Repowering opportunities of wind Turbines in the State of Tamilnadu, India: A systematic review

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Abstract

Wind turbine technology is in existence in India for more than three decades now, and it is a proven technology for power generation. The first wind farms were established in India during the 1990s when the technology was in its infancy, and subsequently, wind farms developed in other parts of the country. During the development stages, the turbine technologies were under evaluation and, with a higher cost, had occupied the best windy sites and continue to operate at low Capacity Utilization Factors (CUFs). In the state of Tamil Nadu, India, almost 53% of Wind Turbine Generators (WTGs) with a capacity less than or equal to 550 kW were installed before the year 2000 and are presently operating with 10% to 15% of CUF. With the new and advanced technologies, the low efficient older WTGs can be replaced with modern multi-megawatt WTGs called as repowering. This result increases higher power output and effective wind power potential usage. Countries like Denmark, Germany, the USA, UK, and Spain started early with wind power generation and are in the phase of the end of the lifecycle and have come up with various policies and guidelines. These experiences will enable Stakeholders involved in the Windfarm projects to make a better-informed decision about the end of the life assessment decisions after 20 years. The various challenges faced during the repowering of wind farms are the lack of a proper business model, ownership issues, and local communities' protests. This paper reviews the existing literature, organizes and highlights the aspects of repowering and various challenges and opportunities, a further recommendation to create a methodology and reason for repowering in the state of Tamil Nadu. The problems can be addressed by repowering in the best windy sites and finding customized site-specific solutions.

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Acronyms and Abbreviations

CO_2	:	Carbon dioxide
CUF	:	Capacity Utilisation Factor
DISCOMS	:	Distribution Companies
GBI	:	Generation Based Incentive
GW.	:	Giga Watt
GWh	:	Gigawatt Hour
IREDA	:	Indian Renewable Energy Development Agency
kW	:	KiloWatt
MNRE	:	Ministry of New and Renewable Energy
MW	:	MegaWatt
PPA	:	Power Purchase Agreement
TEDA	:	Tamil Nadu Energy Development Agency
USA	:	United States of America
WTG	:	Wind Turbine Generators

1. Introduction

Increasing energy demand in developing countries such as India motivates the use of renewable energy resources to afford sustainable development and eco-friendly power supply. The wind energy sector in India is the fastest growing renewable energy; despite 300 days of good sunshine hours, the country is blessed with four to six months of good seasonal wind, at times, eight months of wind due to extended monsoon periods. Besides, to roll back the number of greenhouse gas emissions from the thermal power sector burning fossil fuels and to encourage the transition from traditional sources to renewable, wind energy paves the path. In India, the total installed wind power capacity is about 36.93 GW (as in September 2019 by MNRE), contributing to 10% of the total installed wind power capacity of the world (Riya Rachel Mohan 2016) (R. Sitharthan et al. 2014).

India is globally the fourth position among the top 10 wind turbine power generators in the world after China (168.69 GW), the USA (82.18 GW), and Germany (50 GW). Wind energy holds a significant portion of 44.72% of the 82.59 GW of total renewable energy installed, making it the largest source of clean energy (R. Sitharthan et al. 2014) (Mohit Goyal 2010). The pie chart given in FIG.1 represents the various renewable energy sources available in India.

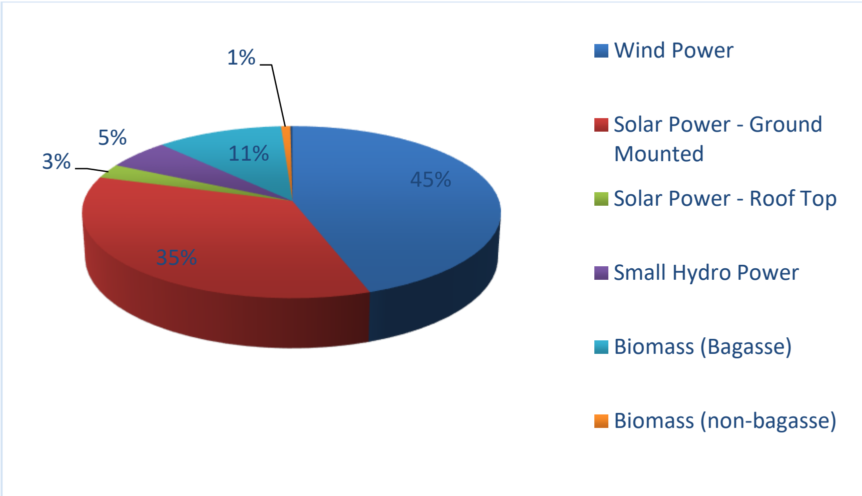

FIG 1: Various renewable energy resources in India (Source: MNRE)

In India, there have been various wind resource assessment campaigns conducted in different parts of the country. The data were collected based on the meteorological mast, ranging from 20m to 120m. Based on this extensive data collection method and applying the flow modeling technique with the appropriate correction, the wind power potential throughout the country was estimated at multiple heights. Based on one such result, in terms of wind power potential, approximately 237 sites are having a WPD of 200 W/m^2 at 50 m height above the ground level (Vikas Khare et al. 2013).

2. Background

Electricity generation from wind has overcome several barriers in terms of technical feasibility, economic feasibility, frequent policy shifts, and land possession disputes. The first wind farms were established in India in the early '90s; the rating of WTG accessible throughout that time was 55kW to 500 kW with lower hub height, and the rotor diameter of the turbine was roughly 30 meters; besides, the CUF was very less. These WTGs had critical and outdated components in the course of operation, generally over a 20-year life period, which resulted in substantial maintenance costs and time overruns, larger downtimes, which intern reduces the total energy production. Numerous disadvantages were also associated with these WTGs, such as weak control mechanisms and regulation, reactive power control, grid friendliness, and unaddressed power quality and quantity. All the WTGs are predicted to have a lifecycle spanning 20 to 25 years. The main question is, what has to do after its service life-ending. The WTGs towards the end of service life exhibits high failure rates, need significant maintenance, and are likely to suffer from a lack of pertinent spare parts (generator, gearbox, blades, etc.).The various strategies that can be adopted are dismantling the WTG and refurbishing WTG to extend operational life or repower. Repowering replaces the first-generation low-capacity WTGs with modern multi-megawatt WTGs.

