Offshore wind power in Mexican seas

Héctor García-Nava[1,2], Emiliano Gorr[1], and Mayra Arredondo-Gamez[1]

1. Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California.
2. hector.gnava@uabc.edu.mx

Keywords—**Offshore wind, capacity factor, levelized cost of energy.**

I. INTRODUCTION

In recent years, Mexico has been actively exploring renewable energy sources to diversify its energy mix and reduce its dependence on fossil fuels. As the country aims to address climate change concerns and achieve its sustainable development goals, offshore wind power has emerged as a promising and viable contributor. Offshore wind offers several advantages over onshore wind farms, including stronger and more consistent wind speeds, reduced visual impact, and the potential to generate larger amounts of electricity [1, 2].

Currently, there are no offshore farms installed in Mexico. However, several areas, spanning the Gulf of Mexico and the Pacific Ocean, have been identified as adequate for offshore wind farming. In particular, coastal areas of the states of Baja California, Oaxaca, Tamaulipas, Tabasco, Campeche and Yucatán, have been pointed out as having an exploitable wind power [3-6]. Previous regional works are based on different data sources, analyze different periods of time, and use different approaches which somewhat difficult a direct comparison of their results.

Here we revisit offshore wind power for all Mexican seas to have a general picture of offshore wind resource and to analyze and compare hotspots along the Mexican coast.

II. METHODS

To compute wind power we use wind speed hourly data from the ERA5 reanalysis. ERA5 has a global coverage with a spatial resolution of 31 km. The period of analysis is from 2010 to 2022.

Wind power density, P, was calculated from wind speed at 100 meters height, U_{100}, as

$$P = \frac{1}{2}\rho U_{100}^{3} \qquad (1)$$

where ρ is the air density. Mean extractable wind power, P_{ext}, was computed for wind turbines with different capacities, as

$$P_{ext} = \sum WTP(U_z)p(U_z) \qquad (2)$$

where WTP is the wind turbine power curve and p is the probability distribution of wind speed U_z at hub height. WTP where obtained from the NREL wind turbine power archive.

The Levelized Cost of energy of different wind turbines was analyzed by adapting the methodology of [7]. Capital (CapEx) and operating (OpEx) expenditures were adjusted and updated to the value of the 2023 U.S. dollar based the Annual Technology Baseline of the National Renewable Energy Laboratory's (NREL's) [8]

III. RESULTS

Offshore wind power in Mexico range from 0.1 MW/m^2 up to 1.2 MWm^{-2}. The Gulf of Tehuantepec has the highest resource available but also presents the largest annual variability. Excluding the Gulf of Tehuantepec, in general terms, the Pacific has a lower resource availability than the Gulf of Mexico and has a somewhat larger variability (Fig. 1 y 2)

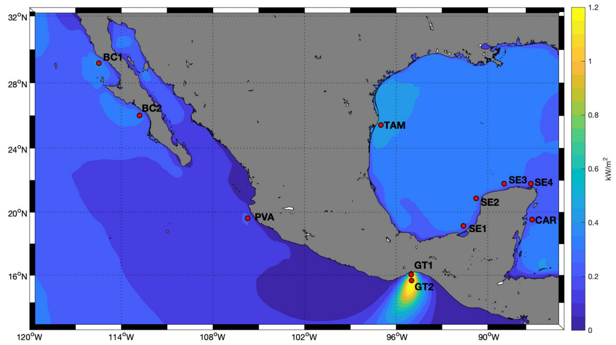

Fig. 1. Mean offshore wind power at 100 m height in Mexican seas for the years 2010 to 2022.

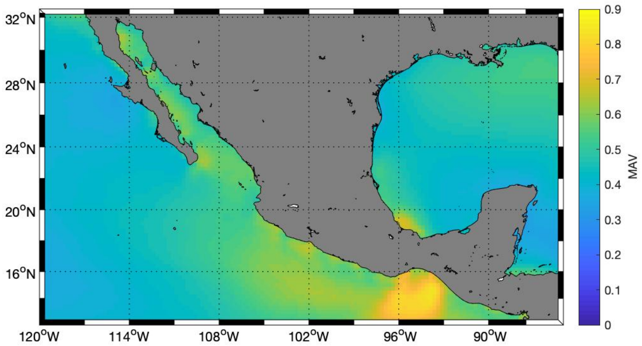

Fig. 2. Mean annual variability (MAV) of wind speed at 100 m height in seas waters for the years 2010 to 2022.

Extractable power was computed for NREL's reference turbines with nominal capacities of 5MW, 10MW, and 15MW. The capacity factor of 10MW and 15MW turbines was almost the same, the capacity factor of the 5MW turbine was lower.

