Because lignite can generate significant amount of liquid hydrocarbons by simple heating in inert atmosphere (pyrolysis), it can be used as a good source of liquid fuel.

We have presented here the results of a reconnaissance study carried out on a limited number of samples. The results indicate moderate potential for conversion of lignite to liquid fuel. Nevertheless, the encouragement received from the preliminary study justifies a more comprehensive and detailed study of the Rajasthan lignite for hydrocarbon generation. Out of the 70,000 sq. km area where Tertiary formations occur, only about 800 sq. km has been explored. There is, thus, tremendous scope for further exploration of lignite in the state both at shallow and at deeper levels. With total lignite reserves of 4225 million tonnes, Rajasthan occupies the second position in India as far as lignite reserves are concerned. The mineable reserves in the Giral and Barsingsar area are of the order of 130 MMT. At present, it is not possible to make an estimation of the total oil potential of lignite in Rajasthan. Nevertheless, based on preliminary studies, assuming an average yield of 90 kg of oil/tonne of lignite, the potential for oil in the Giral and Barsingsar area alone would be about 12 MMT.

Despite significant potential as a source of unconventional oil, the conversion of coal/lignite entails challenges that include environmental concerns and economics of scale. As lignite is a poor-quality coal, extracting energy from it creates particularly high emissions of carbon dioxide. Also, coal-to-liquid fuel plants involve multi-billion dollar investment that necessitates a long-term and large-scale perspective for investors. While these issues are important, a discussion on them is beyond the scope of the present communication.

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Power generation using wind energy in northwest Karnataka, India

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On the backdrop of climate change scenario, there is emphasis on controlling emission of greenhouse gases such as CO_2. Major thrust being seen worldwide as well as in India is for generation of electricity from renewable sources like solar and wind. Chitradurga area of Karnataka is identified as a suitable location for the production of electricity from wind turbines because of high wind-energy resource. The power generated and the performance of 18 wind turbines located in this region are studied based on the actual field data collected over the past seven years. Our study shows a good prospect for expansion of power production using wind turbines.

Keywords: Power generation, plant load factor, turbines, wind energy.

THE concept of harnessing wind energy to generate electricity is gaining momentum around the world. The worldwide installed wind energy capacity was around 194.3 GW by the end of 2010 (ref. 1). In India, the installed wind energy capacity is over 19 GW (ref. 2) and the country ranks fifth in the world. The cost of electricity produced from wind farms in India is at par with the cost of grid electricity. According to the Ministry of New and Renewable Energy guidelines[3], the buyback rate for electricity from wind farms is in the range Rs 3.39/kWh–Rs 5.31/kWh depending on each state, compared to Rs 3.90/kWh–Rs 5.90/kWh for grid electricity. More importantly, using wind to generate electricity emits much less harmful greenhouse gases than during the combustion of fossil fuels that are generously used to generate electricity. It is estimated that there is a saving of 300–500 tonnes of CO_2 emission from a wind farm of 4 MWh electricity generation capacity in India[4].

Currently, about 190 GW electricity generation capacity is installed in India[5], about 11.7% of which is from renewable sources of energy, excluding hydroelectricity. Karnataka has an installed electricity generation capacity of about 11.8 GW (ref. 6) at the end of 2011, out of which about 1.9 GW is from wind energy. Performance assessments of these wind farms are necessary for understanding the wind–energy relationship and possible future improvement in their performance. Most of the wind farms set up in Karnataka are privately owned. Here we

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report the performance of one such privately owned wind farm using 7 years of collected datasets.

There are many wind farms in Chitradurga area in Karnataka. The wind power density in this area is over 200 W/m^2 (ref. 7). The wind farm sites here are about 650 m above sea level. A photograph of the location with some of the wind turbines is shown in Figure 1. The specifications of the turbines are listed in Table 1.

The performance of wind turbines or wind electric generators (WEGs) in this wind farm is studied based on the monthly generation data for several years. The period over which the data are collected is from April 2005 to March 2012.

The annual electricity generated over the period April 2005–March 2012 for all WEGs is plotted in Figure 2. The variation in the power generated among the 18 WEGs under consideration is within 100 MWh (about ± 8% of the mean). This variation could be due to their location on the hill and the strength of wind at that location.

Figure 3 shows monthly variation of electricity generated by WEG#9 during all the years from 2005/06 through 2011/12. The high-wind months of May–September are associated with the monsoon season. Electricity production from WEGs is also high during these months. The electricity generated during monsoon months (June–September) can be about 4–6 times higher than that during non-monsoon months (November–March).