Repowering involves the decommissioning of older existing WTGs and replacing newer WTGs with highly modern standards on the same location resulting in additional value added to the site through larger blades, taller towers, higher WTG capacities, and more efficient turbines. These multi-megawatt machines generate more power and effectively increase the CUF, and there is a technological enhancement in terms of turbine efficiency and reliability. It is the process that uses one-half of the infrastructure, with double the capacity increases and results in triples the energy (Eric Lantz et al. 2013). The Government of India has set an ambitious target of 60 GW of installed wind power generation capacity by the year 2022. This target can be achieved by installing 24

GW wind power capacity in the next four years, with annual capacity addition of 6000 MW per year. This can be done either by installing WTGs in the new Greenfield locations or repowering of WTGs in the existing grey field location. Though India has experience developing onshore wind farms in new areas, it lacks in the skills of repowering the wind power project. India can learn from the experiences of countries where the repowering project not only started but also executed successfully.

The primary focus of this review paper is to bring awareness among the various stakeholder about the last phase of the energy generation from the wind wherein the decision making involves assessing the end of the life cycle assessment and decided a way forward in the form of repowering. This paper provides a review of the

- ❖ Repowering experience of wind turbines/farms in the world
- ❖ Wind power potential available in India
- ❖ Repowering opportunities in Tamil Nadu
- ❖ Various challenges faced and barriers in wind turbine repowering

3. Literature Review

The countries that started wind turbine installations early in promoting wind power are now facing the problem that the land with good wind potential is occupied by older WTGs, as seen in India. The difficulties are facing in seven windy states such as Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, and. Tamil Nadu. Though still, new locations are available for wind farm development, they do not have an adequate high intensity of wind power density. The development of wind farms in new areas may meet increasing resistance from residents. Since the new WTGs have become larger and land with excellent wind opportunities are slowly becoming scarce, the most techno-economic option could be to replace the old WTGs with new WTGs. With the acceptance of the replacement of large capacity WTGs on existing locations, repowering can contribute to the realization of national targets in the reduction of the carbon footprints in the atmosphere. It can be expected that the countries which are started initially with wind energy will also be the leading countries concerning repowering with WTGs older than 10-15 years or scarcity of new locations with good potential.

Globally the installed capacity of wind power reached approximately 487 GW, and the global wind power leaders are Denmark, China, United States, Germany, India, and Spain (World energy resources Report 2016). Wind power technologies in these countries are so extensive that very few onshore sites are available to develop new wind farms. It is expected that global wind power capacity may reach approximately 977 GW in 2030 (905 GW onshore winds and 72 GW offshore winds). To expand the wind power generation, offshore wind farms can be built or can supplement the existing WTGs with new and higher-rated WTGs under repowering.

Repowering of the wind farms first started in the 1990s in Denmark, as the European country thought that replacing older wind turbines would give great value to the economy and environment. Their policies helped them in making wind-driven power as a major electricity generation technology of the 21st century. This section, based on the literature survey available on the open-source domain, the wind energy scenario, and repowering issues around the world, is given below.

3.1 Denmark

Denmark is the world's largest wind energy producer with an installed capacity of around 142 GW. Commercially, Denmark started with wind power consumption in the 1970s, and today, a significant share of WTGs is produced by Danish manufacturers (Vishal Agarwal 2013). Repowering became an essential part of Denmark's wind energy policy, which was established in 1994 and later modified in 2001, giving additional premium over standard feed-in tariff for turbines smaller than 100 kW. With this policy, 1208 turbines were replaced, increasing the capacity by 202 MW. Denmark's repowering projects started in 2001 and ran till 2003, benefiting smaller turbines with a 100 kW rating to install three times the existing capacity. One thousand four hundred eighty turbines with 122 MW capacity replaced with 272 new turbines with 332 MW capacity. Again from 2008 to 2011, another repowering program started in which 175 MW of old turbines were replaced (http://www.irena.org/documentdownloads/publications).

In Denmark, for repowering projects, the main drawbacks have been in capital requirements and ownership issues (Eric Lantz et al. 2013). In addition, some parts of the local communities protested against any further development of onshore WTGs. These have made the development of wind farms by the private sector very burdensome in the last decade. Developers in Denmark experience relatively few interactions with authorities in the planning process leading to lapses in state-provided guidance and practical assistance. Further, the authorities are reluctant to carry out the environmental impact assessment as well as a preliminary investigation of the project, which increases the investment risks (Justin Gerdes 2017) (German wind auctions hike power market risk for repowering projects 2016).

3.2 Germany

In Germany, wind turbines came into operation in the early 1980s in coastal regions. Germany has the largest wind energy market with the installation of more than 1892 MW of new onshore wind projects in 2016 alone (Jeffrey Davis, Robert Goldberg, Isaac Maron 2017). Germany's wind energy industry association is planning to add with a minimum capacity of 15 GW of new wind power capacity by 2020. Germany's repowering potential was estimated to be 6000 MW by the end of 2015. The most extensive repowering program was initiated in the Rhineland-Palatinate region, the southwestern German state. Five 1.5 MW turbines were replaced with five 7.5 MW turbines, increasing the production from 3 GWh to 20 GWh. (http://www.irena.org/documentdownloads/publications).

Repowering in Germany is limited by total turbine height restrictions and limitations in the feed-in tariff laws (Eric Lantz et al., 2013). And also, the country had a lack of long-term policy targets on promotion and expansion of wind power, which can provide stability and security for investors, developers, and producers. In April 2016, the German State of Mecklenburg-West Pomerania passed a law requiring that citizens and municipalities within five kilometers of a wind project must be offered at least a 20% profit share in the project. Repowering projects in Germany have to compete with new developments, often against a background of reduced targets for capacity growth based on new rules implemented in January 2017. These imposed rules are creating a competitive auctioning process for all future onshore wind contracts, requiring developers to bid against each other with a lower tariff. (American Wind Energy Association US 2017).

3.3 The United States

In 1987, the United States started wind power generation with 500 kW capacity wind turbines. In 2016, the total installed capacity became 82.18 GW (Sara Knight 2017). According to American Wind Energy Association, about 3371 MW of total wind capacity is older than 15 years, and 620 MW is nearing 20 years. These wind farms are located in the western coastal regions of California, Oregon, and Washington. Repowering in California is done based on 80/20 rule, under which a repowered WTG may qualify for a new ten-year period of the production tax credit (PTC) if the cost of the latest equipment incorporated into the turbine is at least 80% of the turbine's total market value (Global wind report 2016). In EDF's Shiloh IV farm of California, 235 numbers of 100 kW turbines were replaced with 50 numbers new turbines (http://www.irena.org/documentdownloads/publications). The presently existing tax law helps to provide an incentive to the owners for the repowering projects. The tax law signifies that the projects are getting qualified for the federal Production Tax Credit if at least 80 percent of the property's value is new. (KEMA 2008).

