Offshore wind to meet increasing energy demands in India

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Offshore wind provides a scalable alternative to conventional energy resources. It can be a potential source to meet the increasing energy demand in developing countries like India, for which an attractive policy framework is required. The aim of this study is to provide an insight for evolving onshore wind policy in India and suggest suitable strategies for development of offshore wind sector. Various wind resource maps were reviewed and potential sites identified as Rameswaram and Kanyakumari along Tamil Nadu coast. Suitability analysis was conducted to identify the type of wind turbine recommended at potential sites to achieve high plant load factor, considering the uncertainty in wind speeds. Commercial viability studies were carried out to identify appropriate incentives for development of offshore wind sector in India. Results indicate a levelized cost of energy of Rs 10.8 and Rs 9.6/Kwh at Rameswaram and Kanyakumari for an internal rate of return of 14%.

Keywords: Commercial viability, offshore wind energy, wind potential assessment.

ENERGY demand is rapidly increasing across the world and conventional non-renewable energy sources are depleting. Hence focus is shifting towards identification of alternative sources of renewable energy like wind, solar, tidal, wave, etc. Promotion of these renewable sources of energy can help build a diversified and long-term distributed energy mix offering security against energy supply. Wind energy has gained wide acceptance across the globe and presently the focus is towards development of offshore wind farms. The promising factors for offshore wind development are: (i) powerful and consistent winds compared to onshore; (ii) low sound pollution and visual intrusion; (iii) best benefit to coastal areas due to less transmission losses, and (iv) easy transportation of larger capacity turbines.

Europe is leading the offshore wind market since the inception of its first commercial offshore wind project in 1996 with an installed capacity of more than 8 GW connected to grid. The installed capacities of wind farms in Europe are 8.045 GW (ref. 1), and China and Japan are 0.67 GW, 0.05 GW respectively[2]. Proposals exist to expand the respective capacities to 24 GW in Europe[3], 10 GW in China[4] and 1 GW in Japan[5] by 2020. Actually, more than 90% of the global offshore wind farms were located in European waters and the contribution from various countries is shown in Figure 1. In 2013, the world's largest wind farm 'London Array' with a capacity of 630 MW was commissioned in the United Kingdom[6]. A project with 0.468 GW capacity is under construction in USA with proposals for expanding the capacity to 10 GW by 2020 (ref. 7).

A developing country like India is yet to meet the required energy demands through existing installed capacities of 259 GW (ref. 8). During the fiscal year 2013–14 India experienced energy shortage of 4.2% (960 BU against a demand of 1002 BU) with a peak shortage of 4.5% (130 GW against a demand of 136 GW)[9]. The southern region experienced severe energy shortage of 6.8% with a peak shortage of 7.6% (ref. 9). Tamil Nadu, Andhra Pradesh, Karnataka and Kerala located in this region have a coastline of 3100 km (ref. 10). Offshore wind would be an ideal solution to meet the increasing demand as these coasts are blessed with significant winds. India has initiated efforts towards development of offshore wind energy. For this, there is a need for development of potential locations and policy guidelines under the Ministry of New and Renewable Energy (MNRE). Before an offshore wind policy is finalized in India, it is essential to study the key aspects such as identification of potential sites, selection of wind turbines of suitable capacity and arriving at feasible incentives to promote offshore wind energy.

In 1982 the independent Department of Non-conventional Energy Sources (DNES) was constituted under the Ministry of Energy for policy making, planning, promotion, co-ordination and intensified research and developmental activities in all aspects of renewable energy. DNES along with Indian Institute for Tropical Metrology (IITM) developed the first wind resource assessment using 343 meterological observations[11,12]. DNES also supported the construction of the first grid connected turbine under Public Private Partnership (PPP) between Gujarat Energy Development Agency and JK Synthetics Limited, in 1985 at Veraval, Gujrat[13]. This turbine was an imported 40 kW turbine from Netherlands. In 1987, the Indian Renewable Energy Development Agency was established under DNES to provide soft loans for renewable energy. During the Five Year Plan (1985–1990), in order to attract huge investments from private sector, many incentives were introduced. The most important were 100% accelerated depreciation in the first year, wheeling facility, banking facility, third party sale, tax holidays and relaxation in customs and excise duty[13–15]. These incentives led to significant deployment of wind farms by private firms.

