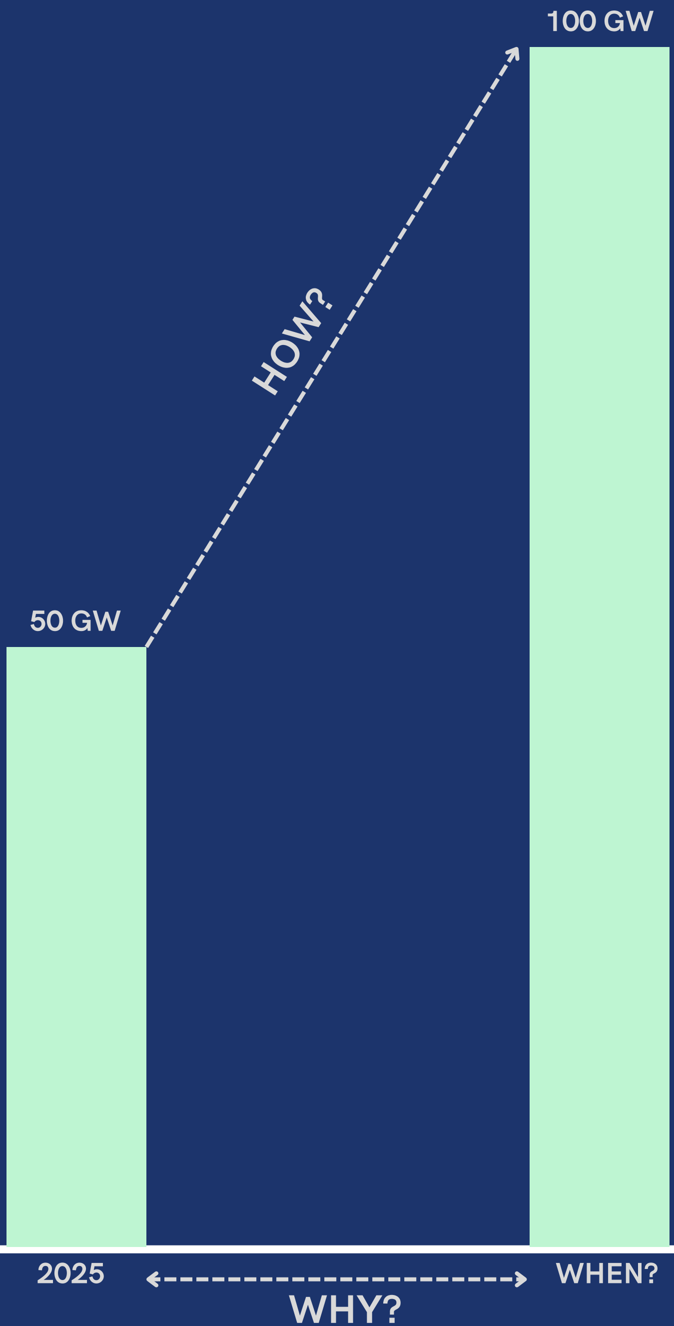
COULD THE WIND SECTOR HAVE ACHIEVED 100 GW ALREADY?



A QUANTITATIVE STUDY ON INDIA'S WIND ENERGY LANDSCAPE

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EXECUTIVE SUMMARY

India is a global leader in the clean energy transition, having already achieved 233 GW out of its 500 GW target by 20301.This growth is primarily driven by the solar sector, and wind, despite having a head start, has struggled to catch up2. This paper focuses on understanding the wind sector's growth and its slowdown in the late 2010s, attempting to isolate the causative factors and estimate a counterfactual trajectory. Hence, the primary research question is: “Could the wind energy sector have reached 100 GW capacity already?”

Initial comparative analysis of the annual cumulative and installed capacity and the CAGR of both the solar and wind sectors revealed a pronounced slowdown of the latter. A counterfactual analysis estimated this lost potential value to be around 37 GW had the CAGR been 13.2% (actual CAGR 2011 - 2016) throughout 2011 to 2024. As the slowdown in 2016-17 coincided with the policy shift from a feed-in tariffs system to a competitive bidding system, Interrupted Time Series models were constructed to assess the impact of this intervention.

The models estimated that the policy shift could have caused an immediate loss of 1839 MW (ITS Policy) and 8703 MW (ITS Tariff) in the annual installed capacity, and the year-on-year changes in additions could have led to an improvement of 296 MW (ITS Policy) and 1517 MW (ITS Tariff). The estimated value of the year-on-year changes due to the wind tariff rates stands at 1443 MW (ITS Tariff), emphasising the observation that while the policy shift might have caused an immediate decline, the sector slowly recovered from the low and even saw an improvement in the annual capacity additions compared to the pre-policy years. It must also be noted that a closed competitive bidding system was adopted in the later periods of 2022-2023 to recover from the stagnation3.

State-level comparative analysis of annual installed capacity of the wind and solar sectors, as well as the event study models with fixed effects and heterogeneity effects, did not yield statistically significant results to draw conclusions. The ITS State Policy Model revealed that the policy shift could have caused an immediate decline of 166 MW at the state level, aligning with the previous observations.

Wind has the estimated commercially exploitable potential capacity of more than 200 GW, and if we’ve been able to reach ~50 GW with 40% of it coming from only two states4, we will be able to achieve ~100 GW much sooner if we are able to push for growth in the sector in all the windy states of India through a bottom-up approach from the states and a robust central mechanism to tackle administrative bottlenecks.

INTRODUCTION

With the total installed renewable energy capacity standing at 233 GW as of June 2025[1], India is a global leader in the clean energy transition. Our country's road to achieving the 'Panchamrit' goals[5] set as National Determined Contributions (NDC) at COP26 of UNFCCC is being driven by a number of strategic and fiscal initiatives including:

- Support for domestic manufacturing through the Special Incentive Package Scheme
- Prioritising small-scale and distributed RE generation
- Targeted lending institutions such as IREDA and PFC which offer loans to RE players at a rate lower than the market
- Accelerated Depreciation which allows for higher initial depreciation, promotes initial investment in RE industries.
- Viability Gap Funding to bridge cost-revenue gaps
- Renewable Energy Certificates and Renewable Purchase Obligations, which mandate the purchase of a certain percentage of clean energy from the markets

Policy frameworks in the renewable energy sector have proven fruitful, as indicated by a record-breaking 24.5 GW of additional solar capacity in 2024[6]. While solar energy serves as the dominant player in India's renewable energy landscape, contributing to 49% of the total installed capacity with 116 GW as of June 2025, wind, hydro and bioenergy contribute 51 GW, 54 GW and 11.5 GW respectively[1].

It is important to note that while India is the third largest in the world in terms of solar capacity and fourth largest in terms of wind[7], the contrast between these two sectors in terms of the trends in the realisation of their potential capacity is staggering. The estimated commercially exploitable potential capacity of wind energy is more than 200 GW[8] and we have utilised around 40% of this with an installed capacity of 51 GW.

