VIABILITY OF BUSINESS MODELS FOR RURAL ELECTRIFICATION IN INDIA: A MULTI-METHOD STUDY

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
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by

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submitted

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Dedicated to my parents.

Certificate

This is to certify that the thesis entitled **"Viability of Business Models for Rural Electrification in India: A Multi-method Study"** submitted by Ms. Payal Dey to the Indian Institute of Technology Delhi, for the award of the degree of "**Doctor of Philosophy**" in the Department of Management Studies, is a record of bonafide research work carried out by her. She has worked under our guidance and supervision, and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The models and research findings presented in this thesis have not been submitted elsewhere for the award of any degree.

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Abstract

The thesis investigates the persistent challenges of access, reliability, and affordability of electricity in rural India despite near-complete electrification, and identifies possible solutions to the problem through a systems thinking approach. The purpose of undertaking this research was to address the nearly 70-year-old challenges pertaining to rural electrification in India, which are presently linked to the attainment of Sustainable Development Goal – 7 by 2030, renewable energy commitments of 500 GW of the Government of India by 2030, as well as achieving Net Zero Emissions by 2070 promised at the Conference of Parties – 26 Summit held in Glasgow, United Kingdom in 2022. After an initial introduction including the motivation, research questions and objectives, scope, overview of the methodology, and chapter plan, a review of the literature is presented. The gaps found in the literature are addressed with four key studies, and their findings are augmented with policy analysis for future action by policymakers.

The literature review that focuses on types of public-private partnership models for rural electrification in developing countries, political perspectives, international experience, and successful business models in India concludes with bibliometric analysis. The findings reveal growth in the publications related to business models in rural electrification over the years with a cumulative number of 49 studies from over 74 countries, with a maximum of 71 publications from India on mini-grids as a business model for rural electrification. Other findings were energy planning and simulation being the leading methodologies for studies, with a shifting trend from development-oriented studies to renewable-based technology-related research – these set a context for the thesis.

The first study conceptualises the challenges and issues of rural electrification in India as a ‘wicked problem’ – a systems-based approach that has been applied to the field of energy

policy since 2013. After an initial understanding of the problems from field visits, the responses from stakeholders were organised in the order of influence through a power-interest matrix, and their responses were captured in a Causal Loop Diagram with both balancing and reinforcing loops. The solutions were further developed into two studies, the first one builds a case for a grid-connected solar mini-grid business model for the electrification of rural areas in India. The second study proposes an Integrated Distribution Framework for addressing the last-mile inefficiencies in the power distribution sector in India, exacerbated in rural areas. Both studies perform an in-depth analysis of existing business models implemented and planned at national, sub-national, and international scales. An operational, financial, regulatory, and implementation roadmap has also been discussed.

The final study is the extension of the systems approach from the conceptualisation stage to model validity through system dynamics. With the help of quantitive data on parameters that define the demand and supply of a grid-interconnect solar mini-grid, a stock and flow diagram has been prepared. The parameters are tested through sensitive analysis, followed by developing scenarios on impact variables including mini, and main grid supply, mini-grid expenses, levelised cost of electricity, average revenue per user and the overall energy deficit. The main results were computing the viability of the business model by breaking even in 4-5 years, and a need for urgent scaling up for meeting the electrification targets.

The future steps of the research could be assessing the viability with historical data and the application of statistical tools for quantitative analysis in system dynamics modelling. The proposed business models could also be studied for similar context-specific environments in rural and remote settings.

सार

थीसिस लगभग पूर्ण विद्युतीकरण के बावजूद ग्रामीण भारत में बिजली की पहुंच, विश्वसनीयता और सामर्थ्य की लगातार चुनौतियों की जांच करती है, और सिस्टम थिंकिंग दृष्टिकोण के माध्यम से समस्या के संभावित समाधान की पहचान करती है। इस शोध को करने का उद्देश्य भारत में ग्रामीण विद्युतीकरण से संबंधित लगभग 70 साल पुरानी चुनौतियों का समाधान करना था, जो वर्तमान में 2030 तक सतत विकास लक्ष्य - 7 की प्राप्ति, सरकार की 500 गीगावॉट की नवीकरणीय ऊर्जा प्रतिबद्धताओं से जुड़ी हुई हैं। 2030 तक भारत, साथ ही 2070 तक शुद्ध शून्य उत्सर्जन हासिल करने का वादा 2022 में ग्लासगो, यूनाइटेड किंगडम में आयोजित पार्टियों के सम्मेलन - 26 शिखर सम्मेलन में किया गया था। प्रेरणा, शोध प्रश्न और उद्देश्यों, दायरे, कार्यप्रणाली के अवलोकन सहित प्रारंभिक परिचय के बाद , और अध्याय योजना, साहित्य की समीक्षा प्रस्तुत की गई है। साहित्य में पाई गई कमियों को चार प्रमुख अध्ययनों से संबोधित किया गया है, और उनके निष्कर्षों को नीति निर्माताओं द्वारा भविष्य की कार्रवाई के लिए नीति विश्लेषण के साथ बढ़ाया गया है।

