

In *Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farm*s, the authors stated, "Because of the presence of the VAWT layer, the turbulence in the wind farm is increased, which enhances the wake recovery of the HAWT. The faster wake recovery more than compensates for the additional momentum loss in the wind because of increased effective surface roughness associated with the VAWTs."[23]

Porous Wind Fence Effect

Dr. Marius Paraschivoiu's modeling shows that there will be a few meters of high turbulence directly above an array of VAWTs. Above that is a zone where the wind speeds increase above ambient. This is caused by the blockage effect of the VAWTs.

A row of VAWTs could be placed upwind of a HAWT at just the right height so that the HAWT blade enters a zone of higher wind speed with no significant increase in turbulence. Arrays of VAWTs placed a short distance downwind of a HAWT can also create a speed-up effect for the upwind HAWT, but the physics are different. The wind speeding up over the VAWTs decreases the pressure there, which increases the pressure difference between the front and back of the HAWT rotor. This in turn would increase the wind speed through the HAWT rotor and thus its energy output.

Just how much this effect could benefit HAWTs was to be a significant focus of the LiDAR studies WHI proposed as part of its R&D proposal to the CEC EPIC Program.

VAWTs Potential to Increase Wind Farm Energy Output

HAWTs in wind farms are placed substantial distances apart. Below is a table comparing land used in some wind farms in California's Wind Resource Areas to other means of estimating the amount of land a HAWT wind farm needs.

Modeling and field testing show that the relative distances between rows/arrays of VAWTs can be much shorter than with rows of HAWTs without the downwind row losing wind speed and energy.[24] The table below shows the VAWT energy densities that can be developed with the following assumptions:

- One-third meter between 3kW VAWTs in a four-turbine array
- One meter between G168 VAWTs in a four-turbine array
- Two rotor diameters (6m and 24m) between arrays in a row
- 5 times rotor height between G168 rows (70m)
- 8 times the rotor diameter between rows of 3kW VAWTs (24m)

Table 1. Comparing Densities of HAWTs to VAWTs

HAWTs	Turbine Size (kW)	Turbine Swept Area (m2)	Swept Area (m2) per sq. km	MWs per sq. km	Turbines per sq. km
NREL[25]	1000	2.289	9,156	4.0	4.0
6 x 7 Rule of Thumb [26]	1000	2,289	18,690	8.2	8.2
3 x 10 Rule of Thumb[27]	1000	2,289	26,167	11.4	11.4
Mountain. View Power Partner [28]	750	1,809	60,795	25.2	33.6
Shilo III, Solano, CA	2050	6,644	34,073	9.5	5.1
VAWTs					
4m x 3m rotor [29]	3	12	105,820	26	8,818
WHI G168[30] - 14m x 12m rotor on ~9m tower	70	168	124,444	52	741
Combined layers			230,265	78	9,559

The layouts in Figures 1, 2 and 3 would lead to ~150-200 MWs of VAWTS on the same land on which 32 MWs of HAWTs now operate in one of the best near-ground wind resources[31] in the San Gorgonio Pass. Dabiri's research on VAWTs predicts a 5-10 times increase in energy density is possible from VAWTs compared to HAWTs. This seems to be eminently doable with two layers of VAWTs set among the same MWs of HAWTs.

***Figure** 2. The Mountain View Power Partner LLC wind farm at the junction of the Whitewater River and Interstate 10 (33° 54' 35.6" -116° 37' 44.4") in the San Gorgonio Pass has 44 300 kW HAWTs (13 MWs) in the ½-square mile outlined in yellow. Rows of G168 VAWTs are envisioned to be along red lines, each set roughly 70m apart. The blue square at the bottom right of the red rows shows the area of Figure 3, below.*

In the Mountain View Power Partner LLC wind farm, the wind is unidirectional from the west. In Figure 3:

- A row of small VAWTs (3kW) maximizes the porous wind fence effect increasing the wind speed into the taller G168 VAWTs a few meters downwind.
- The G168s are a short distance (10-25m) downwind of a HAWT such that the bottom blade tips of the HAWT pass at just the right height above the VAWTs to safely maximize pressure difference the downwind VAWTs create.
- More rows and arrays of small- and medium-sized VAWTs are placed upwind and downwind at roughly a 7-rotor diameter distance apart.

