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Please see the following article that discusses turbines.

Understanding Wake Effects from Onshore and Offshore Windfarms: A Need for Research to Estimate Potential Rates of Landscape Dehydration and the Risk of More Intensive Wildfires

Submission to Senate Offshore Windfarm Hearing, August 2024

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Abstract

Despite almost complete ignorance of their meteorological effects, engineered wind turbine plants have been enthusiastically adopted worldwide as a source of renewable energy. But is this source of electrical power really renewable if it slows the Lagrangian action of laminar flow, inducing regional turbulence? Published evidence now exists of land-based or satellite measurements showing that windfarms do raise localised temperature and landscape dryness. Field studies show that dryness could increase risk of more intense wildfires, as has been experienced recently, rather than highly dispersed warming by greenhouse gas forcings. We recommend that research to measure these localised drying effects of wind farms, whether onshore or offshore with rainfall at sea. This may throw light on the potential risks and costs of placing wind farms in particular locations and provide information on where they might be placed to minimise such risks and costs.

Introduction

Windbreaks have been well known to provide shelter from impacts of winds. They have been shown to affect airflow, microclimates and crop yield (Cleugh, 1998). A well sheltered zone behind a break with low permeability to air flow is typically warmer and more humid, with the ascending turbulent wake zone cooler and dryer than an unaffected control flow.

While onshore wind farms do not affect global wind speeds or patterns (Li et al. 2023), there is published evidence that windfarms do affect local wind speeds tens of kilometres downwind. Moreover, they also generate their own characteristic turbulence independent of any existing in their wind inflow, as shown in wind tunnel experiments (Neunaber et al. 2021).

Evidence for turbulent properties of windfarm wakes

Vees et al. (2019) have identified interference by wind turbine wakes as a major limitation to wind power electricity. Barthelmie et al. (2019) have characterised wind turbine wakes in complex terrain. Satellite imagery and *in situ* measurements reveal offshore windfarm wakes to be several tens of kilometres, with maximum wind speed deficits of 40% at turbine hub height. During unstable conditions in daytime causing turbulent thermal convection, differing from more stable laminar flow at night, disturbed wakes are shorter (Platis et al. 2018); this indicates a greater rate of dissipation of energy in viscous dissipation.

An off-shore windfarm in China has been shown to amplify low-level vertically wind shear and convection offshore, caused by turbines diminishing the downstream axial momentum (Deng et al. 2023). Raining at sea, this may diminish rainfall on land, a result of premature cooling convection.

Roy and Traiteur (2010) recommended that wind farms be located on land with rough surfaces, using wind already turbulent. On shore windfarms in arid northern China have been shown to cause variation on land surface temperature as sensed by satellites, with localised heating of the order of 0.2-0.3 °C near windfarms compared to landscape without turbines ((Liu et al., 2022). No difference between daytime or night warming was detected, disputing the conclusion that night time warming was caused by overturning warmer air during a temperature inversion (Roy and Traiteur, 2010).

Environmental effects regarding warming and evapotranspiration

Miller and Keith (2018) showed for stable night conditions a significant warming effect at 28 operational US wind farms using MODIS satellite detection. They also concluded that this warming can exceed avoided warming from reduced carbon emissions for a long period. Thess and Lengsfeld (2022) reviewed evidence for impacts of farms on air velocity, temperature, moisture and precipitation in their vicinity, with ecological effects. Wang et al. (2023) showed in China that wind farms dry surface soil significantly, both temporarily and spatially. Bodini et al. (2023) using measurements of airflows made on aircraft that turbulence from wind turbine plants reduced axial air speed as much as 30% downwind at hub height to at least 30 km. The turbulent eddies in air flow, delaying axial wind speed, naturally increase the probability of evaporation by greater exposure of soil and vegetation.

Several studies (Zhou et al. 2010; Gao et al. 2017; 2021) have shown that turbulent air is more highly evaporative than air in laminar flow, considered a result of disturbance of the boundary layer that would otherwise be more humid. In novel, least action modelling Kennedy et al. (2023) have shown that air in laminar flow in anticyclones releases vortical latent energy as heat when made turbulent, generating our interest in drying of the landscape.

