

**RENEWABLE ENERGY, INDUSTRIAL
GROWTH AND MARKET MECHANISM: A
STUDY FOR INDIA**

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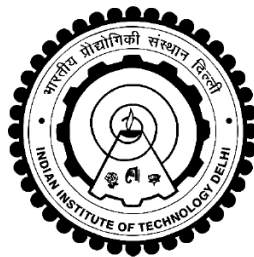
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Submitted

in fulfilment of the requirements for the degree of Doctor of Philosophy

to the



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CERTIFICATE

This is to certify that the thesis titled “**Renewable energy, Industrial growth and Market mechanism: a study for India**”, being submitted by Mr Kaushik Dey 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 PhD. 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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ABSTRACT

Energy consumption contributes to economic growth in the long term (Ayres and Warr, 2009; Kummel et al., 2015). India is the fourth-largest nation globally after China, the United States, and the European Union in energy consumption (India energy outlook 2021). A recent international report revealed that economic growth, population, urbanisation, and industrialisation will be the drivers for the increase in energy demand in India by 2040, as envisaged in the stated policies scenario (India energy outlook 2021, IEA). To meet the ever-increasing energy demand, the role of renewable energy as an alternative energy source has recently come to prominence. It addresses the adverse impacts of climate change due to the consumption of conventional energy sources like coal, oil, and natural gas (Apergis and Payne, 2010).

Review of literature revealed limited studies on the association of segregated renewable energy sources with the industrial production in India. Further, the steps for restructuring the REC trading mechanism to facilitate renewable energy and the impact of the electricity market determinants on the REC market, justified the necessity for this study.

Based on the perspective and gaps in existing literature, certain questions arise- Is there a relationship of segregated RE consumption, e.g., solar, wind, biomass, bagasse, small hydropower, waste-heat, with industrial production in India? Which of the four energy-growth hypotheses (growth, conservation, feedback, and neutrality) applies to India? What factors in the Indian electricity market impact the REC market? How are they related and support the promotion of renewable energy in India? How can the REC mechanism in India be redesigned to increase the uptake of various RE sources in the REC market?

To provide appropriate answers, a comprehensive study has been conducted using both primary and secondary data techniques.

The association of the segregated renewable energy sources with industrial production in India has been studied utilizing quantile regression and non-linear granger causality at the all India level. Secondary research has been validated by conducting interviews of Indian experts in the small hydropower domain and analysing the response of survey questionnaire in order to harmonize the findings and come out with appropriate recommendations. Our findings indicate that the impacts of small hydropower and bagasse energy on IIP are statistically significant in practically all the quantiles. Furthermore, the study findings show unidirectional non-linear Granger causality going from segregated renewable energy source development to industrial growth, suggesting the validity of India's asymmetric "Growth Hypothesis".

The interplay between Indian REC market and the electricity market in the long and short-run has been analysed. The study's novelty is that the symmetric and asymmetric impact of the electricity market variables on the solar and non-solar segment of the REC market in the long and short run are studied. Using symmetric autoregressive distributed lag specification, we found evidence of significant association between the solar and non-solar segment of the REC market in the long run. The association between the REC market and the electricity market is established only in the short-run using ARDL method, wherein there is negative effect of day-ahead market cleared volume on the REC non-solar segment market-clearing price. However, the findings from the asymmetric specification using the NARDL method reveals that the dynamics between the REC and Day-ahead markets is indeed asymmetric. The positive impact of the Day-ahead electricity market-clearing price on the REC non-solar segment market cleared volume, in the long run, validates the argument.

The Renewable Energy Certificate (REC) Mechanism, a market-based tool to facilitate renewable energy growth, was launched in 2010 by the Central Electricity Regulatory Commission (CERC) through REC Regulations. Our study presents the detailed study of the REC mechanism in India since its inception, examines the REC market data available through graphical and empirical analysis to understand the regulatory changes in the REC mechanism and its impact on the REC certificates inventory, and lists the challenges and way forward. The international and national literature review reveals the strength and weaknesses of the green certificates/REC mechanism.

The study came out with few recommendations (1) Small hydropower to aid industrial growth in remote & hilly areas (2) Bagasse based generation for industrial growth in rural areas (3) Stringent REC penal mechanism (4) Need for secondary markets in REC (5) Non-solar REC categorisation (6) Harmonisation of policies across electricity and REC markets.

