Potential Assessment and Decentralized Applications of Wind Energy in Uttara Kannada, Karnataka

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Abstract- Wind is one of the viable renewable energy resources with a promising potential of feasible alternative to fast depleting fossil fuels. Wind mills for grinding grains and pumping water have been used in rural areas since centuries. It can be advantageously harnessed in a decentralized manner for various applications in remote localities and rural areas. Water pumping through decentralized energy promotes multiple cropping, which helps in the provision of local employment and also the development of a region. Wind resource assessment is the primary step towards understanding the local wind dynamics and evaluating available potential of a region. Climatic average datasets of meteorological variables containing wind speed data for the period between 1961 and 1990 (compiled from various sources) were used for the potential assessment of wind speed in Uttara Kannada district, Karnataka State, India. These were validated with the ground data of meteorological observatories at Karwar, Honnavar and Shirali which were obtained from the Indian Meteorological Department, Government of India, Pune. Analyses showed seasonal variations of wind speed in the region. Wind speed varies from 1.9 ms^{-1} (6.84 km/hr) to 3.93 ms^{-1} (14.15 km/hr) throughout the year with minimum in October and maximum in June and July (Monsoon). The district experiences mean annual wind speed of 2.5 ms^{-1} to 3.0 ms^{-1} in all taluks, fostering prospects for Wind Energy Conversion System (WECS) installation. Decentralized electricity generation from WECS and hybridizing wind energy systems with other locally available resources (solar, bioenergy etc.) would assure the supply of reliable energy to meet the energy demand of the respective regions.

Keywords- Windmill, mean wind speed, decentralized generation, hybridization of resources, Wind Energy Conversion System (WECS).

1. Introduction

Energy from wind is one of the oldest energy harvesting technologies that is being used for centuries. Winds are due to the rotation of the earth and temperature gradient in the atmosphere. The total kinetic energy produced by air movement in the atmosphere is estimated to be about 3 x 10^5 kWh per annum or about 0.2% of the total solar energy reaching the earth surface. Theoretical estimates indicate that about 30 trillion kWh energy or more than 30% of the world's present annual energy consumption can be met from wind resources [1]. Hourly wind speed of 7.1 ms^{-1} (25.6 km/h) has power of about 200 watts per square meter of the area swept by the windmill. Nearly 35% of this power gets converted to electricity by a typical wind energy conversion units. The kinetic energy of air can be transformed to mechanical and then to electrical form of energy using fans, gears, turbines and a generator system. In the current scenario, windmills are electricity harvesting technologies which account for more than 280 GW 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 tentative, by optimizing the blade area, maximum energy can be extracted for any particular wind speed at a given place [3].

$$P = (1/2)^* \rho^* A^* V^3 \qquad (1)$$

where, P – Wind power; ρ – Air mass density; A – Swept area (area of wind flow) and V – Wind velocity

The annual mean wind speed at a location is the basic parameter required to quantify wind resource potential. Table 1 categorizes a region based on the annual mean wind speed considering the likelihood of mechanical or electrical energy extraction using wind turbines. [4].

Table 1. Wind resource potential depending on annual mean wind speed

Annual average wind speed @ 10m Ht. (ms^{-1})	Wind potential
less than 4.5	Lower
4.5 to 5.4	Moderate
5.44 to 5.7	Good to Very Good
more than 5.7	Exceptional

Uttara Kannada district, located in the west coast and in Western Ghats region of Karnataka state, is blessed with good wind potential. Decentralised electricity generation from wind resources would help in meeting the local energy demand, as electricity supply in rural areas is unreliable and inadequate. Wind energy potential in the district can cater to the regional electricity demand through wind energy conversion system (WECS), avoiding plenteous greenhouse gas (GHG) emission through burning of fossil fuels. It can be harnessed locally in a decentralized manner in remote rural localities for applications such as water pumping for crops and plantations. Wind driven electricity generation can be utilized as a standalone systems and also to supplement the regional grid supply during peak hours. In densely populated coastal taluks (Karwar, Ankola, Kumta, Honnavar and Bhatkal) in Uttara Kannada District, decentralized electricity generation would help in meeting the irrigation, domestic and local industrial (agro processing- cashew, areca nut etc.) electricity requirement. WECS can be hybridized with solar, biomass or any other available local energy resource to provide reliable power for both domestic and industrial loads as wind flow is more during monsoon which would compensate for lower solar insolation and reduced dry biomass availability [5].