In 1991 economic liberalization was initiated with the goal of making Indian economy more market-oriented and expanding the role of private and foreign investment.

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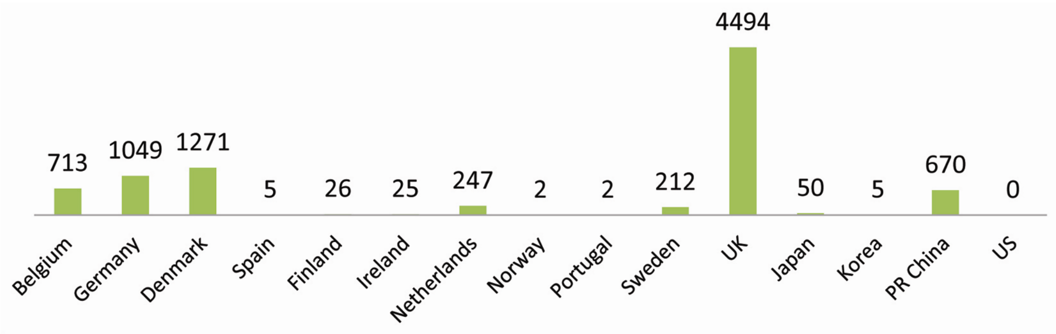

Figure 1. Installed capacity across the world (MW).

So, Indian wind market was open to both domestic and foreign private investors. During this period as part of the policy framework, for the first time, the ministry identified specific tariff for purchase of power generation to create price certainty[16]. In mid-1990 the wind energy market experienced a down trend due to various reasons like lowering of tax benefit, poor installation practices, delays in securing land approvals, performance of turbine lower than anticipated due to inadequate wind resource assessment, non-adaptability of European wind turbine design for tropical climate and difficulty to operate in weak Indian electricity grid[13,14]. In 2003 a new electricity act was introduced which led to introduction of definite tariff for wind energy. This act also gave significant responsibility for the State Energy Regulation Commissions (SERC) to specify certain quota and purchase the same percentage of total consumption from renewable energy in the area of distribution license[17]. This mandate is called renewable purchase obligations.

In 2009, the government implemented generation-based intensive (GBI) to encourage actual power generation rather than capacity addition[18]. This incentive is provided over and above the tariff approved by SERC through IREDA. In 2010, to meet the RPO, government introduced a complimentary mechanism for less endorsed states by purchasing renewable energy certificates from excess states[17]. REC mechanism aimed at addressing the mismatch between availability of renewable energy resources in the state and requirement of the obligated entities to meet the renewable purchase obligation (RPO). It can be understood that over the last two decades, India had varied and complex policy and regulatory framework supporting wind energy, and showed great flexibility in terms of the range of support mechanisms available over time[14].

In brief, India wind energy policy is: the state Electricity Regulatory Commissions, define purchase obligations for renewable energy and tariffs, which are complemented by federal incentives such as generation-based incentive (GBI). This arrangement proved to be effective for attracting large investments in this sector. At present India is the fifth largest onshore wind energy market with an installed capacity of 22.47 GW (ref. 19).

Wind atlas gives good indication of geographical distribution of wind resource and will be useful for decision-making and planning of feasibility studies. However, to meet the bankability requirements, precise measurements are required for couple of years at proposed site(s). Conventionally, wind atlas is generated using analytical wind measurements at a number of sites across the country. As long-term historical wind data is not available in all the terrains in India, the National Institute of Wind Energy (NIWE) used Karlsruhe Atmospheric Mesoscale Model (KAMM)/Wind Atlas Analysis Application (WAsP) developed at Riso DTU national laboratory and generated numerical wind atlas maps for India (Figure 2)[20]. The model results were verified using measured wind speeds and directions from onshore NIWE meterological masts. Offshore winds 100 km away from the coast in the ocean are also generated using the same model. The results need to be verified using measured offshore winds. The offshore wind atlas shows significant potential along southern Tamil coasts (Figure 2).

