Energy Options for Uttara Kannada

Prospects of Wind Energy

Wind resource assessment is the primary step towards understanding the local wind dynamics of a region. Windmills have been used for centuries to grind grain and pump water in rural areas; moreover, it has the advantage of being harnessed locally for applications in rural areas and remote areas. In this article, **Prof. T V Ramachandra** and **Mr Ganesh Hegde,** with Uttara Kannada as a case in point, discuss the importance of harnessing wind energy to meet the energy demand at decentralized levels.

Energy extraction from wind is one of the oldest energy-harvesting technologies that is being used for centuries. Winds are caused by the rotation of the earth and the heating of the atmosphere by the sun. The total annual kinetic energy of air movement in the atmosphere is estimated to be 3 x 105 kWh or 0.2% of the solar energy reaching the Earth. The maximum technically usable potential is estimated to be theoretically 30 trillion kWh per year, or about 35% of the current world total energy consumption.[1] The power in wind blowing at 25.6 km/h is about 200 W/m^2 of the area swept by a windmill. Approximately, 35% of this power can be captured by windmills and converted to electricity. The kinetic energy of the air can be transformed to mechanical and then to electrical form of energy using fans, gears, turbine, and generator system. Windmills—a modern world's electricity-harvesting technology—accounts for more than 2 GW of installed capacity worldwide.[2] Electricity generation from wind is directly proportional to the air density, swept area of blades, and cube of the wind velocity. Since wind velocity is more tentative, hence optimizing the blade area, maximum energy can be extracted for particular wind speed at a given place.[3]

where,	$P = (1/2) * * A * V^\wedge 3$	(1)
	P: Wind power	*p*: Air mass density
	A: Swept area (area of wind flow)	V: Wind velocity

The annual wind speed at a location is useful as an initial indicator of the value of the wind resource. The relationships between the annual mean wind speed and the potential value of the wind energy resource are listed below:

Annual Mean wind speed @ 10 m Ht. (m/s)	Indicated value of wind resource
< 4.5	Poor
4.5–5.4	Marginal
5.44–5.7	Good to Very Good
> 6.7	Exceptional

Uttara Kannada, a district located in the west coast and in the region of Western Ghats region of Karnataka, is blessed with good wind potential. Since electricity supply is unreliable at most times, harnessing of wind energy could play a prominent role in meeting the energy demand in the region since electricity supply is unreliable in most of the times. Wind energy potential in the district could meet the regional electricity demand through wind energy conversion system (WECS) avoiding plenteous greenhouse gas (GHG) emission and fossil fuel. This can be harnessed locally in a decentralized manner for applications in rural areas and remote areas, such as water pumping for agriculture and plantations. Wind- driven electric generators could be utilized as an independent power source and for purposes of augmenting the electricity supply from grids. In coastal, densely populated *taluks*, such as Karwar, Kumta, and Bhatkal in Uttara Kannada District, decentralized production of electricity would help local industries, especially seasonal agro-processing industries, such as cashew, etc. WECS can be hybridized with solar, biomass, and any other available local energy resources to provide 100% reliable power since wind flow is at its maximum during monsoon when solar insolation and dry biomass availability is comparatively lesser.[4]

Wind resource assessment: Wind resource assessment is the primary step towards understanding the local wind dynamics of a region. Wind flow developed due to the differential heating of the earth is modified by its rotation and further influenced by local topography. This results in an annual (year to year), seasonal, synoptic (passing weather), diurnal (day and night), and turbulent (second to second) changes in wind pattern.[5] Increased heat energy generated due to industries and escalating population in urban areas result in heat islands which also affects the wind flow as well.

Objective

The objective of the present study is to assess the *taluk*-wise annual wind potential in Uttara Kannada district and assess techno-economic feasibility of wind energy harvesting options, to meet the regional electricity demand.