1.1. Wind Resource Assessment

Wind resource assessment aids in understanding the local wind dynamics of a region. In order to make precise estimate of wind resource of an area, wind data measurements of at least 10 years is essential; however wind data of a smaller duration would still provide an overview of the potential [6]. GIS (Geographic information system) based spatial assessment of wind resources helps in estimating the potential in the vicinity of wind monitoring stations. Knowledge of variations (spatial and temporal) in wind speed will help in economically viable installation of wind energy conversion system bearing disturbance free operation. It will also provide fundamental information about seasonal changes in wind speed which contributes to wind power potential [7]. A knowledge of constant annual average wind speed facilitates improvement of wind power harvesting plants and assures pre-decided annual generation. Wind flow developed due to the differential heating of earth is modified by its rotation and further influenced by local topography. This results in annual (year to year), seasonal, synoptic (passing weather), diurnal (day and night) and turbulent (second to second) changes in wind pattern [8]. Increased heat energy generated due to industries and escalating population in urban areas result in heat islands which affects the wind flow as well.

2. Objective

The focus of the present study is to assess seasonal and taluk wise (an administrative unit to implement decentralized projects in India) wind potential in Uttara Kannada district and assess technical and economic feasibility of wind energy harvesting options, to meet the regional electricity demand in a decentralized way.

3. Study Area, Data and Method

3.1. Study Area

Uttara Kannada is the fourth largest 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 14,36,847, and about 80% of the people live either in rural areas or in semi urban areas. The district is located in the Western Ghat ranges amongst abundant flora and fauna. More than 75% of the total area is covered by forest and it lies along 140 km of costal belt [9]. Fig. 1 illustrates the topographic undulations of the region. The district lies in three distinct zones based on the topography namely narrow and flat coastal zone, abruptly rising ridge zone, and elevated flattened eastern zone. Taluks in the coastal zone are densely populated with coconut and arecanut plantations. Ridges constitute the main range of Western Ghats, which runs north to south, parallel to the coast. Planes in the east joins the Deccan plateau. Taluks in the coastal region are Karwar, Ankola, Kumta, Honnavar and Bhatkal. Similarly, taluks in ridge regions are: Supa, Haliyal, Yellapur, western Sirsi, and western Siddapur. Eastern plane zone includes Mundgod, Haliyal, 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/].

Uttara Kannada has a mixed topography where the elevation ranges from sea level to 1300 m above mean sea level. Since the wind velocity is dependent on elevation, wind speed is found more in coastal and elevated taluks than on planes. Fig. 1 shows the variation of elevation in the district.

3.2. Data and Method

3.2.1. Synthesized wind data:

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

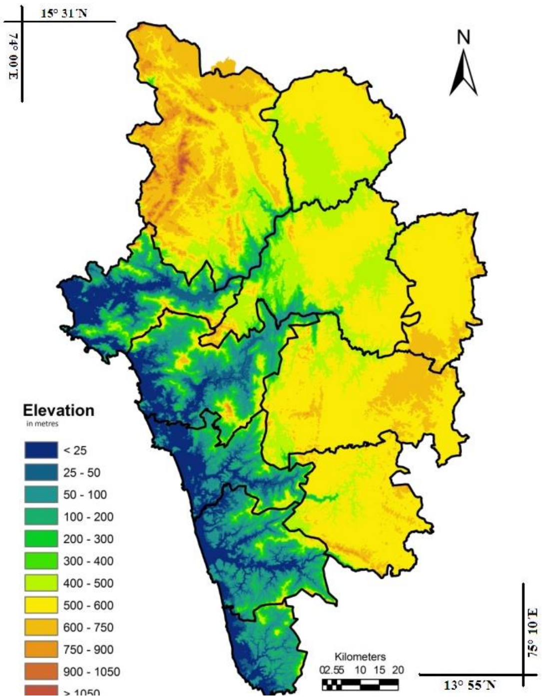

Fig. 1. Digital Elevation Model of Uttara Kannada, Karnataka.

There are various wind speed datasets available of different time periods from sources such as National Aeronautical and Space Agency (NASA), Surface Meteorology and Solar Energy (SSE), National Oceanic and Atmospheric Administration (NOAA-CIRES), and Climate Research Unit (CRU). However, previous studies clearly show that CRU data are reliable and closer to the Indian Meteorological Department (IMD) surface data, and hence, it has been used in the present study [10]. CRU at the University of East Anglia maintains a record of climatic average datasets of meteorological variables which contains wind speed data for the period between 1961 and 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 into 10'×10' (ten minute spatial resolution) elevation grids where every cell with more than 25% land surface represents the average elevation of 100~400 GLOBE elevation points. Those below 25% are considered water bodies. 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, whereas, proximity of a region to the measuring station improves the reliability of the interpolated data. During interpolation, inconsistent data were removed appropriately. This technique was identified to be steadfast in situations of data sparseness or irregularity [11]. The 10'×10' spatial resolution wind speed data as climatic averages were available for all global regions (excluding Antarctica) [12].

Data from Indian Meteorological Department (IMD) stations located in the district were also acquired for respective locations to compare with CRU dataset. There are 4 IMD stations in the districts which are listed in Table 2. Cup counter anemometers having hemispherical cups measuring 7.62 cm in diameter had been used in IMD observatories until 1973. These anemometers were substituted by 3 cup anemometers with 127 mm diameter conical cups during 1973-1979. These were placed at l0 m above ground in an open terrain in conformity with international practice.