Offshore wind potential maps were also generated by Earth System Sciences Organization – Indian National Centre for Ocean Information Services (ESSO–INCOIS) based on daily wind data derived from QuikSCAT, a satellite-based scatter meter. These satellite-derived winds were validated using *in situ* measurements of winds obtained from 5 moored buoys deployed by Earth System Sciences Organization–National Institute of Ocean Technology (ESSO–NIOT) along the Indian Coast. These maps provide the number of windy days with magnitudes above 6 m/s and 8 m/s in a year, 10 m above sea level (Figure 3). It is observed that winds of magnitude 6 m/s or more persist for more than 300 days and 8 m/s or more persist for about 200 days along the southern coasts of Tamil Nadu. The wind potential maps generated by both the institutes indicate Rameswaram and Kanyakumari along the Tamil Nadu Coast as suitable sites for setting up of offshore wind farms.

It is essential to study the detailed wind characteristics at potential locations and suitable wind turbines for working out a reliable financial model. Wind speeds at identified locations were obtained from ESSO–INCOIS at 10 m elevation. This data contains daily wind data (one record

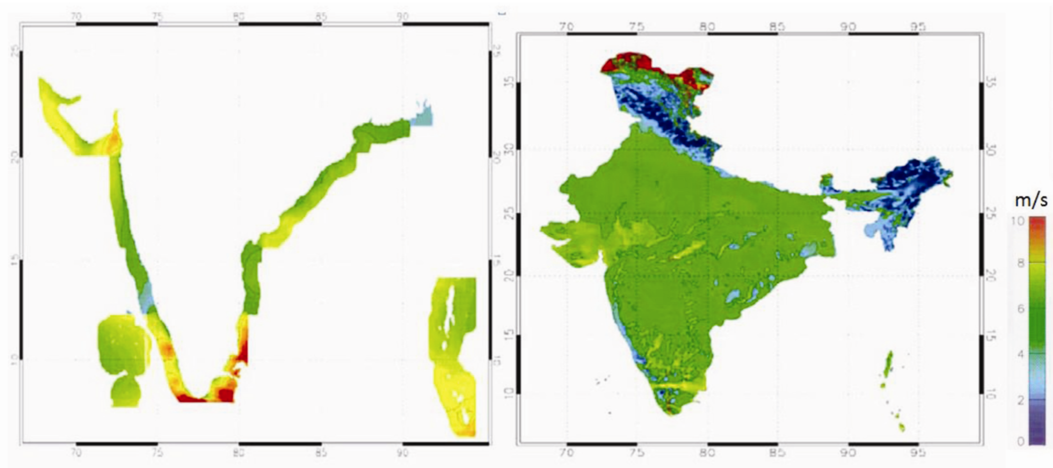

Figure 2. Numerically generated offshore and onshore wind resource maps for India by NIWE.

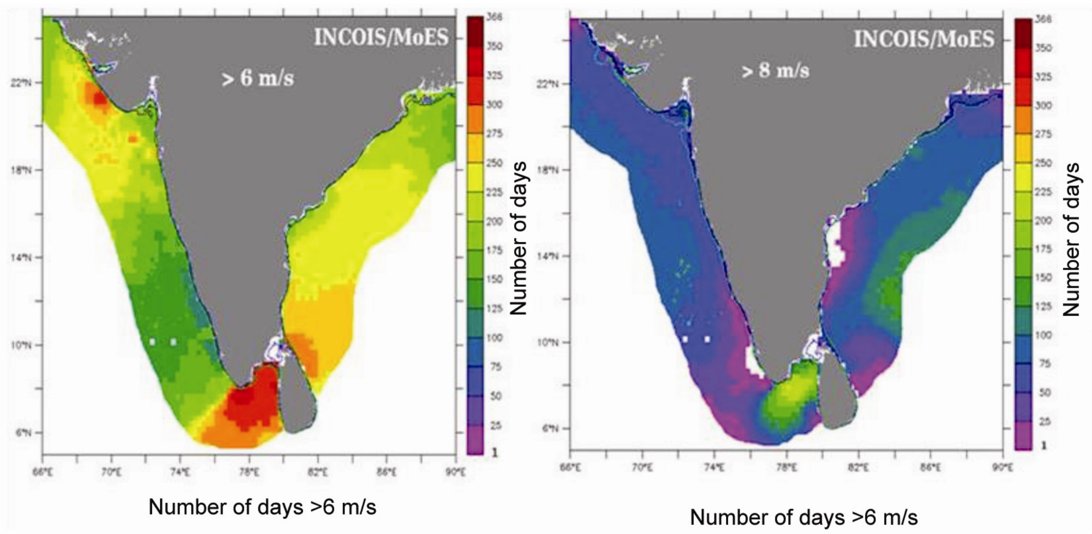

Figure 3. Offshore wind potential maps for Indian Coast by ESSO–INCOIS.