सार

ऊर्जा की खपत लंबी अवधि में आर्थिक विकास में योगदान करती है (आयरेस और वार, 2009; कुमेल एट अल, 2015)। भारत ऊर्जा खपत में चीन, संयुक्त राज्य अमेरिका और यूरोपीय संघ के बाद विश्व स्तर पर चौथा सबसे बड़ा देश है (भारत ऊर्जा दृष्टिकोण 2021)। एक हालिया अंतरराष्ट्रीय रिपोर्ट से पता चला है कि आर्थिक विकास, जनसंख्या, शहरीकरण और औद्योगीकरण 2040 तक भारत में ऊर्जा की मांग में वृद्धि के लिए चालक होंगे, जैसा कि घोषित नीतियों के परिदृश्य (भारत ऊर्जा दृष्टिकोण 2021, आईईए) में परिकल्पित है। लगातार बढ़ती ऊर्जा मांग को पूरा करने के लिए, वैकल्पिक ऊर्जा स्रोत के रूप में नवीकरणीय ऊर्जा ऊर्जा की भूमिका हाल ही में प्रमुखता से आई है। यह कोयला, तेल और प्राकृतिक गैस जैसे पारंपरिक ऊर्जा स्रोतों की खपत के कारण जलवायु परिवर्तन के प्रतिकूल प्रभावों को संबोधित करता है (एपरगिस और पायने, 2010)।

साहित्य की समीक्षा ने भारत में औद्योगिक उत्पादन के साथ पृथक नवीकरणीय ऊर्जा स्रोतों के संबंध पर सीमित अध्ययनों का खुलासा किया। इसके अलावा, नवीकरणीय ऊर्जा की सुविधा के लिए नवीकरणीय ऊर्जा प्रमाणपत्र (आरईसी) व्यापार तंत्र के पुनर्गठन के कदम और आरईसी बाजार पर बिजली बाजार निर्धारकों के प्रभाव ने इस अध्ययन की आवश्यकता को उचित ठहराया।

मौजूदा साहित्य में परिप्रेक्ष्य और अंतराल के आधार पर, कुछ प्रश्न उठते हैं- क्या भारत में औद्योगिक उत्पादन के साथ अलग-अलग नवीकरणीय ऊर्जा खपत, जैसे, सौर, पवन, बायोमास, बैगास, स्माल हाइड्रो, अपशिष्ट का संबंध है? चार ऊर्जा-विकास परिकल्पनाओं में से कौन सी (विकास, संरक्षण, प्रतिक्रिया और तटस्थता) भारत पर लागू होती है? भारतीय बिजली बाजार में कौन से कारक आरईसी बाजार को प्रभावित करते हैं? वे कैसे संबंधित हैं और भारत में नवीकरणीय ऊर्जा को बढ़ावा देने का समर्थन करते हैं? आरईसी बाजार में नवीकरणीय ऊर्जा स्रोतों के उठाव को बढ़ाने के लिए भारत में आरईसी तंत्र को कैसे फिर से डिजाइन किया जा सकता है?

उपयुक्त उत्तर प्रदान करने के लिए प्राथमिक और द्वितीयक डेटा तकनीकों का उपयोग करते हुए एक व्यापक अध्ययन किया गया है।

भारत में औद्योगिक उत्पादन के साथ पृथक नवीकरणीय ऊर्जा स्रोतों के संबंध का अध्ययन अखिल भारतीय स्तर पर क्वांटिल रिग्रेशन और नॉन लीनियर ग्रेंजर कौसालिटी का उपयोग करके किया गया है। स्माल हाइड्रो क्षेत्र में भारतीय विशेषज्ञों के साक्षात्कार आयोजित करके और सर्वेक्षण प्रश्नावली की प्रतिक्रिया का विश्लेषण करके माध्यमिक अनुसंधान को मान्य किया गया है ताकि निष्कर्षों में सामंजस्य स्थापित किया जा सके और उचित सिफारिशें सामने आ सकें। हमारे निष्कर्षों से संकेत मिलता है कि आईआईपी पर स्माल हाइड्रो और बैगास ऊर्जा का प्रभाव व्यावहारिक रूप से सभी मात्राओं में सांख्यिकीय रूप से महत्वपूर्ण है। इसके अलावा, अध्ययन के निष्कर्ष भारत के असममित "विकास परिकल्पना" की वैधता का सुझाव देते हुए, अलग-अलग अक्षय ऊर्जा स्रोत विकास से औद्योगिक विकास तक जाने वाले यूनिडायरेक्शनल नॉन-लीनियर ग्रेंजर कौसालिटी को दर्शाते हैं।

