Resource Variations and Resultant Tariffs for On-shore Wind potential in Karnataka

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Abstract: This paper aims to inform the tariff setting process for wind resource in Karnataka, so that investments in wind infrastructure can be incentivized taking into consideration resource variations. This work presents a range of levelized tariffs for the on-shore wind potential of the state. The range is a result of the variation in capacity utilization factors estimated for various classes of Wind Power Density (WPD) in the state, for waste and scrub forest land categories, at 80 m and 100 m hub heights. Also, capacity which may be installed for the range of tariffs, subject to land availability, is presented.

Keywords: **Wind potential, Wind power, Capacity Utilization Factors, Levelized Tariff**

1 Introduction

The official estimate of the on-shore wind potential in India, has recently been revised to 102 GW at 80 m hub height [1]. Most of the existing potential (about 85%) is concentrated in Tamilnadu, Gujarat, Maharashtra, Rajasthan, Andhra Pradesh, and Karnataka [1]. Of these states, Karnataka accounts for nearly 15% of the potential. Various studies in the recent past too have re-estimated the on-shore wind potential. A few studies have estimated it to be over 2000 GW at 80 m hub height [2], with assumptions of uniform land availability. In Karnataka alone, the potential on waste and scrub forest land, based on spatial intersection of resource potential with land use classification, is estimated to be about 49 GW at 80 m hub height, and about 71 GW at 100 m hub height [3].

These revised assessments are indicative of the advances in turbine technology, which allow installation of turbines at higher hub heights (80 – 120 m). Coupled with recent trends of increase in nameplate capacity (1 – 4 MW), it is now possible to extract more power from stronger winds available at higher hub heights.

This paper presents a range of Capacity Utilization Factors (CUFs) for the wind power potential in Karnataka, and the levelized tariffs resulting from the same, based on tariff calculation norms of the Central Electricity Regulatory Commission (CERC) [4]. Results are presented and discussed, for waste and scrub forest land categories, for 80 m and 100 m hub heights.

2 Data sources and methodology

2.1 Wind power potential estimation

We have based our analysis on the range of WPDs recently calculated for Karnataka, by CSTEP [3]. The study uses wind speed and WPD data sets i.e. monthly average wind speeds, and annual wind frequency histograms at 50 m and 80 m hub heights. The datasets for the state are obtained from 3Tier, at a 3.6 km horizontal resultion. The speeds are derived from a combination of meso-scale weather models and data on elevation and vegetation, to simulate surface processes and jet level dynamics.

Subsequently, the study uses Weibull characterization of annual wind speed histograms at 80 m hub height, to extrapolate WPD at each location to a higher hub height of 100 m. The WPD (in W/ sq. m.), an indicator of the energy generation potential of a site, is then intersected with land-use information to spatially estimate the potential specific to waste and scrub forest land categories. Land Use Land Cover (LULC) data for this purpose, was procured from Karnataka State Remote Sensing Applications Centre (KSRAC), dated 2005 – '06. In addition to land use classification, the World Database of Protected Areas (WDPA) is used to eliminate all areas notified as protected areas and hence strictly unusable for any developmental purpose. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) is used to eliminate areas situated at an elevation above 1500 m, to remove sites that may be inaccessible for construction.

The WPDs thus estimated, are translated to installable capacity (in MW) with a capacity density factor of 6.3 MW/ sq. km.. This is assuming the installation of a Suzlon 2.1 MW turbine with interturbine spacing of a 7D*5D array configuration, where D denotes the rotor diameter of the turbine. This configuration was selected as it has been shown to cause the least array losses for Indian conditions [5].

The potential thus estimated for Karnataka, at 80 m and 100 m, is depicted in Figures 1-4, and summarized in Tables 1 and 2 respectively.