Accelerated downwind environmental drying from turbulent heat release

Using this novel least action method to successfully estimate maximum power from wind turbines, we have predicted (Kennedy et al. 2023, Table 5) that a 70 turbine 105 MW windfarm might cause turbulent heating of air downwind about 3 °C, if all heat is contained in a stream about 100 m high and a kilometre wide. Using the Penman-Monteith equation we estimated the enhancement in evapotranspiration to be 5% at 25 °C ambient temperature. With turbulence, a 10% increase in drying could occur, sustained as long as wind direction and strength is maintained. While this prediction is hypothetical, it can be tested under field conditions. Under Australian conditions winds to generate power from wind farms have been shown as intermittent (Miskelly, 2012). However, the downwind drying effect of such turbulence is cumulative, with water vapour transported elsewhere.

Case studies predicting turbulent wake drying and risks to plant production or fire

Frequently in regions with installed turbine wind plants, more intense wildfires have been observed. In this article we examine first the case of the devastating Maui wildfire of August 2023 that destroyed the town of Lahaina, approximately oner hundred deaths resulted. To maximise power generation, the Kaheawa Windfarm is logically located to take advantage of the prevailing winds to this island, which blow across the island from the south-east towards Lahaina. At question is whether the intensity of the fires in early August might have been enhanced by evapotranspiration in the previous months, elevated by wind farm turbulence. Since the windfarm is still operating, this hypothesis can be tested.