The capacity factors of the different turbines have a very similar spatial pattern along the studied area; as an example, Figure 3 shows the capacity factor of the 10MW turbine. As can be seen, in general terms, the capacity factor is higher in the Gulf of Mexico than in the Pacific but, the highest capacity factors occur in the Gulf of Tehuantepec. Other areas with high capacity factors are the northern coast of Tamaulipas, the Pacific coast of Baja California, and the eastern coast of the Gulf of Campeche.

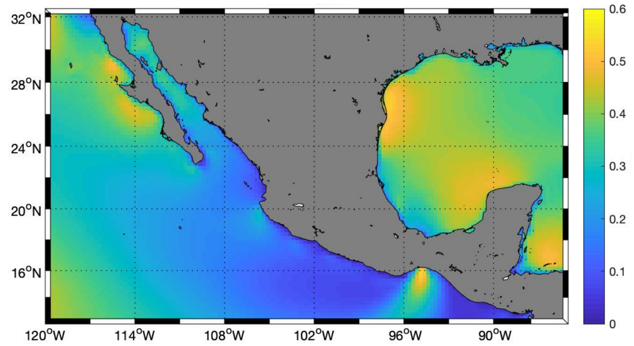

Fig. 3. Mean capacity factor of NREL-5MW wind turbine in Mexican waters for the years 2010 to 2022.

Somewhat surprisingly, capacity factors on the Gulf of Tehuantepec are not much higher than in other areas (Fig. 3, Table I) despite the much higher wind power available in this region (Fig. 1). This is due to the bimodal nature of the wind in the Gulf of Tehuantepec (green lines in Fig. 4); the overall wind speed mode is around 3 m/s with a secondary mode around 15 m/s. In contrast, probability distributions of other hotspots are unimodal with their mode between 6 and 9 m/s (Fig. 4). The winds above 11 m/s, the speed at which turbines reach its full capacity, are much more common in Gulf of Tehuantepec (occur around 40% of the time) however, the rest of the time winds are much milder with speeds bellow 5 m/s.

TABLE I

MEAN WIND POWER DENSITY AND CAPACITY FACTOR AT SELECTED SITES

		P		CF	
Region	**Site**	**w/m2**	**NREL-5MW**	**NREL-10MW**	**NREL-15MW**
Pacific	BC1	427.30	0.40	0.50	0.50
	BC2	340.90	0.33	0.42	0.42
	PVA	232.00	0.22	0.28	0.28
	GT1	1,158.80	0.50	0.54	0.54
	GT2	1,324.20	0.49	0.53	0.53
	Average	**696.64**	**0.39**	**0.45**	**0.46**
Gulf of Mexico and Caribbean	TAM	448.50	0.40	0.50	0.51
	SE1	302.20	0.30	0.40	0.41
	SE2	341.40	0.34	0.44	0.45
	SE3	352.00	0.35	0.45	0.46
	SE4	242.40	0.25	0.34	0.34
	CAR	291.50	0.30	0.40	0.40
	Average	**329.67**	**0.32**	**0.42**	**0.43**

It is interesting to notice that the highest capacity factor occurs is GT1 while the highest wind power density occurs in GT2 (Table I); although, there are higher winds in GT2 that increase the available power, low winds in his site are more common than in GT1 (Fig. 4)

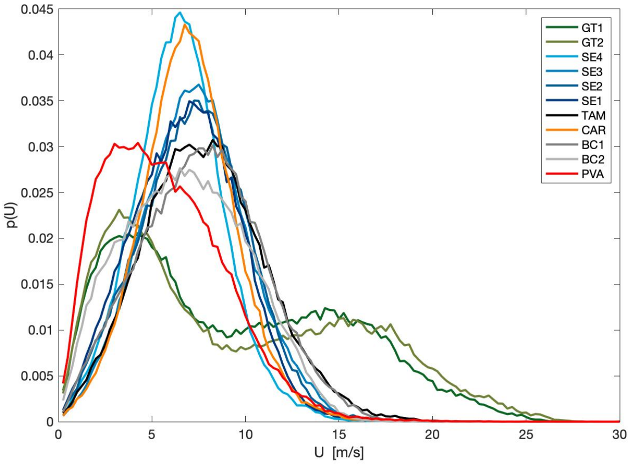

Fig. 4. Probability distribution of wind at the selected locations, shown in Figure 1 as red dots.

As expected, an increase of wind turbine rated capacity decreases the levelized cost of energy (LCoE) however, differences between 10MW and 15MW turbines are less than 1%, a more significant LCoE reduction is observed between NREL-5 MW and the larger capacity models, with differences between 10% to 30%. This occurs because the increase of costs from 5MW to 10MW is overcompensated by the increase in energy production whereas, the increase in costs from 10MW to 15MW is of the same magnitude than the increase in production. Mean LCoE of NREL-5MW, 10MW, and 15MW wind turbines, are 132.6, 104.2, and 103.4 $/MWh, respectively.

