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Technical and Economic Feasibility study on Repowering of Wind Farms

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Abstract

Objective: The main objective of the paper is to perform a repowering assessmentof an old wind farm consisting of 2 bladed turbines located at Gudimangalam near Coimbatore in Tamil Nadu which is a good wind potential site. **Methods/Statistical Analysis:** Repowering refers to the replacement of first generation small capacity wind turbines with modern multi megawatt wind turbines that can produce more energy than before from the same site. Technical analysis of the site is done using WAsP software with the help of wind data collected from a met mast at the site and includes the calculation of Net Annual Energy Production and Wake losses. Net Annual Energy Production and Wake losses are the primary indicators for selecting the best options for repowering. The option selected is further supported by calculating the economic performance indices. The total repowering has been accomplished through partial repowering executed in three stages. Partial repowering refers to the replacement of only few of the turbines from the existing wind farm rather than replacing the whole farm. The economic feasibility of every repowering option has been studied based on the calculation of the economic performance indices like ALCoG, Payback Period and IRR. **Findings:** The study mainly results in framing a procedure for performing total repowering for any site through the optimization of best possible partial repowering options. The existing site comprises 18 turbines of 450 kW rating and is having a net AEP of 14.5 GWh with a wake loss of 3.82%. The Plant Load Factor (PLF) is obtained to be 20.44%. The best possible total repowering option is found to be producing a net AEP of 65.287 GWh with a wake loss of 2.36% and included 9 Suzlon S95 2.1 MW turbine which is four times the AEP of the existing farm. The three stages of partial repowering included replacement of 6 old turbines by 3 new turbines in each stage. Finally the total repowering is reached through the execution of partial repowering options in three stages and it results in close proximity to the best possible total repowering option in both technical and economic aspects. The final repowering eventually attained results in a net AEP of 65.28 GWh with a wake loss of 2.36% which is the exact match of the best possible total repowering option found in the beginning. The total repowering also leads to an improvement in PLF i.e. almost doubles the PLF to 39.42%. **Application/Improvements:** This procedure can be very useful where the initial investment is an important factor. The study infers that performing total repowering through optimization process is more beneficial than performing partial repowering randomly.

Keywords: ALCoG, IRR, Payback Period, Partial Repowering, Repowering, WAsP

1. Introduction

Renewable energy plays an important role in addressing global energy and environmental challenges. Among renewable energy technologies, wind energy has been the fastest growing source in electricity generation[1]. Wind sector has shown to be a great potential to meet a significant proportion of the energy demanded by the modern society as the amount of installed wind power capacity has increased in the last 2-3 years[2]. Annual Energy production (AEP) by Wind Electric Generator (WEG) in a given area depends on many factors. These include the conditions related to both, the site as well as the WEG. The other important parameter is the