The United States struggles in terms of policy & regulatory challenges and the lack of economic incentive to develop a favorable wind repowering market (Mark Del Franco 2017). There are limited incentives for projects that are running and generating revenue. Project permits and contractual arrangements for the repowered projects need to be newly obtained or negotiated based on the licenses, leases, and other project contracts for the existing facility. This depends on the terms of the permits and contracts, which need to be carefully reviewed (Eric Lantz et al. 2013). The valuation and economic aspects are challenging, and they introduce some challenges, so developers and investors are likely to be turning to counsel for security before moving too far down the road on an aggressive repowering qualification strategy (Antonio Colmenar-Santos et al. 2015).

3.4 Spain

The first wind turbine installation in Spain started in 1992, but the most substantial growth has occurred since 1998 due to the stability provided by Law 54/1997. In order to provide low-cost energy, a guarantee for continuous electricity supply, and the highest quality standards to the public, the electricity sector established a new regulatory framework based on the law. To create a specific regulation, the electricity sector designed the structure based on conducting free competition with only the intervention of the administration (Global wind energy council 2017). At the end of the year 2016, the installed capacity of commercially operating wind farms in Spain was 23074 MW (http://tnebldc.org/reports1/peakdet.pdf). The repowering potential capacity currently in Spain is around 2.3 GW, which is greater than or equal to 13 years of operation (Global wind energy council 2017).

In Spain, due to legislative changes, no new wind energy development took place after 2013. This new regulation completely removes subsidies and incentives but allowing only a 40 % increase of the actual installed power (without needing new permits). The decision to implement the repowering project depends on the profitability of the electricity price and forecast its evolution. The development of a large-sized wind energy market with sustainable growth is at a slower pace in recent times due to the lack of specific regulation

3.5 United Kingdom

The UK installed its first wind farms in the early 1990s when wind energy technology was in its initial phase and also accelerated progress towards meeting carbon targets. Further development of wind energy development can be achieved by replacing old wind turbines with new, higher capacity wind turbines. The onshore wind farms across England, Scotland and Wales show that there are close to 60 wind farms smaller than 1 MW and will reach 20 years of operation within the next 5 years. With a combined capacity of more than 440MW and upwards of 750 individual wind turbines, these projects offer a clear potential to boost UK onshore wind supply, without developing new sites. Repowering these sites would increase the capacity of more than 1.3 GW, reduce the prices, and increase the net energy yield by more than 3 TWh (Terra Watt-hour) in a year, which is enough to power more than eight lakh homes (conservative estimation).

Repowering these sites and taking advantage of the ever-lower prices of onshore would yield a net increase in capacity of more than 1.3 Giga Watts (GW), and electricity output of more than 3 terawatt-hours (TWh) per year enough to power nearly 800,000 homes, based on conservative estimates.

This is an option in areas where the use of taller turbines is not possible or where grid constraints limit an increase in capacity and allow re-use of existing tracks, crane pads, and cable trenches to keep costs down. If larger turbines cannot be installed, an alternative is to install turbines comparable to those already in place at the existing locations. While this can lead to lower construction costs, the use of existing infrastructure will limit turbine size, restricting output and curbing benefits from re-powering.(http://tnebldc.org/reports1/peakdet.pdf)

The challenges and issues that are faced by these countries and how they overcame are detailed below in Table 1. This will help us to recommend the formulation of guidelines and boosting polices for the repowering.

Table 1: Repowering issues faced by various countries and measures to overcome these issues

Country	*Repowering issue*	*Various measures to overcome these issues*
Denmark	❖ Capital requirement to carry out the repowering of a wind farm. ❖ Ownership issue when no of wind turbines are reduced in repowering ❖ Local community and public protest against new construction due to lack of awareness ❖ Lesser interaction with the authorities ❖ Lack of guidance ❖ Unwillingness to carry out the environmental impact assessment studies due to existing wind farms and projecting it for the repowered wind farm.	❖ With a set of new legislation, an e subsidy scheme for wind power development is improved ❖ Introduction of a price guarantee ❖ Link repowering mechanism with the dynamics of local and regional development.
Germany	❖ Restriction in overall hub height and total turbine height ❖ Limitation in the feed-in tariff laws Lack of long-term policy targets on promotion and expansion of wind power program. ❖ Repowering projects are having to compete with new developments ❖ The imposed rules implemented in January 2017 are creating a competitive auctioning process for all future onshore wind contracts, requiring developers to bid against each other with a lower tariff	❖ The German State of Mecklenburg-West Pomerania passed a law in April 2016 law requiring that citizens and municipalities within five kilometers of a wind project must be offered at least 20% in the project.
United States	❖ Policy and regulatory challenges ❖ lack of economic incentive to develop a favorable wind repowering market ❖ limited incentives to projects that are running and generating revenue ❖ Project permits and contractual arrangements for the repowered facility will need to be newly obtained or negotiated	❖ US wind industry is driven by the wind production tax credit (PTC). ❖ Wind farm owners have until the end of 2019 to repower old schemes and qualify for an additional ten years of PTC support (Kulkarni, S.H. et al. 2018).

	❖ Meteorological data for the existing project is not sufficient for the contemplated repowering project ❖ Evaluation of the economics of the development	
Spain	❖ Completely removing of subsidies and incentives ❖ The decision to implement the repowering project depends on the profitability of the electricity price, and the possibility to forecast its evolution. These could make an essential contribution to the decision to implement repowering. ❖ The development of a large-sized wind energy market with sustainable growth is at a slower pace in recent times.due to the lack of specific regulation	❖ A few large operators own wind turbines with long term o wind data available with them, which will be helpful (Kulkarni, S.H. et al. 2018).
United Kingdom	❖ Grid constraints limit the increase in capacity ❖ Availability of existing potential sites	❖ A similarly rated capacity turbine can be installed in the same place with better technological advancement ❖ The use of existing infrastructure will limited turbine size, restricting output, and benefits from repowering. ❖ Re-use of existing tracks, crane pads, and cable trenches to keep costs down.

Based on the gained experience analyzing international scenarios of the major countries, India can implement repowering to the wind farms completing the life cycle with the main objectives of

- ❖ Promote wind energy with better technological advancement
- ❖ Address the end of the life cycle issues
- ❖ Overcome the energy supply gap
- ❖ Better utilization of the wind-rich sites
- ❖ Enhance wind power generation, complied to grid
- ❖ To bring wind energy as a leading source of electricity
- ❖ Achieve the Government's target to implement more and more renewable energy

4. Repowering in India

In India, there is a more excellent opportunity of repowering as wind power development started in early 1990, and machines with a rated capacity of 80/90/200/225/500/550 kW were used at that time. Around 69% of the WTGs were installed in India, having a capacity range between 225kW and 1,000kW. There is a non-uniformity in the distribution of the wind potential across India. States such as Tamil Nadu in the South and Gujarat in the west have maximum wind capacity installed due to high wind velocity, followed by Andhra Pradesh, Maharashtra, Rajasthan, Madhya Pradesh, Kerala, and North-Eastern regions.

