

**POLICY ANALYSIS AND GROWTH
DETERMINANTS OF SOLAR AND WIND POWER
SECTORS IN INDIA**

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by

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DEPARTMENT OF MANAGEMENT STUDIES

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CERTIFICATE

This is to certify that the thesis titled “**Policy Analysis and Growth Determinants of Solar and Wind Power Sectors in India**”, being submitted by **Mr. Sapan Thapar** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and has fulfilled all the requirements for the submission of the thesis, which has attained the standard required for a Ph.D. degree of this institute. The results presented in this thesis have not been submitted in part or full to any other university or institution for any degree or diploma.

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“The Sun Lord is auspicious and bestows auspiciousness. He subdues grief and worries and nourishes life.”

- *Rig Veda*

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(Sapan Thapar)

ABSTRACT

Climate change has been identified as the one of the greatest challenges encountered by human civilization in recent times. An effective instrument to promote sustainable development and mitigate greenhouse gas emissions is use of renewable energy. The deployment of renewable technologies has progressed remarkably since the last decade, spurred by innovation, competition and policy support, with the total capacity crossing 1000 GW at the end of 2017, comprising about 540 GW of wind and 400 GW of solar assets. Despite the significant progress made in terms of capacity deployment, their actual contribution in terms of energy supply is not large enough to make any meaningful impact. Moreover, their growth has been non-homogenous across regions, with spatial and temporal variations seen in terms of capacity deployment, which may be on account of factors attributed to policies, technologies and associated socio-economic and commercial aspects.

Though there exists a significant body of academic work analyzing renewable energy policies, the literature lacks studies assessing the impact of non-policy variables on the growth of solar and wind power sectors; the research gap is all the more acute in Indian context. These gaps throw up certain questions which need a deeper assessment - Which drivers influenced the growth of wind and solar power sectors? What are the reasons for variation in wind deployment across Indian states? Which national and local factors influenced the outcome of solar auctions in India? What are the views of sector experts with respect to the growth drivers as well as barriers? What kind of measures can ensure sustainable growth of wind and solar power sectors?

To answer these questions, a comprehensive study has been conducted using both primary and secondary data techniques. For the international analysis, focusing on Germany, India, Japan and the United States, (which are among the top five countries in terms of renewable capacity deployment) panel data has been utilized to identify key determinants impacting wind and solar power sectors. Likewise, the Indian wind sector has been examined using panel data for the six windy states, followed by a region-wise assessment,

while the Indian solar sector has been analyzed using multivariate regression of data pertaining to auctions related to utility-scale projects. Secondary research has been validated by primary survey of Indian experts in order to harmonize the findings and come out with appropriate recommendations.

The international study found wind driven by energy security issues, while solar majorly driven by commercial factors like ease of business and module prices; any sudden disruption in policy resulted in boom-bust cycles. It found a muted impact of wind and solar addition on GHG emissions, possibly due to continued dominance of fossil fuels, with a high share of non-electricity form of energy usage, coinciding with a decline in generation of nuclear power in Germany and Japan.

With regard to the Indian wind sector, the study found its growth displaying temporal and spatial variance across the six windy states, possibly due to the influence of several local factors. In the panel regression, creditability of utilities reflected as a significant factor due to perceived risks of power curtailment and payment delays. The average procurement cost (APPC) also reflected as a key driver as a high differential between feed-in tariff (FIT) and APPC biased utilities from off-taking wind power. Quantum of FIT came as a marginal factor as regulators cap returns on investment (with lower tariff being offered in areas with high wind velocities). Percentage of wind potential harnessed in a state reflected negatively due to saturation of good sites. Roads, required for moving large size machinery, came out as a key infra variable. Disaggregated analyses revealed variations in some of the drivers across states.