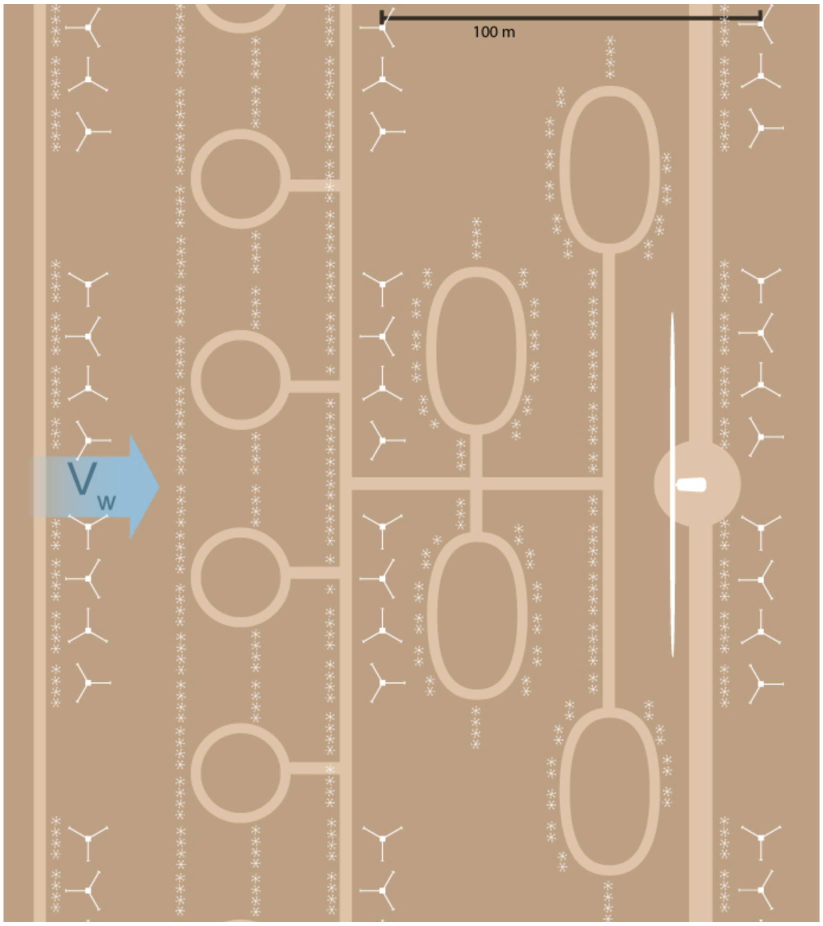

***Figure 3** This 250 X 250 sq. meter slice of the Mountain View Power Partner wind farm in Figure 1 shows one way in which VAWTs of different heights could be placed around a newly installed 2 MW HAWT on a 65m tower. In this graphical representation, there are 428 of the 3kW VAWTs and 39 of the WHI's 70kW VAWTs and one 2 MW HAWT.*

Next Steps to Adding VAWT Layers to Wind Farms

In the last round of wind energy grants through the CEC's EPIC Program, there were three applications to advance the development of VAWTs toward installation in existing wind farms. All three were either disqualified or failed to score enough points to qualify. The main objections from reviewers included the following misunderstandings:

- Near-ground wind resources won't be developed because wind shear causes the wind speed to be too low to ever be competitive with simply adding new wind farms of HAWTs.[32] *(Note: High wind shear occurs in wind farms in the Great Plains but not in California or other areas with passes and ridgelines)*.
- VAWTs have such a terrible history of commercialization that grants should not be made for their development until after they have been certified.[33] *(Note: Grants should be available to help renewable energy technology get through the most difficult part of the commercialization process – certification.)*
- Funding should not be spent on how VAWTs can best be sited in a wind farm because R&D on HAWT placement is already commercialized.[34] *(Note: Very little is known about how VAWT wakes will interact with HAWT wakes in different topographies and wind conditions.)*