Study Area, Data, and Methods

Uttara Kannada, located between 13°55′ and 15°31′N and 74°9′ and 75°10′E, is the fourth biggest district of Karnataka state, located between 13°55′ and 15°31′N and 74°9′ and 75°10′E. Total population of the district is 1,436,847 and more than 70% of the people live in rural areas or in semi-urban areas. The district is located in the Western Ghats shelters ranges sheltering abundant flora and fauna. More than 75% of the total area is forest covered and has with140 km

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[1] Wilbur LC. 1985. *Handbook of Energy Systems Engineering: Production and Utilization*. New York: John Wiley and Sons.

[2] 'Global Wind Report Annual Market Updates'. 2012. http://www.gwec.net/?id=180; last retrieved on June 25, 2013.

[3] Ramachandra TV, Subramanian DK, and Joshi NV. 1997. Wind Energy Potential Assessment in Uttara Kannada District of Karnataka, India. *Renewable Energy* **10**(4): 585–611.

[4] Balamurugan P, Ashok S, and Jose TL. 2009. Optimal operation of biomass/wind/PV hybrid energy system for rural areas. *International Journal of Green Energy* **6**: 104–116.

[5] Hester RE and Harrison RM. 2003. Sustainability and environmental impact of renewable energy resource. *Royal Society of Chemistry, United Kingdom* <http://dx.doi.org/10.1039/9781847551986.

of costal belt.[6] Figure 1 illustrates the topographic undulations of the region. Topographically, the district lies in three distinct zones, namely, narrow and flat coastal zone, abruptly rising ridge zone, and an elevated, flatter eastern zone. The coastal zone is thickly populated with coconut- clad villages. The ridge zone is a part of the main range of the Western Ghats, which runs north to south, parallel to the coast. The flat eastern zone joins the Deccan plateau. The *taluks*, which comprise the narrow flat coastal zone, are: Karwar, Ankola, Kumta, Honnavar, and Bhatkal. Similarly, *taluks*, which comprise the ridge zone, are: Supa, Haliyal, Yellapur, western Sirsi, and western Siddapur. The flatter eastern zone includes Mundgod, eastern Sirsi, and eastern Siddapur. Four agro-climatic zones based on geography and climate are coastal, evergreen, dry deciduous, and moist deciduous. There are 1,291 villages, 7 towns, 5 city municipal corporations/town municipal corporations/outward growth/census towns, and 2 reservoirs in the district (http://uttarakannada.nic.in/, last retrieved on March 14, 2017).

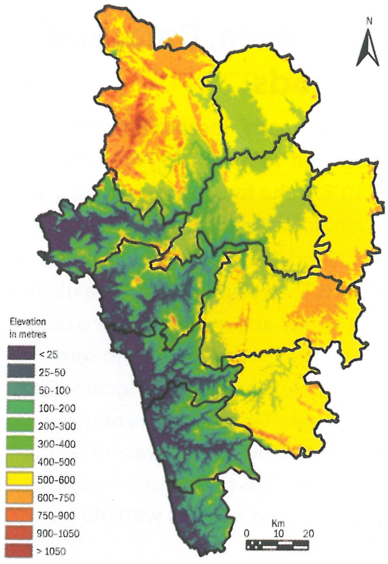

Figure 1 Digital Elevation Model of Uttara Kannada, Karnataka

Data and Method

Synthesized wind data: This wind data available from various sources provide a preliminary understanding of the wind regime of a specific region. Depending on the physiographical features and climatic conditions, these data help in assessing wind potential in the region of interest validated by long- term surface wind measurements.