The Tamil Nadu state has emerged as a pivot point for the development of renewable energy, as of now, approximately 40% of India's total renewable installed capacity is from sources such as wind, solar, biomass, biogas, small hydro, etc. Renewable energy provides a feasible option for on and off-grid electrification. According to Tamil Nadu Transmission Corporation Ltd., the total renewable energy-based installed capacity in Tamil Nadu as of 20.07.2019 is 12000 MW, which includes 3000 MW from solar projects, 9000 MW of wind-based projects and 889.4 MW from other renewable resources (J. Jeslin Drusilla Nesamalar et al. 2017). With superior landscape and higher wind velocity with low surface roughness, wind energy has emerged as the most successful renewable energy option in Tamil Nadu. The potential area suitable for setting up wind generators is available in the south (Aralvoimozhi pass and Shengottai pass) and southwestern (Palghat and Cumbum pass) parts. The largest WTGs cluster in Asia around 3000 machines with a capacity of about 1500 MW installed in Muppandal, Aralvaimozhi Pass. (Policy for repowering of the wind power projects 2015). High winds of 5.5 m/s to 7 m/s intensity are characteristic of this part of the state. Additionally, in India, only the state of Tamil Nadu has the largest cluster of WTG in capacity ranging from 180 kW to 550 kW.

4.1 India's policy for repowering

To promote optimum utilization of wind energy resources, MNRE has released an Indian policy for the repowering of wind turbines/farms. The eligible wind turbines for repowering is the WTG capacity 1 MW and below. To promote repowering, the Government provides an additional interest rate repayment of 0.25% through IRDA, over and above the interest rate rebate given to new wind projects, also with all fiscal and financial benefits. The implementation of the repowering project will be done through State Nodal Agencies. Micrositing for placing wind turbines 7Dx5D will be exempted. During the execution of repowering, the PPA will not be applicable, and repowering projects can avail of Accelerated Depreciation benefit or GBI as per the conditions applicable to new wind power projects (Windpower scenario 2017).

4.2 Repowering opportunities: Tamil Nadu

Tamil Nadu is blessed with favorable natural metrological and topographical settings for wind power generation. With nature's gift, Tamil Nadu has three major wind passes and a valley. Due to the tunneling effect during South West Monsoon, the passes and valley experiencing high wind speed with an annual average of 5 to 7 m/s. Many numbers of wind turbines are installed in the exit path of these passes/valleys. In Tamil Nadu, the total installable potential is 33.799 GW, and the installed wind energy capacity is 7957.215 MW of which consists of 11,699 WTGs and is connected to 110 pooling substations (Vibrant winds blowing across India 2016). To understand the availability of wind turbines and to characterize them carefully, these WTGs are separated based on location in these passes. Based on the database available of 10127 no of WTGs with NIWE, the details of the passes and the average wind speed, number of wind turbines in the exit path of passes are given in Table 2, Google map representation in FIG.2.(a), 2.(b) and 2.(c) with the description of WTGs in terms of capacity in FIG.3.

Table 2: wind turbines in the exit path of passes in Tamil Nadu

Wind Pass in Tamil Nadu	No of WTGs <=550 kW	Average wind speed m/s	Capacity MW.
Shencottah Pass	1106	5.00 -6.11	308.88
Aralvaymozhi pass	1867	5.27-6.97	507.96

Palghat Pass	2424	5.00 -6.11	655.945
Kambam valley	0	5.27-6.97	0
Total WTGs	5397		1472.79

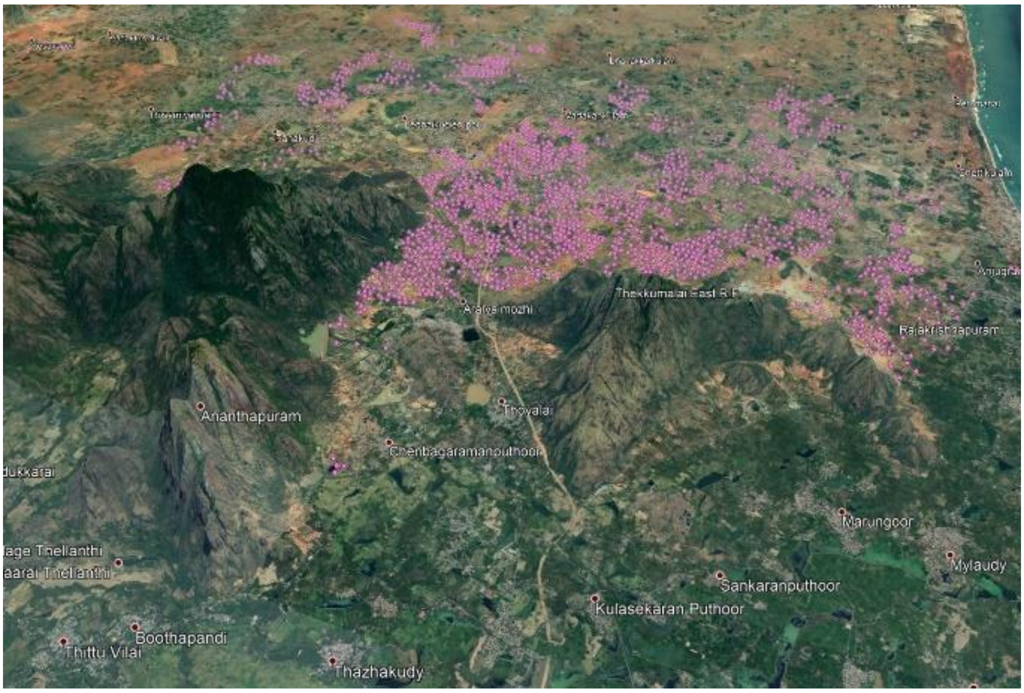

FIG.2(a): Aralvaimuzhi pass WTG<=550 kW (Google earth image)

