Impact of Spatial Variation in Wind Generation of Karnataka

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***Abstract*— The installed capacity of wind power plants in India is expected to reach 60 Gigawatts by 2022. The increasing share of electric power generation from wind will pose new challenges for grid stability as wind power is intermittent by nature. Three major types of variations in wind generation are, seasonal, diurnal and minute to minute. This paper investigates the possibility of smoothing of diurnal variation of wind generation through physical dispersion of wind power plants across the state. Wind power plants are located across Karnataka in the form of clusters. Our study shows that two plants located within 10km radius show a correlation of more than 80% in power generation while, the wind plants located further away show a correlation that is around 40% or less. Two groups of plants having similar total generation located in two different regions with different diurnal variation can contribute to geographical smoothing.**

Keywords-wind energy; geographycal smoothing; Karnataka wind energy; wind plant siting;

I. Introduction

The installed capacity of wind power plants in India is expected to reach 60 Gigawatts by 2022. As per the "Tentative State-wise break-up of Renewable Power target to be achieved" [1], Karnataka is expected to have 6200 MW wind capacity by 2022. Karnataka has 3245 MW of wind power plants installed till now [2]. This means that Karnataka has to double its installed capacity of wind power plants by 2022.

An optimal location of these new wind power plants is important from the perspective of grid stability. On the other hand its effect on the local environment needs to be considered. From health and safety point of view noise level and shadow flickering related to rotating windmills need to be considered [3].

Wind is intermittent by nature and exhibits fluctuations over a range of time scales (from milliseconds up to a season). The increasing share of wind energy in the total energy mix will pose new challenges for grid stability. The mean absolute forecast error percentage (day-ahead scheduling) for wind generation at substation level is 12-15% across the states of India [4]. The variability of wind energy decreases when fluctuations are averaged in the aggregate power feeding the grid from geographically distributed wind plants, a mechanism referred to as geographic smoothing [5].

In Karnataka, there are three major types of variation in wind energy, seasonal, diurnal and minute to minute. There is a considerable similarity in variations of seasonal wind across Karnataka. Throughout the state wind energy generation is higher during the monsoon months compared to other seasons. However, the diurnal wind cycle has different peaks. Hence merging of power generated by plants located at different region may result in geographical smoothing of diurnal variation of energy generation. Spatial smoothing can play a role in decreasing the forecast error as well as reducing the volatility of wind generation.

An increase in geographical diversity among wind plants would bring in spatial smoothing. Before installing further wind mills it would be very useful to investigate the performance of the existing wind farms. In this study we analyze the performance of wind plants located in various parts of Karnataka and examine the possibility of geographical smoothing at diurnal cycle scale.

II. Literature Review and data

A. Literature Review

Geographical smoothing has been recommended as one of the solutions to reduce the effects of intermittent energy generation by the wind power plants [6]. Distribution of wind power plants over a large area can cause geographical or spatial smoothing. The wider the geographical area the larger is the potential for smoothing. Total power production is thus less volatile if wind plants are spread over a large area. A recent report shows the effect of geographical smoothing on Germany and recommends similar study for India [6]. Another paper has used time- and frequency-domain techniques to quantify the extent to which long-distance interconnection of wind plants in the United States would reduce the variability of wind power [7]. The same authors have also studied geographical smoothing of solar energy in the context of Gujarat, India [8]. The report "Greening the grid" has discussed the spatial smoothing of wind energy in the context of India [4]. Using advanced weather and power system modeling, the study team explores the operational impacts of meeting India's renewable targets and identifies actions that may be favorable for integration of the renewable in the grid. The report states that simulations where the current generation profiles of existing wind sites are increased to meet future capacity targets would create unrealistically high-ramping generation profiles. This would happen as it would assume building more wind plants exactly at existing sites without taking spatial smoothing into consideration. In this paper we investigate the possibility of geographical smoothing of wind generation in the context of Karnataka, using plant-wise wind generation data for two years.

B. Data

We have used the following data for the study,

- Minute wise generation data for the different wind plants in Karnataka in 2015 and 2016 from the Supervisory Control and Data Acquisition (SCADA) system of State Load Dispatch Centre (SLDC), Karnataka.
- Wind speed data for different weather stations like, Jogimatti, Kappattaguda, Chikkodi, Sogi, Gokaka, Godekere, Somaguddu, Soundatti, Karajaga, Hulkoti, Hulihalli, hanmasagar, Sangunda, Arikunte, Ramgad and Beeramangala from National Institute for Wind Energy (NIWE), Chennai.
- Data related to location, manufacturer, operator and hub height was collected from the document "Commissioned Status" for wind shared by Karnataka Renewable Energy Development Ltd. (KREDL).
- To indicate the coordinates of the wind plants Google map was used as the base map.