There are many wind speed data sets that are available of different time periods, such as National Aeronautical and Space Agency (NASA), Surface Meteorology and Solar Energy (SSE), National Oceanic and Atmospheric Administration (NOAA-CIRES), Climate Research Unit (CRU), etc. However, previous studies have evidently showed that CRU data are reliable and are closer to the Indian Meteorological Department (IMD) surface data, and hence used in the present study.[7] CRU at the University of East Anglia maintains climatic average datasets of meteorological variables which contains wind speed data for the period of 1961–~1990 compiled from different sources. Further, inter- and intra variable consistency checks are performed to minimize data consolidation errors. The Global Land One-km Base Elevation Project (GLOBE) data of the National Geophysical Data Center (NGDC) were re-sampled to 10′×10′ (ten- minute spatial resolution) elevation grids where every cell with more than 25% land surface (those below 25% being considered water bodies) represents the average elevation of 100~400 GLOBE elevation points. The climatic average of wind speeds measured at 2 to 20 m anemometer heights (assumed to be standardized during collection) collated from 3,950 global meteorological stations together with the information on latitude, longitude, and elevation were interpolated based on a geo-statistical technique called thin plate smoothing splines. Elevation as a co-predictor considers topographic influence on the wind speed and proximity of a region to the measuring station improves the reliability of the interpolated data. During interpolation, inconsistent data was removed appropriately. This technique was identified to be steadfast in situations of data sparseness or irregularity.[8] The 10′×10′ spatial resolution wind speed data as climatic averages were available for all global regions (excluding Antarctica).[9]

Data from IMD stations located in the district are also acquired for respective locations and which gave the satisfactory results comparing with CRU data set. There are four IMD stations in the districts which are listed in Table 1. Cup counter anemometers with hemispherical cups measuring 7.62 cm in diameter were used in Indian Meteorological Department (IMD) observatories until 1973. During 1973–1979, these anemometers were are replaced with three cup anemometers with 127 mm diameter conical cups, which are placed at 10 m above ground level, over open terrain, in conformity with international practice.

Table 1 IMD stations in Uttara Kannada

Location	Latitude	Longitude	Elevation (m)
Karwar	14° 47′	74° 08′	4
Kumta	14° 26′	74° 25′	8
Honnavar	14° 17′	74° 27′	26
Shirali	14° 05′	74° 32′	45
Sirsi*	14° 62′	74° 85′	610

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[6] Uttara Kannada official website, http://uttarakannada.nic.in/districtprofile.htm, last retrieved on June 27, 2013.

[7] Ramachandra T V and Gautham Krishnadas. 2012. Prospects and challenges of decentralized wind applications in the Himalayan terrain. *Journal of Energy Bioscience* **3**(1): 1–12.

[8] New M, Lister D, Hulme M, and Makin I. 2002. A high-resolution data set of surface climate over global land areas. *Climate Research* **21**: 1–25.

[9] Climate Research Unit, University of East Anglia, http://www.cru.uea.ac.uk/cru/data/hrg/tmc/, last retrieved on June 10, 2013.

Data from the meteorological observatories at Karwar (for the period 1952–1989), Honnavar (for the period 1939–1989), and Shirali (for the period 1974–1989) obtained from the Indian Meteorological Department, Government of India, Pune, and daily wind data for the period 1990–1993 for these observatories, from the IMD, Bangalore. The primary data obtained by installing a cup counter anemometer with mechanical counter fixed on a 5 m tall guyed masts at Sirsi and Kumta. The anemometer readings were noted down every three hours during the day and mean wind speeds were obtained.

Anemometeres at different meteorological stations are set at different heights levels. The wind speed recorded at each station has to be adjusted to any constant height prior to analysis. The standard height according to the World Meteorological Organization is 10 m above the ground level which is used for the analysis.[10] The horizontal component of the wind velocity varies a great deal with height under the influence of frictional and impact forces on the ground. The most common model for the variation of horizontal velocity with height is given by the logarithmic wind profile equation 2:[11]

$$(V_1/V_2) = (H_1/H_2) \qquad (2)$$

Where V_1 is a wind speed at height H_1 of 10 m above ground level, V_2 is a wind speed at height H_2 above ground level, and is the roughness factor which is determined by substituting the wind speed data obtained with anemometer height in various wind directions, and found to be 0.30. Table 2 gives the month- wise average wind speed in the respective locations.

Figure 2 shows the comparison of mean wind speed in five IMD stations. At higher elevations in the district as well as in coastal regions, mean wind speed is comparatively higher and also in coastal region. Wind speed recorded at Honnavar and Shirali stations are lower which are placed at an elevation of 26 m and 45 m, respectively.