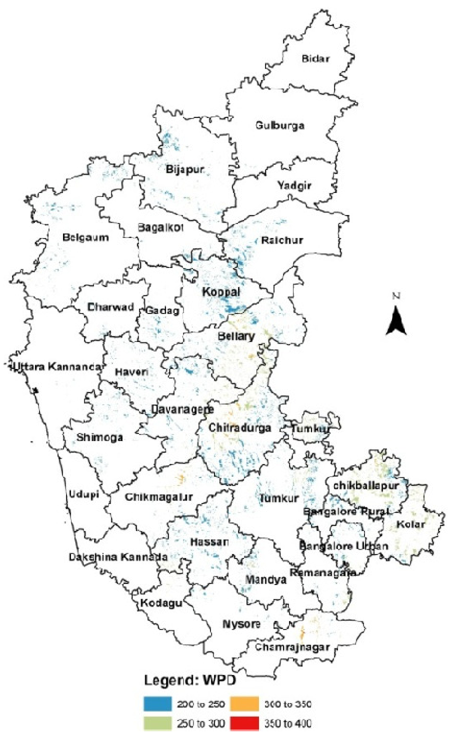


Figure 1: Wasteland - 80 m hub height

Figure 2: Wasteland - 100 m hub height

Table 1: Area and potential available from wasteland at different hub heights and WPD

Hub height (m)	WPD ranges (W/ sq. m.)				
	200 – 250	251 – 300	301 – 350	351 – 400	> 400
	Area of suitable wastelands (sq. km.)				
80m	3,121	1,484	224	5	0
100m	2,566	2,405	1,395	448	41
	GW Potential				
80m	19.66	9.35	1.41	0.03	0
100m	16.17	15.15	8.79	2.82	0.26

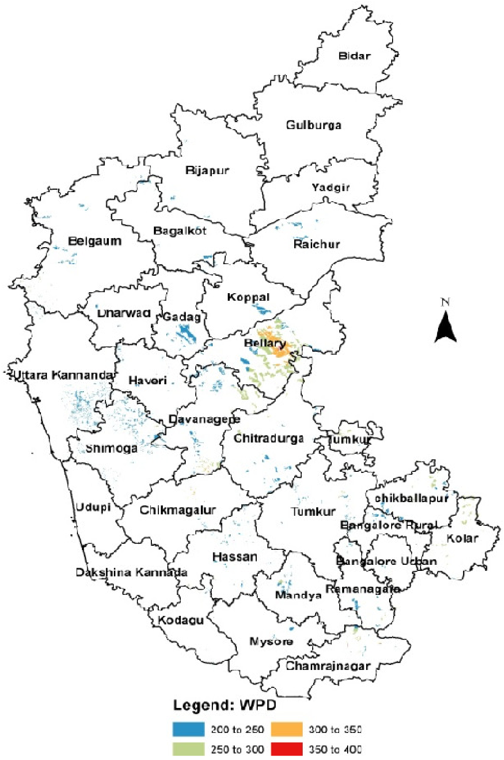


Figure 3: Scrub forests - 80 m hub height

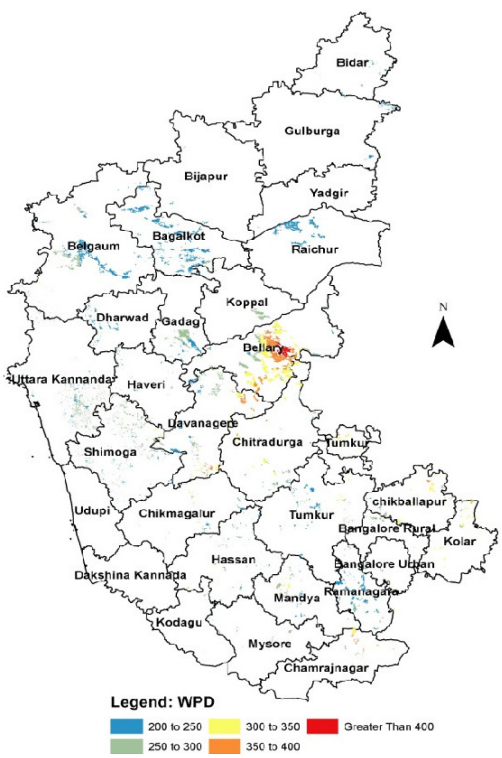


Figure 4: Scrub forests - 100 m hub height

Table 2: Area and potential available from scrub forest lands at different hub heights and WPD