WHI's proposal to the EPIC Program called for the use of its G168 VAWTs in a 140-280 kW project on ranch land in the Solano Wind Resource Area. There, San Jose State University LiDAR and its transportable meteorological mast with sonic anemometers would have been used to collect wake data from the VAWT array. Modeling would have been done with the help of Stanford University's Large Eddy Simulation CFD model. WHI committed to placing the resulting data into the public domain, so other universities and companies could begin to validate their own modeling codes for VAWT wakes.

More field data on arrays of VAWTs is needed. LiDAR is the key to measuring the changes in wind speeds and turbulence created from different ways of linking together co-and counter-rotating VAWTs. Then data will be needed on how those VAWT wakes interact with HAWT wakes. Given the capabilities of modern wake and topography modeling, it shouldn't take long to confirm basic "rules of thumb" for how vertical turbines can be safely and effectively installed along ridgelines and among the wind turbines in rich resource areas like the flat desert lands of the San Gorgonio Pass.

Wildlife

VAWTs will eventually enter the wind farm market. Before large numbers are installed, their potential impact on birds and bats needs to be evaluated and mitigated through the California Environmental Quality Act (CEQA) and other land use planning processes. Both Dabiri's and WHI's most recent EPIC proposals included new ways of documenting how birds and bats react to VAWTs. Biologists[35] theorize that these animals evolved to fly around three-dimensional objects, such as trees and VAWTs, and will have an easier time avoiding their blades than they do those of two-dimensional HAWTs. Producing field data to try to disprove this hypothesis is a fundamental first step.

VAWT development in existing wind farms reduces the pressure to develop new HAWT projects and their longer transmission lines in more pristine and wildlife rich areas.

The fastest way to produce bird and bat impact data would be for all 100+kW VAWT projects like the one WHI is pursuing to use 24/7 motion detection and recording systems with binocular, high-definition cameras. Such tools can be field validated and then relied upon to capture far more animal-turbine interactions than traditional field observation methods. In-field, mortality studies should accompany the camera data analysis to compare the two methodologies until the mortality studies are no longer needed to accurately count fatal interactions.

Given the potential for VAWTs to be safely installed in valuable wind resource lands containing endangered species' habitat, grant funding of VAWT wildlife research would be a wise investment. This is especially so if it helps commercialize the VAWTs

<u>Benefits to Ratepayers and Slowing Climate Change</u>

Installing thousands of megawatts of new VAWT capacity in existing wind farms with good near-ground wind resources promises to be of significant help to ratepayers and local economies, especially if some of the VAWT components can be manufactured near the new installations.

Layering VAWTs among HAWTs in high-value wind resources should result in a lower Levelized Cost of Energy than any other renewable energy option. With 40% Capacity Factors and a 14% "learning curve" for price reductions in the technology, by 2025, the LCOE of VAWTs installed among HAWTs should drop to $.05 per kWh, which is less than the wind energy alternatives for places like California, where it is very difficult to permit new wind farms, and the alternatives are expensive offshore projects or installing new transmission lines to large projects in places like Wyoming.

According to Project Drawdown, the second-best way to meet carbon reduction goals is with on-shore wind development. Making double use of existing wind farm infrastructure to harvest the lower wind layers of some of the best wind resources in a region *should be a priority on the world's road map for achieving its carbon and pollution-reduction goals while keeping ratepayer costs low*.

<u>Summary</u>

- Approximately 20% of the world's wind farms, including all in California, have good-to-excellent, but turbulent, near-ground wind resources that presently cannot be harvested by traditional horizontal axis wind turbines (HAWTs).

- Vertical axis wind turbines (VAWTs) can handle the turbulence, but it is only recently that VAWT designers have had available aeroelastic modeling similar to what HAWT engineers use to ensure 20-plus-year fatigue life in wind farm-strength winds.