III. Analysis

We have converted all the data sets to hourly values for the purpose of this study.

A. Wind power plants in Karnataka

To analyze the performance we need to understand the present electricity generation and distribution scenario of Karnataka. Electricity distribution in Karnataka is handled by five companies, Bangalore Electricity Supply Company Limited (BESCOM), Hubli Electricity Supply Company Limited (HESCOM), Mangalore Electricity Supply Company Limited (MESCOM), Gulbarga Electricity Supply Company Limited (GESCOM) and Chamundeshwari Electricity Supply Corporation Limited (CESC).

Seven percent of Karnataka's total electricity need was supplied by wind plants in the year 2014 [9]. Wind power plants are located in different parts of Karnataka. HESCOM area houses the majority of the wind plants (51%). BESCOM (32%) and GESCOM (12%) are in the second and third position with respect to wind installation capacity (Fig. 1). ESCOMs are responsible for submitting day-ahead generation schedule to SLDC. ESCOMs collect the generation forecast from Independent Power Producers (IPPs).

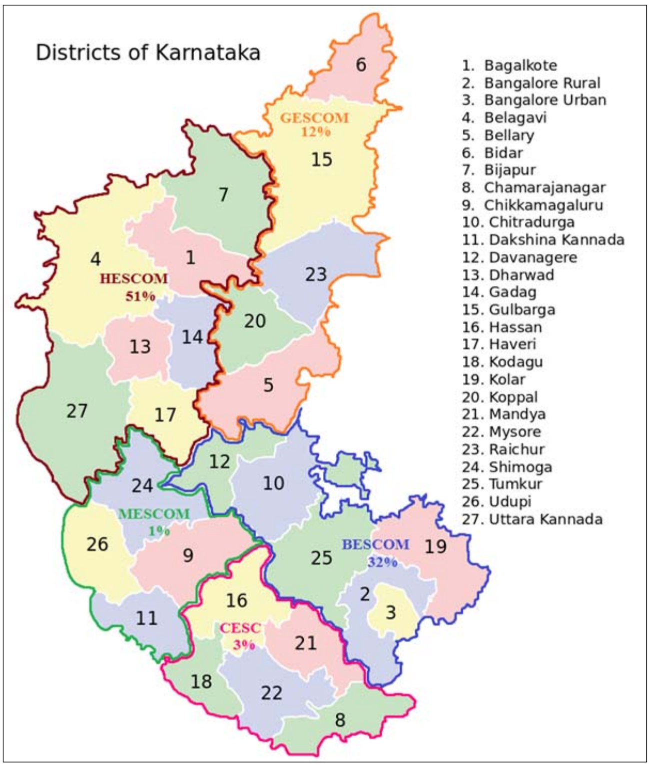

Figure 1. ESCOM wise wind installation in Karnataka
District of Karnataka map source: PlaneMad/Wikimedia (https://en.wikipedia.org/wiki/Outline_of_Karnataka#/media/File:Karnataka_districts-new.svg)

Wind energy is highly variable and hence accurate forecasting of generation is difficult. To accommodate large wind energy in the total energy mix, the grid system needs to be more flexible. Three major ways to increase grid flexibility are incorporation of huge storage units, adding spinning reserve and incorporation of flexible generation in the system. In India major part to the electric energy is supplied by coal power plants which have a limited flexibility. On the other hand, large storage system and spinning reserves are unavailable in the Indian grid and are expensive. The grid operators face difficulty while incorporating wind generation in the generation mix and would face even bigger challenges when large wind plants come online by 2022 [1].

B. Wind speed pattern over Karnataka

With 56 GW wind power potential (at 100m above ground level) Karnataka is one of the seven Indian states which have good wind potential [10]. During monsoon (June, July and August) the wind speed is high and wind flows from west and southwest, while during winter (December, January) the wind changes its direction and flows mainly from the east. Although the entire state witnesses higher wind speed during the monsoon months, there is a large difference in mean wind speed among different regions of the state. The histogram of wind speed from different weather stations across Karnataka is shown in Fig. 2. Jogimatti weather station in Chitradurga region located at 1200m above mean sea level shows the highest

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mean wind speed. The second highest mean wind speed value is observed in Gadag region (Kappattaguda weather station located at 1000m above mean sea level(AMSL)). Next comes Chikkodi (785m AMSL) region.