per day) for 10 years received from QuickSCAT and corrected using 5 moored buoys of ESSO–NIOT. In this study the hub of the wind turbine was considered at 80 m elevation and the wind speeds at this elevation were estimated using power law with shear coefficient of 0.14 (ref. 21). The wind speed distribution at 80 m elevation at identified locations is shown in Figure 4. The arrived mean wind speed at Kanyakumari is 9.1 m/s and at Rameswaram it is 8.5 m/s. As per IEC standards[22], class II wind turbines will be appropriate for both such sites. The properties of various class II wind turbines available in literature, in the range of 2–7 MW were considered in this study to identify suitable turbines (Table 1). The power-curves for these turbines are shown in Figure 4.

To establish a reliable financial model for wind energy project investment, it is essential to consider well-defined uncertainties in wind speeds. A summary of uncertainty elements associated with the wind speed is listed below:

Measurement uncertainty: Wind speeds measured using satellites were corrected using anemometers on moored buoys by ESSO–INCOIS. An uncertainty of 2% was observed in this process[23]. There may be additional uncertainties arising from manufacturing defect of anemometer or damages incurred in field. A typical range of estimates for single anemometer subjected to high quality validation process is 1.3–2.5% (ref. 23). As anemometers are located on buoys in harsh environment an uncertainty of 2.5% was considered in this study. The total uncertainties due to two exclusive events were estimated using the sum of squares rule and the resultant uncertainty was 3.2%.

Future wind resource: The uncertainty about future wind velocities may be due to variability in wind climate and risk of long-term climate change. The uncertainty due to normal variability in wind climate is the ratio of standard deviation as percentage of mean wind speeds to

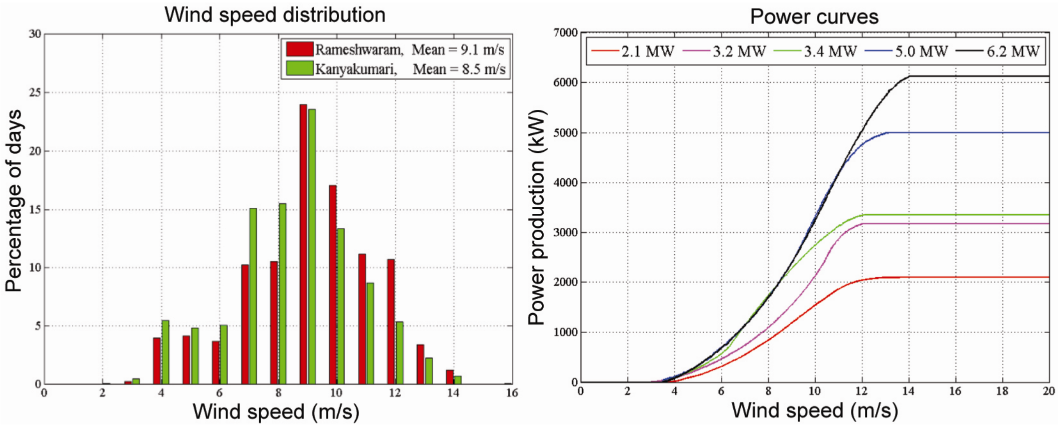

Figure 4. Wind and turbine characteristics.