Figure 1. Wind farm near Chitradurga.

Table 1. Specifications of the installed wind turbines

Specification	Value
Rated power	230 kW
Height of the tower	48 m
Length of the blades	15 m
Sweep area	706.858 m^2
Cut-in wind speed	2.5 m/s
Cut-off wind speed	25 m/s
Highest rpm	50
Tip speed ratio	9.42–3.14

Efficiency of a wind mill is measured by a performance coefficient metric. The plant load factor (PLF) or the performance coefficient of the wind farm is defined as the ratio of the extracted energy by all WEGs to the available energy in the wind. It is defined as

$$\text{PLF}(\%) = \frac{\text{Power output from all WEGs}}{\text{Power available in the wind}} \times 100$$

$$= \frac{P}{\sum_{i=1}^{N}(1/2\rho\pi r_i^2 V_i^3)} \times 100, \quad (1)$$

where ρ is the density of air (kg/m^3), r the radius (m) of the circle the rotor makes when rotated, V the velocity of air (m/s), N the number of WEGs in the farm and P the measured power output (W) from all WEGs. In other words, PLF is the efficiency with which WEGs have performed in the available wind energy to generate electricity. The annual average PLF of all the 18 WEGs in the farm is shown in Figure 4 for the years under consideration. The wind farm is performing at an efficiency of ~ 35% over the past 7 years, which is comparable to or higher than the reported wind farm performance in the country[8,9]. The monthly PLF for the year 2011–12 is plotted in Figure 5. During strong-wind months of May–September, PLF is higher than 50%, reaching the highest value of 70% in July. The machine availability during these months was over 99.5% and grid availability was close to 99%. Machine availability is indicative of WEG reliability and is impacted by design, local operating environment and wind farm maintenance.

The mechanical power of a WEG is a function of the design parameters of the rotor and the wind inflow velocity. For a given WEG design, the performance is known to depend on the tip speed ratio (TSR)[10]. TSR is defined as the ratio of the speed of the rotor tip to the wind speed[11].

$$\text{TSR} = \frac{\text{Velocity of the rotor tip}}{\text{Wind speed}} = \frac{v}{V} = \frac{\omega r}{V} = \frac{2\pi fr}{V}, \quad (2)$$

where r is the rotor blade length (m) and f the rotational frequency. If TSR is too low, too much wind passes between the blades without getting harnessed for power generation. On the other hand, if TSR is too high, the wear and tear on the blade tip and other mechanical parts of the turbine will be high. Also, when a blade rotates in the air it leaves behind turbulence and if the next blade rotates through this turbulence, it will not extract power from the wind efficiently. Hence it is necessary for the rotor blades to turn at a speed that is chosen by the optimum TSR. The optimal value of TSR for a wind turbine is given by the equation

$$\text{TSR} \approx 4\pi/n, \quad (3)$$

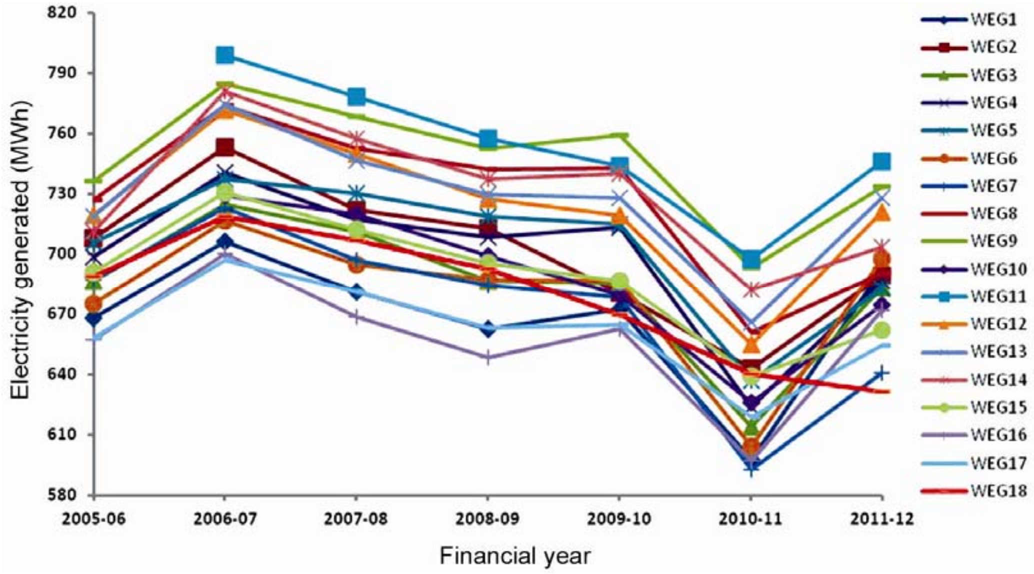

Figure 2. Graph of electricity generated by the 18 wind electric generators in each financial year from 2005 to 2011.