Despite being a pioneer in the renewable energy sector with the first wind turbines installed in 1986[9], India's wind energy growth has been stalled ever since the late 2010s[10], with annual additions significantly slowing down for a decade. This paper aims to investigate the policy landscape of the wind energy sector in India in the period 2011 to 2024, to address the causes of this slowdown and to design a model to analyse what would have happened had the wind energy sector followed a different trajectory.

As renewable energy itself is a growing sector, it is natural for it to undergo trials and errors when it comes to promoting or incentivising energy generation in these sectors. Wind energy has experienced numerous such policies, including the introduction of 100% accelerated depreciation in the mid-90s, feed-in tariffs in 2003, generation-based incentives in 2009, and renewable energy certificates in 2010[11]. The evolution of the sector as a result of these policy changes has been steady, though there were bumps every four or five years, as seen in 2008 or 2013[11]. The wind sector eventually reached a record-breaking high of 5 GW in additional installations in 2016[1], after which the sector took a backseat as solar gathered all the limelight.

Even though there was steady growth, high tariff costs were always a part of the package, with wind being a renewable source. With the aim of reducing these tariffs and making wind energy more affordable, the government suggested a shift from feed-in tariffs, which had been the norm until then in the wind sector, to a reverse auction bidding scheme. This competitive reverse auction bidding scheme was not introduced as an experimental policy, as it had already been tested in the solar energy sector. It had resulted in record-low tariffs, which slowly promoted the sector to a point where solar PV generation costs are now cheaper than the cost of fossil fuel based alternatives[12].

But the wind sector did not follow the same trajectory. The open competitive bidding system, where investors bid for the lowest prices, is said to have been detrimental to the wind sector[13], and it was amended to a closed competitive bidding system in the years 2022-2023.

This paper is focused on understanding the growth of the wind sector from 2010 to 2024, by attempting to isolate the causative factors for the slowdown in the late 2010s and estimating what would have happened had the wind energy sector followed a different trajectory. Hence, the primary question this paper aims to address is: "Could the wind energy sector have reached 100 GW capacity already?"

METHODOLOGY

DATA SOURCING

This paper aims to analyse the growth of the wind sector over the years 2011 to 2024 and attempts to isolate the causative factors for the notable slowdown of the sector. Two national-level datasets on annual cumulative and installed capacity and a state-level dataset on annual installed capacity are utilised for the purpose. The national level datasets of both wind and solar are used for comparative analysis of the annual cumulative and installed capacity in order to quantify the differences between these sectors.

The ‘Annual Cumulative Capacity’ dataset for the years 2011 to 2024 was sourced from the India Climate and Energy Dashboard website of NITI Aayog. The ‘Annual Installed Capacity’ dataset for the years 2011 to 2024 was created by differencing the subsequent annual cumulative capacity values from the ‘Annual Cumulative Capacity’ dataset.

The state-level dataset of annual installed capacity for wind and solar for the years 2015 to 2024 was created by calculating the installed capacity by differencing the subsequent annual cumulative capacity values from the annual ‘Cumulative Capacity’ reports of the Ministry of New and Renewable Energy. The state-level annual installed capacity of wind for the years 2011 to 2014 was gathered from the website indianwindpower.com of the Indian Wind Turbine Manufacturers Association.

For further investigation into the slowdown of the wind sector, the annual tariff dataset (2011-2023) created from the reports of the Central Electricity Regulatory Commission (CERC) and the Levelised Cost of Electricity (LCOE) dataset (2011-2023) sourced from the International Renewable Energy Association (IREA) were utilised.

DESCRIPTIVE PLOTTING - NATIONAL LEVEL SOLAR VS WIND

The project begins with a comparative analysis of the solar and wind sectors by plotting a line graph of their annual cumulative capacity data at the national level. Following a visual inspection of the line graph, another one comparing their annual installed capacity was plotted. These graphs played a key role in understanding the trends of the solar and wind sectors.

CAGR AND COUNTERFACTUAL ANALYSIS

In order to quantify the differences captured by the graphs, an analysis of the annual cumulative capacity of both these sectors using Compound Annual Growth Rate (CAGR) was performed. The CAGR was calculated for three batches: 2011-2024, 2011-2016, and 2016-2024. This underscored the slowdown of the wind sector post 2016, marked by a loss of around 5% of CAGR against the 2011-2016 trends.

Prompted by the evidential decline of the wind sector, a counterfactual was calculated[14] to visualise the growth of the wind sector had it followed a consistent pace from 2011 to 2024. The counterfactual plot revealed the lost potential of the wind sector owing to its slowdown in the years following 2016.

$$Counterfactual\_Wind\_MW = (targeted\_CAGR + 1)^{(years\_from\_base)} * wind\_base\_capacity \tag{1}$$

ITS MODELS

As the literature on the evolution of the wind sector points to a policy shift from feed-in tariffs to a competitive bidding system sanctioned in 2016 and implemented in 2017 as the major reason for the slowdown of the sector post 2016, Interrupted Time Series (ITS) Models were constructed[15] to assess the statistical significance of these claims.

Three ITS Models were constructed: the ITS Policy, the ITS Tariff and the ITS Differenced LCOE using the national level 'Annual Installed Capacity' dataset and the ITS States Policy using the state level 'Annual Installed Capacity' dataset.The 'Annual_Installed_Capacity_MW' is the dependent variable in the ITS Models, whose value is determined by a combination of independent variables. The ITS Models are constructed using FEOLS() as it was chosen to be a suitable method that would absorb the heteroskedasticity and autocorrelation, as it was suspected that these effects exist to some extent between the independent variables.

```
its_policy_model <- feols(Annual_Installed_Capacity_MW ~ Years_after_policy + Policy_shift,     (2)
                          data = its_data,
                          vcov = "hetero")
```

```
its_tariff_model <- feols(Annual_Installed_Capacity_MW ~ Years_after_policy + Policy_shift +     (3)
                          Solar_Avg_Tariff_Centered + Wind_Avg_Tariff_Centered +
                          I(Wind_Avg_Tariff_Centered * Years_after_policy),
                          data = its_data,
                          vcov = "hetero")
```

```
its_lcoe_model <- feols(Annual_Installed_Capacity_MW ~ Years_after_policy +     (4)
                        LCOE_centered + Years_after_policy:LCOE_centered,
                        data = its_data,
                        vcov = "hetero")
```

All the models used the 'Years_after_policy' variable which calculates the number of years since the policy shift in 2017, defined by the variable 'intervention_year' (e.g. for 2018, 'Years_after_policy' would be 1). 'Policy_shift' was a binary variable used as a proxy for isolation of the years after the policy intervention from the years before. The ITS Policy Model estimates the values of the 'Policy_shift' and 'Years_after_policy' variables, quantifying the immediate impact of the policy shift and the year-on-year average impact of the policy in the years following the intervention in 2017.