Table 1. Performance of wind turbines at potential sites (plant load factor)

		Kanyakumari			Rameswaram		
Company	Capacity (MW)	(P_{90})	(P_{75})	(P_{50})	(P_{90})	(P_{75})	(P_{50})
Suzlon	2.1	0.43	0.45	0.47	0.37	0.38	0.40
Re power	3.2	0.40	0.42	0.44	0.33	0.34	0.36
Re power	3.4	0.51	0.53	0.55	0.43	0.45	0.46
Re power	5.0	0.39	0.40	0.42	0.33	0.34	0.35
Re power	6.2	0.31	0.33	0.34	0.30	0.31	0.32
Plant load factors after incorporating losses in power production							
Re power	3.4	0.43	0.45	0.46	0.37	0.38	0.39

square root of plant life[24]. The estimated values for Rameswaram and Kanyakumari were 1.2% and 1.5%. The uncertainty due to risk of long-term climate change for plant with 20 to 25 years life was 2% (ref. 24). The total uncertainty in future wind resource was estimated using the sum of squares rule and the resultant uncertainties were 2.33 and 2.5 for Rameswaram and Kanyakumari respectively.

Wind shear: In this study wind shear of 0.14 was considered as per IEC standards for offshore, but few studies recommended a wind shear of 0.10 for calm sea[25,26]. An uncertainty of 8.7% associated with wind shear of 0.14 from 10 m to 80 m (hub level) was considered using eq. (1)[24]

$$\sigma = 100\left[\left(\frac{H_h}{H_z}\right)^{\Delta\alpha} - 1\right], \quad (1)$$

where σ is the uncertainty, H_h the height of hub, H_z the height of measured wind and $\Delta\alpha$ is the uncertainty in wind shear.

The resultant uncertainty due to measurement uncertainty, future wind resource and wind shear was arrived at as 9.6% and 9.5% for Rameswaram and Kanyakumari respectively. These uncertainties were applied for measured wind speeds at Kanyakumari and Rameswaram. The annual power production for 10 years was estimated using power curves and scaled wind speeds after considering uncertainties. It was assumed that values for annual energy production fall into normal distribution. The central estimate of the annual power production using normal distribution where 50% of time energy yield predicted would be achieved is P_{50} (Plant Load Factor). In P_{50} the probability of reaching a higher or lower annual energy production is 50 : 50 with a risk of 50%. Similarly, P_{75} and P_{90} are the common terms used by bankers, where P_{75} is the annual energy production with a reach of 75% and P_{90} with a reach of 90%. From a financier's point of view it is preferable to use P_{90} or P_{75} due to the lower risks compared to P_{50}. Values exceeding 50%, 75% and 90% were estimated for each turbine (see Table 1). It was observed that re-power 3.4 MW turbine performed well at the identified locations.

The power production from wind turbine needs to be accounted with various losses like turbine unavailability with 3% (ref. 27), wake effects losses with 8% (ref. 28) and electrical losses of 5% (ref. 29). The total losses due to above factors account for 15.3% losses. The plant load factors for re-power 3.4 MW turbine after incorporating these losses are given in Table 1.