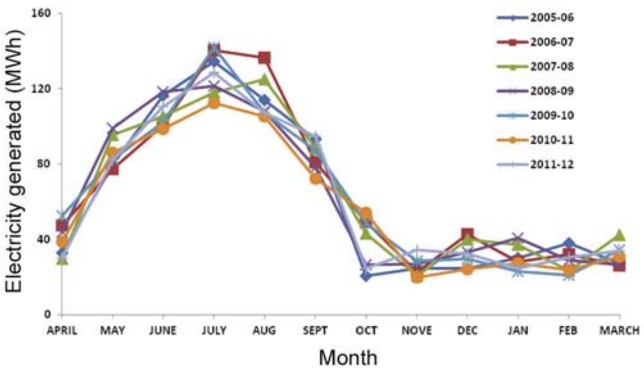

Figure 3. Monthly electricity generated by WEG #9 for the period 2005–2011.

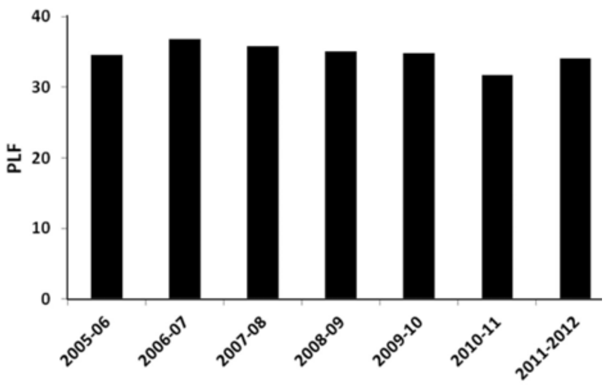

Figure 4. Annual average percentage of plant load factor (PLF) of the 18 WEGs for the financial years 2005–2011.

where n is the number of blades. For a three-blade turbine, the optimal TSR is about 4.19. It is known that by proper rotor blade airfoil profile designs[12], the optimal TSR can be as high as 6–7. The TSR calculated from the geometry and the rated revolutions per minute for a given wind speed of WEGs in the wind farm under consideration is found to be 9.42 and 3.14 for the wind speeds of 5 and 25 m/s respectively as shown in Figure 6. Also shown in Figure 6 is the rated power generation by WEGs at different wind speeds. For wind speeds greater than 12.5 m/s, the rotor rotation frequency is highest with 50 rpm and is maintained constant. It is known that for wind speeds less than the cut-in speeds, WEG does not generate any power. For wind speeds between the cut-in and the rated speed (12.5 m/s for these machines), the power generated increases steadily and stays constant up to the cut-off speed (25 m/s for these machines). Beyond the cut-off speed brakes are applied on the rotor of WEGs for safety reasons. Optimal TSR for these machines is around 6.2 at the rated wind speeds of 12.5 m/s to generate maximum rated power of 220–240 kW, which is close to that reported earlier[13,14].

In an attempt to understand the actual relationship between wind speed and power generated by these wind mills, we have used wind data measured at the farm under consideration and those analysed by a numerical model. The European Centre for Medium Range Weather Forecast (ECMWF) global general circulation model (GCM) used enhanced observations throughout the globe during May 2008 through April 2010 as a part of the initiative called Year of Tropical Convection (YOTC). The model used for this purpose was at a resolution of 799 waves with triangular truncation that corresponds to about 25×25 km^2 horizontal grid spacing near the equator. Precipitation and temperature forecasts over the Indian region by this model were found to be reasonably good up to about 5 days in advance[15]. Since wind speed at the surface is closely related to convection (precipitation) and temperature, we hope that analysed wind by this model also will be reasonably good. Moreover, because this model uses high-resolution grid, it can capture the complex orography features better compared to coarser resolution (model) analysis datasets. The monthly mean wind speed at 10 m height above the ground during July 2008 obtained from the YOTC/ECMWF analysis over the northwest part of Karnataka is shown in Figure 7. Also shown in Figure 7, by the star mark, is the approximate location of the wind farm under consideration. Note that the wind farm is located in a region where availability of wind energy is high.