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economic feasibility of the project[3]. Pre assessment of the performance of the WEG at the site using commercially available programs is important before selecting a turbine for a site. The most popular of these software packages is WAsP[4]. Different types of wind turbines are commercially available in the market at present ranging from less than 20kW to as large as 5MW or more[5]. It is always desirable to select a wind turbine which is best suited for a particular area in order to obtain the AEP. The general requirements while selecting a wind turbine were studied by in[6] which reveals product reliability, production volume, cost and availability factors and organization of maintenance as important factors[6]. Another important factor is the site availability for wind farm installation. India, having the fourth largest wind energy installations in the world with more than 25 GW of installed capacity[7], has around 10% of its installed capacity comprising of WEGs with ratings less than 500 kW and that too at sites having Wind Power Density (WPD) of greater than 250W/m2 at 50m height which are underperforming now and hardly do any justice to the site with respect to the advancement in technologies in the recent years[8]. The advancement of technology has also introduced another opportunity of Repowering[9]. Repowering refers to the dismantling and replacement of turbine equipment at an existing site[10]. Estimated repowering potential for WEGs with size less than 500 kW and installed prior to 2000 is 2458 MW with Tamil Nadu and Gujarat being the leaders with 1731 MW and 199 MW respectively. Repowering can play a key role in meeting the fixed reference target of 15000 MW in new capacity addition during the 12th plan period (April 2012 to March 2017). Even the Government will be unveiling a policy framework for repowering including the provision of incentives like interest rebate and already available benefits of Accelerated Depreciation (AD) and Generation Based Incentives (GBI). A detailed study regarding the repowered windfarm layouts has been done in 2013 at Kayathar site by in[11]. This study suggested a layout for total replacement of the old wind farm. A further detailed technical as well as economical study was performed at the same site by in. The author suggested a new option of partial repowering instead of performing total repowering depending on the initial investment which can eventually lead to total repowering. Economic performance indices like Annual Levelized Cost of Generation (ALCoG), Payback Period and Internal Rate of Return (IRR) were calculated for every partial and total repowering options. The selection of the best option was done based on these indices. However, this study performed partial repowering in a random fashion which may or may not lead to the best feasible total repowering option for the site. This paper proposes a plan to perform total repowering by optimization of the best feasible partial repowering options for the selected site. Initially, the best option out of many total repowering options is selected based on the highest net AEP value and least wake losses. The next step includes the partial repowering option selection. The first partial repowering option is selected such that it provides the location of new turbines close to locations obtained in the selected total repowering option with highest net AEP, least wake losses and minimum no. of old turbines to be removed. The economic performance indices are also calculated for every option. These indices are also considered while the selection of the best option. In the same way next partial repowering option is selected and in the final step, it should be matching the total repowering option selected.

2. Case Study

The site selected for the case study is the Dharapuram site consisting of 18 Windia 450 kW 2 bladed turbines which have crossed their life of operation. Wind resource assessment of the selected site using WAsP is freshly carried out in the beginning[12]. Figure 1 shows the actual view of the site which was taken using Google Earth. The blue circles indicate the exact locations of the old 2 bladed turbine.

Figure 1. Actual Layout of Dharapuram site.

The 2 bladed turbines at the actual site is shown in Figure 2. The study was started only after the collection of relevant inputs like time series wind speed data and direction, geographical data, WTG characteristics and specifications etc. from reliable sources. The time series wind data was collected from the nearby met mast. The met mast wind data at a height of 65 m was used to create the wind rose and wind speed frequency distribution for the site which further provided the information like wind regime characteristics, the Weibull parameters (shape and scale parameters) and the prevailing wind direction. Figure 3 represents the wind rose and Figure 4 represents the wind speed frequency distribution of Dharapuram site respectively. The information regarding the terrain, roughness of the site, geographical locations of the turbines etc. are provided in the vector map. The vector map of the site was created with the help of Google Earth, Mapping software's and WAsP Map Editor[12-13]. Power density distribution around the site has been calculated at a hub height of 80 m. The power density varies between 328 W/m2 and 338 W/m2. Vector map of the site is shown in Figure. 5 whereas the Spatial distribution is shown in Figure 6.

Figure 2. Awo Bladed Turbines at Dharapuram site.

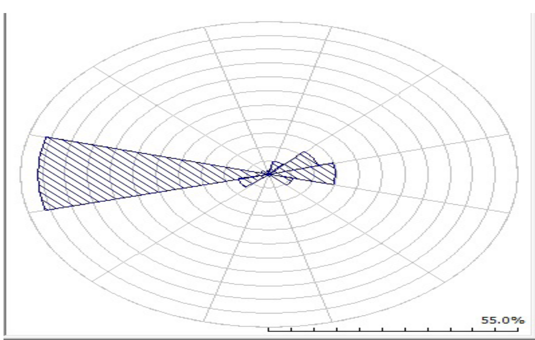

Figure 3. Wind Rose of Dharapuram site at 65m.

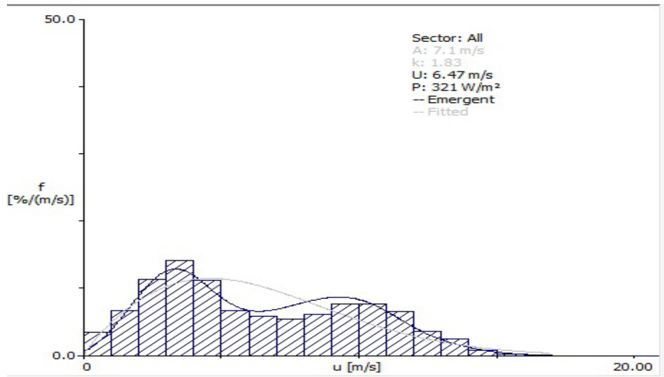

Figure 4. Frequency Distribution of Dharapuram site.