Results and Discussion

Wind profile of Uttara Kannada: Wind speed is seasonal as well as dependent and is, typically, at its maximum during the monsoon. Throughout the year, wind speed varies from 1.9 m/s (6.84 km/hr) to 3.93 m/s (14.15 km/hr) resulting in its minimum in October and maximum in the months of June and July. An annual average wind speed in the district ranges from 2.54 ± 0.04 m/s (9.144 ± 0.144 km/hr) in Haliyal *taluk* to 2.70 ± 0.05 m/s (9.72 ± 0.18 km/hr) in Karwar *taluk*. Figure 3 gives a *taluk*-wise annual average wind speed of the district. Ample amounts of electrical energy can be generated using blowing wind through wind farms which could meet a major fraction of the current electricity demand of the district through decentralized generation.

Seasonal variation of wind speed: Wind speed of Uttara Kannada is quite uncertain and dependent on ambient temperature and pressure, vegetation cover, elevation, topography of the

Table 2 Monthly variation in mean wind speed (km/hr)

Month	Karwar	Kumta	Honnavar	Shirali	Sirsi
January	5.96	5.95	5.95	6.78	6.92
February	6.55	7.76	6.00	6.87	6.88
March	8.15	9.09	6.10	7.03	7.20
April	9.65	9.42	6.20	7.25	8.38
May	11.82	9.87	7.21	7.84	9.09
June	12.01	11.83	7.50	8.30	11.19
July	15.27	13.03	7.72	8.50	18.17
August	11.98	11.54	6.66	7.64	14.19
September	7.44	6.71	4.87	5.56	11.14
October	5.41	6.59	4.55	5.42	8.39
November	4.75	6.29	5.04	6.76	7.72
December	5.04	7.73	6.00	9.51	8.42

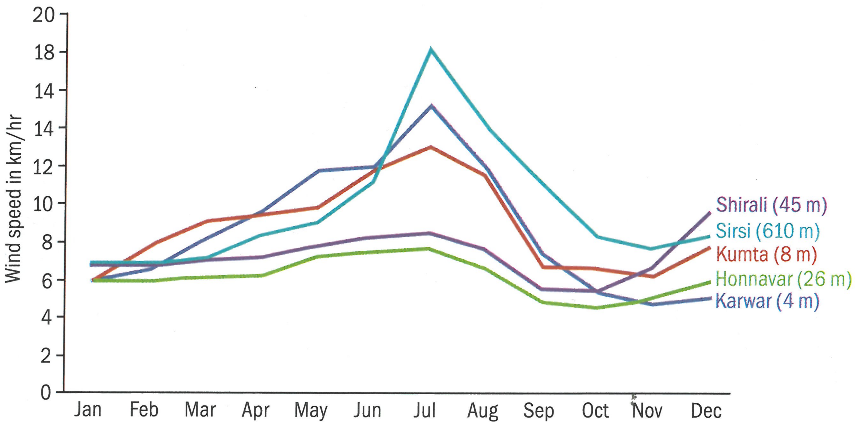

Figure 2 Monthly variations in wind speed

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[10] World Meteorological Organization. 1964. *Guide to Meteorological Instrument and Observing Practices*, 4th Edition. WMO, No. 8, TP. 3 Geneva, Switzerland,

[11] Lysen H. 1983. *Introduction to Wind Energy*, 2nd Edition. Consultancy Services, Wind Energy, Developing Countries (CWD) 82–1, The Netherlands.