The ITS Tariff Model used 'Solar_Avg_Tariff_Centered' and' Wind_Avg_Tariff_Centered', which represented the solar and the wind tariff values centred around their mean values, respectively. The estimates of these variables help in understanding the overall impact of the tariff on the dependent variable. The tariff values are centred to reduce multicollinearity while defining interaction terms. An interaction term, I(Wind_Avg_Tariff_Centered * Years_after_policy), was used to assess the year-on-year impact of the wind tariff values in the policy years.

The ITS Differenced LCOE Model used the 'LCOE_centered' variable which is the centred value of the 'LCOE_Difference' variable around its mean. This model quantified the impact of the trends in the differenced LCOE values of the solar and wind sectors on the annual installed capacity of the wind sector. The ITS Differenced LCOE Model also uses an interaction term 'Years_after_policy: LCOE_centered' to evaluate the year-on-year impact of the differences in LCOE values on the annual installed wind capacity in the years following the policy shift.

```
its_states_policy_model <- feols(Annual_Installed_Capacity_MW ~ Years_after_policy +
                                 Policy_shift | States_Uts,
                                 data = its_states_data,
                                 vcov = ~States_Uts)
```
(5)

The ITS States Policy Model is constructed with fixed effects for 'States_Uts' to absorb the unobserved, time-invariant characteristics unique to each state that might influence wind capacity additions, thereby allowing for a cleaner estimate of the policy's impact. The model assessed the impact of the 'Policy_shift' and 'Years_after_policy' variables on the 'Annual_Installed_Capacity_MW' of the wind sector for the nine windy states.

The 'Policy_shift' variable quantified the immediate impact of the policy on the dependent variable. The 'Years_after_policy' variable estimated the average impact of the intervention in the policy years after 2017.

DESCRIPTIVE PLOTTING - STATE LEVEL SOLAR VS WIND

A state-level comparative analysis of the annual installed capacity of the solar and wind sectors was performed to identify the trends in each of the nine windy states. These line graphs played a key role in understanding the differential landscape of the wind sector at the state level.

EVENT STUDY MODELS - STATE LEVEL WIND

In addition to the ITS States Policy Model, two event study models[16] were designed to analyse the state-level data on annual installed capacity of the wind sector for the years 2011 to 2024. An event study with fixed effects for 'States_Uts' was conducted to absorb the time-invariant effects across the states throughout the timeline chosen for the study.

```
wind_event_study_model <- feols(Annual_Installed_Capacity_MW ~  i(time_to_event, ref = -1) | States_Uts,
                                data = wind_data,
                                cluster = ~States_Uts)
```
(6)

Upon visual inspection of the descriptive plots of the annual installed capacity of the nine windy states, it was observed that Gujarat and Tamil Nadu have continued to outperform the other states despite the policy intervention in 2017. An event study with heterogeneity effects for Gujarat and Tamil Nadu was conducted to isolate the differential impact of the policy compared to the overall impact on all the other states, if there existed any difference in the policy impact.

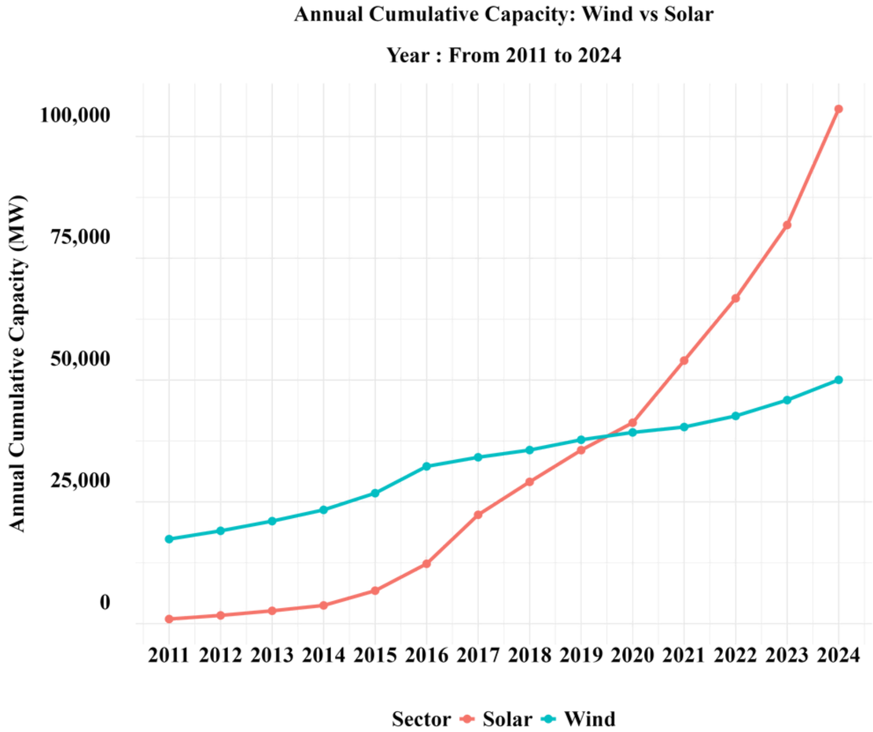
```
wind_hetero_event_study_model <- feols(Annual_Installed_Capacity_MW ~ i(time_to_event, ref = -1) +
                                       i(time_to_event, is_GT_TN, ref = -1) | States_Uts,
                                       data = wind_hetero,
                                       cluster = ~States_Uts)
```
(7)