Hub height (m)	WPD ranges (W/ sq. m.)				
	200 – 250	251 – 300	301 – 350	351 – 400	> 400
	Area of suitable wastelands (sq. km.)				
80m	1,631	995	363	11	0
100m	1,730	1,353	858	462	95
	GW Potential				
80m	10.28	6.27	2.29	0.07	0
100m	10.9	8.52	5.41	2.91	0.6

2.2 Capacity utilization factors (CUFs) for estimated potential

In the study [3], the Weibull curves of median WPD values (representative of the ranges of WPDs estimated), are intersected with the power curve of a Suzlon 2.1 MW turbine which can be installed at 80 and 100 m heights, in order to derive a correponding range of CUFs indicative of the potential in Karnataka. Net electricty generated by the turbine is used to derive the net CUF for a median wind site which is a representative of the WPD range it lies in. The net CUFs account for reductions owing to site specific conditions such as turbulence, auxiliary consumption, and availability.

Table 3 provides the range of CUFs derived for the WPD ranges in the above manner.

Table 3: CUFs across range of WPDs

WPD range (W/sq. m.)	80 m	100 m
200 – 250	20%	24%
251 – 300	24%	28%
301 – 350	26%	30%
351 – 400	27%	31%
> 400	29%	32%

2.3 Determination of levelized tariffs

Our analysis aims to determine the representative levelized tariffs for the WPD ranges for Karnataka. The capital costs for this purpose, is based on the estimates derived in [3]. Here, publicly available CDM project financials available for projects commissioned in India have been referred, to determine the capital cost of wind turbine erection and balance of plant activities, at a baseline hub height of 80 m. A median value for this cost is observed to be Rs. 590 Lakhs/ MW, from a set of 10 projects. This baseline cost at 80 m, is scaled to a height of 100 m, based on inputs from consultants with experience in installations of turbines in the US market. The capital cost increases to Rs. 648 Lakhs/ MW at 100 m hub height, at the higher end of the estimated increase in costs.

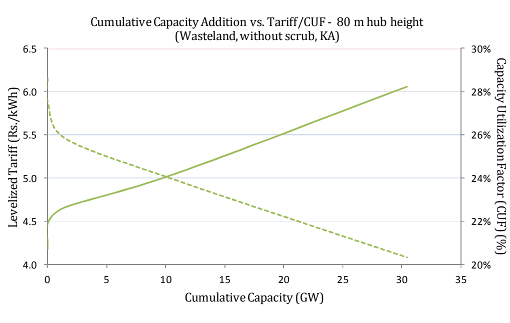
Apart from capital cost, and CUFs, the remaining assumptions for maintenance costs, plant lifetime, D/E ratio, and other financial terms are based on norms for tariff determination by CERC [4]. For this purpose, the *"Renewable Energy Tariff and Financial Analysis Tool"*, developed by Prayas Energy Group [6], is used to determine the levelized tariffs corresponding to the WPD ranges estimated. Results of this calculation are presented in Table 4.

3 Results and discussion

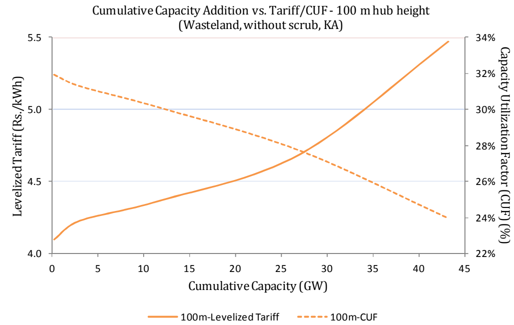
Table 4: Levelized tariffs across range of WPDs

WPD range (W/sq. m.)	CUF (%)		Levelized Tariff (Rs./ kWh)	
	80 m	100 m	80 m	100 m
200 – 250	20	24	6.1	5.5
251 – 300	24	28	5.0	4.7
301 – 350	26	30	4.7	4.4
351 – 400	27	31	4.5	4.2
> 400	29	32	4.2	4.1

If we consider cumulative capacity addition of potential across the WPD ranges, in a manner that utlilizes the best potential first, following ranges for levelized tariffs, and the corresponding CUFs to them, are observed (Figures 5, 6):