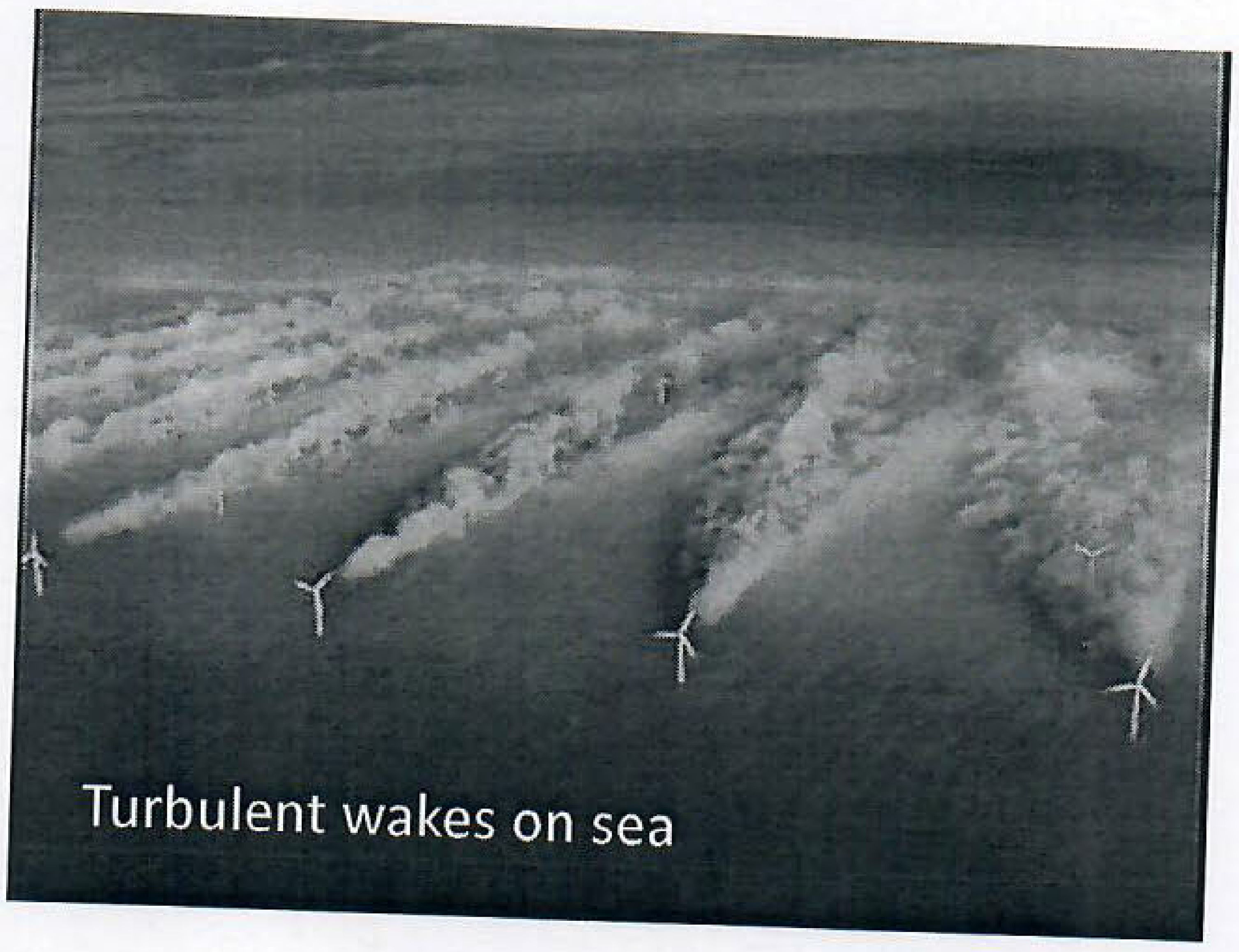


Figure 1. Moisture-laden cooling wakes in an offshore windfarm near Denmark.

A second case is in Western Australia, north of Perth in Gingin and surroundings near Wooroloo and Bindoon. Here fires have destroyed hundreds of homesteads with loss of human lives and livestock. This recent history has required a major response in the establishment of the Gingin Volunteer Fire and Rescue which mobilises 1600 personnel each summer fire season. The prevailing winds in the winter rainfall season are also consistent with enhanced drying of the landscape.

The now approved establishment of a much larger offshore Illawarra Windfarm, 100 km south of Sydney could threaten rainfall in the Warragamba catchment, by causing premature precipitation at sea as a result of the turbulent convective effect identified by Deng et al. (2023). Little or no research data exists to test this hypothesis though it could be conducted at relatively little cost, given the potential future risk if it operates ten years from now.

Conclusion

The meteorological effects of windfarms and the downwind turbulence they generate have already been shown as significant. Relatively little research has been done, in comparison with the scale of windfarm introductions, driven by fear of climate change. Whether these impacts are sufficient to include major effects on local weather, such as generating thunderstorms, is undecided. However, the initiation of thunderstorms is poorly understood and the ability of turbulence to generate convective conditions (Platis et al. 2018) is a necessary precondition. Management of these risks demands a response as diligent research, by investors in windfarms or regulators, to ensure safer environmental location of wind farms.

Case 1: The Tragic 2023 Maui, Hawai Wildfire

About 20 percent of Maui's electrical power is derived from windpower and more is planned. A devastating wildfire occurred in August 2023. The August 8th-9th wildfires in Hawaii resulted in the United States' deadliest wildfire recorded. The coastal and upcountry fires caused widespread destruction and loss of life, predominantly in the town of Lahaina. The Lahaina fire was speculated to have been from downed power lines, which sparked and ignited dried vegetation in areas experiencing moderate (D1) to severe (D2) drought conditions, according to NOAA.

Figure 1. Coastal Maui showing Kaheawa Windfarm dispatching 51 MW of electricity at around 1000 m elevation on the Lahaina Pali Trail. Lahaina is located downwind in the north-western corner where more than 100 died in the August 2023 wildfire.

Enhanced drying of the downwind landscape

Obviously, Lahaina and the upwind terrain will frequently experience windfarm turbulence, almost normal to the line of the wind turbines. The distance involved for drying of vegetation and human structures being less than 10 kilometres. Our hypothesis of warming and enhanced evapotranspiration from turbulent airflow could increase the flammability of the landscape by a significant factor. Fire intensity is highly responsive to dryness, given that the major cooling effect of evaporation is limited, allowing unimpeded combustion.