Data from IMD stations located at Karwar (for the period 1952-1989), Honnavar (for the period 1939-1989) and Shirali (for the period 1974-1989) were obtained from the Indian Meteorological Department, Government of India, Pune. Daily mean wind velocity data for the period 1990-2012 were also obtained from the Indian Meteorology Department (IMD) of Bangalore for these observatories. Field data was also obtained by installing a cup counter anemometer with mechanical counter fixed on 5 m tall guyed masts at Sirsi and Kumta. The anemometer readings were recorded every 3 hours during the day and mean wind speeds were computed for those observations.

Table 2. IMD stations in Uttara Kannada

IMD stations	Latitude	Longitude	Elevation (m above mean Sea level)
Karwar	14° 47'	74° 08'	4
Kumta	14° 26'	74° 25'	8
Honnavar	14° 17'	74° 27'	26
Bhatkal (Shirali)	14° 05'	74° 32 '	45
Sirsi	14° 62'	74° 85'	610

Due to topographical limitations, anemometers at different meteorological stations are set at various height levels. The wind speed recorded at each station has to be calibrated to a constant height prior to analysis. The standard height according to the World Meteorological Organization is 10 m above the ground level which has thus been used for the analysis [13]. The wind speed greatly varies with the height, where the horizontal component of the wind velocity varies under the influence of frictional and impact forces on the ground. The variation of horizontal wind velocity with height is given by the logarithmic wind profile equation 2 [14],

$$(V_1/V_2) = (H_1/H_2)^{\alpha} \qquad (2)$$

where V_1 and V_2 are wind speeds at height H_1 (10 m above ground level) and H_2 (at measured level) and α is the roughness factor which is determined by substituting the wind speed data obtained with anemometer height in various wind directions, and it has been obtained as 0.30. Table 3 gives the month wise average wind speed in the respective locations. Fig. 2 gives the comparison of mean wind speeds in five IMD stations.

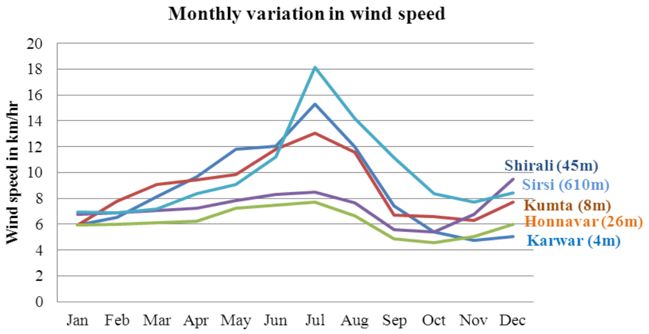

Fig. 2. Variability in monthly wind speeds

Table 3. Monthly variation in mean wind speed (km/hr) [3]

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

At higher elevations and in coastal region, mean wind speed is comparatively higher than in the other parts of the district. Wind speed recorded at Honnavar and Shirali stations, which are located at an elevation of 26 m and 45 m respectively, are lower

4. Results and Discussion

4.1. Wind profile of Uttara Kannada

Wind speed is seasonally dependent which is normally highest during the monsoon season. Wind speed varies from 1.9 ms^{-1} (6.84 km/hr) to 3.93 ms^{-1} (14.15 km/hr) throughout the year with minimum in October and maximum in June and July months. Annual average wind speed in the district ranges from 2.54 ± 0.04 ms^{-1} (9.144±0.144 km/hr.) in Haliyal taluk to 2.70 ± 0.05 ms^{-1} (9.72±0.18 km/hr.) in Karwar taluk. Fig. 3 gives the talukwise annual average wind speed of the district. Ample amount of electrical energy can be generated using wind through wind farms which could meet the major fraction of the current electricity demand of the district through decentralized generation.

4.2. Seasonal Variation of Wind Speed

The speed of wind is quite uncertain and is dependent on ambient temperature and pressure, vegetation cover, elevation, and the topography of the site. Uttara Kannada has a mixed topography that constitutes the coastal belt, low and high elevation areas with forest cover, and also planes. From February to May, the district experiences summer with higher temperature along the coasts (Karwar, Honnavar, Kumta, Bhatkal and Ankola) and in planes (Mundgod and Haliyal), whereas, it experiences comparatively lower temperature in taluks of higher altitudes (Sirsi, Siddapur, Yellapur and Supa). Fig. 3 depicts the average annual wind speed in the district along contours. Wind speed varies from 2.5 ms^{-1} (9 km/s) to 3 ms^{-1} (10.8 km/s) throughout the district annually. The coastal regions (Karwar, Kumta, Ankola and Honnavar) experience higher wind speed ranging from 2.63 ms^{-1} to 2.79 ms^{-1}. Taluks at higher altitudes (Sirsi, Siddapur and Yellapur) witness comparatively lower wind speeds ranging from 2.55 ms^{-1} to 2.63 ms^{-1} and the planar regions (Haliyal and Mundgod) experienc lower wind speeds ranging from 2.47 ms^{-1} to 2.55 ms^{-1}.