Variation of monthly average wind speed as a function of the power generated by the 18 WEGs in the wind farm is plotted in Figure 8. A second-order trendline curve fit suited the data. According to the following equation

$$P = K \times \rho \times r^2 \times v^3 \times t, \quad (4)$$

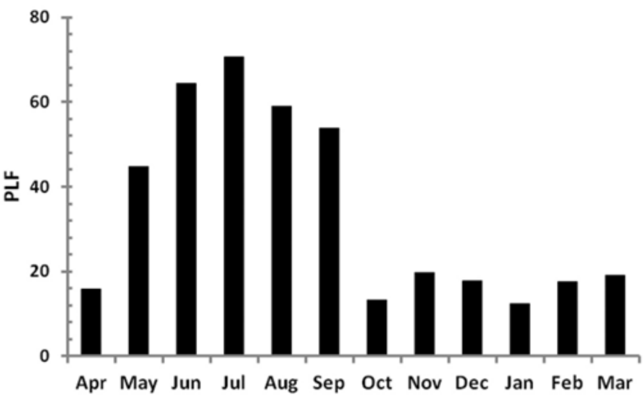

Figure 5. Average monthly plant load factor (PLF) of the 18 WEGs during April 2011 to March 2012.

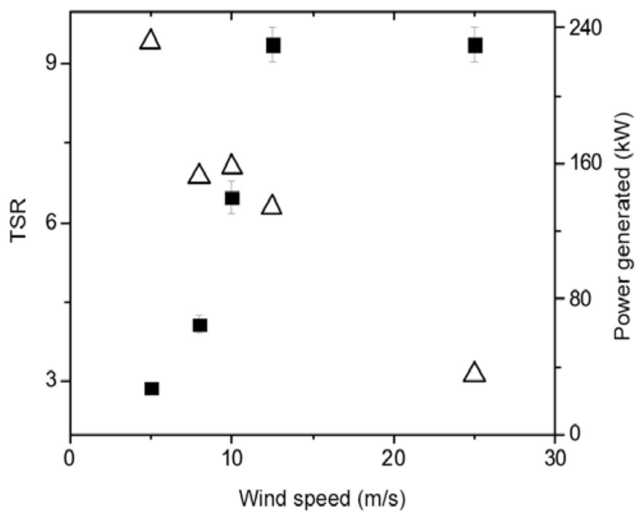

Figure 6. Variation of tip speed ratio (TSR; Δ) and power generated (■) by WEGs as a function of wind speed.

power (P) is proportional to the cube of wind velocity. However, Mathew *et al.*[16] have derived the equation relating the power generated to the wind velocity

$$P_V = P_R \frac{V^n - V_I^n}{V_R^n - V_I^n}, \quad (5)$$

where P_R is the rated power of WEG at wind velocity of V_R, V_I the cut-in wind speed and n is the velocity–power proportionality. n changes from a standard value of 3 depending on the design aspects. For these WEGs, substituting the known values of V_I, V_R, P_R, V and P_V of

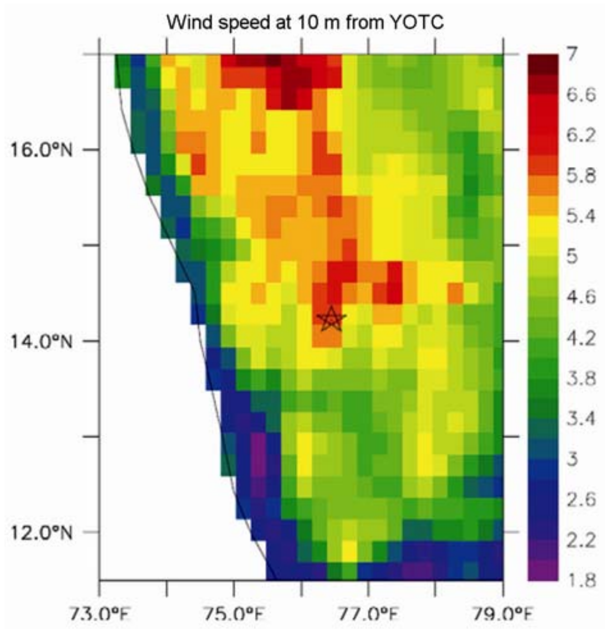

Figure 7. Monthly mean wind speed at 10 m above ground for July 2008 from YOTC/ECMWF analysis. The star is the location of the wind farm.