The closed region in black box in Figure 5 is the exact location of the Dharapuram site. Next step of the study was the performance analysis of the existing wind farm with the 18 old 2 bladed turbines.

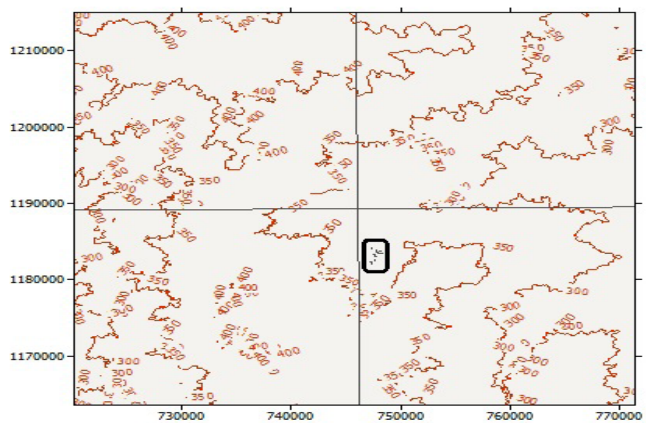

Figure 5. Vector Map of Dharapuram site.

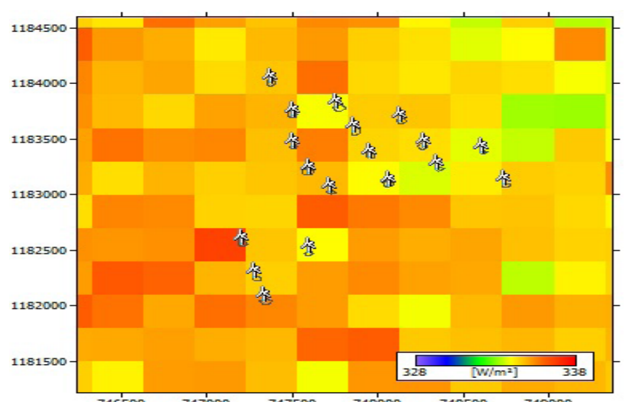

Figure 6. Power Density at 80m Hub Height.

The net AEP of 18 machines was found using WAsP to be 14.5 GWh and total wake loss of 3.82%. This indicates roughly 806 MWh per machine. The Plant Load Factor (PLF) was obtained to be 20.44%. Figure 7 shows the power curve in red color and Cp curve in blue color for the 450 kW machine. The x-axis represents the wind speed and y-axis represents power and Cp value respectively. Figure 8 shows the actual layout of the existing wind farm whereas the generation details are shown in Figure 9.

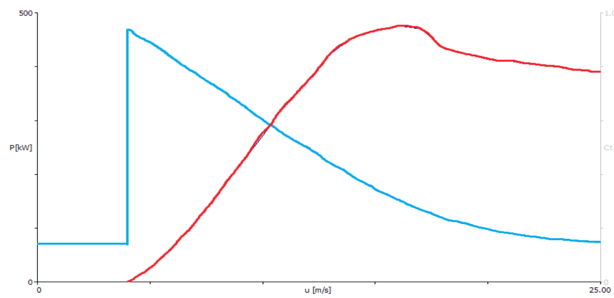

Figure 7. Power and Cp curve for 2 bladed turbines.