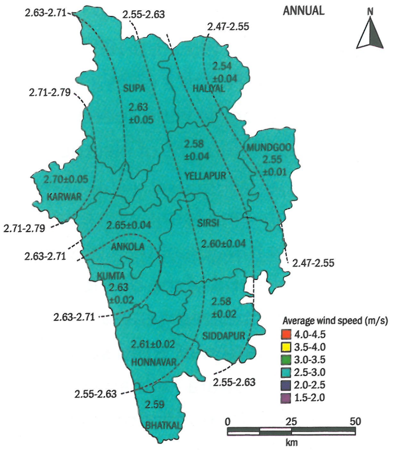

Figure 3 Average annual wind speed of Uttara Kannada

site, etc. Uttara Kannada has a mixed topography, which includes the coastal belt, low and high elevation area with forest cover, as well as planes. From February to May, the district experiences summer with higher temperature in coastal areas (Karwar, Honnavar, Kumta, Bhatkal, and Ankola) and in planes (Mundgod and Haliyal), and a comparatively lower temperature in *taluks* of higher altitudes (Sirsi, Siddapur, Yellapur, and Supa). Figures 4 to 6 give the mean wind speed variability in the district during summer, winter, and monsoon months.

Wind Energy Conversion System (WECS): This is used to extract energy from wind which is in turn converted to mechanical and then electrical energy. Main components of WECS are blades, gears, turbines, generators, and pillars to mount all the equipment at the required height. Wind potential assessment is a prominent pre-installation procedure to assure a perfect selection of site and to harness maximum energy. In order to explore the potential of wind technologies at an increased hub height, hourly surface wind speed measurements at IMD stations were estimated and represented in Figure 7. In almost all the *taluks*, more than 45% of the wind speed is above 2.5 m/s except Honnavar (39.58%). Over 20% of the measured hours crossed 3.5 m/s wind speeds in Karwar, Kumta, and Supa, in which Karwar was the highest (27.38%). These findings along with relatively higher wind speeds (>2 m/s in high elevation zone) observed in seasonal wind profiles (based on CRU data) are indicative of the prospects of small- and medium-scale wind applications in Uttara Kannada which are technically achievable and economically viable.[12] Some of these are listed in Table 3. Wind pump for drawing water is an attractive small-scale wind technology for rural energy needs. The agriculture- and horticulture-intensive zones of Uttara Kannada may benefit by wind pumps that function at low wind speeds. The vertical axis wind turbine (VAWT) that can function in wind speeds as low as 1 m/s could be more effective during low wind speed seasons in the region.[13]

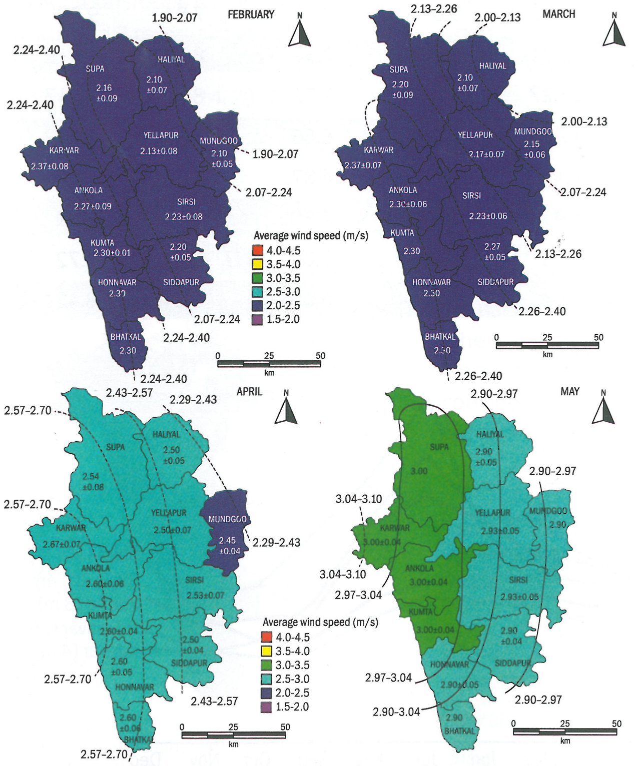

Figure 4 Wind speed variation during summer (m/s)