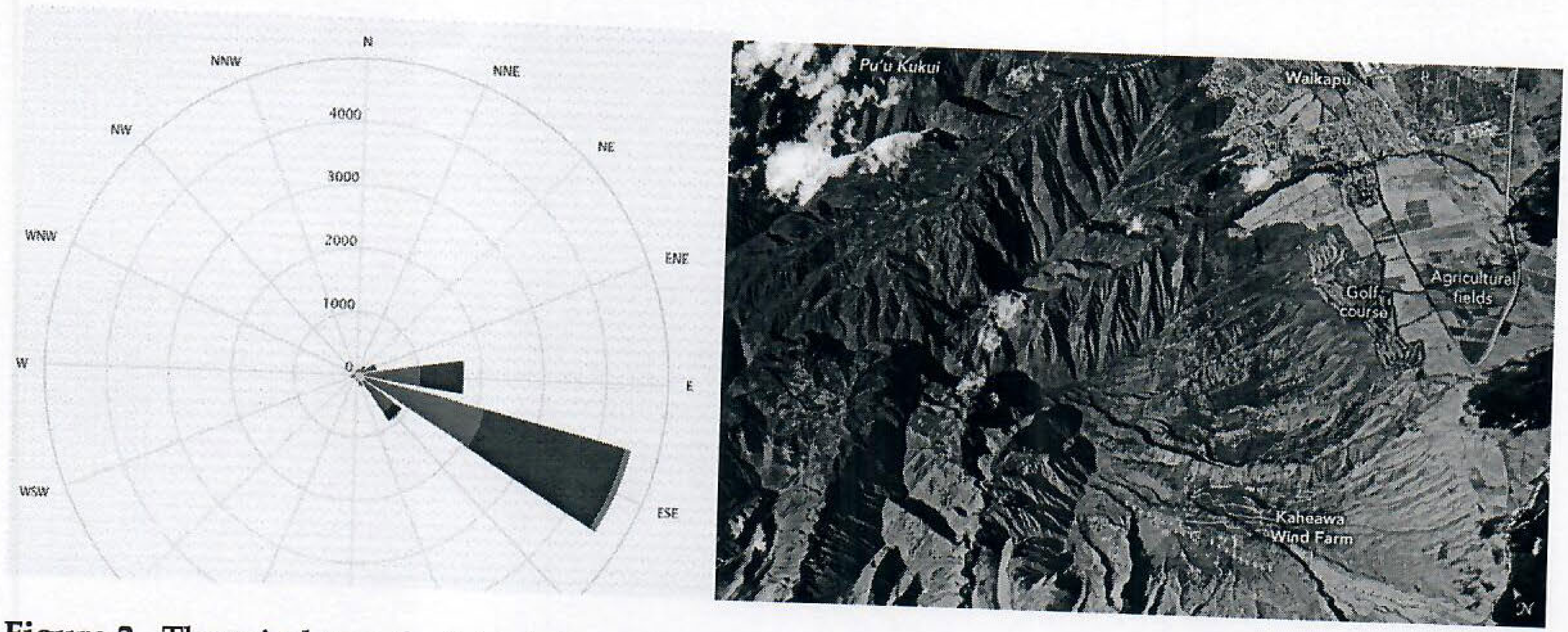


Figure 2. The wind rose for Maui shows how many hours per year the wind blows from the indicated direction. Strongest windpower from the northern trade winds blow towards west-northwest, explaining the strategic location of the Kaheawa Windfarm.

Conclusion

Although local wind roses are sometimes dominated by local topology, the predominant turbulent airflow clearly disposes the landscape leading up from the Kaheawa Winffoarm directly to Laihana. No other townsite in Maui is at so much risk from a tinder-dry situation. The theory that the fire was initiated by sparks from strong winds bringing down a power line actually recorded as a flash is consistent with this hypothesis.

https://earthobservatory.nasa.gov/images/147527/capturing-wind-on-maui

Case 2: Gingin, Wooroloo, Bindoon Fires North-east of Perth

In recent years, since wind power has begun being used for electricity, a pattern of bushfires north of Perth in lightly forested areas has emerged. In 2021, 71 dwellings were destroyed near Wooroloo, but every year, 1600 volunteer members of Gingin Volunteer Fire & Rescue are challenged by bushfires. Previously, summer bushfires were not so typical of this area. More usually, they were more located in forested areas, south of Perth. Since rainfall in southwestern Australia is predominantly in winter months from May, the possibility exists that turbulent winds blowing in that season could predispose the area affected to summer bushfires, when additional drying occurs. In winter, the Gingin Wind Rose indicates winds are mainly from the north in June and July, from the region south of Dandaragan.