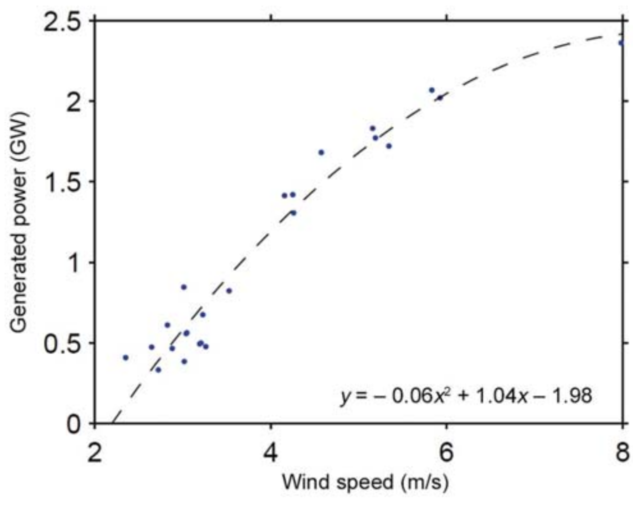

Figure 8. Variation of monthly averaged wind speed against the power generated by all the 18 WEGs in the farm. Wind speed source – YOTC data at 10 m height from May 2008 to April 2010 interpolated to latitude and longitude of 76.4°E and 14.2°N.

2.5 m/s, 12.5 m/s, 230 kW, 10 m/s and 140 kW, *n* is calculated to be 2.13. The wind speed data presented in Figure 8 are at 10 m height and the WEG machine rotor is at 48 m and the data are only at lower wind speeds compared to the rated wind speed.

In conclusion, the performance of the wind farm of 18 WEGs near Chitradurga, Karnataka is analysed using field data from the farm. The period considered is from April 2005 to March 2012. The average plant load factor for the period under study is 34.68. The monsoon season seems good for electricity generation from the wind farm. From April 2005 to March 2012, roughly 86.7 GWh of electricity is generated in this farm and supplied to the grid. Assuming that 1000 g of CO_2 is liberated from a coal thermal plant during production of 1 kWh of electricity, roughly 86.7 kilo tonnes of CO_2 is prevented from entering the atmosphere. Our study shows that Chitradurga has high potential for generation of power from wind energy.

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Two thousand years of iron smelting in the Khasi Hills, Meghalaya, North East India

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Radiocarbon dating of charcoal from iron slag revealed evidence of continuous iron smelting in the Khasi Hills, Meghalaya, NE India spanning the last two millennia. The slag layer, which is dated to 2040 ± 80 years BP (353 BC–AD 128), is the earliest iron smelting site studied in the entire region of NE India. The presence of wüstite, fayalite, glass and metal iron, together with spinels such as hercynite in the slag, indicates that it was an acid product of a bloomery iron-making process. The relative isolation of the Khasi people, who inhabited a highly elevated plateau, is evidence of the indigenous origin of this manufacturing technology, although diffusion of knowledge through cultural and technical contacts or population migration cannot be excluded.

Keywords: Ancient metallurgy, furnace, iron slag, radiocarbon dating.

THE discussion on the early development of iron metallurgy in India has been shaped by two primary concepts. The first assumed a diffusive spread of iron smelting technology related to the migration of the Aryans, an Indo-European speaking people, who entered the Indian subcontinent from the northwest[1–3]. The second concept postulates that there was an independent origin and development of iron-ore mining, extraction and manufacturing technology, founded on the raw materials that were contemporaneously available in India[4–7].

However, in both cases, North East (NE) India was not taken into consideration. The reason for this was the difficulties involved in archaeological exploration of areas of hilly terrain with frequent heavy rain and dense vegetation cover, as well as evidence of the strong material, linguistic and genetic connection of the region with cultures of East Asia and Southeast Asia, at least from the Neolithic period[8–10]. These are clearly visible in the case of the central part of Meghalaya, which is inhabited by the Khasi, an Austro-Asiatic speaking people, representing the remnants of an ancient migration from Southeast Asia[11,12].

No demonstrable archaeological evidence of the Iron Age in Meghalaya has yet been found, although the first

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