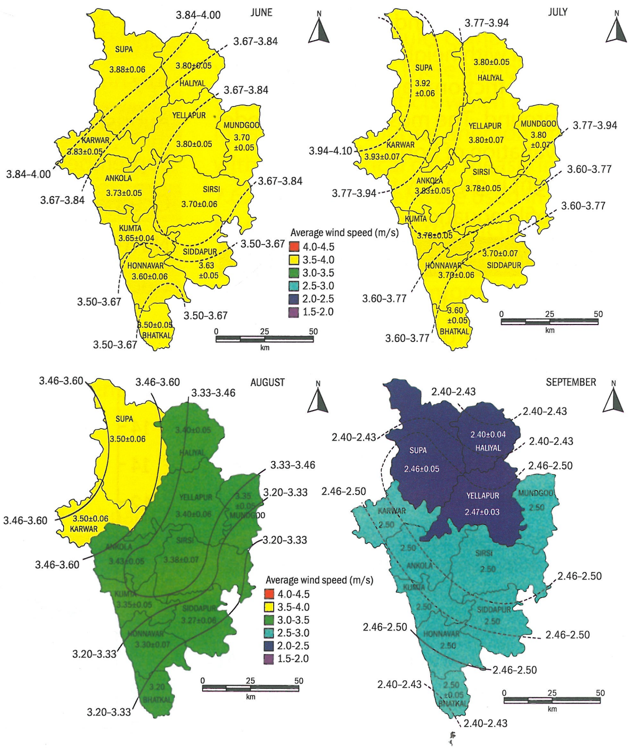

Figure 5 Wind speed variation during monsoon (m/s)

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[12] Cabello M and Orza JAG. 2010. Wind speed analysis in the province of Alicante, Spain: Potential for small-scale wind turbines. *Renewable and Sustainable Energy Reviews* **14**(9): 3185–3191.

[13] Ayhan D and Saglam S. 2012. A technical review of building-mounted wind power systems and a sample simulation model. *Renewable and Sustainable Energy Reviews* **16**(1): 1040–1049.

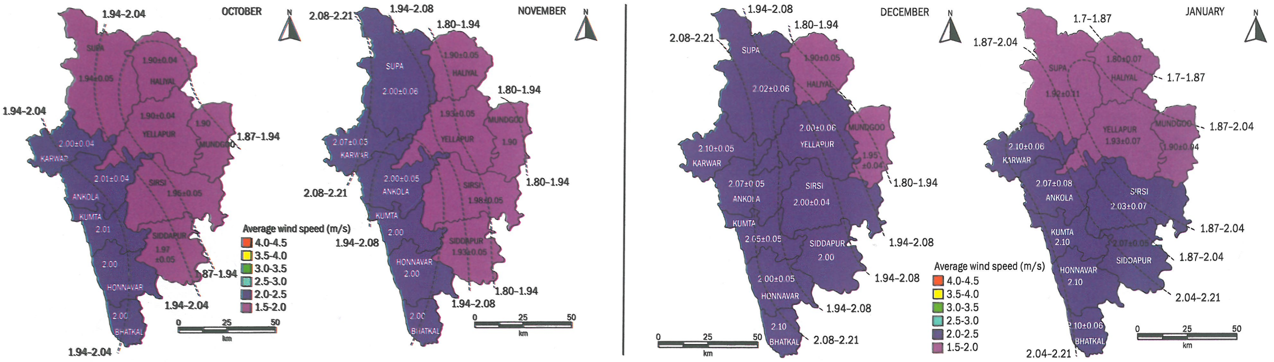

Figure 6 Wind speed variation during winter (m/s)

Reduction in wind speeds and duration could be compensated by hybridizing wind with available alternative resources. Assessment of solar energy potential substantiates that it receives monthly average global insolation (incoming solar radiation) > 5 kWh/m²/day.[14] Hence, wind–solar hybrid systems could be considered for endured energy supply in the region. Small-scale wind turbines could also be used in conjunction with biomass gasifies/diesel generators, especially in remote areas, although diesel is not a clean option.[15] Battery charging based on wind systems supplements the energy requirements during reduced wind speeds.