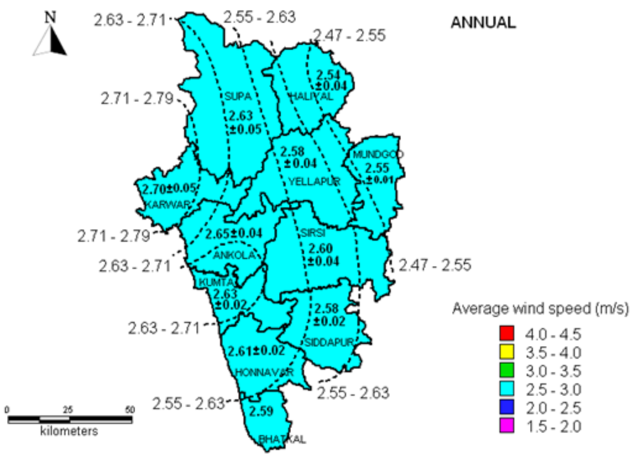

Fig. 3. Average annual wind speed of Uttara Kannada

Fig. 4 to 6 provide the comparisons of mean wind speed variability in the district during summer (February to May), monsoon (June to September) and winter (October to January) seasons. In February and March, wind speed varies from 2 ms-1 to 2.5 ms-1 throughout the district. Since the climate changes from winter to summer, wind speed is less during the early days of summer, which increases during the end of March. In April, excluding Mundgod (2 ms-1 to 2.5 ms-1), all other taluks experience higher wind speeds ranging from 2.5 ms-1 to 3 ms-1 annually. During monsoons, the district experiences higher wind speeds ranging from 3.5 ms-1 to 4 ms-1 which decreases as winter approaches.

Highest annual average wind speed is experienced in June and July months (3.5 ms-1 to 4 ms-1). In August, all the taluks experience wind speeds ranging from 3 ms-1 to 3.5

ms-1 excluding Supa and Karwar (where wind speed ranges from 3.5 ms-1 to 4 ms-1). Northern part of the district witness lower wind speed of 2 to 2.5 ms-1 than the southern region (2.5 to 3 ms-1).