Solar capacity targets and RPO came out as key drivers in the analysis of Indian solar auctions due to a strong policy thrust; as in wind, performance of utilities echoed loudly. Module prices reflected moderately due to plateauing in their price decrease and their declining share in the project cost. The analysis showed tender spacing of four months or more leading to maximum tariff reductions. In the primary survey of Indian experts, wind FIT and GBI as well as solar auctions and solar park were marked as key policy instruments. Commercial variables like cost of funds and equipment price as well as utility's credentials also got high scores for both these sectors.

The study came out with some recommendations (1) Consistency in policies with a defined long-term role of energy resources (2) Improvement in parameters related to business environment and market strategies for utilities (3) Facilitating inter-regional trade of green power and tariff rationalization across consumers (4) Spatially and temporally spaced tenders for allocating large contracts (5) Aggregation of energy demand under different usage formats like heating, transportation and power generation

The study adds to the existing literature in terms of highlighting the influence of local factors and non-policy variables on the growth of wind and solar power sectors in India, with a convergence observed across both primary and secondary techniques. The recommendations may be perused to address the current and emerging challenges faced by the wind and solar power sectors and accelerate their deployment towards meeting the sustainable development goals as well as climate targets.

सार

जलवायु परिवर्तन को हाल के दिनों में मानव सभ्यता के सामने सबसे बड़ी चुनौतियों में से एक के रूप में पहचाना गया है। सतत विकास को बढ़ावा देने और ग्रीनहाउस गैस उत्सर्जन को कम करने के लिए एक प्रभावी साधन अक्षय ऊर्जा का उपयोग है। नवीकरणीय प्रौद्योगिकियों की तैनाती पिछले दशक से उल्लेखनीय रूप से आगे बढ़ी है, 2017 के अंत में कुल क्षमता 1000 GW को पार करने के साथ नवाचार, प्रतिस्पर्धा और नीति समर्थन से प्रेरित है, जिसमें 540 GW की पवन और 400 GW की सौर संपत्ति शामिल है। क्षमता परिनियोजन के संदर्भ में की गई महत्वपूर्ण प्रगति के बावजूद, ऊर्जा आपूर्ति के संदर्भ में उनका वास्तविक योगदान कोई सार्थक प्रभाव डालने के लिए पर्याप्त नहीं है। इसके अलावा, उनकी वृद्धि क्षेत्रों में गैर-समरूपता रही है, जिसमें क्षमता की तैनाती के संदर्भ में स्थानिक और लौकिक विविधताओं को देखा गया है, जो नीतियों, प्रौद्योगिकियों और संबद्ध सामाजिक-आर्थिक और वाणिज्यिक पहलुओं के लिए जिम्मेदार कारकों के कारण हो सकता है।

यद्यपि अक्षय ऊर्जा नीतियों का विश्लेषण करने वाले शैक्षणिक कार्यों का एक महत्वपूर्ण निकाय है, साहित्य में सौर और पवन ऊर्जा क्षेत्रों के विकास पर गैर-नीति चर के प्रभाव का आकलन करने वाले अध्ययनों का अभाव है; अनुसंधान का अंतर भारतीय संदर्भ में अधिक तीव्र है। इन अंतरालों से कुछ ऐसे प्रश्न सामने आते हैं जिनकी गहराई से मूल्यांकन की आवश्यकता होती है - कौन से ड्राइवर्स ने पवन और सौर ऊर्जा क्षेत्रों के विकास को प्रभावित किया? भारतीय राज्यों में पवन तैनाती में भिन्नता के क्या कारण हैं? भारत में सौर नीलामी के परिणाम ने किन राष्ट्रीय और स्थानीय कारकों को प्रभावित किया? विकास के साथ-साथ बाधाओं के संबंध में क्षेत्र के विशेषज्ञों के विचार क्या हैं? किस तरह के उपायों से पवन और सौर ऊर्जा क्षेत्रों की सतत वृद्धि सुनिश्चित हो सकती है?