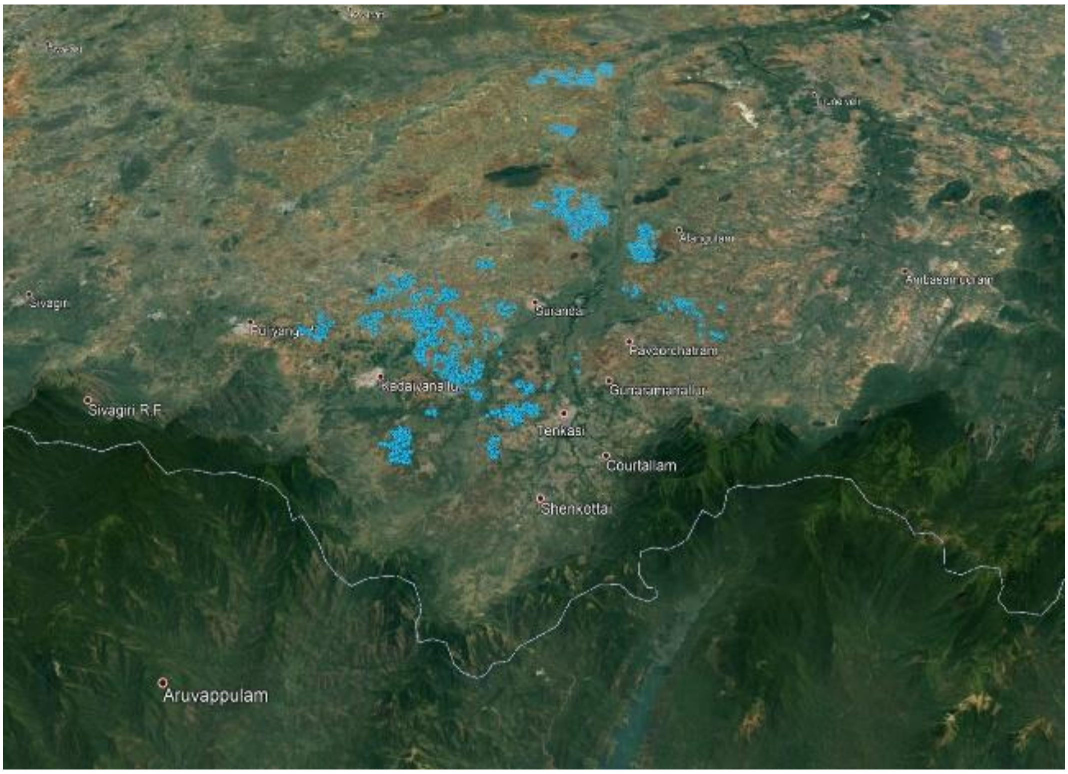

FIG.2(b): Sengottai pass WTG<=550 kW (Google earth image)

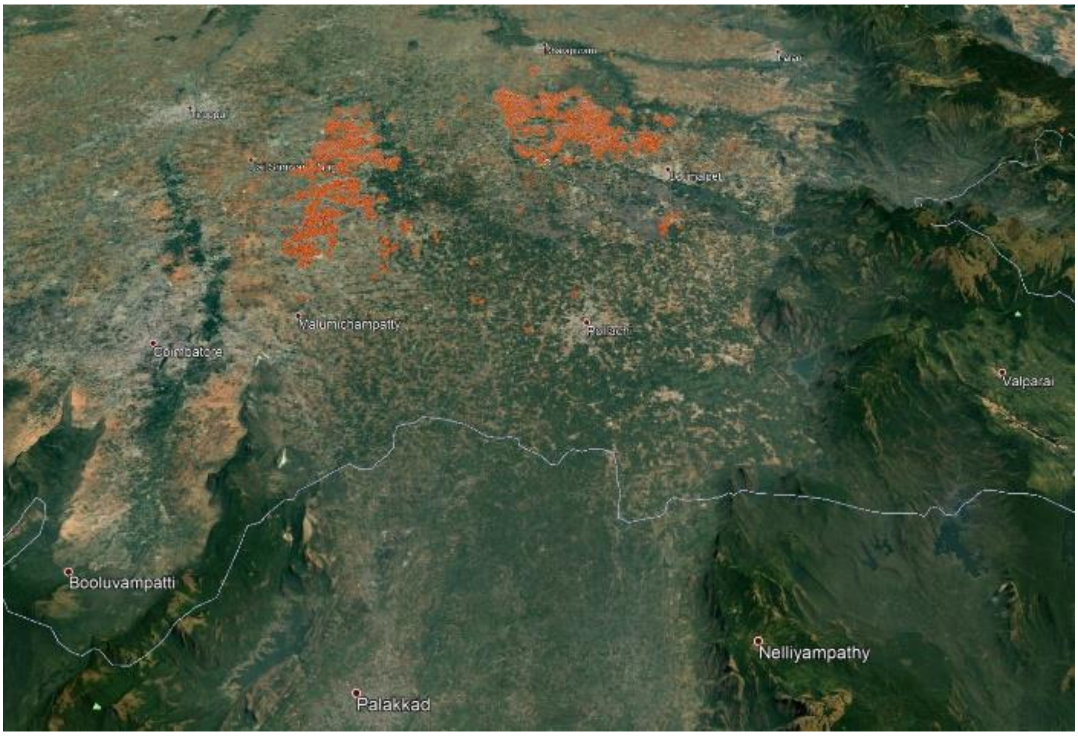

FIG.2(c): Palghat Pass WTG<=550 kW (Google earth image)