Heat production from wake turbulence is inherent in the function of wind turbines and farms with significant environmental effects and reduced ecological productivity and increased bushfire risk predicted (Kennedy et al. 2023). Though a hypothetical prediction, it is recommended that the downwind turbulent heating and increased drying be assessed regarding effects of evapotranspiration on plants and soil.

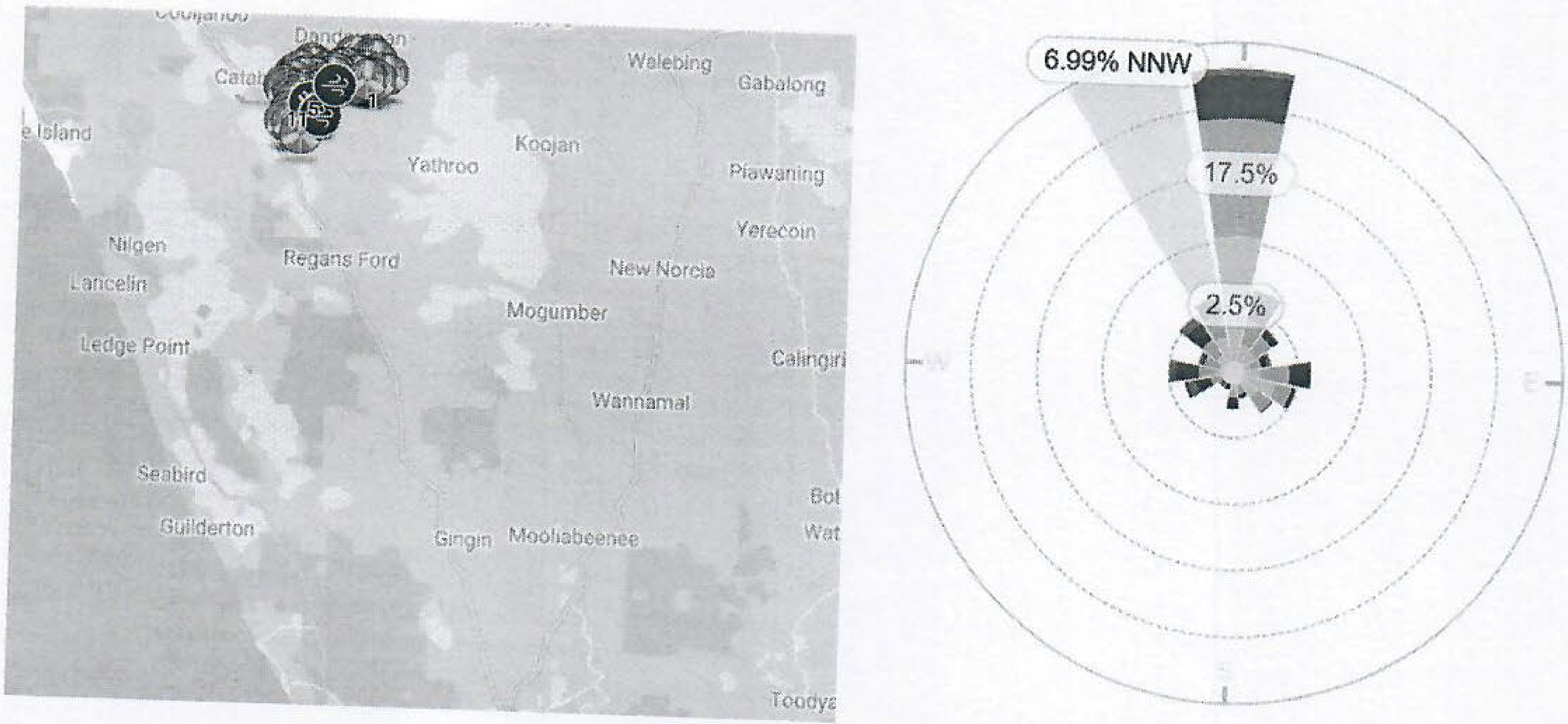


Figure 3. Dandaragan Windfarm shown yields 100 MW of dispatchable electricity, when strong winds blow, is about 85 km north of Gingin where previously rare bushfires now occur intensely more frequently. The July Wind Rose shows turbulent drying can occur in June and July after winter rainfall.