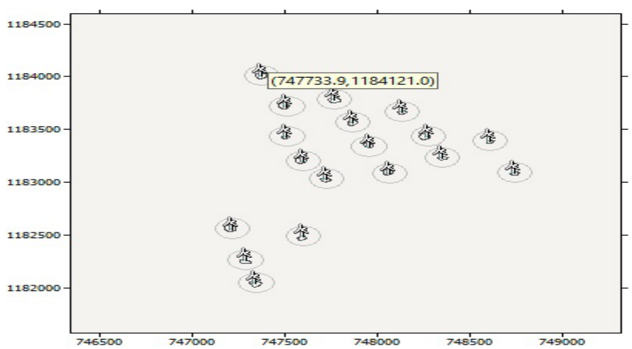

Figure 8. Layout of Existing Wind farm.

Variable	Total	Mean	Min	Max
Total gross AEP [MWh]	15084.088	838....	835....	841....
Total net AEP [MWh]	14508.093	806....	732....	838....
Proportional wake loss [%]	3.82	-	0.03	12.28
Mean speed [m/s]	-	5.67	5.66	5.68
Power density [W/m2]	-	232	231	233
RIX	-	-	0.0	0.0

Figure 9. Results for Existing Wind farm.

Next step is the selection of best total repowering option based on highest net AEP and least wake losses. Layout of the selected total repowering option has been shown in Figure 10. It consist of 9 new Suzlon 2.1 MW turbines with a hub height of 80m and sweep diameter of 88m placed after replacing the old 18 turbines and using the same land area. Figure 11 shows the power curve and Cp curve for the Suzlon S88 2.1 MW turbine with the same axes as in Figure 7[14].

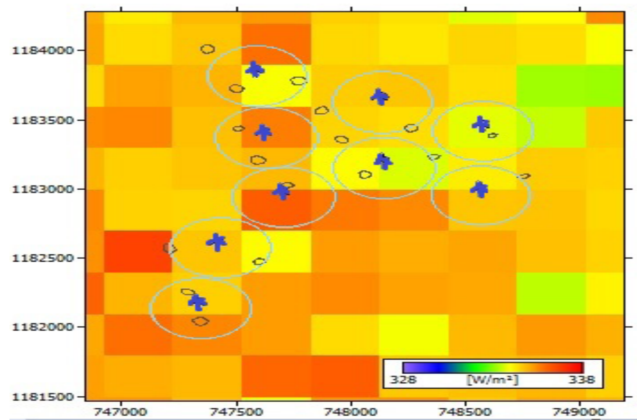

Figure 10. Layout of Total repowering option.

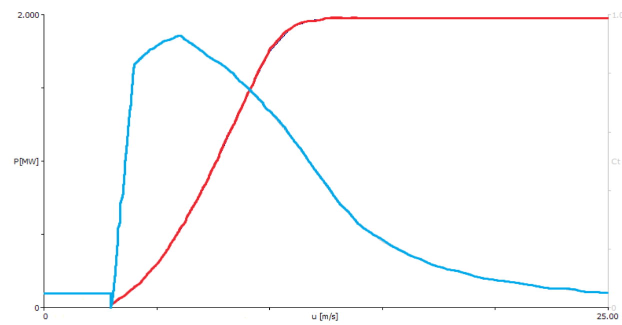

Figure 11. Power and Cp curve for Suzlon 2.1 MW turbine.

Total repowering resulted in a net AEP of 65.287 GWh with a wake loss of 2.36%. It is important to note that the wake loss in the totally repowered farm is below 5%. Figure 12 presents the WAsP screenshot of the results for total repowering. The results displayed is the total AEP and wake losses for the complete wind farm consisting of the new turbines.

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	66.868	7.430	7.423	7.437
Total net AEP [GWh]	65.287	7.254	7.026	7.417
Proportional wake loss [%]	2.36	-	0.26	5.42
Mean speed [m/s]	-	6.83	6.82	6.83
Power density [W/m2]	-	384	383	385
RIX	-	-	0.0	0.0

Figure 12. Results for Total Repowering.

The partial repowering options are now selected with reference to the above selected option. Next step is the first phase of partial repowering which includes the replacement of 6 old turbines with 3 new Suzlon 2.1 MW turbines. Other options were also tried out with removal of different no. of turbines but they resulted in lesser net AEPs and higher value of wake losses. Figure 13 presents the layout of the selected partial repowering option with a spacing of 5D x 5D between the turbines and Figure 14 shows the corresponding results obtained in WAsP. This option results in a net AEP of 31.856 GWh and wake losses of 1.51%. Each of the three new turbines produced a net AEP off 7.4 GWh with a wake loss of less than 0.25%. However, the old turbine produced 0.7 GWh each with a wake loss within 10%. Actual layout of the partial repowered site in Google Map is shown in Figure 15 with the white circles having 5 times the sweep diameter.