- VAWTs also may now use the coupled vortex effect, occurring when VAWTs are placed very close together in arrays, bringing their efficiencies to the levels of modern HAWTs.

- In large-scale installations in existing wind farms, VAWT projects will eventually achieve a lower cost per MW and MWh than new HAWT projects can realize, primarily because they are able to use land and infrastructure that has already been paid for.

- Wind farm capacities and energy densities can be dramatically increased with layers of VAWTs.

- The theory that VAWTs can enhance the energy output of HAWTs when placed around and beneath them needs more field testing and modeling before layers of VAWTs can be safely and effectively installed in existing wind farms.

- Human field observation, along with motion-detection technology, must be done before the hypotheses can be proven that birds and bats will avoid the three-dimensional VAWTs better than they do the blades of the two-dimensional HAWTs.

- Government agencies need to become aware of the value of topographically enhanced near-ground wind resources and the potential contribution VAWTs can make to developing these valuable renewable resources.

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Key Research Questions

1. Rows of VAWTs will enhance recovery of the mean wind speed above, but the turbulence fluctuations in the wind layer above will likely increase significantly[36].
    - How far above and downwind of a field of VAWTs do HAWTs have be so that the higher turbulence doesn't harm the lifetime of the HAWTs' blades and drive trains?
    - How problematic is the turbulence created by different types and placement patterns of VAWTs?
    - Does the shape of the VAWT blade tips matter to the turbulence that might impact HAWTs?

2. VAWTs and HAWTs layered in the densities of Figures 1, 2 and 3 could increase the 800 MWs of HAWTs in the San Gorgonio Wind Resource Area to more than 6000 MWs and rotor-swept area by a similar percentage. Could this more-intense extraction of energy and lowering of the boundary layer have either positive or negative impacts for regional and even distant weather patterns and intensities?

3. Families of species have similar attributes, behaviors and physiologies. How much field research needs to done before scientists can accurately predict whether a species that has never seen a VAWT will be able to avoid being hit by its blades? For example, if research proved that vultures were able to consistently avoid arrays of VAWTs with carrion placed underneath, would studies still be needed on whether condors in Chile were always able to avoid VAWT blades before VAWTs were allowed in condor habitat in the U.S. where the bird is an endangered species?

End Notes:

[1] In 2014, WHI conducted a cursory review of wind farms around the world to evaluate them for topographies and roughness that were conducive to creating near-ground wind speed-up effects. At that time, approximately 20-25% of wind farms had the topographies, wind shears and wind speeds that should produce 15-20 mph average annual wind speeds at 10-20m above ground level.

[2] The politics of zoning and permitting are influenced by concerns over views, habitat, aviation and wildlife impacts.

[3] The large setback requirements needed by rows of HAWTs are well documented. New HAWTs cannot be installed within most existing wind farms without reducing the wind speeds or increasing the turbulence realized by their neighbors.

[4] "Land-Use Requirements for Solar Power Plants in the United States" states that an average of 2.8 acres is required to produce 1 GWh of solar energy from ~550kW of solar panels. According to Southern California Edison, 1 kW of PV will produce 1500-1800kWh per year. In comparison, each kW of capacity for VAWTs like WHIs will result in 3500 kWh per year. Four G168s (280kW) would produce 1 GWh on 1.3 acres (per Table 1) with farming, grazing and other activities possible beneath and around them. Hardware, installation and project costs for VAWTs are expected to drop over time at similar rates as prices dropped for HAWTs. For more discussion on this, see Benefits to Ratepayers. In addition, wind in places like California's wind resource areas blow well into the night.

[5] "Wind Energy Prospecting in Alameda and Solano, CA", a report by PG&E to the California Energy Commission, 1980. Publicly available documentation for California's wind resource areas is not easy to find, but all the meteorologists listed will confirm that similar wind speeds exist in Southern California's three wind resource areas.