The diurnal cycle of wind also varies from region to region. Fig. 3 shows diurnal cycles of wind speed from different parts of Karnataka. It is evident that the wind speed at Chitragurga region peaks at midnight, while other areas like Kappattaguda have peak wind speed in the evening. The coupling of wind generation between plants located at Chitradurga and Gadag region will result in reduction in the variability of wind generation or smoothing at diurnal cycle level.

C. Wind plants of Karnataka - Performance

From SLDC and KREDL, we received data for 74 wind power plants in Karnataka. We have studied the generation during the monsoon season of 2015 and 2016 in this paper. After filtering the generation data for possible errors we calculated the average hourly Capacity Utilization Factor (CUF) for monsoon season for 56 wind power plants in Karnataka. The hourly CUF is defined as the ratio of actual hourly generation in MWh and the expected generation if the plant was generating energy with full capacity during that hour. Equation (1) is used for calculating hourly CUF.

Hourly CUF = Hourly Generation / (Capacity x 1Hr) (1)

Based on the maximum CUF achieved in the monsoon, the wind plants can be segregated into six groups (Table 1). A map showing various groups are shown in Fig. 4.

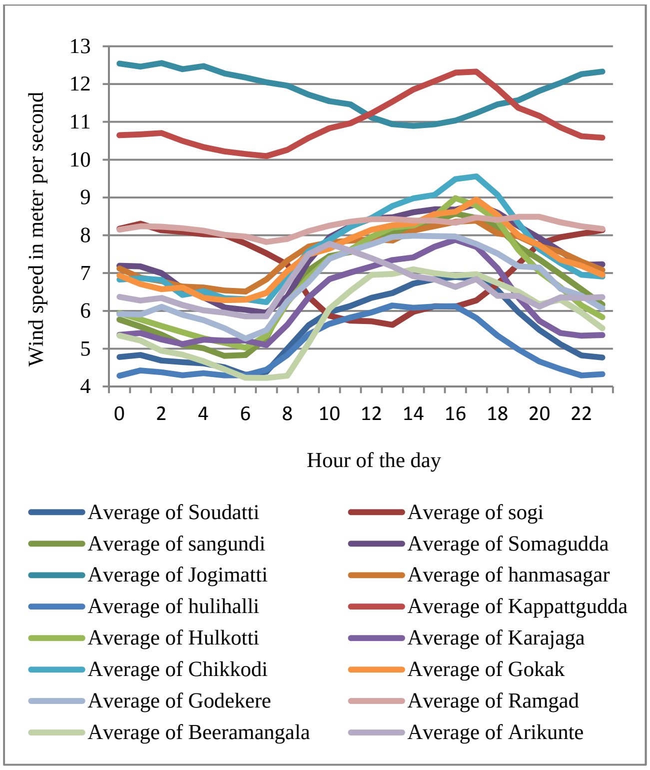

Figure 3. Diurnal cycle of different wind areas in Karnataka

TABLE I. GROUPING OF THE WIND PLANTS BASED ON MAXIMUM CUF IN THE MONSOON SEASON

Sl No	Maximum CUF	Group Number	Colour
1	>= 0.6	Group -A	
2	>= 0.5 <0.6	Group -B	
3	>= 0.4 <0.5	Group -C	
4	>= 0.3 <0.4	Group -D	
5	>= 0.2 <0.3	Group -E	
6	< 0.2	Group - F	