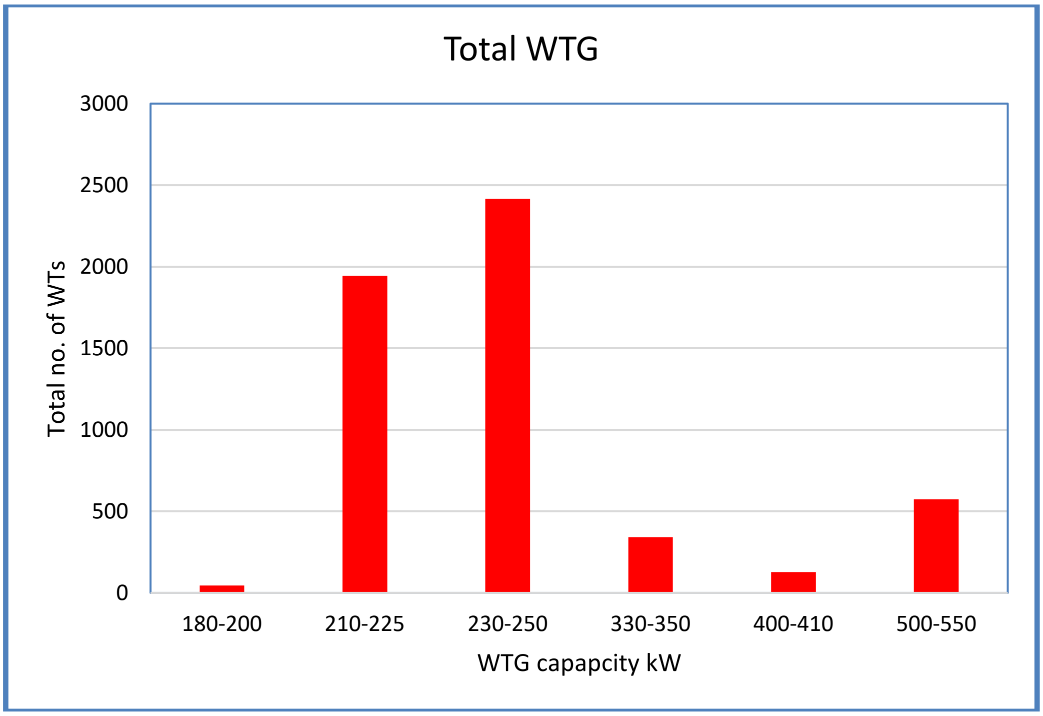

FIG.3: Capacity wise WTG representation

In these installed turbines, approximately 53.09 % are small WTGs with a capacity lesser than or equal to 550 kW and were installed before the year 2000, occupying high windy areas and operating with lower CUF ranging from 10% to 15%. (BS. Nivedh et al., 2013). Based on FIG.2, it is represented that WTGs of capacity 210 to 250 are the majority in the state. In the past, most of the wind farm owners/developers were focusing more on short-term results and not looking 20 years ahead or the end of the life span of WTGs. Old WTGs were placed at locations where the wind speeds are very high is shown in the Tamil Nadu wind power potential map at 100 m height published by NIWE in 2015 in FIG.4. This wind potential map is derived based on authentic latest available datasets of wind as well as land geologically spread across India. This thematic map represents the possible potential in terms of colors, where red represents a high potential region.

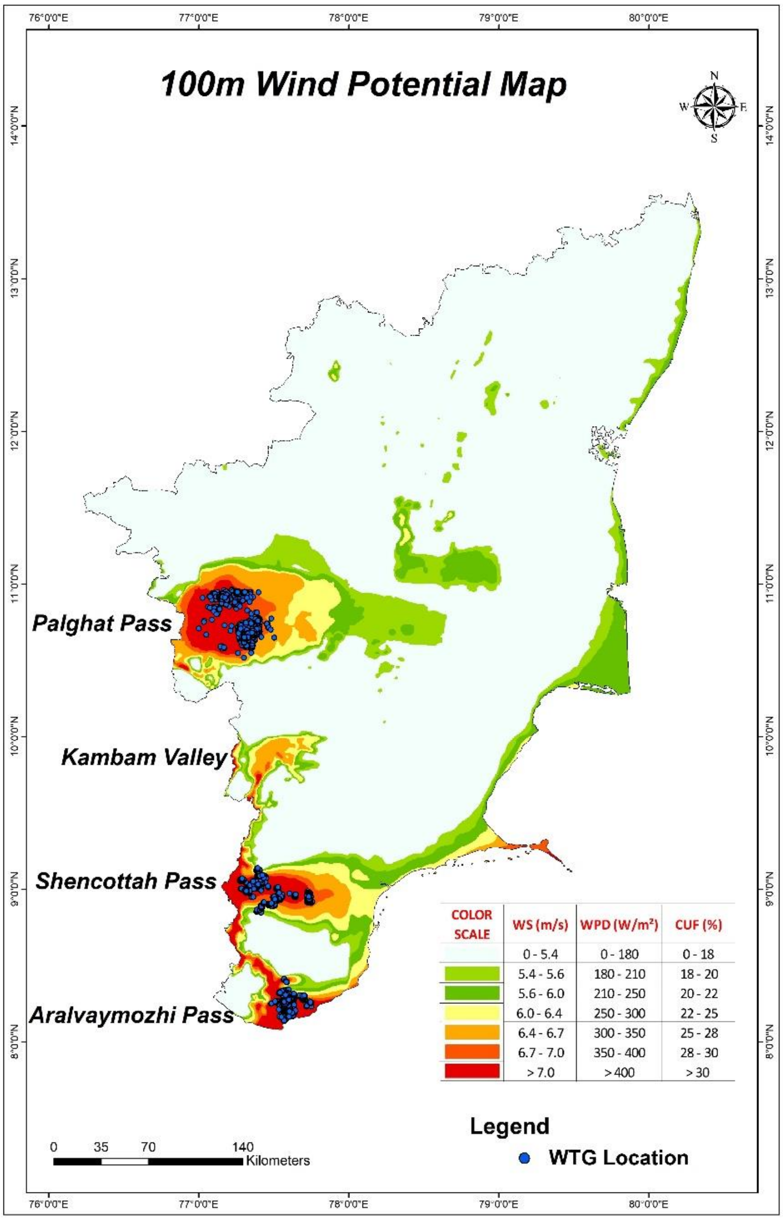

FIG.4: Wind power potential map of Tamil Nadu at 100 m height superimposed with WTG locations (source: NIWE)

The advanced technological WTGs are almost comparable to conventional power plants in terms of cost, capacity ratings, and control of wind farms using central communications, which offers comfort for the grid operators. The standard commercially available WTG size 15 years ago was 150 kW to 500 kW, it has now increased up to 2500 kW-3000kW (Manoj Verma et al. 2015). Consequently, the CUF will also double for new installations over the older plants ranging from 25 to 30 percent in the same sites. As compared to old turbines that run at higher speeds, modern turbines reduce the visual impact by spinning slower, consequently with much lower acoustic noise levels. For example, in the 1990s, turbines rotate 40 to 60 rotations per minute, while the newer ones only spin 10 to 20 times without much noise and better power generation and safety aspects

4.3 Benefits of repowering

4.3.1 Beyond service life of wind turbines are in Primary windy locations: Wind energy development started in the mid-1980s, and all the major windy sites were chosen to foster its growth. With the available technologies at the time, the small (Sub-Mega Watt) rated WTGs installed in the best wind resource locations are depicted clearly in FIG 1. With the advanced technological /modern and higher capacity wind turbines, the installed capacity may increase if replaced in these areas, and the net energy generation will increase up several times.

4.3.2 Fewer numbers of WTGs: New locations for wind farm development is less due to the scarcity of land, competition from solar PV plants, environmental protection, evacuation issues, and resistance from local people. Repowering can also be used for wind-power integration with the residential locality (Dahl, E.L et al. 2015). Good visual impact and superior landscape can be formed repowering with a reduced number of turbines, even in paddy fields.