[6] The following wind industry meteorologists and companies will confirm that there are good to excellent average annual speeds and high turbulence in the near-ground wind in California's Wind Resource Areas. Note that titles and associated organizations are used for identification purposes only:

Allen Becker, Consulting Meteorologist
John Bosche, President and Principal Engineer at ArcVera Renewables
Neil Kelley, Applied Meteorologist (retired)
Pep Moreno, CEO, Vortex
Ron Nierenberg, Consulting Meteorologist
Lucile Olszewski, General Manager, Ensemble Wind

Richard Simon, Consulting Meteorologist
John Wade, Senior Meteorologist, Ensemble Wind
ArcVera Renewables, Wind Prospecting and Resource Assessment
WindSim, CFD Wind Resource Assessment

[7] Turbulence problems created in HAWT blades, gearboxes, and bearings HAWTs are documented in multiple places in this wind engineering textbook, "Wind Energy Explained: Theory, Design and Application," J.F. Manwell, J.G. McGowan, A.l. Rogers; John Wiley, U of Mass Amherst, 2002.

[8] David Malcolm, PhD, structural engineer, retired from Det Norske Veritas/Gemanischer Lloyd

[9] WHI's G168 VAWTs have ~168 square meters of rotor swept area and 50-70+ generators which will vary based on the wind resource. For specifications see: http://windharvest.com/g168-vawt/

[10] WHI's G168 design files have been sent to the Small Wind Certification Council, which follows the IEC 61400-2 certification requirements for small wind turbines under 100kW in size.

[11] "Validation of the EOLE suite of codes for the structural response of vertical axis wind turbines," David Malcolm. March 2017. Report to Wind Harvest International

[12] WHI used a Frequency Response and Fatigue Model first created and field validated by Sandia National Labs on its Darrieus-type VAWTs. Using strain gauge data from the G168 prototype in Denmark, WHI validated the loads predicted in its Midas FEA model and these other two models. For more information on the DTU's aeroelastic model, contact Dr. Peggy Friis at DTU.

[13] "Modeling Blade Pitch and Solidity in Straight Bladed VAWTs", Iopara Inc, Bob Thomas and Kevin Wolf, February 12,2012, Final Report to the California Energy Commission's Energy Innovations Small Grant Program.

[14] Sandia National Labs' field research on a Darrieus-type VAWT showed it was capable of achieving a maximum of around a 42% efficiency or Cp max. See "A Retrospective of VAWT Technology", Herbert J. Sutherland, Dale E. Berg, and Thomas D. Ashwill, SANDIA REPORT (SAND2012-0304), January 2012

[15] WHI's G168 VAWTS are made of extruded, aircraft quality (6061-T6) aluminum. Bob Thomas, a founder of the Wind Harvest Company and the inventor and lead engineer of their Windstar turbines determined that a NACA 0018 blade profile to be effective and easy to extrude with internal walls.

[16] For a full build-out of a wind farm's understory, new transmission lines and substations will be needed. For a "capacity factor enhancement" project where VAWTs are added to the wind farm but turned off as the substation reaches capacity, now new transmission lines or substations are needed.

[17] "Reactive Power Compensation - Using a Northern Power® NPS 100TM or NPS 60TM wind turbine to manage power factor", NPS Engineering Bulletin

[18] In Dr. Marius Paraschiviou's letter to the CEC in support of WHI's grant application, he stated "…after the CEC Innovations grant was completed, we conducted additional aerodynamic modeling on downwind wakes that showed VAWTs like WHI's G168 will be able to be placed about six rotor heights downwind of an upwind VAWT array and realize the full wind speed that entered the rotors of the upwind array."

[19] A number of Dr. John O. Dabiri's papers show that VAWTs as placed in their field studies can regenerate ~95% of the full wind speed at 7 rotor diameters downwind. (Kinzel M, Mulligan Q, Dabiri J., Energy exchange in an array of vertical-axis wind turbines. *Journal of Turbulence* 2012; 13: 1–13. Note that in his field studies, Dabiri's placement of VAWTs are as close together as they are in Paraschivoiu's modeling. The tighter spacing and the resulting increase in wind speed in the gaps between the VAWTs that was used in Paraschivoiu's modeling probably is the reason for the difference

[20] "Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind turbine arrays". John O. Dabiri, *Journal of Renewable and Sustainable Energy* 3, 043104 (2011) and Benefits of Co-locating Vertical-Axis and Horizontal-Axis Wind Turbines in Large Wind Farms.