Conclusion

The deficit in soil and vegetation moisture probably caused in winter may provide conditions in early summer where fire, once ignited from whatever cause, burns more intensely, less heat being absorbed as latent heat of vaporisation. We recommend a research program using recording of wind speeds, turbulence and evaporimeters to measure drying rates with respect to distance from windfarms to test this hypothesis. The more intense wildfires being reported in recent years often occur in regions having installed wind turbine plants. For example, Greece has invested heavily in wind power, installing fleets of turbines on mountain ridges. Fires out of control in summer are now typical, even requiring human evacuations from islands such as Rhodes.

Case 3: Illawarra, NSW declared offshore wind area

An offshore windfarm is proposed south of Sydney, from the Illawarra region. The hinterland consists of coastal rain forest some 20 km inland on the slopes behind Shellharbour. Beyond that is the Nattai National Park forested are and the Upper Nepean River Catchment, leading to Burragorang region where Sydney's water supply is retained behind Warragamba Dam.

Given that windfarm wake turbulence has been shown to extend more than 50 km, a pertinent question relates the possible meteorological effects that could extend as far as the Nepean Catchment. Since near-farm wakes involve convection lifting of air possibly encouraging precipitation of rain in the 20 km to shore, how much depletion of rainfall in the Illawarra hinterland will occur. Doubtless, there will be some effect in the on-shore weather. Depleted windflows are a feature in the case of German Baltic Sea wind flows to the point where added new turbines produce diminishing electrical power. What