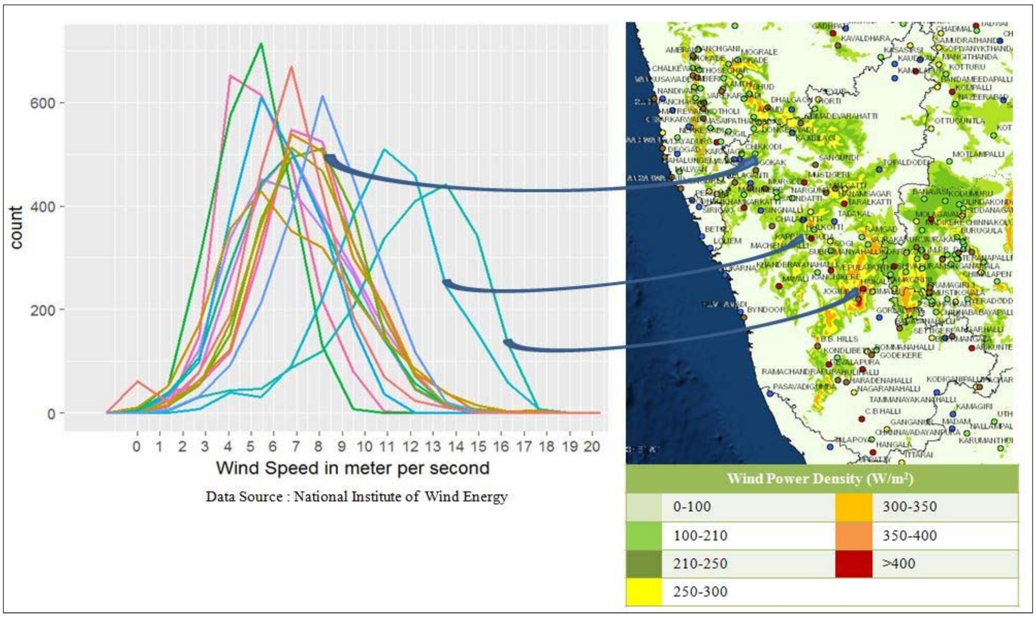

Figure 2. Wind histograms from different wind areas in Karnataka

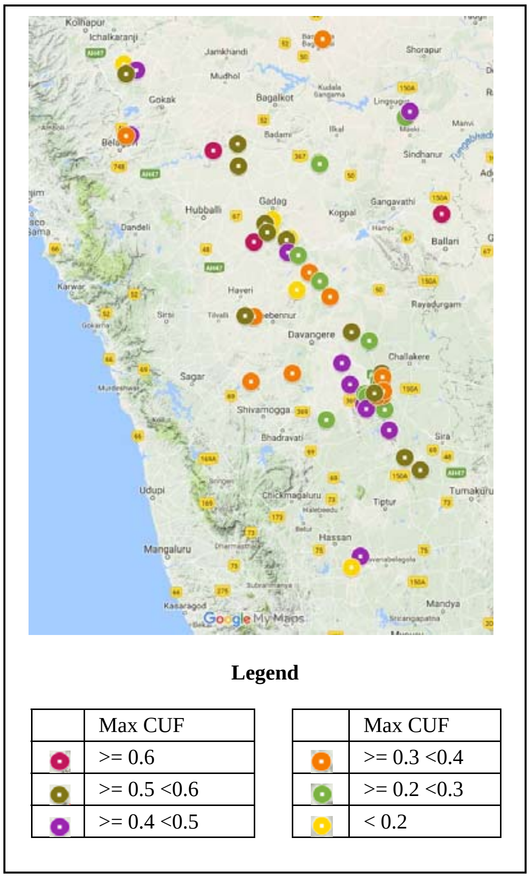

Figure 4. Maximum CUFs at various wind plant sites of Karnataka during monsoon

C. *Regional generation pattern*

Fig. 5 shows a closer view of Chitradurga region. It is evident from Fig. 5 that even for wind plants located very near to each other, the maximum CUF achieved during monsoon period may vary over a wide range. The local topography and related local wind play a major role in the wind energy generation. However, the pattern of generation remains similar for a particular region. The diurnal cycle also remains same for the entire region. We have checked the correlation matrix for generation from different plants in the same region to verify the same. Fig. 6 shows the correlation of generation from different plants located in Chitradurga region during the same time period. The correlation factors are in the range of 70% to 80% for the region.

On the other hand correlation between generations from plants located in different regions is much less. For example the correlation factor between Chitradurga 1 and Gadag 3 wind plant is only 0.48 although the maximum CUF in monsoon season is similar for both the plants. Hence, generation from the plants in these areas can be used for geographical smoothing.