इन सवालों का जवाब देने के लिए, प्राथमिक और माध्यमिक डेटा तकनीकों दोनों का उपयोग करके एक व्यापक अध्ययन किया गया है। अंतरराष्ट्रीय विश्लेषण के लिए, जर्मनी, भारत, जापान और संयुक्त राज्य अमेरिका पर ध्यान केंद्रित कर रहे हैं, (जो अक्षय क्षमता परिनियोजन के मामले में शीर्ष पांच देशों में शामिल हैं) पैनेल डेटा का उपयोग पवन और सौर ऊर्जा क्षेत्रों को प्रभावित करने वाले प्रमुख निर्धारकों की पहचान करने के लिए किया गया है। इसी तरह, भारतीय पवन क्षेत्र की जांच छह पवन राज्यों के लिए पैनेल डेटा का उपयोग करके की गई है, इसके बाद एक क्षेत्र-वार मूल्यांकन किया गया है, जबकि उपयोगिता-पैमाने की परियोजनाओं से संबंधित नीलामी से संबंधित डेटा के बहुभिन्नरूपी प्रतिगमन का उपयोग करते हुए भारतीय सौर क्षेत्र का विश्लेषण किया गया है। निष्कर्षों का सामंजस्य बनाने और उचित सिफारिशों के साथ बाहर आने के लिए भारतीय विशेषज्ञों के प्राथमिक सर्वेक्षण द्वारा माध्यमिक अनुसंधान को मान्य किया गया है।

अंतरराष्ट्रीय अध्ययन में पवन ऊर्जा ऊर्जा के मुद्दों से संचालित पाया गया, जबकि सौर प्रमुख रूप से व्यावसायिक कारकों द्वारा संचालित होता है जैसे व्यापार और मॉड्यूल की कीमतों में आसानी; नीति में किसी भी अचानक व्यवधान के कारण बूम-बस्ट साइकिल बन गई। यह जीएचजी उत्सर्जन पर पवन और सौर के अतिरिक्त प्रभाव का एक मौन प्रभाव पाया गया, संभवतः जीवाश्म ईंधन के निरंतर वर्चस्व के कारण, ऊर्जा उपयोग के गैर-बिजली के एक उच्च हिस्से के साथ, जर्मनी और जापान में परमाणु ऊर्जा के उत्पादन में गिरावट के साथ।

भारतीय पवन क्षेत्र के संबंध में, अध्ययन में पाया गया कि इसकी वृद्धि छह हवा वाले राज्यों में अस्थायी और स्थानिक विचरण दिखाती है, संभवतः कई स्थानीय कारकों के प्रभाव के कारण। पैनल के प्रतिगमन में, उपयोगिताओं की साख शक्ति विचलन और भुगतान देरी के कथित जोखिमों के कारण एक महत्वपूर्ण कारक के रूप में परिलक्षित होती है। औसत खरीद लागत (APPC) भी फीड-इन टैरिफ (FIT) और APPC पक्षपाती उपयोगिताओं के बीच ऑफ-टेक विंड पावर से उच्च अंतर के रूप में एक प्रमुख चालक के रूप में परिलक्षित होती है। एफआईटी की मात्रा सीमांत कारक के रूप में आयी, जिसमें निवेश पर कैपिटल कैप रिटर्न (उच्च पवन वेग वाले क्षेत्रों में कम टैरिफ की पेशकश के साथ) था। एक राज्य में हवा की संभावित क्षमता का प्रतिशत अच्छी साइटों की संतृप्ति के कारण नकारात्मक रूप से परिलक्षित होता है। बड़े आकार की मशीनरी को स्थानांतरित करने के लिए आवश्यक सड़कें, एक महत्वपूर्ण इन्फ्रा वेरिएबल के रूप में सामने आईं। अलग-अलग विश्लेषणों से राज्यों में कुछ ड्राइवरो में भिन्नताएं सामने आईं।