Techno-economic feasibility: Power harnessed by the WECS can be expressed using expression as given below:

$$P_{avail} = (1/2) \times p \times A \times V^3 \times Cp \quad (3)$$

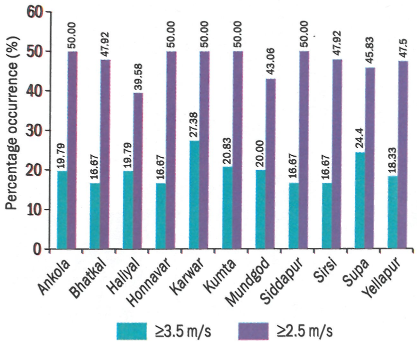

Figure 7 Percentage occurrence of wind speeds

Table 3 Available small-scale wind turbines[16]

Rated power, Prated (kW)	Rotor swept area (m²)	Sub-category
$P_{rated} < 1$ kW	$A < 4.9$ m²	Pico wind
1 kW $< P_{rated} <$ 7 kW	$A < 40$ m²	Micro wind
7 kW $< P_{rated} <$ 50 kW	$A < 200$ m²	Mini wind
50 kW $< P_{rated}$ < 100 kW	$A < 300$ m²	(Not defined)

Wind potential available in the district is estimated using equation 3 given in Table 4.

Where,	P: Wind power	p: Air mass density
	A: Swept area (area of wind flow)	V: Wind velocity
and	C_p: Beltz constant (maximum = 59.3%)	taken as 0.4

Estimation shows that Micro and Mini WEC systems are feasible for the district since minimum and maximum power that can be harnessed ranges from 1,611.49 kW to 2,091.91 kW for the swept area of 30 m² (micro model) and

Table 4 Wind power potential estimation

Month	Wind speed m/s		Power harnessed at A= 30 m² (kW)		Power harnessed at A= 160 m² (kW)	
	Min	Max	Min	Max	Min	Max
January	1.80	2.10	42.69	67.79	228.61	363.03
February	2.10	2.37	67.79	97.44	363.03	521.83
March	2.10	2.37	67.79	97.44	363.03	521.83
April	2.45	2.67	107.65	139.33	576.48	746.14
May	2.90	3.00	178.53	197.64	956.05	1058.40
June	3.50	3.88	313.85	427.57	1680.70	2289.71
July	3.60	3.93	341.52	444.31	1828.92	2379.38
August	3.20	3.50	239.86	313.85	1284.51	1680.70
September	2.40	2.50	101.19	114.38	541.90	612.50
October	1.90	2.01	50.21	59.44	268.87	318.33
November	1.90	2.07	50.21	64.93	268.87	347.69
December	1.90	2.10	50.21	67.79	268.87	363.03
Total			**1,611.49**	**2,091.91**	**8,629.85**	**11,202.58**

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[14] See Footnote 7.

[15] Mathew S, Pandey KP, and Kumar AV. 2002. Analysis of wind regimes for energy estimation. *Renewable Energy* **25**: 381–399.

[16] See Footnote 12.

from 8,629.82 kW to 11,202.58 kW for swept area of 160 m^2 (mini model). Cost of the wind turbines depends on the size, since the transportation and installation difficulties increase with the size. Cost per kilowatt of typical wind turbine ranges from $1,050 to 1,350 in India.[17] As the capacity increases cost/kW decreases, but the size of the turbine and blade length increases. Table 5 gives the cost estimation of the WEC system.

A typical 1 kW turbine can generate electrical energy of 1,000–3,000 kWh per annum depending on the power density of wind.[18] About 70% of the total system cost is only for wind turbine followed by 9% for battery and 4% for civil work.[19,20] Unit cost of electricity generated from WECS varies from USD 0.5 per kWh to USD 0.75 per kWh. However, with technology improvement and system optimization, lower generation costs can be achieved.

Table 5 Cost estimation of WECS

Particulars	**Capacity of the turbine**	
	1.5 kW	10 kW
Manufacturing cost	1,950	13,000
Battery bank	237	1422
Civil work and installation	105	702
Inverter	79	527
Maintenance charge & others	263	1756
Total cost	2,634	17,407
Annual energy generated (kWh)	3,500	30,000
Unit cost of electricity (USD/kWh)	0.75	0.58

Scope for renewable energy exploitation: Decentralized electricity generation through renewable sources is gaining importance due to environmental problems with supply-oriented approaches in planning driven by conventional, centralized power generation and distribution. Dispersed generation based on renewable energy (RE) sources addresses issues related to reliability, voltage-profile management, and the associated economic aspects. Micro grids help in exploiting locally available RE sources, which are also fundamental units of smart grid architecture. However, the region's available energy potential and seasonal variability assessment is the primary step to map the viable regions for power harvesting.