4.3.3 High efficiency with lower costs: The modern turbines with enhanced features utilize the available proven best wind resource in the most economical ways. The production cost will significantly reduce over time.

4.3.4 Better grid integration: Repowering facilitates to redesign the wind-power plant layout, minimizing environmental impacts on the landscape (http://www.wsp-pb.com/en/WSP-UK/Who-we-are/Newsroom/features/Repowering-windfarms--Three-key-emerging-issues/

). The modern turbines are integrated with the grid as they use a similar connection method to conventional power plants, and this helps to achieve a higher CUF.

4.3.5 Repowering cost savings: The land cost saving from repowering activities will encourage repowering (Eric Lantz et al. 2013). There is a need for repowering from the viewpoint that advanced WTG technologies will have significant benefits with land utilization per megawatt of installed capacity, meeting electricity needs (Akshay Urja 2011). In addition, to avoid expensive repairs and scarcity of spares which drive up operation and maintenance costs will be a big motivation for replacing old turbines. Repowering will preserve as well as provide jobs to the local people compared to decommissioning without new knowhow learning

5. Issues and challenges in repowering

Despite the vast advantages of repowering, there exist some complications that cannot be overlooked. First and foremost, there are yet few promising sites with good wind potential that are available, making repowering a secondary option. Besides, these possibilities of offshore wind energy development are extensively explored on the Indian coast. With lesser obstacles in the wind flow, offshore wind energy will help more power generation. Wind farm repowering can become expensive if we assess the dismantling and disposing costs of old WTG components, towers, and foundations. Replacement, up-gradation of electrical networks, and lying of access roads may also become uneconomical and delay the repowering works. It is implicated that there will be an increase in resulting CUF from higher towers and greater rotor diameter, but in some places, there are regulatory restrictions on height and space (Study of Repowering of Wind Power Projects 2014). In sites where environmental damage has occurred during the initial commissioning of a wind farm, the repowering activity can be more complicated. The concept of repowering is quite simpler, but the process of implementation is not that quick and easy. Even with the presence of some of the infrastructure, the process is time-consuming and cost-wise similar to the new wind farm development. The other challenges for repowering are:

5.1 Residual life assessment: The average design life of a WTG is 20 years. In Tamil Nadu, most of these Sub-Mega Watt wind turbines completed its life span or near to it. Old wind turbines need enormous maintenance costs and a reduction in power conversion and efficiency. Yet the wind power plants that give a considerable generation with a positive may not pursue repowering. The Kayathar wind farm established by TEDA in 1990 continues to generate electricity, even after completion of life span and an additional 9 years beyond 20 years.

5.2 Nature Conservation Issues: Wind farms significantly impact local landscapes and local ecology and act as a key element in climate restraint. A similar situation can occur in the case of repowered wind farms (Akshay Urja 2011).

5.3 Permanent wind farm: Wind farms are constructed for 20 to 25 years, making wind farms a temporary feature on the landscape. Under repowering wind, farms can be present for a much longer time than initially predicted. This will disappoint some investors and could also provide a further challenge for wind farm repowering (Akshay Urja 2011).

5.4 Turbine and land ownership: WTGs with multiple owners and wind turbines/farmland may create a lot of issues under repowering projects. During the repowering of a wind farm, the number of turbines will be reduced. Thus, creating an effect of ownership as well as a lost opportunity to a few owners owing revised spacing of wind turbines.

5.5 Additional cost: In this, the cost associated with the disposal of the existing turbines is taken into consideration .along with cost relayed to updating the link roads, grid, etc.

5.6 Micro-siting for repowering site: For the replacement of older turbines, the existing meteorological data will not be sufficient for effective micro-siting, with wind flow modeling in the site in "as is where is" condition. Micro-siting becomes challenging with the presence of turbines in the existing site. In micro-siting, the correct inter-machine distance needs to be maintained. Any error in micro-siting will result in turbulences with lower than expected outputs in repowered projects (Study of Repowering of Wind Power Projects 2014).

5.7 Electricity evacuation: The grids are designed to handle existing power supply, in case of repowering the boost in power output require replacement of equipment and evacuation infrastructure systems (Manoj Verma et al. 2016).

5.8 Disposal of existing turbines: In the decommissioning process of the WTGs for repowering projects, various options are to be analyzed based on the cost of the existing turbine-like scrap value, buy-back by manufacturer, relocation, etc. (Dr. Rohit Verma 2013). In dismantling old wind power plants, some of the parts can be recycled as scrap metal, but the disposal of many parts may cause some issues.

5.9 Policy package: Repowering decisions are not only motivated by the wind resource and economic consideration, but the government policies may also aid or discourage repowering. Power purchase agreements (PPA's) are long-term agreements ranging for 15 to 25 years; before the end of that period, re-powering may cause difficulties (http://membership.awordaboutwind.com/blog/why-are-us-wind-farm-owners-repowering-their-projects).

6. Conclusion

The objective of repowering is to generate the highest possible power output level and utilize the high wind power potential region. Repowering of WTGs could lead to better utilization of wind-rich sites by installing the latest technology as WTG models, which can increase the capacity utilization factor by two to three times. It documented that replacing vast numbers of old turbines with much lesser numbers of larger and more efficient modern turbines helps in maintaining sustainability in the environment; at the same time, there is a substantial increase in the power output.

Most of the small Sub-Mega Watt WTGs have occupied a resource-rich location in thick clusters with multiple owners; hence, to conduct repowering project willingness, their perspective needs to be considered. Similarly, to perform the micro-siting for the initial stage wind turbine owners, consent is mandatory. Since most of the small WTG is connected to 11 kV line, and established depending on the power generated based on these small WTG, research activities will be followed for its up-gradation and establishment. After considering all these aspects of repowering, in the case where the repowering of wind farms is not feasible, refurbishing can be adopted utilizing the existing infrastructure.

Denmark and Germany are leading in repowering of old wind turbines with their good repowering policy, followed by California and Spain. India can learn from its experiences. The various issues faced by the wind power producer around the world that are beneficial in this study will help to formulate methodologies for the repowering projects in India. In Denmark, there is a lack of interaction with authority in the implementation of the repowering project. Hence, the process for upgrading becomes tedious; also, there is constant opposition from the local section of the society. While in Germany, there is inadequacy in incentives provided by the Government, and repowering projects have to compete with new projects. Similar to Germany, the US also lacks policy and regulatory challenges. Profitability is a significant concern in Spain, and with new regulation, there is the complete removal of subsidies and incentives, while height is a major constrain in repowering in the United Kingdom

Based on the policy issued by MNRE, wind farm qualifies WTG with a capacity of 1 MW and below to undergo repowering. In the state of Tamil Nadu alone, over 8072 WTGs were rated below 1 MW with an aggregate capacity of 3420.64 MW and were ideal for repowering. In India, there is a vast potential for repowering. For the initial analysis, the WTGs with rated capacity, less than 550 kW capacity, have been considered. In the state of Tamil Nadu, over 5397 WTGs were installed before 2002, rated below 550 kW with an aggregate capacity of 1472.79 MW and operational for more than 10 to 15 years, were ideal for repowering.