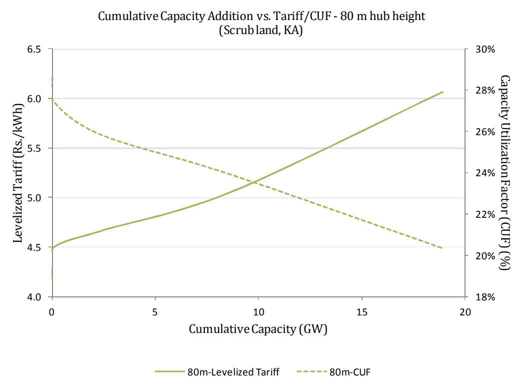


(a)

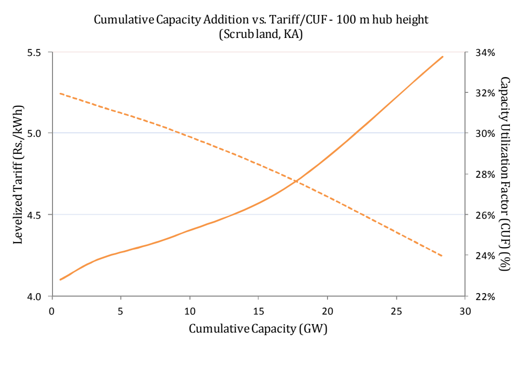


(b)

Figure 5 (a), (b): Cumulative capacity addition by wasteland type, in Karnataka



(a)



(b)

Figure 6 (a), (b): Cumulative capacity addition by scrub forest land type, in Karnataka

The CUFs hence observed for the potential in Karnataka, ranges from 20% to 29% at 80 m, and between 24% to 32% at 100 m hub height. Correspondingly, the levelized tariff requirement varies from Rs. 6.1/ kWh to Rs. 4.2 kWh at 80 m and between Rs. 5.5/ kWh to Rs. 4.1/ kWh at 100 m repectively, for a project Internal Rate of Return (IRR) of 13%.

The absolute values of the tariffs may vary based on changes in assumptions of the underlying capital cost estimates. However, it can be observed that there exists a relative reduction in tariff of almost 30% to 25%, between the weakest and best potential sites, at 80 and 100 m respectively. Hence, there is opportunity to determine the tariffs based on the WPD class observed at the site, in order to appropriately incentivize the development of large-scale wind power in the state.

4 Conclusions

Based on the above results, there is upto 18 GW of installable capacity at 80 m, for a levelized tariff of less than Rs. 5/ kWh on combined waste and scrub forest land in Karnataka. Similarly, upto 56 GW of capacity may be installed at 100 m. The realization of this capacity is subject to land availability, and other factors such as grid connectivity, road connectivity, and socio-ecological impacts.

The maximum tariff requirement for the weakest wind sites (WPD: 200 – 250 W/ sq. m.) is Rs. 6.1/ kWh and Rs. 5.5/ kWh at 80 and 100 m respectively. The lowest tariff requirement for the best wind sites (WPD: > 400 W/sq. m.) is Rs. 4.2/ kWh and Rs. 4.1/ kWh at 80 m and 100 m respectively. In comparison, the present tariff for wind power purchase agreements in Karnataka is fixed at Rs. 3.7/ kWh [7].

A reduction in CUF of around 30% based on maxiumum variation in the quality of windy sites at 80 m, results in an increase in requirement of levelized tariff by about 45% at 80 m, for a project IRR of 13%. Similarly, a reduction in CUF of around 25% results in an increase in levelized tariff by about 35%, in order to make the project feasible at an IRR of 13% at 100 m.

The above values of the calculated tariffs may vary based on changes in site-specific wind measurements and capital cost assumptions. However, the relative variations in the tariffs would hold, in terms of the impact of the relative variations in CUFs based on the spread of the quality of WPDs observed in the state. Hence, in order to ensure uptake of large-scale capacity addition of wind power, we recommend setting of feasible tariffs for project development, taking into consideration the quality of the WPD value indicative for a particular wind zone/site at the state level.

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