Decentralized generation (DG) is the electric energy production at the distribution side of the power supply network or closer to the load centre itself. Distributed energy generation can play a pivotal role to meet the electricity demand in a reliable and environment-friendly way. Dispersed generation exploits locally available

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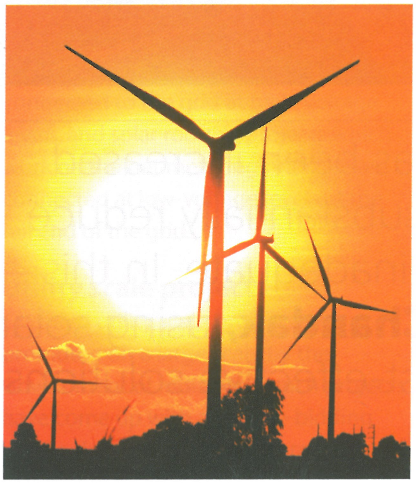
[17] IRENA, Working Paper. 2012. *Renewable Energy Technologies: Cost Analysis Series*. 1(5).

[18] Shandong Huaya Industry Co., Ltd., http://www.huayaturbine.com/te_product_a/2010-12-25/228.chtml, last retrieved on June 28, 2013.

[19] Gökçeka M and Genç MS. 2009. Evaluation of electricity generation and energy cost of wind energy conversion systems (WECSs) in Central Turkey. *Applied Energy* 86: 2731–2739.

[20] Celik AN. 2007. A techno-economic analysis of wind energy in Southern Turkey. *International Journal of Green Energy* **4**: 233–247.

energy resources which will reduce the exploitation of conventional energy resources and also the congestion of generating units. DG-based on RE sources promotes higher penetration of RE resources in the grid. DG plants have the unique advantage of operating in islanded mode (grid isolation mode), during the outage of the central grid. Grid connection can be restored as the grid is energized and electricity can either be transferred to the grid or drawn from the grid. Micro grids are the building units of dispersed generation, which essentially exploit locally available RE resources. Micro grid is an emerging technology which has evolved as smart grids with higher reliability, limited greenhouse gas (GHG) emission, and reduced transmission and distribution (T&D) losses. Smart grid architecture is in the infancy stage which integrates renewable energy-based distributed generation with the conventional system using control strategies over a two-way communication link.



As Karnataka is facing severe energy and peak-power crisis, decentralied solar and wind energy integration to the grid would narrow down the supply–demand gap. Micro grids need to be promoted to meet the community-level demand through locally available energy resources. Wastelands in the interior *taluks* are best suited for grid connected hybrid energy generation, while, micro grids and rooftop generation can be promoted in metropolis and biodiversity-rich Western Ghat *taluks*. The share of energy sources in installed capacity can be decided depending on the variability and geographic location. Renewable energy exploitation with grid integration needs to be promoted through appropriate policy interventions to mitigate the GHG emission through reduced dependence on fossil fuels.

Conclusion

Wind is one of the promising renewable sources which can substitute fast-depleting fossil fuel sources. Wind energy potential in the district could meet the electrical energy consumption in the domestic sphere through decentralized generation and wind turbine driven pumps and can even decrease the dependency on grid supply for irrigation. Districts experience an annual average wind of 2.5 m/s to 3.0 m/s in all *taluks* which opens a wide range prospects for WECS installation. Hybridizing wind energy systems with other locally available resources (such as solar and bio energy) would assure a reliable energy supply for domestic and irrigation demands. Small- and medium-scale WEC systems are feasible for community-level installations which lead to a massive reduction in carbon dioxide emission. EF

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