All repowering activities are site-specific, and exact repowering potential can be found during analysis only. Integrating the wind farm with the community with a significant concentration on the EIA aspect will help us in better promotion of the wind farms. Formulation of the guidelines where various aspects of the repowering are depicted wherein considering the perspectives of stakeholders. Repowering is vital. Hence, proper in-built guidelines need to be addressed in every proposal to optimize Annual Energy Production (life span).

Future research work: A semi-structured interview with plant owners/operators/developer firms and utility owners providing insights into their project and reasons for having repowered or not, as well as an opportunity to acquire feedback on inputs and results has been planned. Further, a site will be analyzed, and repowering analysis will be performed, thus creating a standard methodology that can be employed for other locations too.

References

[1] Riya Rachel Mohan. Repowering India's wind sector. Repowering India's wind sector Infra circle; September 12, 2016

[2] R. Sitharthan and M. Geethanjali. Wind Energy Utilization in India: A Review. Middle-East Journal of Scientific Research 22 (6): 796-801, 2014

[3] Mohit Goyal. Repowering—Next big thing in India. Renewable and Sustainable Energy Reviews 14 (2010) 1400–1409

[4] Vikas Khare, Savita Nema, Prashant Baradar. Status of solar-wind renewable energy in India. Renewable and Sustainable Energy Reviews 27 (2013) 1–10

[5] Eric Lantz, Michael Leventhal, and Ian Baring-Gould. Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects. Technical Report NREL/TP-6A20-60535 December 2013

[6] World energy resources Report by World energy council, 24th edition; October 2016 Report by International renewable energy agency. 30 YEARS OF POLICIES FOR WIND ENERGY-lessons from 12 wind energy Markets

[7] Vishal Agarwal. Re-powering of Old Wind Turbines in India. Energetica India; Nov-Dec 2013

[8] Report by IREDA, http://www.irena.org/documentdownloads/publications

[9] Justin Gerdes. Repowering North America's Aging Wind Turbines Is a $25 Billion Opportunity. DECEMBER 01, 2017 https://www.greentechmedia.com/articles/read/could-repowering-be-the-solution-for-north-americas-aging-wind-turbines

[10] German wind auctions hike power market risk for repowering projects; November 08, 2016, http://analysis.windenergyupdate.com/operations-maintenance/german-wind-auctions-hike-power-market-risk-repowering-projects

[11] Jeffrey Davis, Robert Goldberg, Isaac Maron. Is repowering worth it. Aug 2017 https://issues.nawindpower.com/article/is-repowering-worth-it

[12] American Wind Energy Association US Wind Industry Fourth Quarter 2016 Market Report a product of AWEA Data Services Released January 26, 2017

[13] Sara Knight. Europe's repowering drive struck in bottom gear. Wind power monthly; March 2017 http://www.windpowermonthly.com/article/1425160/europes-repowering-drive-stuck-bottom-gear

[14] Global wind report-Annual Market update 2016 by Global wind energy council report

[15] KEMA. A Scoping-Level Study of the Economics of Wind Project Repowering Decisions in California. California Energy Commission. August 2008 Publication number: CEC-300-2008-004

[16] Mark Del Franco. Study Details Renewables impact on California's economy; Aug 2017 https://issues.nawindpower.com/article/is-repowering-worth-it

[17] Antonio Colmenar-Santos, Severo Campíñez-Romero, Clara Pérez-Molina, Francisco Mur-Pérez Repowering: An actual possibility for wind energy in Spain in a new scenario without feed-in-tariffs. Renewable and Sustainable Energy Reviews 41 (2015)319–337

[18] Global wind energy council. Global wind statistics report; February 10, 2017

[19] Tamil Nadu Transmission Corporation Ltd: (A Subsidiary of TNEB Ltd.), http://tnebldc.org/reports1/peakdet.pdf

[20] J. Jeslin Drusila Nesamalar, P. Venkatesh, S. Charles Raja. The drive of renewable energy in Tamilnadu: Status, barriers, and prospect. Renewable and Sustainable Energy Reviews 73 (2017) 115–124

[21] Policy for repowering of the wind power projects. Ministry of new and renewable resources. Order no. 66/175/2015-WE

[22] Report of Energy department, Government of Tamil Nadu. Wind power scenario; March 2017

[23] Vibrant winds blowing across India: New developments in the wind energy sector, Akshay Urja Dec 2016

[24] BS. Nivedh, Dr. R.P. Kumudini Devib, Dr. E. Sreevalsan. Repowering of Wind Farms - a Case Study. Wind engineering volume 37, NO. 2, 2013

[25] Manoj Verma, Siraj Ahmed, J. L. Bhagoria.A Review: Repowering of Indian Wind Farms. International Journal on Emerging Technologies 6(1): 12-18(2015)

[26] Dahl, E.L., May, R., Nygård, T., Aström, J. and Diserud, O., 2015. Repowering Smøla wind-power plant. An assessment of avian conflicts. NINA Report, 41.

[27] http://www.wsp-pb.com/en/WSP-UK/Who-we-are/Newsroom/features/Repowering-windfarms--Three-key-emerging-issues/

[28] Akshay Urja October 2011 Volume 5, Issue 2

[29] Study of Repowering of Wind Power Projects, WinDForce Management Services Pvt. Ltd Dated: December 26, 2014

[30] Manoj Verma, Siraj Ahmed, and J.L.Bhagoria. An Analysis for Repowering Prospects of Jamgodarani Wind Farm using WASP. IJCTA, 9(21), 2016, pp. 155-161

[31] Dr. Rohit Verma. Repowering Potential of Wind Farm in India. International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463 Vol. 2 Issue 12, December-2013

[32] http://membership.awordaboutwind.com/blog/why-are-us-wind-farm-owners-repowering-their-projects

[33] Kulkarni, S.H., and Anil, TR, 2018. Renewable Energy in India—Barriers to Wind Energy. Strategic Planning for Energy and the Environment, 38(2), pp.40-69.