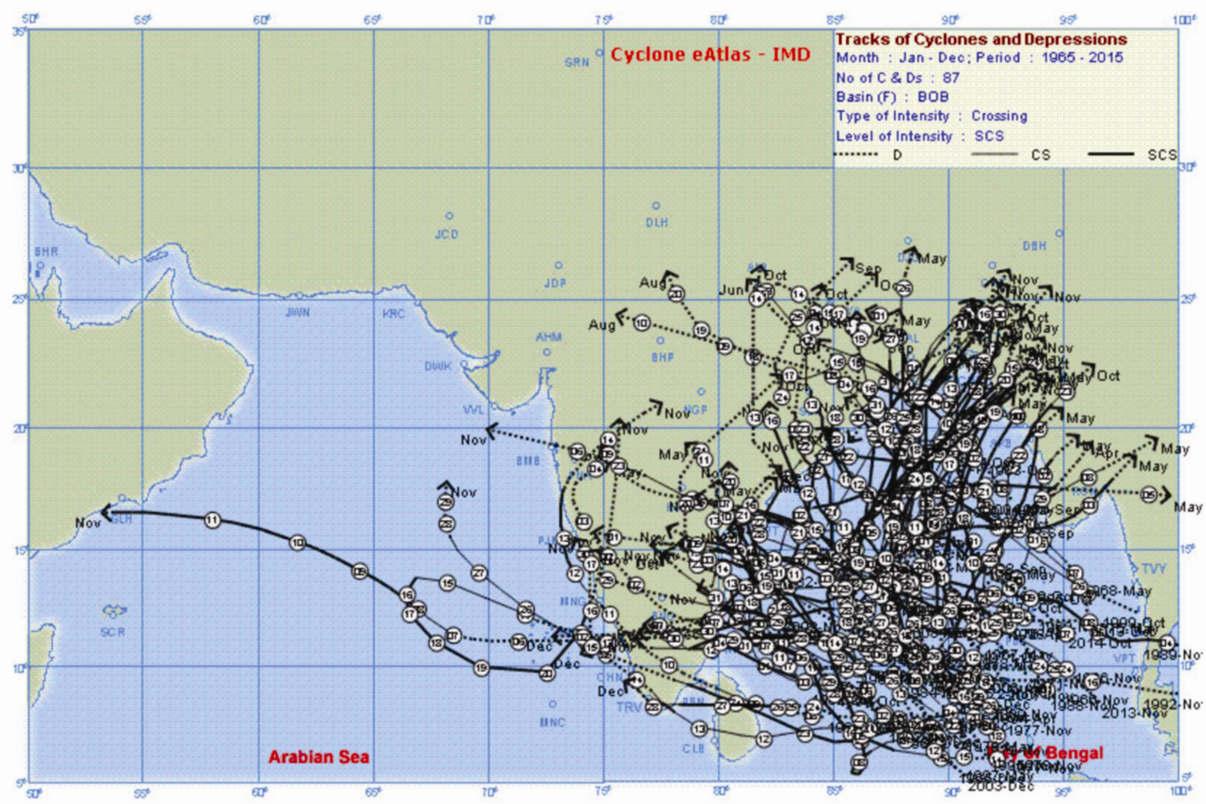

Figure 5. Tracts of various cyclone storms in last 50 years by the India Meteorological Department.

Cyclones are associated with high wind speeds and severe sea state conditions. The wind forces impact turbine blades, whereas wave forces impact platform, foundations and power evacuation. Assessment of intensity and the duration of cyclones are important to avoid unanticipated breaks during installation and maintenance. High winds can cause extreme loads, vibrations and fatigue on blades which lead to turbine shutdown, once it reaches the cut-off speed (generally 25–30 m/s). So installation of turbines in cyclone-prone zones will significantly increase the operation and maintenance cost.

The east coast of India is subjected to severe cyclonic storms. Figure 5 shows the tracts of various cyclone storms during the last 50 years as given by the India Meterological Department. It can clearly be observed that on the east coast Rameswaram and Kanyakumari are subjected to very few cyclones when compared to other sites in the north making these sites more suitable for offshore wind energy establishments in terms of safety.

Wind turbines are slender structures with large mass at the top. The high top mass may induce increased inertia force[30]. Hence, most of the modern wind farms are located in areas with low seismic risk. The potential sites of Rameswaram and Kanyakumari are located in zone II as per IS 1893:2007 (ref. 31). As zone II is the zone with low seismic risk, minimal impact on design and economics of wind farm in this zone is expected.

The cost of offshore wind turbine systems is significantly higher than land-based systems because of the higher cost for foundations, installation, operation and maintenance and complex logistics. The components that affect the initial cost of the wind turbine are (i) wind turbine along with installation, (ii) substructure cost along with installation, and (iii) electrical systems (includes collection system, integration system, transmission system and supervisory control and data acquisition/energy management system). The cost of various components[32], operation and maintenance cost[33] is taken from literature. The critical parameters for estimating the cost of 170 MW offshore wind farm with 50 units of 3.4 MW at Rameswaram and Kanyakumari are given in Table 2 and item-wise sample calculation for Rameswaram is provided in Table 3. As these costs are estimated as per equations provided in 2011, an increase in construction cost of 35% (ref. 34) is considered to account for inflation till 2014.