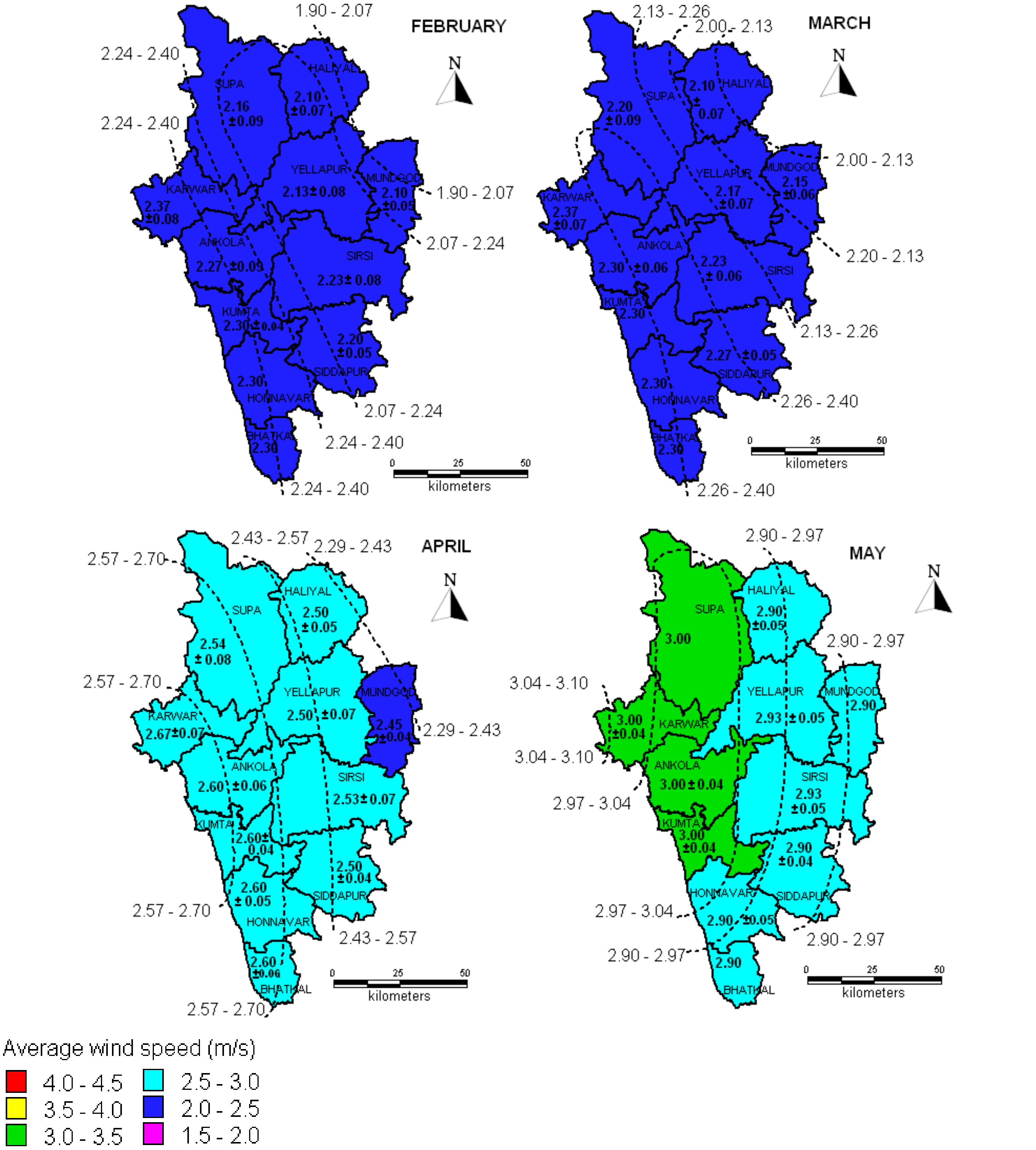

Fig. 4. Wind speed variations during summer (February to May)

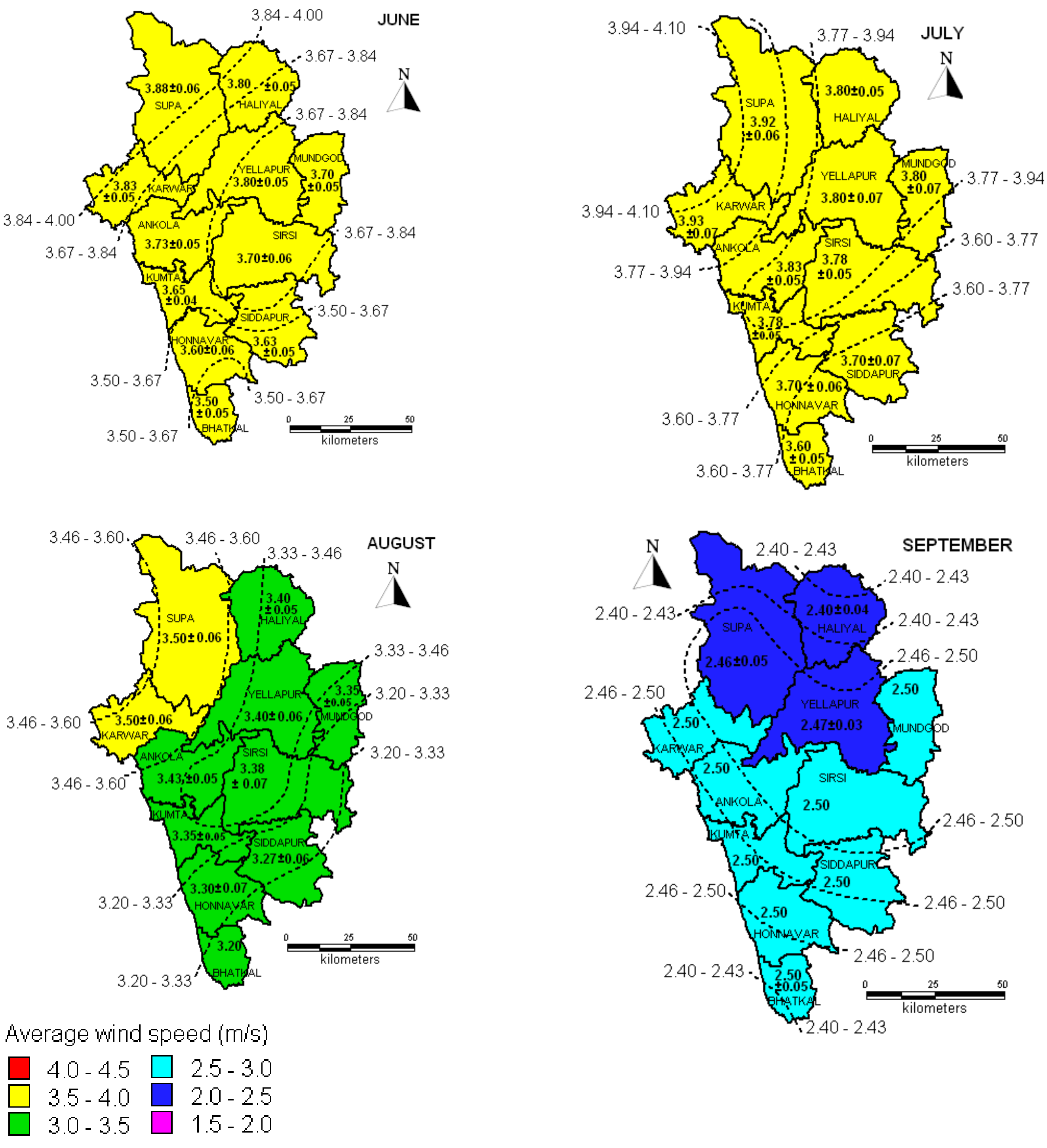

Fig. 5. Wind speed variations during monsoon (ms^{-1})