FINDINGS

DESCRIPTIVE PLOTTING - NATIONAL LEVEL SOLAR VS WIND

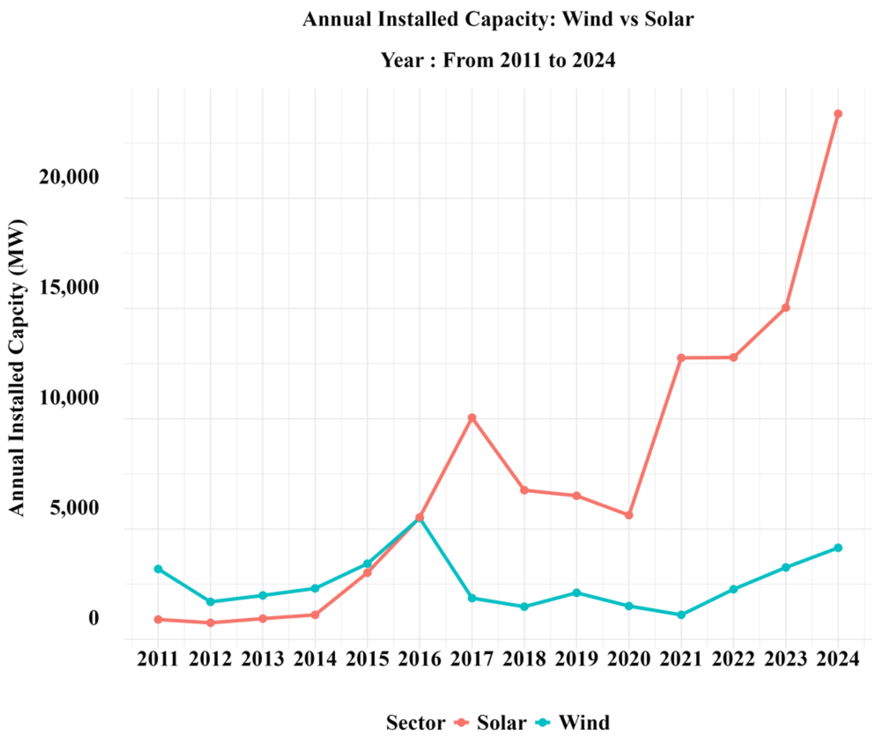
The line graph of the annual cumulative capacity of solar vs wind showed that while solar capacity was growing slowly until 2016, it saw an explosive growth afterwards, reaching from ~12 GW in 2016 to ~100 GW in 2024. It was also discovered that the wind sector has grown at a slow and steady rate throughout the timeline chosen for study. In comparison to the solar sector, it can be found that while solar added ~88 GW in 8 years starting from 2016, the wind sector, which already had a strong base of ~32 GW in 2016, has added only ~18 GW in capacity reaching to ~50 GW in 2024.

While the wind energy could have afforded a slow growth rate given its already established base capacity when the solar sector was beginning to grow, the fact that solar capacity stands at double the wind capacity led to a question of whether the wind sector saw low capacity additions after 2016. In an attempt to answer this, a line graph comparing the annual installed capacity of both sectors was plotted.



The annual installed capacity plot revealed that in the period of 2012-2016, the wind sector was growing at a gradual pace, peaking its annual capacity additions in 2016 with 5.5 GW. In the same period, the solar capacity was beginning to grow, catching up to the wind sector with 5.53 GW additions in 2016. Though the solar sector faced a decline in its additions from 2018 - 2020 after a strong growth from 2014 - 2017, the annual installed capacity bounced back in 2021 and the sector never turned back.

On the other hand, the wind sector had a fall in its annual capacity additions in 2017 and it struggled till 2021, only to see a gradual growth from then on till 2024. It must be noted that in the period from 2018 to 2020, while both sectors had a slow growth rate with respect to the standards set in the previous years, the solar sector was able to bounce back harder, unlike the wind sector.



As the visual inspection of both the annual cumulative capacity and annual installed capacity pointed out to a slowdown after 2016, it was required to analyse whether the wind sector had actually slowed down or was just following its own path, which was a gradual and steady growth rate. This analysis was important because it was necessary to know if wind could have afforded the decline in the capacity additions, given that the sector had a head start before solar.

CAGR AND COUNTERFACTUAL ANALYSIS

The Compound Annual Growth Rate (CAGR) of both the solar and the wind sectors was calculated to understand the actual growth of the sectors. Firstly, the CAGR was calculated for the entire timeline of the study from 2011 to 2024.

Sector	2011	2024	CAGR
Wind	17350	50040	**0.084891**
Solar	940	105650	0.437968

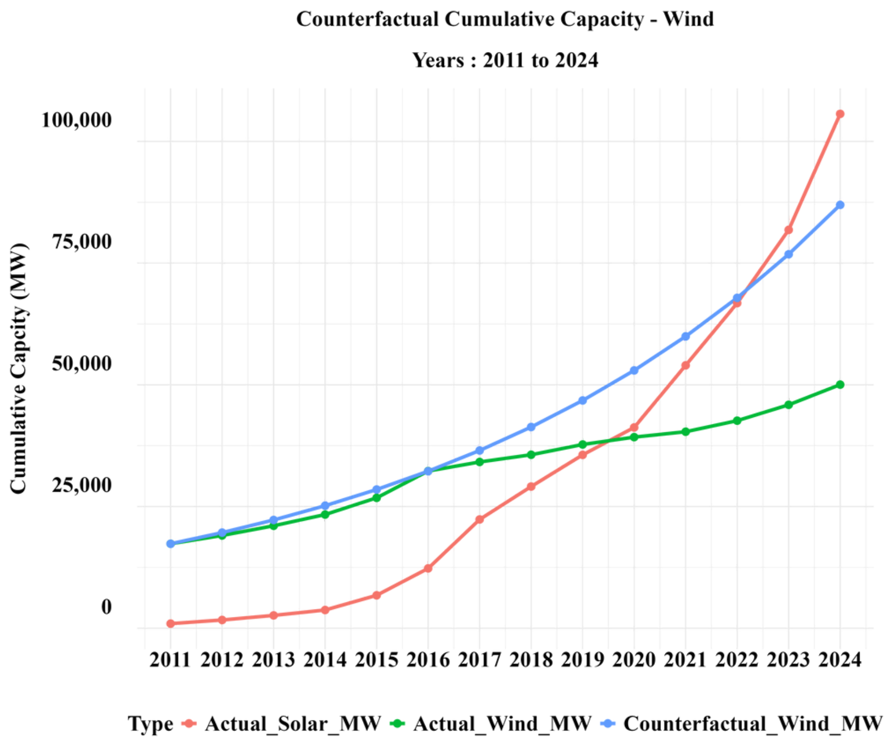
It revealed that while solar had grown at a rate of 43.7% from 2011 to 2024, the wind sector saw a growth rate of only 8.4%. This led to further investigation on whether this was a consistent rate or if the rate declined after some point, notably after 2016. So, CAGR was calculated for two batches from 2011 to 2016 and from 2016 to 2024.

Sector	2011	2016	CAGR
Wind	17350	32280	**0.13221**
Solar	940	12290	0.672187

Sector	2016	2024	CAGR
Wind	32280	50040	**0.056326**
Solar	12290	105650	0.308548

It was discovered that while the wind sector grew at a rate of 13.2% from 2011 to 2016, the rate slowed down to just 5.6% after 2016 till 2024. In the same period, solar grew at 67% from 2011 to 2016 and at a rate of 30% from 2016 to 2024. While it could be argued that the solar sector also slowed down after 2016 and that wind could have afforded a slowdown of around 7% of its previous growth rate, the fact that wind stands at a cumulative capacity of half of solar's proves otherwise. So, a counterfactual analysis was conducted to quantify the lost potential due to this decline from 13.2% to just 5.6%.