A study was conducted to check the commercial viability of offshore wind farms along the Tamil Nadu coast. The general cash flow for a wind turbine is shown in Figure 6. The capital cost for setting up a wind turbine is raised by investors with certain equity and rest as debit from bank at an interest rate during loan tenure. In India IREDA provides soft loans for 70% of capital cost with interest rate of 11.90–12.50% based on grade for a tenure

Table 2. Critical parameters in estimation of cost for offshore wind turbine

Item	Rameswaram	Kanyakumari
Water depth (m)	10	15
Distance from coast (km)	5	5
Port availability (km)	175 Nagapattinam port	125 Tuticorin port
Capital cost per turbine (Rs in crores) ref. 30	67.97	69.70
Operation cost (Rs/kwh) ref 31	1.28	1.28

Table 3. Item-wise capital cost for Rameswaram

	Item-wise cost for Rameswaram	Wind turbine (1000 Euros)	Wind turbine (crore Rs)
1	Wind turbine	3234.94	22.64
2	Installation of turbine	323.49	2.26
3	Foundation	1236.81	8.66
4	Installation of turbine foundation	618.41	4.33
5-A	Collection system	463.62	3.25
5-B	Integration system	490.87	3.44
5-C	Transmission	702.67	4.92
5-D	SCADA/EMS	75.00	0.53
6	Development and permits	46.80	0.33
	Total investment cost in 2011	7192.61	50.35
	Total investment cost in 2014 with 35% Inflation		67.97

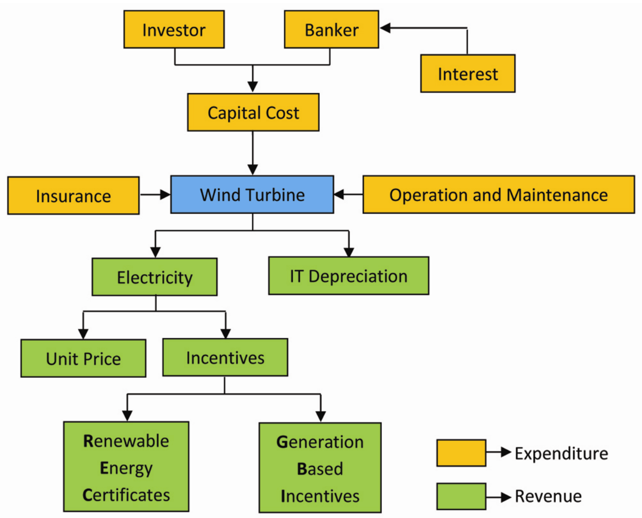

Figure 6. Cash flow for wind turbine project.

of 10 to 15 years[35]. However if the tenure is more than 12 years an additional interest rate is charged. In this study an interest rate of 12.5% for tenure of 12 years was considered. After commissioning the wind farm, components that contributed to cash out flow were insurance (0.1% of initial cost) and O and M charges. The returns included unit price paid for electricity produced, fiscal incentives and income tax depreciation. The main incentives provided by Indian government for wind energy were generation-based intensive (GBI) and renewable energy certificates (RECs). GBI of Rs 0.50 per kWh was provided with a cap of Rs 1 crore per MW for ten years through IREDA[18,36]. CERC notified that the floor and ceiling prices range from Rs 1.5 to Rs 3.9 per unit (for nonsolar RECs)[17]. In this study RECs of Rs 1.5 per kWh were considered. Accelerated depreciation of 80% in first year was reinitiated in 2014 (ref. 37). All these incentives were considered in this study.

Developers should structure the repayments which give lenders a comfort zone and aim for higher debt-service coverage ratio (DSCR). For banks to finance a wind farm an average DSCR of 1.3 at P90 PLF levels is required[38]. The unit prices of electricity of Rs 6.54 and 5.71 for Rameswaram and Kanyakumari were arrived for a DSCR of 1.3 at P90 PLF level considering various incentives by the government of India. However, if the incentives were not provided the unit price equals the LCOE, i.e. 10.78 and 9.61 for Rameswaram and Kanyakumari respectively. The commercial viability of the project for this unit price was evaluated in terms of internal rate of return (IRR), return on investment (ROI), payback period (PP) and levelized cost of energy (LCOE) for a plant life of 20 years. These commercial viability parameters are given in Table 4 and LCOE sample calculation is provided in Table 5.