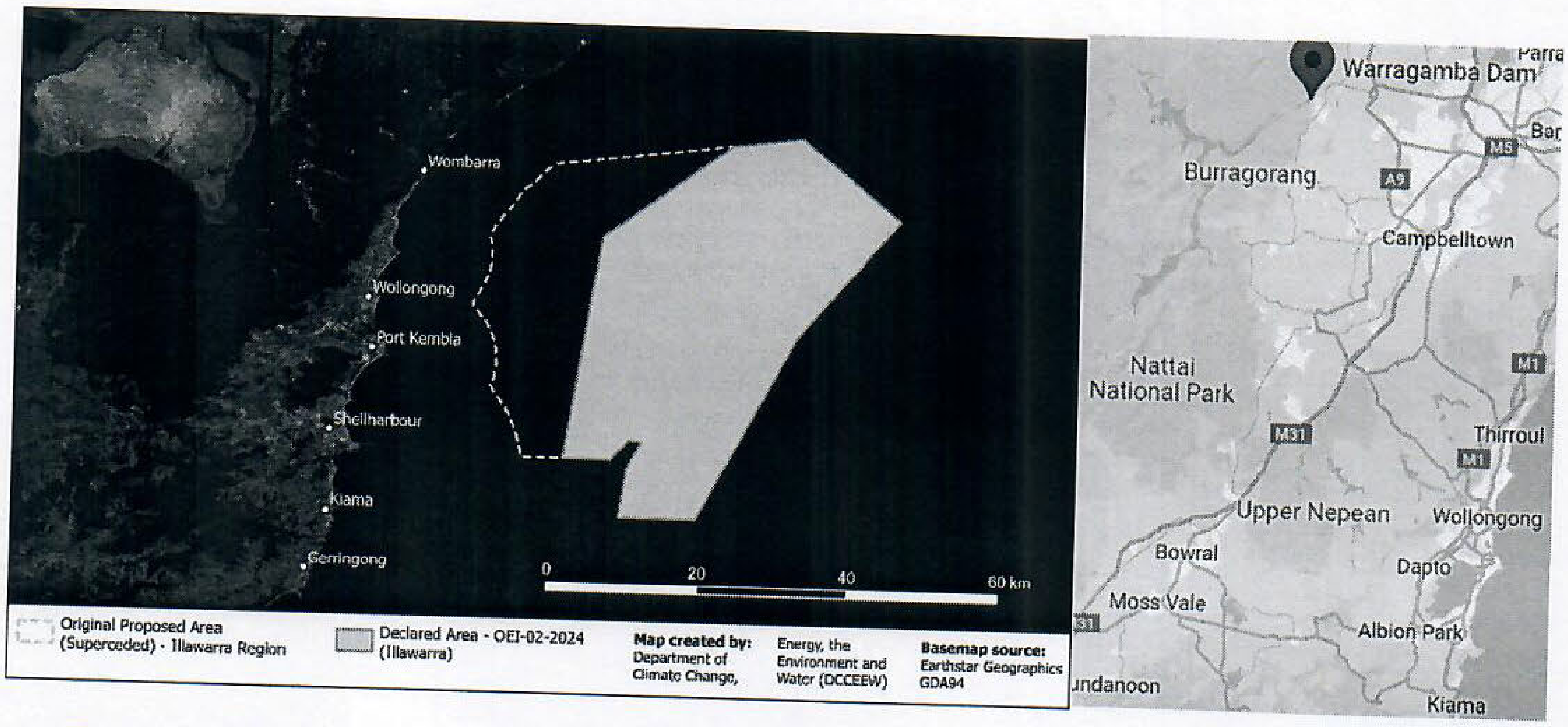
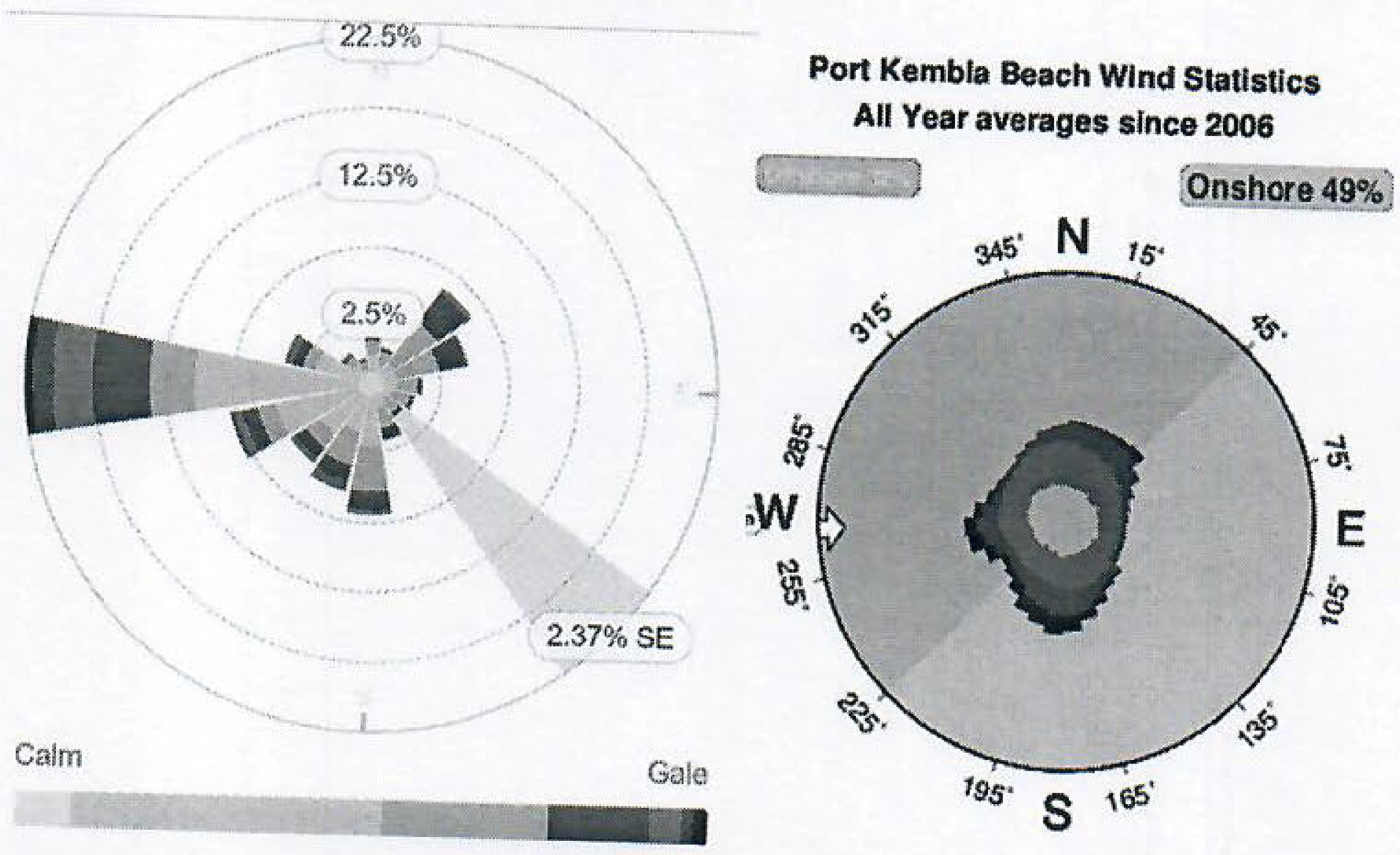