Year	Actual Capacity	Counterfactual Capacity
2011	17350	17350
2012	19050	19640.2
2013	21040	22232.71
2014	23350	25167.42
2015	26780	28489.52
2016	32280	32250.14
2017	34150	36507.16
2018	35630	41326.1
2019	37740	46781.15
2020	39250	52956.26
2021	40360	59946.49
2022	42630	67859.42
2023	45890	76816.87
2024	50040	**86956.7**



The counterfactual data of the annual cumulative capacity of the wind sector was calculated to answer the question, 'What if the wind sector had grown at a consistent rate since 2011 at 13.2%?'. The counterfactual data highlighted that had the wind sector grown at a rate of 13.2% from 2011 to 2024, it would have achieved a cumulative capacity of ~87 GW in 2024. The actual cumulative capacity of 50 GW pales in comparison to the ~87 GW, showing a lost potential of 37 GW in 8 years. This highlights the tangible impact of the sector's slowdown, indicating the importance of a holistic policy and implementation landscape that is essential for a sector's growth, which India overlooked with the wind sector.

This analysis led to two more questions. Firstly, did the policy shift in 2016-2017, followed by a decline in the tariff rates of the wind sector lead to the slowdown after 2017? Secondly, despite having a headstart of 17.3 GW in 2011 when solar had only 0.9 GW capacity, if the wind sector could have reached only ~87 GW compared to ~105 GW of the solar cumulative capacity in 2024, was the 'slow and steady' growth rate of the wind sector never aligned with the potential it had due to its inherent nature and the overall policy landscape itself, besides the policy shift in 2016? Both of these questions are attempted to be answered through the construction of several ITS Models.

ITS MODELS

ITS POLICY MODEL

term	estimate	std.error	statistic	p.value	*	RMSE	Adj. R2
(Intercept)	3020	584.2357	5.169147	0.000309	***	970.3	0.183491
Years_after_policy	296.9048	111.3123	2.667314	0.021899	*		
Policy_shift	-1839.17	713.5882	-2.57735	0.025711	*		

The ITS Policy Model using the national level annual installed capacity data of the wind sector from 2011 to 2024 estimated a baseline of 3020 MW in 2011. The 'Policy_shift' variable's estimated value tells us that there was an immediate drop of 1839 MW with respect to this baseline following the policy intervention in 2017. This means that, from the baseline of 3020 MW in 2011, as the wind sector faced a policy shift, its capacity was 1839 MW lower than what it would have been if the pre-policy trend simply continued. The 'Years_after_policy' variable implies that the annual installed capacity saw an add-on of 296 MW on average every year in the years following the policy intervention.

This highlights that while there was an immediate drop, the sector recovered as we move across from the timeline, indicated by the improvement in the year-on-year additions in capacity compared to the pre-policy years. The statistical significance of these values makes them reliable and interpretable. The RMSE value suggests that there could be an overall error of 970 MW in the estimates of the dependent variable. This is further reflected by the low adj R2 value which points out that only 18% of the model could be statistically explained and this is expected in a complex real-world scenario such as a policy shift in an energy sector.

ITS TARIFF MODEL

term	estimate	std.error	statistic	p.value	*	RMSE	Adj. R2
(Intercept)	6914.185	2545.167	2.716594	0.029912	*	571.7	0.55486
Years_after_policy	1517.897	395.5408	3.837522	0.006395	**		
Policy_shift	-8703.93	4567.285	-1.90571	0.098376	.		
Solar_Avg_Tariff_Centered	-407.449	192.3883	-2.11785	0.07195	.		
Wind_Avg_Tariff_Centered	-2051.48	1476.213	-1.38969	0.207217			
I(Wind_Avg_Tariff_Centered * Years_after_policy)	1443.739	457.6535	3.154656	0.016047	*		

IThe ITS Tariff Model using the national level annual installed capacity data of the wind sector from 2011 to 2024 estimated a baseline of 6914 MW in 2011. The 'Policy_shift' variable's estimated value indicates an immediate drop of 8703 MW from this baseline following the 2017 policy intervention, reflecting a capacity lower than what would have occurred had the pre-policy trend simply continued. The 'Years_after_policy' variable implies that the annual installed capacity saw an add-on of 1517 MW on average every year in the years following the policy intervention.

This tells us that while there was an immediate drop, the sector recovered as we move across the timeline, demonstrated by the improvement in the year-on-year additions in capacity compared to the pre-policy years. The negative value of the 'Solar_Avg_Tariff_Centered' implies that a unit increase in the solar tariff could have caused a drop in the wind capacity additions and the magnitude indicates that, the trend of the solar has on average caused a drop of 407 MW in the annual installed capacity additions in the wind sector. The interaction term of wind tariffs and years after policy implies that the trend in the wind tariffs caused an add-on of 1443 MW on average every year in the years following the policy intervention. This reinforces the observations from the previous model that there was a decline due to the sudden fall in prices following the policy shock, but the sector slowly adapted to the tariff trends.

The statistical significance of these estimates makes them reliable and interpretable. While the individual wind tariff estimate was not statistically significant, this can be attributed to its effect being absorbed by the significant interaction term, which provides a more reliable estimate of the tariff's dynamic impact. The RMSE value of 570 MW indicates the typical error in the dependent variable's estimates. This is further reflected by the decent adjusted R2 value of 55%, suggesting that the model statistically explains a notable portion of the variance, and that the trend in tariff rates offers a better explanation for the observed slowdown compared to the previous model.

It should be noted that the primary objective of the policy shift was to decrease tariff rates; while the immediate drop in tariffs might have initially impacted the sector, it eventually adapted once the tariffs became feasible and affordable. This highlights the sensitivity of the wind sector to tariff structures and how there needs to be a delicate balance between energy-producing profit margins for the investors, as well as being affordable for the customers.

ITS DIFFERENCED LCOE MODEL

term	estimate	std.error	statistic	p.value	*	RMSE	Adj. R2
(Intercept)	2625.982	504.3339	5.206832	0.000559	***	1,058.50	-0.18681
Years_after_policy	-2500.47	1432.221	-1.74587	0.114787			
LCOE_centered	-2810.8	8294.117	-0.33889	0.742465			
Years_after_policy: LCOE_centered	-46094.8	27147.99	-1.69791	0.123752			

ITS Differenced LCOE Model using the national level annual installed capacity data of the wind sector from 2011 to 2024 estimated a baseline of 2625 MW in 2011. While the variables ‘Years_after_policy’, ‘LCOE_centered’, and the interaction term ‘Years_after_policy: LCOE_centered’ indicate a decline in the annual installed capacity, none of the values turned out to be significant. The model itself is highly unreliable, reflected by a negative adj R2 value and a high RMSE value.

Hence, it could not be concluded with statistical evidence whether or not the trends of LCOE had an influence on the slowdown of the wind sector from this specific model. The presence of a number of factors which couldn't be quantified or modelled might be driving the LCOE's impact on the sector, which explains the insignificance of the model and the variables.