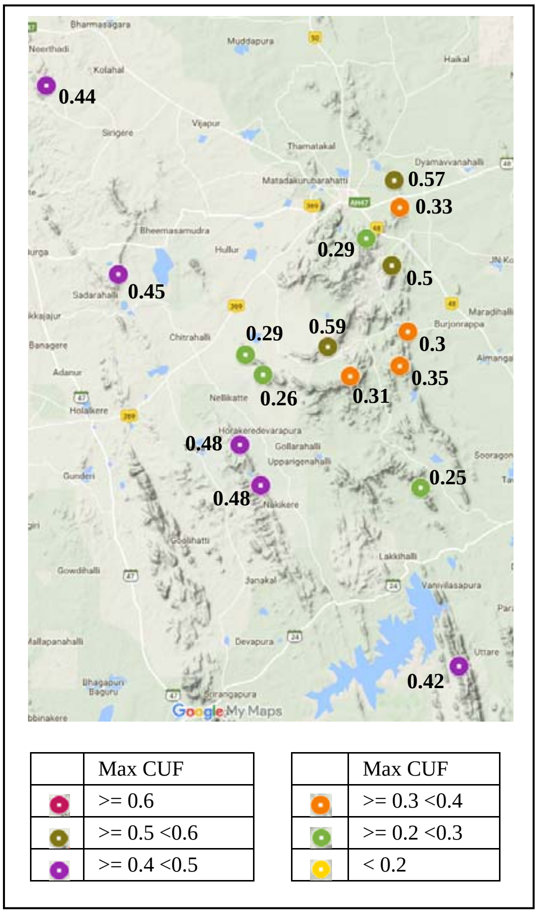

Figure 5. Maximum Capacity Utilization Factor for various wind power plants in Chitradurga Region during Monsoon of 2015 and 2016

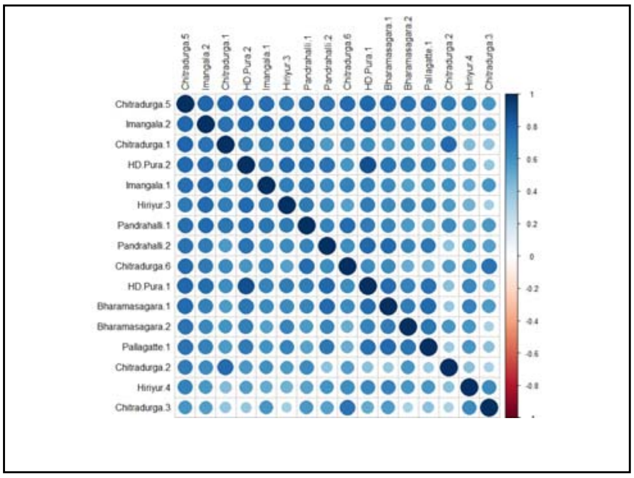

Figure 6. Correlation of generation from different plants located in Chitradurga region

IV. Diurnal Variation in Wind Generation

Being stochastic by nature predicting wind power generation is challenging and the errors might be in the range of 12-15% at substation level. However, if wind plants from diverse region is strongly connected with each other, geographical smoothing can reduce the forecast error by certain extent [4].

Fig. 8 shows hourly average CUF for monsoon season for two plants, Chitradurga 1 and Gadag 3 plant. It is evident that the Chitradurga 1 plant has a peak generation at 17:00hrs. However, Gadag 3 plant has a peak generation at 21:00hrs. Hence, with installation of plants having similar total generation in both the areas can reduce diurnal variation of wind gneration. Similar type of smoothing occurs in the case of another three plants as well (Fig. 7). Fig.8 shows that the plants from Gadag, Hiriyur and Pallagatte region have some scope for geographical smoothing.

The mean wind speed during monsoon season varies from region to region (Fig.2). This would mean that, two plants with same rated capacity located at different region will have different total generation. To achieve similar total daily generation from plants located in various regions we need to vary the rated capacity according to the mean wind speed.