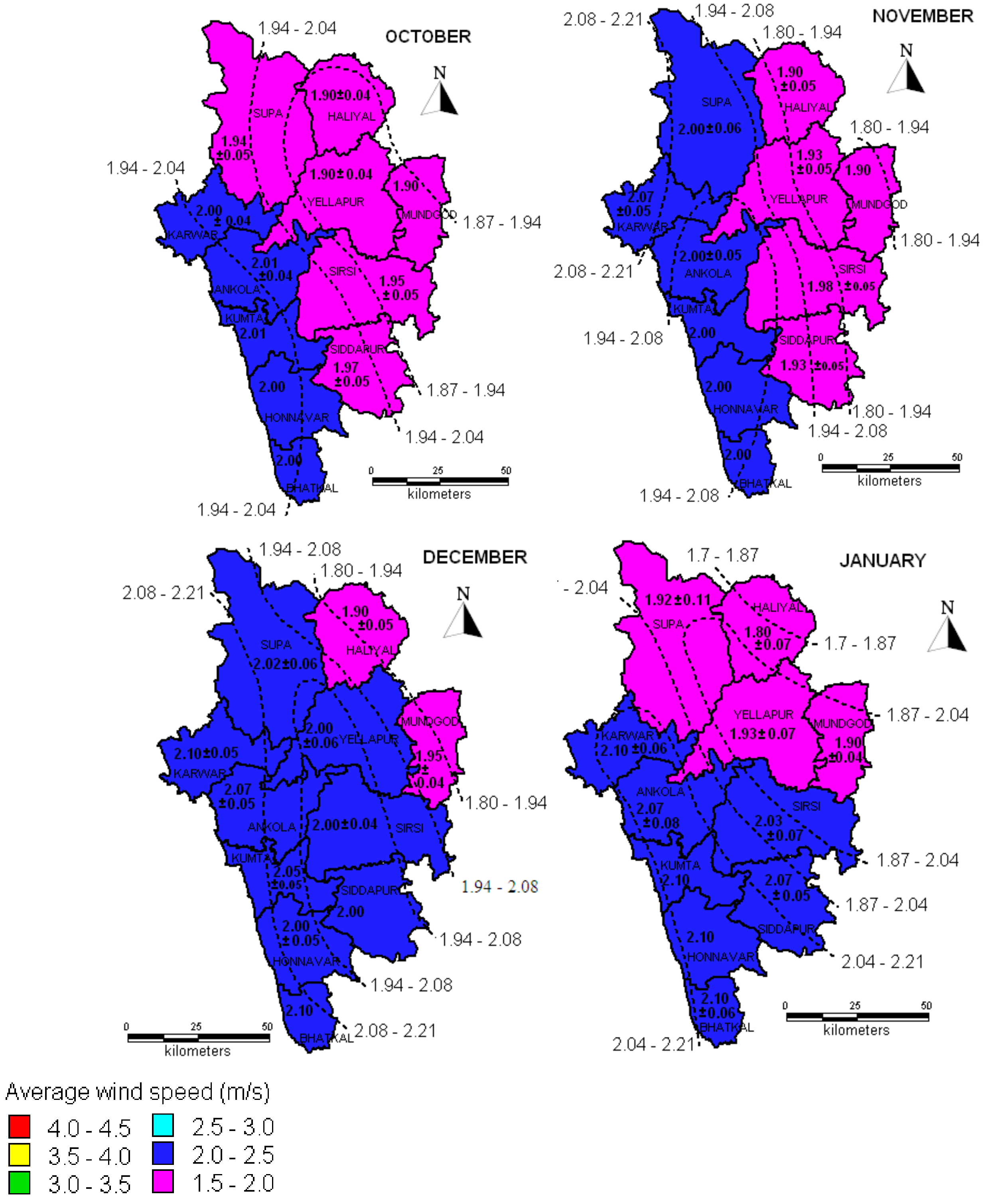

Fig. 6. Wind speed variations during winter (ms^{-1})

The district experiences lower wind speeds during winter season which will be less than 2.5 ms^{-1} in all the taluks. Wind speed in the coastal taluks is more during October and November than in the planes and higher altitude regions. In December, except Mundgod and Haliyal (where wind speed ranges from 1.5 ms^{-1} - 2 ms^{-1}), all other taluks witness wind speeds ranging from 2 ms^{-1} to 2.5 ms^{-1}. In January, northern part of the district experiences lower wind speeds of 1.5 ms^{-1} to 2 ms^{-1} than the southern region (bearing wind speeds ranging from 2 to 2.5 ms^{-1}).