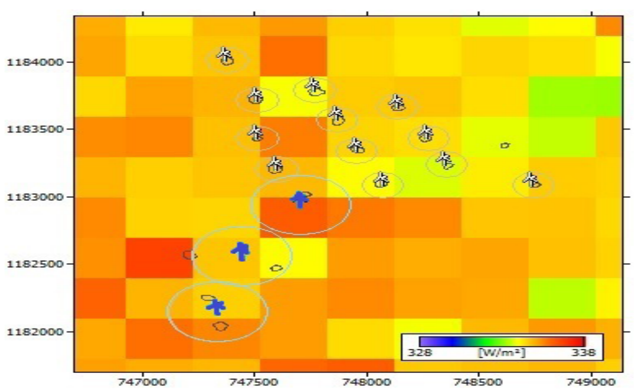

Figure 13. Layout of First Partial Repowering.

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	32.346	2.156	0.836	7.434
Total net AEP [GWh]	31.856	2.124	0.767	7.425
Proportional wake loss [%]	1.51	-	0.12	8.58
Mean speed [m/s]	-	5.90	5.66	6.83
Power density [W/m2]	-	262	231	385
RIX	-	-	0.0	0.0

Figure 14. Results for First Partial Repowering.

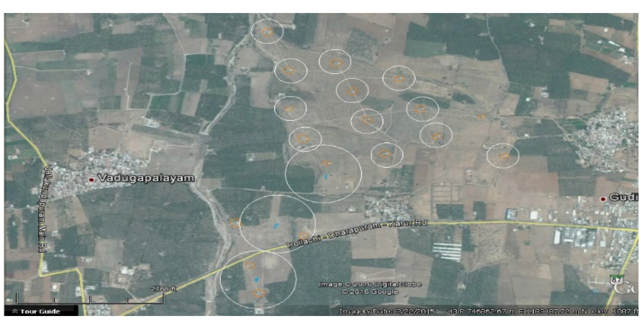

Figure 15. Actual site view of First Partial Repowering.

In similar manner, the second phase of partial repowering was carried out. Another 6 old turbines were replaced by 3 new Suzlon turbines in this option which eventually resulted in replacement of 12 old turbines with 6 new turbines. Figure 16 and Figure 17 presents the actual layout of the repowering option and its associated results respectively. Net AEP produced in this option was 51.193 GWh with a wake loss of 1.76%. The 6 new Suzlon 2.1 MW turbines produced 7.3 GWh each with a wake loss of less than 3% and the old turbines produced 0.8 GWh each. The layout changes in the site are presented in Figure 18.

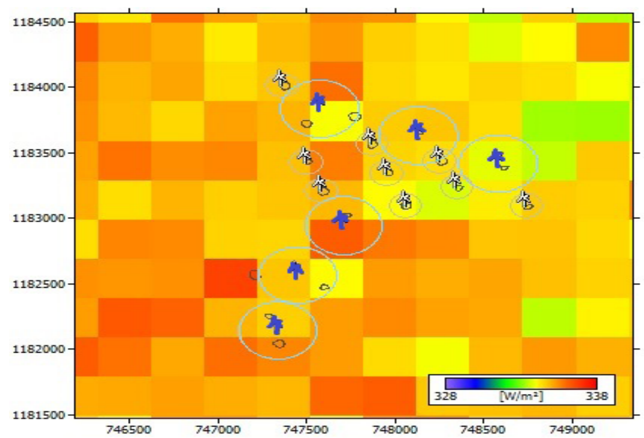

Figure 16. Layout of Second Partial Repowering.