Figure 4. Illawarra Windfarm area and water catchment hinterland behind Wollongong, Port Kembla.



Port Kembla Wind Rose

Figure 5. Port Kembla Wind Rose and wind statistics for Port Kembla Beach since 2006.

It is of interest that wind roses for coastal towns indicate wind from all directions, varying slightly seasonally. Wind roses for the windfarm area have not been obtained, though it can be expected that trade winds towards the shore will predominate further to sea.

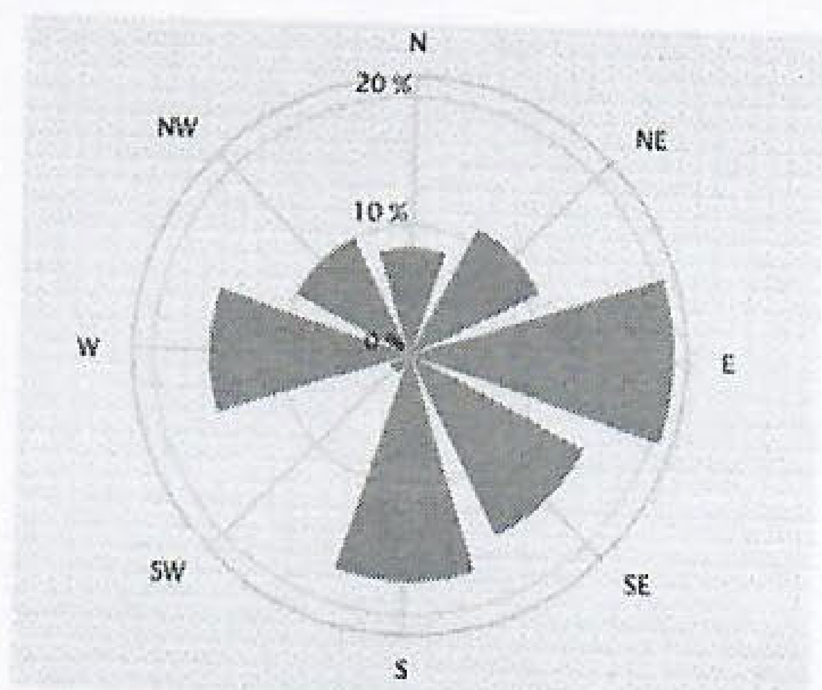


Figure 6. Kiama's annual wind rose is much more oriented from the ocean.

The main risk factor identified relates to reduced rainfall on land because of lower loadings of winds impacting the coastal regions. To our knowledge, little or no research data is available to assess this risk. Diligent risk management requires that this be obtained by appropriate research.

Conclusion

Modelling should be conducted taking into account this hypothesis of redistributing more rain at sea and correspondingly less on land. Data testing this hypothesis may be available in the northern hemisphere, such as in the Baltic Sea where offshore farms are more than 20 km from the coast.

NASA-FIRMS, Global current fires available at https://firms.modaps.eosdis.nasa.gov/map/ Earth Observatory:

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