भारतीय आरईसी बाजार और बिजली बाजार के बीच लंबी और छोटी अवधि में परस्पर क्रिया का विश्लेषण किया गया है। अध्ययन की नवीनता यह है कि लंबी और छोटी अवधि में आरईसी बाजार के सौर और गैर-सौर खंड पर बिजली बाजार चर के सममित और असममित प्रभाव का अध्ययन किया जाता है। सममित ऑटोरेग्रेसिव डिस्ट्रिब्यूटेड लैग विनिर्देशन का उपयोग करते हुए, हमें लंबे समय में आरईसी बाजार के सौर और गैर-सौर खंड के बीच महत्वपूर्ण संबंध के प्रमाण मिले। आरईसी बाजार और बिजली बाजार के बीच संबंध केवल एआरडीएल पद्धति का उपयोग करके अल्पावधि में स्थापित किया जाता है, जिसमें आरईसी गैर-सौर खंड बाजार-समाशोधन मूल्य पर बिजली बाजार की मंजूरी का नकारात्मक प्रभाव पड़ता है। हालांकि, एनएआरडीएल पद्धति का उपयोग करते हुए असममित विनिर्देशन के निष्कर्षों से पता चलता है कि आरईसी और बिजली बाजारों के बीच की गतिशीलता वास्तव में असममित है। आरईसी गैर-सौर खंड बाजार पर बिजली बाजार-समाशोधन मूल्य का सकारात्मक प्रभाव, लंबे समय में तर्क को मान्य करता है।

नवीकरणीय ऊर्जा प्रमाणपत्र (आरईसी) तंत्र, अक्षय ऊर्जा विकास को सुविधाजनक बनाने के लिए एक बाजार-आधारित उपकरण, 2010 में केंद्रीय विद्युत नियामक आयोग (सीईआरसी) द्वारा आरईसी विनियमों के माध्यम से लॉन्च किया गया था। हमारा अध्ययन भारत में आरईसी तंत्र का विस्तृत अध्ययन प्रस्तुत करता है। यह आरईसी तंत्र में नियामक परिवर्तनों और आरईसी प्रमाणपत्र सूची पर इसके प्रभाव को समझने के लिए ग्राफिकल और अनुभवजन्य विश्लेषण के माध्यम से उपलब्ध आरईसी बाजार डेटा की जांच करता है, और चुनौतियों और आगे के रास्ते को सूचीबद्ध करता है। अंतरराष्ट्रीय और राष्ट्रीय साहित्य समीक्षा से हरित प्रमाणपत्र/आरईसी तंत्र की ताकत और कमजोरियों का पता चलता है।

अध्ययन कुछ सिफारिशों के साथ सामने आया (1) दूरस्थ और पहाड़ी क्षेत्रों में औद्योगिक विकास में सहायता के लिए स्माल हाइड्रो (2) ग्रामीण क्षेत्रों में औद्योगिक विकास के लिए बैगास ऊर्जा उत्पादन (3) कठोर आरईसी दंड तंत्र (4) आरईसी में द्वितीयक बाजारों की आवश्यकता (5) गैर-सौर आरईसी वर्गीकरण (6) बिजली और आरईसी बाजारों में नीतियों का सामंजस्य।

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ABBREVIATIONS

Abbreviation	Full form.
RE	Renewable energy
REC	Renewable energy certificate
SHP	Small hydropower
CO ₂	Carbon dioxide
DAM	Day-ahead market
MCP	Market clearing price
MCV	Market clearing volume
IIP	Index of Industrial Production
CPI	Consumer price index
IEA	International energy agency
CEA	Central electricity authority
CERC	Central electricity regulatory authority
SERC	State electricity regulatory authority
SNA	State nodal agency
RPO	Renewable purchase obligation
TGC	Tradable green certificates
MU	Million unit
MWh	Mega-watt hour
IPCC	Inter panel climate change
CPP	Captive power consumers
MNRE	Ministry of new and renewable energy
FIT	Feed-in tariff
OECD	The Organisation for Economic Co-operation and Development
UNCHE	United Nations Conference on Human Environment
UNEP	United Nations Environment Programme
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
UNCORE	United Nations Conference on Renewable Energy
COP	Conference of Parties
EU	European Union
EU ETS	European Union emission trading scheme
ARDL	Autoregressive distributed lag
NARDL	Non-linear autoregressive distributed lag
BDS	Brock, Dechert, Scheinkman test
INDC	Intended nationally determined contribution
NEP	National energy policy
GBI	Generation-based incentive
NIWE	National institute of wind energy
DMIC	Delhi Mumbai Industrial Corridor
MHP	Micro Hydro Power Plant
TANGEDCO	Tamil Nadu Generation and Distribution Corporation

p.u.	Per unit
INR	Indian rupees
GOI	Government of India
APPC	Average power purchase cost
CPP	Captive power producer
PXIL	Power Exchange of India Limited
IEX	Indian Energy Exchange
UREDA	Uttarakhand Renewable Energy Development Agency
NAPCC	National action plan for climate change

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