[21] The energy in the wind is the cube of the wind speed so a small increase in wind speed results in a significant increase in the energy available for the turbine to convert to electricity.

[22] "Low order physical models of vertical axis wind turbines", Anna E. Craig[1,a)], John O. Dabiri[2], *and* Jeffrey R. Koseff[3,] *Journal of Renewable and Sustainable Energy, Feb. 2017*

[23] Page 15, "Benefits of collocating vertical-axis and horizontal-axis wind turbines in large wind farms" Shengbai Xie1, Cristina L. Archer, Niranjan Ghaisas and Charles Meneveau, *Wind Energy*, 2016

[24] See footnotes 11 and 12.

[25] "Land-use Requirements for Wind Turbines in the U.S.", Paul Denholm, Maureen Hand, Maddalena Jackson, and Sean Ong, NREL, August 2009. Note that NREL's study covers "Total Wind Plant Area" which is considered the "footprint of the project as a whole" and includes more land than the Rule of Thumb methods of determining land use per MW of wind turbines.

[26] Six rotor diameters between turbines in a row and 7 rotor diameters between rows.

[27] Three rotor diameters between turbines in row and 10 rotor diameters between rows.

[28] Satellite imagery of the 750kW NEG Micon turbines. Mountain View Power LLC, Riverside County, California. *Note that this specific location might not be appropriate for many more VAWTs because of their roughness impact on flood events from the Whitewater River. A hydrological modeling analysis would be needed before CEQA requirements could be met.*

[29] Assumes four VAWTs in a 13m long array with two rotor diameters between each 12kW array in a row.

[30] The blade tips of and vortices shed from the VAWTs create turbulence, vertical mixing and roughness should bring faster-moving wind into the taller G168 arrays. An array of the 9m tall VAWTs only meters upwind of G168 VAWTs on 8-10m tall towers would block the wind, and if positioned right send more into the VAWTs above. Together, the field of VAWTs could have a greater positive impact on the wind speed increases realized by the HAWTs.

[31] WHI operated its Windstar 1066 and a Windstar 530 VAWTs in this section of the San Gorgonio Pass for years and recorded average annual wind speeds of 16mph at 10m above ground level.

[32] Jocelyn Brown Saracino, Wind Energy Manager with the US DOE in her critique of WHI's grant proposal states, "(WHI's) 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 near-ground wind is too turbulent. Wind resource

is much greater at height and this calls into question the resource potential for VAWTs deployed in this fashion.”

[33] In Jocelyn Brown Saracino’s comments onWHI’s CEC EPIC proposal, which were similar to her critique of Dabiri’s proposal, she stated “To date no VAWT has received certification in the US due to technical challenges associated with their performance (energy production on average lower than predicted and also due to issues associated with reliability and maintenance). I do not recommend providing funding for VAWT turbine installation until after certification has been obtained”

[34] The Technical Review of WHI’s proposal disqualified it because “In the questions and answers for the solicitation, answer #30 states that “Projects focused mainly on siting or optimally locating wind turbine including wind pattern modeling, are outside of this solicitation.”

[35] The author has talked with numerous ornithologists who hypothesize that birds, especially many birds of prey, will see and avoid the shorter, vertically rotating turbines. Hawks, raptors, vultures and similar soaring and hunting birds have their eyes focused close to the earth, often in the 10m zone above the ground. Above that they haven’t evolved the need to see the fast moving, two dimensional HAWT blades. Because VAWTs have horizontal arms with wide fairings that attach to their vertically aligned blades and because they are close to the ground, these birds should easily see VAWTs as obstacles similar to trees but on which they cannot land because the “branches” are moving.

[36] Communication with Dr. John Dabiri.