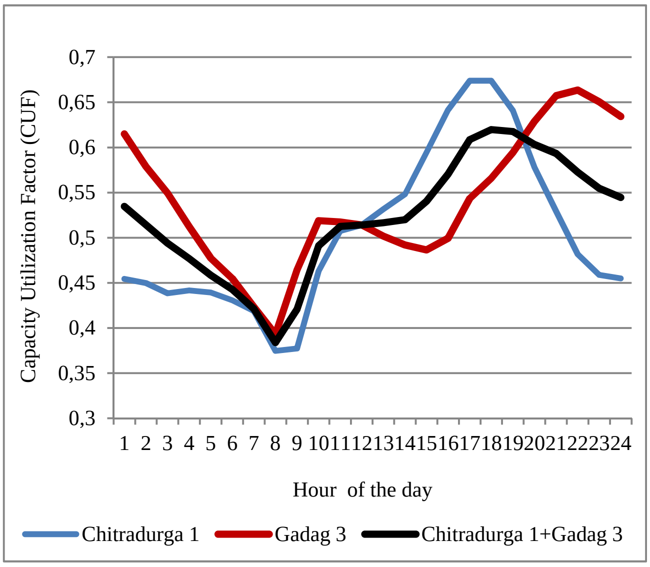

Figure 7. Hourly average CUF for Chitradurga 1 and Gadag 3 plant

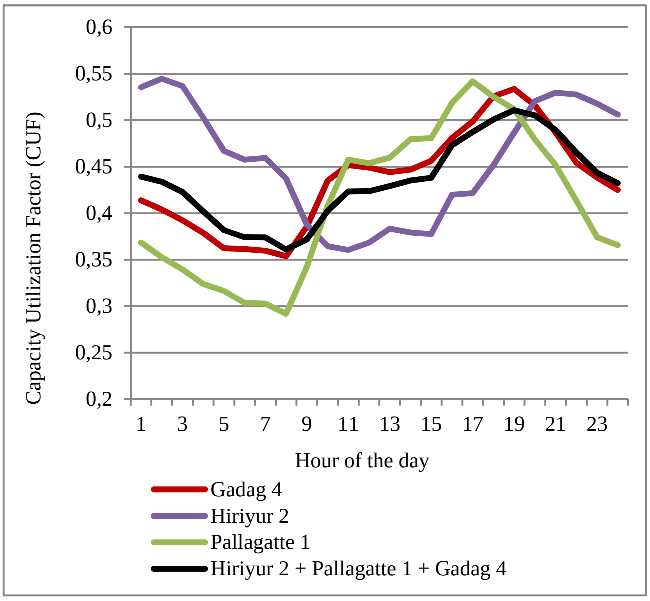

Figure 8. Hourly average CUF for Gadag 4, Hiriyur 2 and Pallagatte 1 plant

V. Conclusion

As per the wind capacity target declared by MNRE, Karnataka is expected to double its wind plant capacity by 2022. For new plants, if the sites are selected as per the wind speed data alone, then the new wind plants will be located in the vicinity of the old plants. Hence, geographical smoothing may not play any role in reducing the volatility of wind generation. However, if the new wind plants are located keeping in mind the advantage of diversified siting, geographical smoothing can be used to mitigate the variability of wind generation.

A strong coupling between solar and wind energy may also result in smoothing on seasonal as well as diurnal cycle level. Solar produces higher energy during non monsoon months, while wind produces higher energy during monsoon months. Hence, coupling of solar and wind plants producing similar energy would have seasonal smoothing. In the diurnal cycle level, solar has maximum generation during the day (approximately 13:00hrs). However, wind plants have maximum generation during evening or late night hours. Hence, strong cuopling between solar and wind plants will result in smoothing at diurnal cycle level. These issues will be explored in our future work.

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BIOGRAPHICAL INFORMATION

Anasuya Gangopadhyay was born in Kolkata, India. She completed her graduation in Electrical Engineering from Bengal Engineering and Science University (BESU) ,Shibpur, (Presently known as IIEST, Shibpur), India in 2007. She also holds a Post Graduate Diploma in Operations Management (2013) from Symbiosis centre for Distance Learning, Pune. Her major field of study is renewable energy and energy policy.

Presently she works as Project Assistant in Divecha Centre for Climate Change, Indian Institute of Science, Bangalore. Earlier, she has worked as Peoject Manager in ABB (for 5 years), one of the market leaders in Electrical Industry and a German MNC Conergy (for 1 year) which was involved in solar EPC projects in India.

She started her academic career with National Institute of Advanced Studies in December, 2013 and worked on a project funded by Power System Operation Corporation Limited to reduce the future (2022) electricity deficits of Karnataka using solar and wind energy along with Pumped Hydro Storage facility. Her publications include, “Wind and Solar Energy for reducing Karnataka’s Electricity Deficits”, Current Science, Vol. 111, No. 5, 10 September 2016, “Institutional Rooftop Solar – NIAS Experience with a 100kWp Solar System”, National Institute of Advanced Studies Report: SP8-2017, 11 January 2017 and report titled “Wind and Solar Energy for meeting Karnataka’s Future Electricity Demand”, NIAS and POSOCO, March 2015.

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