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	52.112	3.474	0.836	7.434
Total net AEP [GWh]	51.193	3.413	0.766	7.422
Proportional wake loss [%]	1.76	-	0.17	8.71
Mean speed [m/s]	-	6.13	5.66	6.83
Power density [W/m2]	-	292	231	385
RIX	-	-	0.0	0.0

Figure 17. Results for Second Partial Repowering.

The final step is the selection of last partial repowering option which eventually leads to the total repowering of the site. This layout should be selected keeping in mind the selected total repowering layout in the beginning. Figure 19 shows the layout of the last partial repowering option whereas Figure 20 presents the corresponding results. This option replaced the remaining 6 old turbines with further 3 new Suzlon turbines. Eventually the final repowering resulted in producing a wind farm having 9 new Suzlon 2.1 MW turbines.

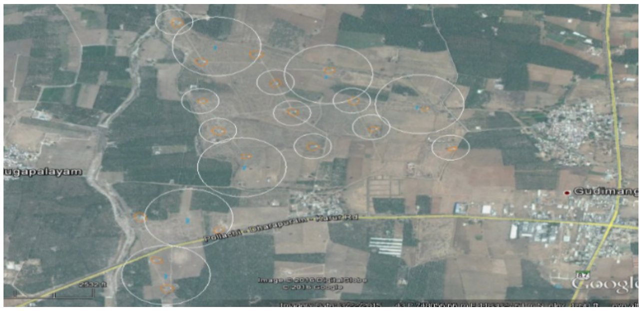

Figure 18. Actual Site View of Second Partial Repowering.

The results of last partial repowering option shows that the net AEP is similar to the net AEP of the selected total repowering option in the beginning i.e. 65.28 GWh and wake loss also similar in both cases i.e. 2.36%. Thus, the actual site will be as shown in Figure 21 after total repowering. The final repowering option results in an improved PLF of 39.42%.Eventually the area utilized for the complete repowering was within the existing wind farm area limit of 3 km2. Table 1 summarizes the details of all the selected options along with the results i.e. Net AEP and wake losses. The least wake loss was found in first partial repowering while the highest was found in final repowering option and that too close to the selected best total repowering option. However, all the wake losses are within the limit of max 5% wake loss.

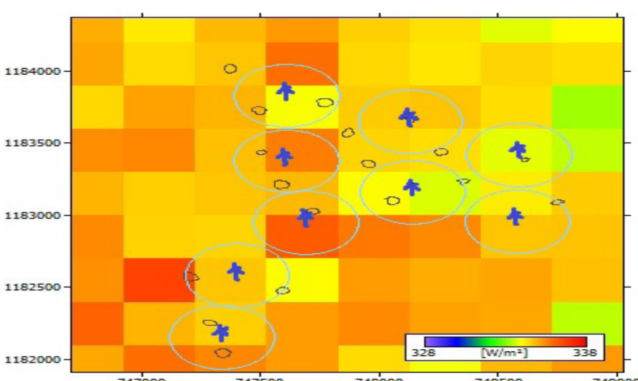

Figure 19. Layout of Last Repowering Option.

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	66.867	7.430	7.423	7.434
Total net AEP [GWh]	65.285	7.254	7.026	7.415
Proportional wake loss [%]	2.37	-	0.26	5.49
Mean speed [m/s]	-	6.83	6.82	6.83
Power density [W/m2]	-	384	383	385
RIX	-	-	0.0	0.0

Figure 20. Results for Last Repowering Option.

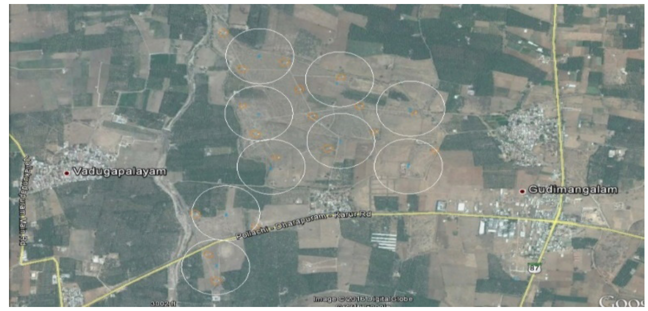

Figure 21. Actual Site view of Last Repowering Option.