4.3. Wind Energy Conversion System (WECS)

Wind Energy Conversion System (WECS) uses wind to convert mechanical energy into electrical energy. Main components of WECS are blades, gears, turbine, a generator and a pillar to mount all the equipment at the required height. Wind potential assessment is a prominent pre-installation procedure to assure perfect selection of a site 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 Fig. 7. In almost all the taluks, more than 45% of the wind speeds are above 2.5 ms^{-1} except for Honnavar (39.58%). Over 20% of the measured hours had wind speeds greater than 3.5 ms^{-1} in Karwar, Kumta and Supa, in which Karwar accounted for the highest (27.38%). These findings, along with relatively higher wind speeds (> 2 ms^{-1} in high elevation zone) observed in seasonal wind profiles (based on CRU data), foster the prospects of small and medium scale wind applications in Uttara Kannada which are technically achievable and economically viable [15]. Some of these are listed in Table 4. 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 could get benefited by wind pumps that function at lower wind speeds. The Vertical Axis Wind Turbine (VAWT) that can function at wind speeds as low as 1 ms^{-1} could be more effective during low wind speed seasons in the region [16]. Reduction in wind speeds and duration could be compensated by hybridizing wind with available alternative resources. Assessment of solar energy potential substantiates that the district receives a monthly average global insolation (incoming solar radiation) of greater than 5 kWh/m^2/day [10]. Hence, wind–solar hybrid systems could be considered for an enduring energy supply in the region. Small-scale wind turbines can also be used in conjunction with biomass gasifier/diesel generators especially in remote areas although diesel is not a clean option [17]. Battery charging based on wind systems supplements the energy requirements during reduced wind speeds.

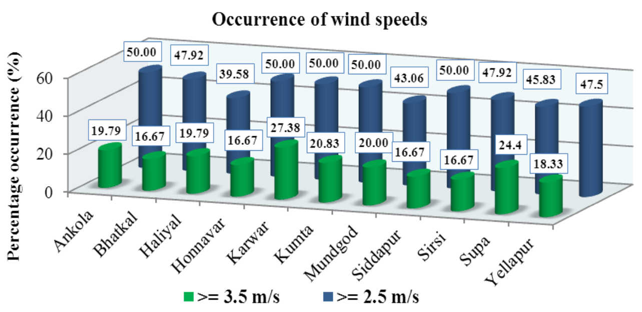

Fig. 7. Percentage occurrence of wind speeds

4.4. Techno-economic Feasibility

Power of the wind turbine is directly proportional to the variables' wind speed and swept area. Maximum power obtained from any WECS is limited to 59% of the total kinetic power available in wind which is given by Betz constant (Cp). Power harnessed by WECS can be obtained using the expression given below;

$$P_{avail} = (1/2)^* \rho^* A^* V^3 {}^* C_p \quad (3)$$

where, P_{avail} – wind power, ρ – air mass density, A – swept area (area of wind flow), V – wind velocity and C_p – Betz constant (maximum = 59.3%) assumed as 0.4 (40%)

Table 4. Available small-scale wind turbines [15]

Rated power output, P_o (kW)	Rotor swept area, A (m^2)	Turbine Category
P_o < 1 kW	A < 4.9	Pico
1 kW < P_o < 7 kW	4.9 < A < 40	Micro
7 kW < P_o < 50 kW	40 < A < 200	Mini
50 kW < P_o < 100 kW	200 < A < 300	(Not defined)

Analysis shows that wind power potential ranges from 42.69 kW to 341.52 kW in the district considering lower wind speeds in January and July respectively. However the annual wind power potential in the district varies from 1611.5 kW to 2091.9 kW for minimum and maximum wind speeds respectively (A=30 m^2). By considering larger swept area, power generation can be increased although it requires more area for installation of turbines. Estimation shows that Micro and Mini WEC systems are feasible for the district since the decentralized generation is more reliable and efficient.

Cost of the wind turbines depend on their size because the transportation and installation difficulties increase with the size. Cost per kilowatt of a typical wind turbine ranges from USD 1,050 to 1,350 in India [18]. 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 WECS system.

Table 5. Cost estimation of WECS

Particulars	Capacity of the turbine	
	1.5 kW	10 kW
Manufacturing cost	1950	13000
Battery bank	237	1422
Civil work and installation	105	702
Inverter	79	527
Maintenance charge & other costs	263	1756
Total cost	2634	17407
Annual energy generated (kWh)	3500	30000
Unit cost of electricity (USD/kWh)	0.75	0.58

A typical 1 kW turbine can generate electrical energy of 1,000- 3,000 kWh per annum depending on the power density of wind [19]. About 70% of the total system's cost is only for wind turbine followed by 9% for battery and 4% for civil work [20, 21]. Unit cost of electricity generated from WECS varies from USD 0.5 per kWh to USD 0.75 per kWh. However, with technology improvements and optimizing the system, lower generation cost can be achieved.