ITS STATES POLICY MODEL

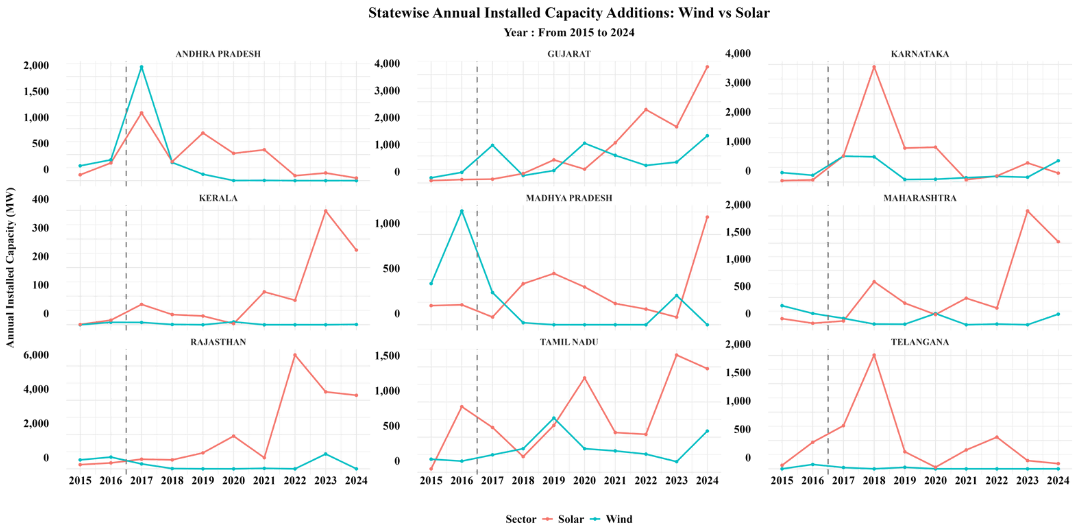
term	estimate	std.error	statistic	p.value	*	RMSE	Adj. R2	Within R2
Years_after_policy	18.834	19.23826	0.979026	0.356241		325.5	0.233	0.0342
Policy_shift	-166.91	68.8393	-2.42463	0.041549	*			

The ITS States Policy Model utilised state-level annual installed capacity data for the wind sector from 2011 to 2024, incorporating fixed effects for the nine windy states. With respect to the pre-policy trends, there seems to be an immediate drop of 166 MW in the annual installed capacity across the states as indicated by the statistically significant 'Policy_shift' variable. Though there could have been an average annual increase of 18 MW in the installed capacity across the states, this interpretation is inconclusive due to the lack of significance of the 'Years_after_policy' variable.

The insignificance could be attributed to the fact that even though fixed effects are employed for the states, they had a very fluctuating trend and hence a single estimate could not be averaged out for all the states considering the different geographical as well as the policy landscape. This is deepened by the fact that the literature point out the relatively better trends of states like Gujarat and Tamil Nadu as well as from insights of the descriptive plots.This highlights that the wind policy landscape and its resultant state-level growth or post-policy recovery are highly localised, making broad, conclusive statements challenging.

The RMSE of 325 MW indicates the typical error in the dependent variable's estimates. This is further reflected by the low adjusted R2 value of 23%, suggesting that the model statistically explains only a limited portion of the variance. The within R2 value of 3.4% further reflects the model's challenge in capturing state-level effects, which is anticipated in a complex real-world energy scenario influenced by diverse geographical, policy, and implementation factors.

DESCRIPTIVE PLOTTING - STATE LEVEL SOLAR VS WIND

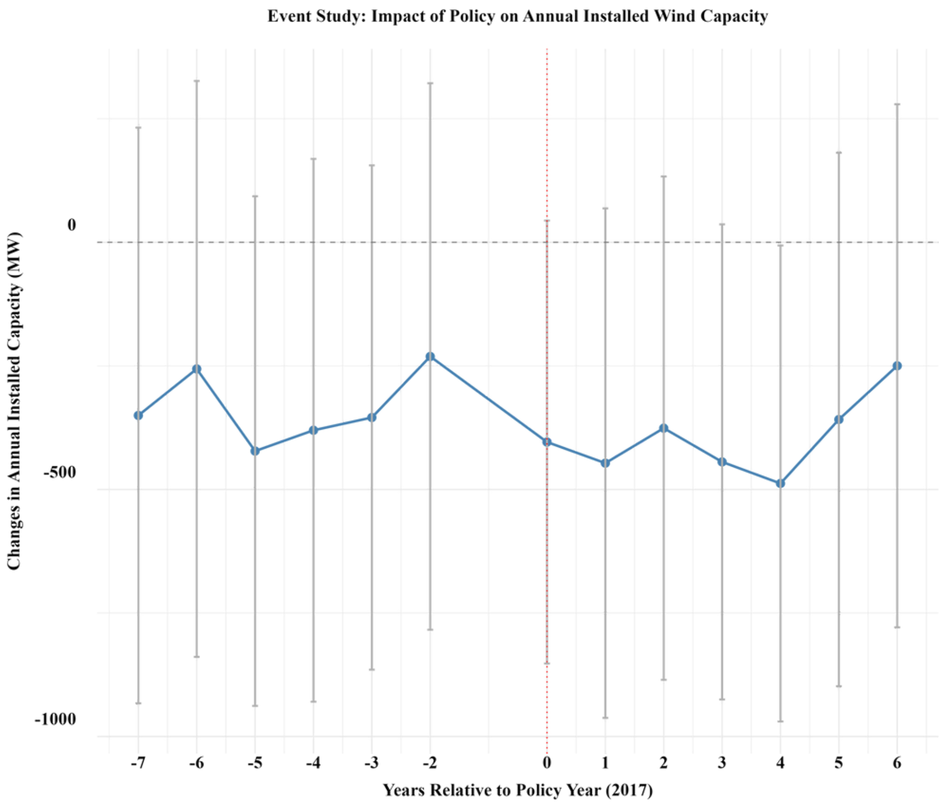


The line graphs of the annual installed capacity of the nine windy states were plotted for the years 2015 to 2024. The graphs revealed that the states had fluctuating trends with respect to both the solar and the wind sectors and no common trend could be derived. It could be seen that except for Andhra Pradesh and Madhya Pradesh, in all the other windy states, the peak addition value of the solar sector in various years across the states has been much greater than any peak additions of the wind sector.