TABLE II

LEVELIZED COST OF ENERGY AT THE SELECTED SITES

		LCOE	$USD/MW	
Region	**Site**	**NREL-5MW**	**NREL-10MW**	**NREL-15MW**
Pacific	BC1	110.56	88.64	87.82
	BC2	133.69	105.84	104.93
	PVA	203.02	155.46	154.54
	GT1	88.07	81.13	80.88
	GT2	88.90	82.70	82.56
	Average	**124.85**	**102.75**	**102.15**
Gulf of Mexico and Caribbean	TAM	109.06	87.52	86.73
	SE1	144.66	109.18	108.21
	SE2	128.87	98.80	97.79
	SE3	126.57	97.42	96.49
	SE4	177.04	129.16	128.25
	CAR	147.86	109.84	108.92
	Average	**139.01**	**105.32**	**104.40**

On average, the selected sites in the Pacific have lower LCoE than sites in the Gulf of Mexico and Caribbean Sea. The lower LCoE occurs in the Gulf of Tehuantepec with values between 80.9 to 88.9 $USD/MW, followed by the sites near the coast of Baja California and Tamaulipas where LCoE is in the range from 86.7 to 110.6 $USD/MW. The sites along the coast of the Gulf of Campeche and the Caribbean, have LCoE values between 96.5 and 177.0 $USD/MW (Table II)

IV. CONCLUSIONS & FUTURE WORK

The results presented here show a broad picture of the offshore wind resource in Mexico; we show that coastal regions, spanning the Gulf of Mexico and the Pacific Ocean, provide wind resources that could be harnessed for electricity generation. The availability of promising locations presents a great opportunity to tap into renewable energy potential and bolster energy security in Mexico.

The Gulf of Tehuantepec is the best of the analyzed areas for offshore wind generation, this area has the lowest LCoE and the highest capacity factors. However, the sites off the coast of Baja California and Tamaulipas has similar capacity factors with little higher LCoE values. The sites in Baja California are particularly relevant because this area is disconnected from the national grid and its regional grid is highly dependent on fuel-burning electricity generation.

Further analyses are needed to better determine the suitability of potential areas for wind farming. The LCoE values presented here are based on a very simple algorithm used to compare different sites and stand-alone turbines, we plan to improve our estimates by 1) using more detailed costs and including the cost of different types of mooring based on depth, 2) include the economy of scale by simulating wind farms of different sizes, and 3) taking into account an amount of time that turbines could be out of service to compute energy production. Additionally, site selection should consider restricted areas, such as natural protected and fishing areas, where it will be not possible to install wind farms and sensible areas where wind farming could cause negative ecological or social impacts.

REFERENCES

[1] J. Li and X. B. Yu. “Onshore and offshore wind energy potential assessment near Lake Erie shoreline: a spatial and temporal analysis”, *Energy*, vol. 147, pp. 1092-1107, 2018.

[2] X. Costoya, M. deCastro, D. Carvalho, and M Gómez-Gesteira. “On the suitability of offshore wind energy resource in the United States of America for the 21st century”. *Applied Energy*, vol. 262, 114537, 2020. DOI: 10.1016/j.apenergy.2020.114537

[3] V. Magar, M. S. Gross, L. González-García. O”ffshore wind energy resource assessment under techno-economic and social-ecological constraints” *Ocean & Coastal Management*, vol. 152, 77-87, 2018.

[4] J. P. Arenas-López and M. Badaoui. “Analysis of the offshore wind resource and its economic assessment in two zones of Mexico”, *Sustainable Energy Technologies and Assessments*, vol. 52, 101997, 2022.

[5] D.A. Canul-Reyes, O. Rodríguez-Hernández, and A. Jarquin-Laguna. “Potential zones for offshore wind power development in the Gulf of Mexico using reanalyses data and capacity factor seasonal analysis”. *Energy for Sustainable Development*, vol. 68, pp. 211–219, 2022.

[6] H. García-Nava and M. Arredondo-Gámez. “Offshore wind power in the peninsula of Baja California,” in *2nd International Congress on Marine Energy*, vol. 1, pp. 105-106, 2022

[7] L. Vega and D. Michaelis, “First generation 50 MW OTEC plantship for the production of electricity and desalinated water,” in *Annu. Offshore Technol. Conf*, 2010, pp. 2979–2995, doi: 10.4043/20957-MS.

[8] National Research Energy Laboratory, “Annual Technology Baseline,” 2022. https://atb.nrel.gov/electricity/2022/offshore_wind (accessed Mar. 15, 2023).

ACKNOWLEDGMENT

This work is a contribution of the CEMIE-Océano project funded by CONACyT/SENER sustentabilidad energética (Project No. 249795).