A sensitivity analysis was carried out for both the potential sites to see the influence of investment cost and discounted rate on LCOE (Figure 7). The variation in LCOE and discounted rate was studied for investment cost in the range of Rs 5000–9000 lakhs. It was observed, that for a discounted rate of 14% the LCOE increased by 66% for an increase in capital cost by 80% for both the potential sites. These graphs can also be used to obtain

Table 4. Commercial viability parameters

Item	Rameswaram	Kanyakumari
Unit price of power apart from incentives (Rs)	6.54	5.71
Project internal rate of return, IRR	13.87	13.97
Return on investment, ROI	0.79	0.78
Payback period (months)	132	131
Levilized cost of energy at IRR, LCOE (Rs/kWh)	10.78	9.61

Table 5. Sample calculation for LCOE

Initial cost	67.97 crore
Operation and maintenance cost with discounted rate of 13.87 IRR	10.94 crore
No of units produced with discounted rate of 13.87 IRR	732 Lakh unit
LCOE = (1 + 2)/3	10.78 Rs/kWh

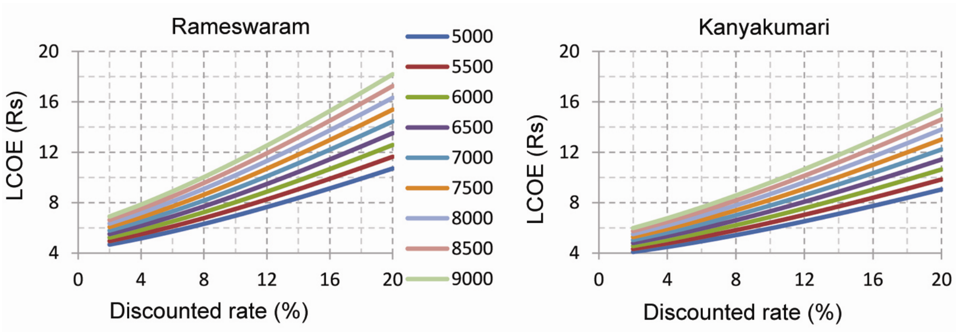

Figure 7. LCOE for different discounted rates with varying investment costs.

the break-even cost of power at an IRR for a given initial investment.

The need to minimize dependency on conventional fossil fuels is realized across the world. Initiatives have been taken by various countries to develop various renewable technologies like wind, solar, hydropower, biomass, wave, etc. South India is facing huge deficit in electricity which can be compensated to some extent by offshore wind plants as the Indian coast is blessed with significant winds. However, the cost of offshore wind energy plants will be significantly higher compared to onshore. As offshore wind industry is not mature across the world and implemented for the first time in India, a significant reduction in investment costs and cost of energy can be anticipated in future. An attractive policy framework is required to promote offshore wind sector and make it commercially viable over a period. In India onshore wind sector was initiated in the mid-1980s and the wind policy was subjected to many resolutions to provide effective incentives for this sector. At present, 11.5% of installed capacity in the county is from onshore wind.

In this study, various wind resource maps generated by various institutions were reviewed and potential sites were identified along the Rameswaram and Kanyakumari coast of Tamil Nadu. Suitability analysis was carried out to identify suitable capacity of wind turbine at potential sites and identified that 3.4 MW turbine performs at high PLF. The annual power production is estimated using 10 years' data of winds obtained from satellite observations. Uncertainty analysis was carried out for reliable estimate of plant load factor at potential sites. The initial cost of 50 units of 3.4 MW turbines was estimated as per literature[32]. It was observed that investment costs of offshore installations were higher than onshore and the greater energy production from offshore plant compared to onshore plant cannot compensate for the initial investment. This study tries to identify a suitable feed-in tariff at potential sites in Rameswaram and Kanyakumari to compensate for higher capital cost.

Commercial viability was studied for selected wind farm as per prevailing onshore wind policy by considering incentives at central and federal level. A suitable feed in tariff of 6.54 and 5.71 was identified at potential sites of Rameswaram and Kanyakumari for DSCR of 1.3 at P_{90} PLF level with an IRR 13.87 and 13.97 respectively. The LCOE corresponding to these IRR were 10.78 and 9.61 at Rameswaram and Kanyakumari respectively. It can be concluded that wind farm at Kanyakumari was more viable compared to Rameswaram. At present Tamil Nadu offers the same unit price for the entire state, but the variation in LCOE as identified shows the need for varied tariff based on wind speed and marine environment. Engineering innovations in the offshore wind sector can facilitate further development, but political willingness to provide attractive incentives and feed in tariff would lay the path towards reality for future of offshore wind in India.

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