Table 1. Results of all Repowering Options

Option for Repowering	Farm Size	Net AEP (GWh)	Wake Loss (%)
Selected Total	9 x 2 MW	65.287	2.36
First Partial	3 x 2 MW 12 x 450 kW	31.856	1.51
Second Partial	6 x 2 MW 9 x 450 kW	51.193	1.76
Last Partial	9 x 2 MW	65.285	2.37

3. Economic Feasibility study

Evaluation of economic performance indices were also performed to study the economic and financial feasibility of every repowering option and helps in selecting the best option. The economic performance indices for a wind farm are (a) Annual Levelized cost of Generation (ALCoG), (b) Payback Period and (c) Internal Rate of Return (IRR). The correction factors for power curve adjustment, machine availability, grid availability and electrical losses on the net AEP were considered before analyzing the economic indices.

The tariff rate as approved by The Tamil Nadu Electricity Regulatory Commission (TNERC) decides the revenue from wind farms and that is at present 3.51 Rs/kWh[15-16]. 0.5 Rs/kWh will also be added as per the Generation Based Incentive approved by The Union Govt. of India. The evaluation of the Economic Indices were started only after procuring all the required necessary information for the process.

3.1 ALCoG

AEP was estimated with uncertainty levels of 10% and 15% for probability levels of 50%, 75% and 90%.The results for all options proposed above are shown in Table 2 – Table 4 and they are based on the net AEPs of the new wind turbines in every option.

Table 2. Net AEP (GWh) of First Partial Option

Uncertainty	10%	15%
P50	19.579	
P75	18.258	17.598
P90	17.069	15.815

Table 3. Net AEP (GWh) of Second Partial Option

Uncertainty	10%	15%
P50	43.73	
P75	40.78	39.31
P90	38.13	35.33

The AEPs were found to be increasing with the increasing no of new turbines as the options followed. Also the 50% probability i.e. P50 produced highest AEP than P75 and P90.

Table 4. Net AEP (GWh) of Last Partial Option

Uncertainty	10%	15%
P50	57.45	
P75	53.58	51.64
P90	50.1	46.41

Table 5- Table 7 presents the ALCoG calculation results for the three options. It was found to be almost same in every option.

Table 5. ALCoG (Rs/kWh) of First Partial Option

AEP	i (%)	10 %	15%
P50	8	2.44	
	12	3.16	
P75	8	2.61	2.71
	12	3.39	3.52
P90	8	2.79	3.02
	12	3.63	3.92

Table 6. ALCoG (Rs/kWh) of Second Partial Option

AEP	i (%)	10 %	15%
P50	8	2.18	
	12	2.83	
P75	8	2.34	2.43
	12	3.04	3.15
P90	8	2.5	2.7
	12	3.25	3.51

Table 7. ALCoG (Rs/kWh) of Last Partial Option

AEP	i (%)	10 %	15%
P50	8	2.49	
	12	3.23	
P75	8	2.67	2.77
	12	3.47	3.59
P90	8	2.86	3.08
	12	3.71	4.0

3.2 Payback Period

3.2.1 Simple Payback Period

The simple payback period for all the options were calculated considering the maintenance cost and its annual escalation rate. The maintenance cost is considered as 2% of the initial investment for the first 5 years. It is assumed to escalate by further 2% every year for the next 5 years and saturates at the last value. Table 7 – Table 10 represents the Simple Payback Period of first, second and last option respectively.Simple Payback period was found to be lying between 5 to 7 years for all the options. Highest period was 6.8 years for 90% probability at 15% interest for the last partial repowering option and 4.8 years being the least for 50% probability in the second partial repowering option.