सौर क्षमता लक्ष्य और आरपीओ एक मजबूत नीति के कारण भारतीय सौर नीलामियों के विश्लेषण में प्रमुख चालकों के रूप में सामने आए; हवा के रूप में, उपयोगिताओं का प्रदर्शन जोर से गूँज उठा। मॉड्यूल की कीमतों में मामूली रूप से परिलक्षित होने के कारण उनकी कीमत में कमी और परियोजना लागत में उनकी गिरावट का हिस्सा है। विश्लेषण ने चार महीने या उससे अधिक के टेंडर रिक्ति को अधिकतम टैरिफ में कमी के लिए दिखाया। भारतीय विशेषज्ञों के प्राथमिक सर्वेक्षण में, पवन एफआईटी और जीबीआई के साथ-साथ सौर नीलामियों और सौर पार्क को प्रमुख नीति उपकरणों के रूप में चिह्नित किया गया था। कमर्शियल वैरिएबल जैसे कॉस्ट ऑफ फंड्स और इक्विपमेंट प्राइस के साथ-साथ यूटिलिटी के क्रेडेंशियल्स को भी इन दोनों सेक्टर के लिए हाई स्कोर मिले।

अध्ययन में कुछ सिफारिशों के साथ सामने आया (1) ऊर्जा संसाधनों की परिभाषित दीर्घकालिक भूमिका के साथ नीतियों में स्थिरता (2) उपयोगिताओं के लिए व्यावसायिक वातावरण और बाजार की रणनीतियों से संबंधित मापदंडों में सुधार (3) हरित शक्ति के अंतर-क्षेत्रीय व्यापार को सुगम बनाना और उपभोक्ताओं के बीच टैरिफ युक्तिकरण (4) स्थानिक और अस्थायी रूप से बड़े आवंटन के लिए निविदाएं

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ABBREVIATIONS

Abbreviation	Full Form
AD	Accelerated Depreciation
APPC	Average Power Procurement Cost
ARR	Annual Revenue Requirement
ATC	Average Technical and Commercial (loss)
BNEF	Bloomberg New Energy Finance
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CII	Confederation of Indian Industry
CO2	Carbon Dioxide
CoP	Conference of Parties
DISCOM	Distribution (Power) Company
EIA	Energy Information Agency, United States
EU	European Union
FY	Financial Year
FDI	Foreign Direct Investment
FEM	Fixed Effects Model
FIT	Feed in Tariff
FY	Financial Year
GBI	Generation Based Incentives
GDP	Gross Domestic Product
GHG	Greenhouse Gas

GSR	Global Status Report
GW	Gigawatts
IRENA	International Renewable Energy Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ITC	Investment Tax Credits
kWh	Kilo Watt Hours
LCOE	levelized Cost of Energy
MNRE	Ministry of New and Renewable Energy
MOP	Ministry of Power
MW	Megawatts
NAPCC	National Action Plan on Climate Change
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NREL	National Renewable Energy Laboratory (US)
NSM	National Solar Mission
PFC	Power Finance Corporation
PTC	Production Tax Credits
PURPA	Public Utilities Regulatory Policy Act
PV	Photo Voltaic
RBI	Reserve Bank of India
RE	Renewable Energy
REC	renewable Energy Certificate
RECAI	Renewable Energy Country Attractiveness Index
REM	Random Effects Model

RPS	Renewable purchase standards
RPO	Renewable Purchase Obligations
SBI	State Bank of India
SERC	State Electricity Regulatory Commission
SECI	Solar Energy Corporation of India
SDG	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
WRI	World Resources Institute
VRE	Variable Renewable Power (Solar and Wind)
VGF	Viability Gap Funds

Indian States

AP	Andhra Pradesh
CH	Chhattisgarh
GUJ	Gujarat
HRY	Haryana
JH	Jharkhand
KTK	Karnataka
MAH	Maharashtra
MP	Madhya Pradesh
PB	Punjab
RAJ	Rajasthan
TN	Tamil Nadu
UP	Uttar Pradesh