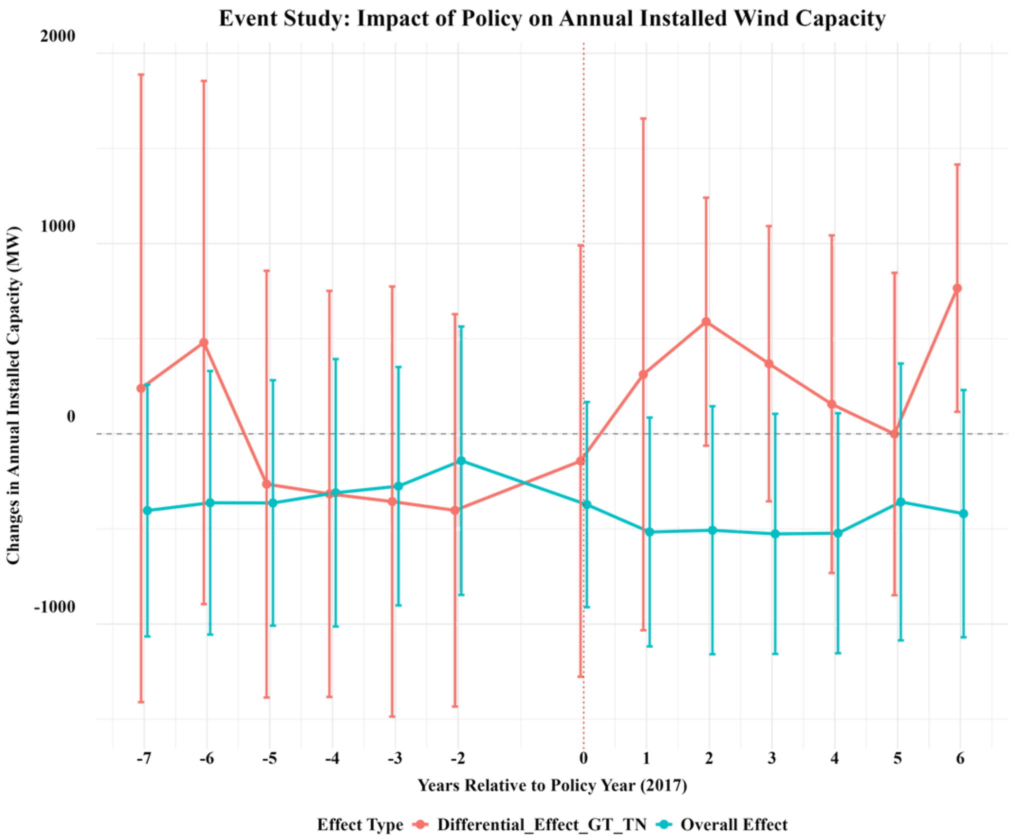
This tells us that, besides the geographical concentration of the energy itself, even in these states, the wind sector might not have had a dedicated push. This remains crucial in understanding if the wind capacity has slowed down owing to the geographical barriers. No conclusive evidence can be drawn from the graphs on whether the policy shift in 2017 caused a slowdown because of the highly fluctuating trends. This variability at the state level underscores the need for a nuanced, state-specific approach to wind energy policy, rather than a one-size-fits-all national strategy, to effectively address regional challenges and capitalise on local potential.

With ~10 GW cumulative capacity in Gujarat and Tamil Nadu each, the graphs indicate that both of them have attempted to some extent to push both the solar and the wind sectors, with Gujarat showing a more pronounced growth in recent years. The states of Andhra Pradesh and Madhya Pradesh have had peak installations around the years 2016 and 2017 and a visible slowdown and stagnation after that. Further investigation is required on why the wind capacity did not pick up in these states, analysing if it is because of a desirable environment in some other states, such as Gujarat and Tamil Nadu or an unfavourable environment, including but not limited to land availability or state-level policies. Further insights on the state-level annual installed capacity of the wind sector are provided through the ITS Models as explained above and the Event study Models.

EVENT STUDY MODELS - STATE LEVEL WIND



The event study was conducted on the state-level annual installed capacity of the wind sector for the years 2010 to 2023 with fixed effects for states to understand the changes in the annual installed capacity relative to the event, i.e, the policy intervention in 2017. The plot revealed that with respect to the reference year, 2016, while there was a negative change across the timeline, it could not be statistically concluded if the policy had an impact on the annual installed capacity due to wide confidence intervals.



The event study with heterogeneity effects for Gujarat and Tamil Nadu was conducted to analyse if these states had a differential impact of the policy intervention in 2017. With reference year at 2016, the event study highlighted that the states of Gujarat and Tamil Nadu had a pronounced positive trend even after the policy shift in 2017, though with fluctuating growth. The overall effect remained negative in both pre- and post-policy years. But with wide confidence intervals crossing the zero line, no statistically significant conclusion could be drawn regarding whether or not the states of Gujarat and Tamil Nadu had a net positive trend post the policy intervention.

The inconclusive nature of these event studies, despite observed trends, suggests that the policy's impact at the state level may be overshadowed by other confounding factors or that its effects are highly heterogeneous and not uniformly captured by these models. This highlights the challenges of isolating specific policy impacts in complex, multi-faceted energy markets and points to the need for more granular data or alternative analytical approaches to fully understand state-level responses.

LIMITATIONS

SMALLER DATABASE

The national level study was conducted for the timeline 2011 to 2025. While it was initially assumed that 15 years of annual data would be sufficient to analyse the overall trend of the wind and the solar sectors, the construction of ITS models using lm() revealed the inefficiencies of the relatively smaller dataset. The primary aim of the study was to isolate the causative factors for the slowdown of the wind sector.

Though qualitative analysis has been conducted within the scope of the research question, the complex interplay of a number of factors in the real world energy sector, some of which were not exactly quantifiable posed difficulty in constructing models with high reliability (Adj R2 values: 0.183491(ITS Policy), 0.55486(ITS Tariff), -0.186808(ITS Differenced LCOE) and 0.233748(ITS States Policy). Further interpretation of the results involved careful considerations of these limitations, as the model as a whole did not explain a significant amount of variance in the installed capacity, the dependent variable.

UNQUANTIFIABLE FACTORS

The limited level of statistical significance of the overall model highlights that while the policy shift was one of the contributing factors for the slowdown in the annual installed capacity additions of the wind sector, it may not have been the sole or primary causative factor. Existing literature cites reasons such as issues of land availability, difficulty in land procurement, high investments, transmission line issues, sub-station with inadequate power capacity, DISCOMS issues, etc, all of which have to work in coordination for the wind sector to run smoothly. The findings suggest the presence of these factors. Lack of consistent datasets for the above factors is accounted for while interpreting the results of the models.

FUTURE PROSPECTS

Acknowledging these limitations, the future study will try to utilise a larger database if available to produce more robust results. Nevertheless, this research poses statistical evidence of the slowdown of the wind sector, and it is expected that incorporating variables such as project-level land acquisition data, grid connectivity status, DISCOM payment reliability, and state-level land acquisition timelines will enable the construction of a more comprehensive and statistically robust model.