Table 8. Simple Payback Period of the Repowering Cost for First Partial Option

AEP and uncertainty	Payback period (years)
P50	5.3
P75 (10%)	5.7
P75 (15%)	5.9
P90 (10%)	6.2
P90 (15%)	6.6

Table 9. Simple Payback Period of the Repowering Cost for Second Partial Option

AEP and uncertainty	Payback period (years)
P50	4.8
P75 (10%)	5.1
P75 (15%)	5.3
P90 (10%)	5.5
P90 (15%)	5.9

Table 10. Simple Payback Period of the Repowering Cost for Last Partial Option

AEP and uncertainty	Payback period (years)
P50	5.5
P75 (10%)	5.8
P75 (15%)	6.1
P90 (10%)	6.3
P90 (15%)	6.8

3.2.2 Discounted Payback Period

Discounted payback period calculation considers the interest accumulated on the loan as well as the interest due on the revenue. Calculations are performed for two cases of interest on loan: (i) 12% and (ii) 8 %. The Discounted Payback Periods calculated for three options are shown in Table 11 – Table 13.

Table 11. Discounted Payback Period for the First Partial Option

AEP and uncertainty	Payback period for i = 8% (years)	Payback period for i = 12% (years)
P50	10	13
P75 (10%)	11	14
P75 (15%)	12	15
P90 (10%)	12	16
P90 (15%)	13	20

Table 12. Discounted Payback Period for the Second Partial Option

AEP and uncertainty	Payback period for i = 8% (years)	Payback period for i = 12% (years)
P50	9	11
P75 (10%)	10	12
P75 (15%)	10	13
P90 (10%)	10	13
P90 (15%)	12	15

Table 13. Discounted Payback Period for the Last Partial Option

Uncertainty	IRR (P50)	IRR (P75)	IRR (P90)
10%	16%	15%	13.5%
15%		14%	12%

Discounted Payback period is higher than Simple Payback period as it considers the time value of money. It was calculated considering the increase in Annual maintenance cost also year by year after five years.

3.3 IRR

The interest rate at which the present worth of costs equals the present worth of the benefits accrued at the end of the life term of the plant is called the internal rate of return. It also indicates the maximum value of interest for loan permissible in order to make profit. Table 14 – Table 16 shows the calculated Internal Rate of Return for the three options.

Table 14. IRR for the First Partial Repowering

AEP and uncertainty	Payback period for i = 8% (years)	Payback period for i = 12% (years)
P50	10	13
P75 (10%)	12	15
P75 (15%)	12	16
P90 (10%)	13	17
P90 (15%)	14	21

Table 15. IRR for the Second Partial Repowering

Uncertainty	IRR (P50)	IRR (P75)	IRR (P90)
10%	17.5%	17%	15%
15%		16%	14%

Table 16. IRR for the Last Partial Repowering

Uncertainty	IRR (P50)	IRR (P75)	IRR (P90)
10%	16%	14.5%	13.5%
15%		14%	12%

4. Discussion

The government is aiming to add 175 GW of renewable power capacity by 2022 out of which it is expected to have a contribution of 100 GW by solar and 60 GW by wind resource[17]. With India having a high repowering potential of 2458 MW considering wind farms installed prior to 2000 and comprising of WEGs with ratings less than 1000 kW, repowering can play a very important role in achieving the high profile target. The constraints associated with repowering are also to be considered while trying to achieve the target of 60 GW. The profound restrictions are land ownership, turbine ownership, Power Purchase Agreement (PPA) modifications, feasibility of evacuation infrastructure, new substation creation, disposal of used turbines etc. The Government policies and incentives providing the framework for repowering can play a great role here in accelerating the process of repowering. The Central Government of India will be soon unveiling a policy with an objective of promoting optimum utilization of wind energy resources by creating facilitative framework for repowering. Indian Renewable Energy Development Agency (IREDA) will be providing an additional interest rebate of 0.25% over and above the interest rebates available to new wind projects financed by it. Also the benefits available to the new wind projects i.e. AD and GBI as per applicable conditions will also be available to repowering projects.

5. Conclusion

The study presents a new procedure for performing partial repowering for any existing wind farm that is of optimizing the partial repowering options which will be eventually resulting in the best possible total repowering option. This is presented as an improvement on the previous study at Kayathar site. The option of repowering proves to be a feasible option in terms of both technical as well as economic aspects. The PLF was are found to be improved for the repowering as compared to old wind farms. The wind farm investors must therefore promote repowering based on its technical and economic feasibility along with the utilization of the new policy frameworks for repowering.

6. Acknowledgement

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