4.5. Decentralized Wind Energy Option for the District

Uttara Kannada has a mixed topography which includes coastal areas (Kumta, Ankola, Karwar, Honnavar, Bhatkal taluks), high elevated regions or Sahyadri (Western Ghat region), and planes in the eastern part (Haliyal and Mundgod taluks). Coastal taluks and hilly areas (Sirsi, Siddapur, Yellapur and Supa) experience higher wind speed compared to plane regions. From Fig. 7, it is evident that in coastal taluks, occurrence of wind speed ≥3.5 ms^{-1} (and/or ≥2.5 ms^{-1}) is higher than other taluks in the district. Installation of

WECS near the coastal belt of the district would be optimum because it has the highest potential. Since the wind turbines need a larger disturbance free area, the coastal belt from Karwar to Bhatkal is best suited for its installation. This also adds attraction to the natural scenic beauty of the region. Also, with improvement in technology and optimizing the system, a lower generation cost can be achieved.

Regions at higher altitude in the district (Sahyadri) experience high wind speeds particularly in monsoon, which can compensate for the lower solar insolation. Since these regions lie in Western Ghats which shelters various flora and fauna, site selection for wind energy systems must be done without any ecological disturbance. Micro and pico level installation or hybridizing wind resource with solar and biomass is a technically feasible and economically viable option in this region. Planes also have enough potential for wind power which could meet the local energy demand particularly through wind pumps and mills. Wind pumps can reform irrigation practices by reducing the electricity bills.

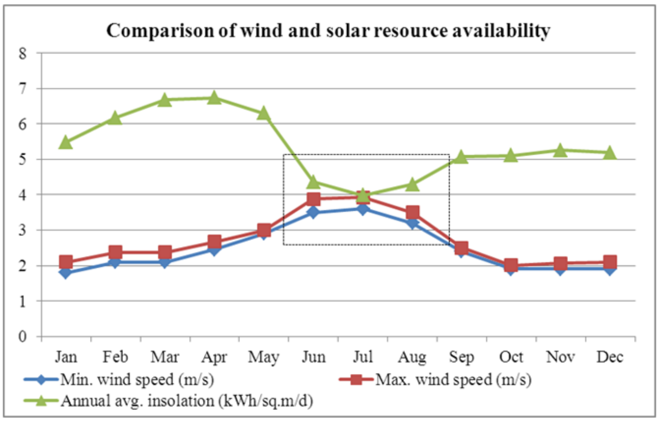

Fig. 8. Comparison of solar and wind energy potentials

Table 6. Wind power potential estimation

Month	Wind speed (ms^{-1})		Power harnessed at A= 30 m^2 (kW)		Power harnessed at A= 160 m^2 (kW)	
	Min	Max	Min	Max	Min	Max
Jan	1.80	2.10	42.69	67.79	228.61	363.03
Feb	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	1680.7	2289.71
July	3.60	3.93	341.52	444.31	1828.9	2379.38
Aug	3.20	3.50	239.86	313.85	1284.5	1680.70
Sept	2.40	2.50	101.19	114.38	541.90	612.50
Oct	1.90	2.01	50.21	59.44	268.87	318.33
Nov	1.90	2.07	50.21	64.93	268.87	347.69
Dec	1.90	2.10	50.21	67.79	268.87	363.03
Total			1611.5	2091.9	8629.8	11202.58

Fig. 8 compares the month wise availability of wind and solar resources in the district. It represents that during monsoon (June to September), lower insolation availability could be compensated by higher wind speed, thus promising reliable generation. Integrated energy system consisting of wind and solar resources, and also having biomass gasifier with generator meet the local electricity demand reliably and efficiently without polluting the environment.

5. Conclusion

Wind is a very promising renewable energy resource for decentralized electricity generation which can substitute the fast depleting fossil fuels. Wind energy potential in Uttara Kannada district can meet the electrical energy consumption for domestic demand through decentralized generation and wind turbine driven pumps can decrease the dependency on grid supply for irrigation. The district experiences mean annual wind speed ranging from 2.5 to 3.0 ms^{-1} in all the taluks which opens up wide range opportunities for WECS installation. Hybridizing wind energy systems with other locally available resources (solar and biomass) would assure reliable energy supply for domestic and irrigation demands. The estimate shows that 1600 kW to more than 11000 kW can be harvested through WECS. Small and medium scale WECS are technically feasible and economically viable for being hybridized with solar and biomass plants to meet the community level domestic and irrigation load throughout the year. Such systems are environmental friendly, reliable, efficient and sustainable which also leads to reduction of abundant amount of carbon dioxide emission.

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