POLICY SUGGESTIONS

WHY IS A MORE ROBUST APPROACH THE NEED OF THE HOUR?

With a current peak energy demand of approximately 250 GW (FY2024-25 estimate), our nation has successfully achieved 50% of its installed power generation capacity from non-fossil fuel sources. This accounts for 220.10 GW as of March 31, 2025, and this huge accomplishment is driven by a number of targeted, innovative, and robust policies.

While it is important to acknowledge the growth of the solar sector, which contributes 49% of India's total renewable installed capacity and is the 4th largest in the world, it is equally important to look for insights from this growth. The solar sector teaches us that while flexibility in the incorporation of a technology itself is a huge factor in the growth of a particular type of energy, it is not a single subsidy scheme or a dedicated policy with ambitious targets in isolation that would yield the expected results.

While solar could have garnered attention because of the favourable global trends and cheaper technology, it is important to note that the wind sector has half the cumulative installed capacity (51 GW) of solar, with half the number of policies and schemes dedicated to it. This tells us that with targeted policies, wind definitely has the potential to grow, and this is demonstrated through the shift in trends in the years 2024 and 2025[1], as we have begun to turn our attention to the wind sector.

The study underscores that the wind sector, with half the breadth of the solar policy landscape and twice the time in delays, has achieved only half of what solar has achieved. This is despite having a headstart of 17 GW in 2011 when solar was just finding its footing, both literally and figuratively.

HOW CAN INDIA ACHIEVE HER WIND ENERGY TARGETS?

A national-level mission, followed by a strategic auction mechanism that led to competitive tariffs that aligned with global trends, coupled with ambitious and lucrative projects such as mega solar parks and rooftop solar installations, all while supported by a number of subsidy schemes, formed the backbone of the solar sector[17].

With ambitious targets, India must strengthen its foundational elements. While the issues of land availability and procurement, and the lack of sufficient transmission networks, are common to both solar and wind, if we want to achieve our target of 140 GW of wind power by 2030, we have to come up with innovative solutions to solve these issues.

Some of the suggestive measures are discussed in the following section.

DEDICATED WIND ENERGY ZONES

Dedicated wind energy zones in states that haven't realised their wind potential substantially yet could be facilitated with single-window clearances.

PRODUCTION LINKED INCENTIVES (PLI)

Despite a significant domestic manufacturing base, it is underutilised due to the overall slowdown of the sector, and it could heavily benefit from Production Linked Incentive schemes[18].

ENERGY STORAGE INCENTIVES

Energy storage solutions could be incentivised and actively promoted by a bottom-up approach, leading to improved grid stability and reduced curtailment.

ADDRESSING WIND-SPECIFIC CHALLENGES

The primary reason for this lies in the fact that these issues affect the wind sector more than the solar sector due to its inherent characteristics, including its geographical constraints, remote locations, and requirement for larger patches of land.

ADAPTATION OF NEW TECHNOLOGIES

Scaling up the wind energy sector despite these challenges would need speeding up of decentralized windfarms through adoption of small windmill and bladeless turbines technology.

POTENTIAL DECENTRALIZED WINDFARMS

As notified by the National Institute of Wind Energy that wastelands in India have a potential of about 150 GW of wind energy[19], resources could be directed towards installations in such lands which would lighten the struggle for land procurement and the associated socio-economic challenges.

A MORE ENTHUSIASTIC APPROACH FROM THE STATES

With the wind sector highly concentrated, many initiatives and much enthusiasm are expected from the individual states, and we must come up with a robust centralised mechanism to reduce delays.

ADDRESSING SYSTEMIC CHALLENGES

While administrative bottlenecks are deeply ingrained in our system, it is high time that we reduce their influence because the wind sector represents the 'lost potential' driven by issues arising from within the system.

KEY POLICY LESSONS

While COVID can be listed as a reason for the delay in reverting to reverse bidding for at least a couple of years, this evolution offers two critical policy lessons.

Firstly, a policy successful in one energy sector may not yield identical results when applied to another, underscoring the critical need for sector-specific policy design and adaptation rather than direct transplantation. While closed competitive bidding was introduced in the wind sector with a proven track record in the solar sector, it did not demonstrate the same positive results.

Secondly, with a highly complex sector such as energy, it may take a longer time before we can come to conclusions about whether a policy works positively or negatively, requiring patient, long-term evaluation to truly ascertain its efficacy. However, for a sector like wind, which had a consistent (though gradual) growth rate, it is evident that the delay in concluding the policy shift did not bring about the expected positive change, even as the sector clearly struggled to adapt.

This underscores the imperative for agile policy review and timely adjustments when initial indicators suggest a lack of adaptation.

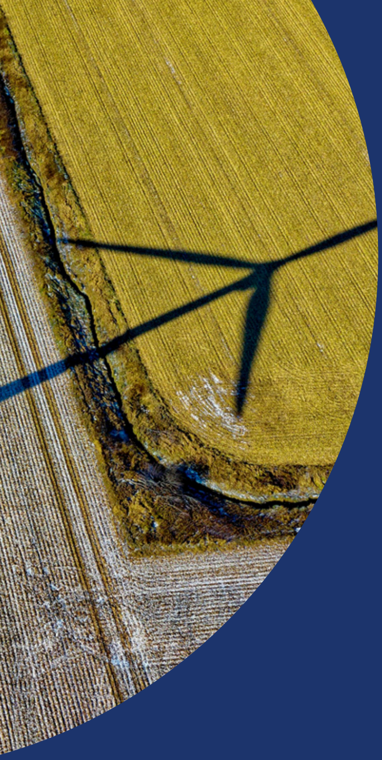
CONCLUSION

The sharp contrast between the estimated potential of the wind sector and the actual realisation of its potential led to the question of, ‘Why has the wind sector utilised only a fraction of its potential and could the wind sector have achieved more, probably 100 GW by 2024, had it followed a different trajectory?’.

This paper, through its counterfactual analysis, showed us that there was indeed a significant lost potential of 37 GW driven by the entire landscape of the sector itself, whose inefficiencies and systemic gaps were left bare open by the policy shift in 2016. A policy that worked wonders for solar and put India on the global renewable energy map, but failed to pull the same results with wind.

The Interrupted Time Series Models only strengthened our presumption that it was not the policy shift that solely caused the slowdown of the sector, but rather the inherent nature of India’s renewable energy landscape itself. The recovering trend highlighted by the ITS models in the later years coincides with the amendment to the closed competitive bidding system, which led to feasible trends of the tariff prices. It must be noted here that the wind sector was resilient enough to hold on and show some decent growth despite the slowdown.

But the inconsistency in the growth trajectory and recovery across the states underscores the lack of adequate state-level targeted policies and enthusiasm. With an undeniable potential and ambitious targets in the renewable energy sector, India must work on its foundational problems to realise its potential across the energy sources.



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