विकासशील देशों में ग्रामीण विद्युतीकरण के लिए सार्वजनिक-निजी भागीदारी मॉडल के प्रकार, राजनीतिक दृष्टिकोण, अंतर्राष्ट्रीय अनुभव और भारत में सफल व्यवसाय मॉडल पर केंद्रित साहित्य समीक्षा ग्रंथसूची विश्लेषण के साथ समाप्त होती है। निष्कर्षों से पता चलता है कि पिछले कुछ वर्षों में 74 से अधिक देशों के 49 अध्ययनों की संचयी संख्या के साथ ग्रामीण विद्युतीकरण में व्यावसायिक मॉडल से संबंधित प्रकाशनों में वृद्धि हुई है, जिसमें ग्रामीण विद्युतीकरण के लिए एक व्यवसाय मॉडल के रूप में मिनी-ग्रिड पर भारत से अधिकतम 71 प्रकाशन शामिल हैं। अन्य निष्कर्षों में ऊर्जा नियोजन और सिमुलेशन अध्ययन के लिए अग्रणी पद्धतियां थीं, विकास-उन्मुख अध्ययनों से नवीकरणीय-आधारित प्रौद्योगिकी-संबंधित अनुसंधान में बदलाव के साथ - ये थीसिस के लिए एक संदर्भ निर्धारित करते थे।

पहला अध्ययन भारत में ग्रामीण विद्युतीकरण की चुनौतियों और मुद्दों को एक 'दुष्ट समस्या' के रूप में दर्शाता है - एक सिस्टम-आधारित दृष्टिकोण जिसे 2013 से ऊर्जा नीति के क्षेत्र में लागू किया गया है। क्षेत्र के दौरे से समस्याओं की प्रारंभिक समझ के बाद, हितधारकों की प्रतिक्रियाओं को एक शक्ति-हित मैट्रिक्स के माध्यम से प्रभाव के क्रम में व्यवस्थित किया गया था, और उनकी प्रतिक्रियाओं को संतुलन और सुदृढ़ीकरण लूप दोनों के साथ एक कारण लूप आरेख में कैप्चर किया गया था। समाधानों को आगे दो अध्ययनों में विकसित किया गया,

पहला भारत में ग्रामीण क्षेत्रों के विद्युतीकरण के लिए ग्रिड से जुड़े सौर मिनी-ग्रिड व्यवसाय मॉडल के लिए एक मामला बनाता है। दूसरे अध्ययन में भारत में बिजली वितरण क्षेत्र में अंतिम छोर तक की अक्षमताओं, जो कि ग्रामीण क्षेत्रों में विकराल हो गई हैं, को दूर करने के लिए एक एकीकृत वितरण ढांचे का प्रस्ताव किया गया है। दोनों अध्ययन राष्ट्रीय, उप-राष्ट्रीय और अंतर्राष्ट्रीय स्तर पर कार्यान्वित और नियोजित मौजूदा व्यावसायिक मॉडल का गहन विश्लेषण करते हैं। एक परिचालन, वित्तीय, नियामक और कार्यान्वयन रोडमैप पर भी चर्चा की गई है।

अंतिम अध्ययन सिस्टम गतिशीलता के माध्यम से अवधारणा चरण से मॉडल वैधता तक सिस्टम दृष्टिकोण का विस्तार है। ग्रिड-इंटरकनेक्ट सौर मिनी-ग्रिड की मांग और आपूर्ति को परिभाषित करने वाले मापदंडों पर मात्रात्मक डेटा की मदद से, एक स्टॉक और प्रवाह आरेख तैयार किया गया है। संवेदनशील विश्लेषण के माध्यम से मापदंडों का परीक्षण किया जाता है, इसके बाद मिनी और मुख्य ग्रिड आपूर्ति, मिनी-ग्रिड व्यय, बिजली की स्तरीकृत लागत, प्रति उपयोगकर्ता औसत राजस्व और समग्र ऊर्जा घाटे सहित प्रभाव चर पर परिदृश्य विकसित किए जाते हैं। मुख्य परिणाम 4-5 वर्षों में व्यापार मॉडल की व्यवहार्यता की गणना करना और विद्युतीकरण लक्ष्यों को पूरा करने के लिए तत्काल स्केलिंग की आवश्यकता थी।

अनुसंधान के भविष्य के कदम ऐतिहासिक डेटा के साथ व्यवहार्यता का आकलन करना और सिस्टम डायनेमिक्स मॉडलिंग में मात्रात्मक विश्लेषण के लिए सांख्यिकीय उपकरणों का अनुप्रयोग हो सकते हैं। प्रस्तावित व्यवसाय मॉडल का अध्ययन ग्रामीण और दूरस्थ सेटिंग्स में समान संदर्भ-विशिष्ट वातावरण के लिए भी किया जा सकता है।

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Nomenclature

ABC	Anchor Loads, Business and Community
AERC	Assam Electricity Regulatory Commission
AMDA	Africa Minigrid Developers Association
APDCL	Assam Power Distribution Company Limited
APL	Above the Poverty Line
APS	Announced Pledge Scenario
ARPU	Average Revenue per User
AT&C	Aggregate Technical and Commercial
BAU	Business as Usual
BERC	Bihar Electricity Regulatory Commission
BOO	Build-Own-Operate
BOOT	Build-Own-Operate-Transfer
BPL	Below the Poverty Line
BREDA	Bihar Renewable Energy Development Agency
BST	Bulk Supply Tariff
C&C	Content and Carriage
C&I	Commercial and Industrial
CAS	Complex Adaptive Systems
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CEED	Centre for Environment and Energy Development
CERC	Central Electricity Regulatory Commission
CESU	Central Electricity Supply Utility
CLD	Causal Loop Diagram

CSE	Centre for Science and Environment
CUF	Capacity Utilization Factor
DBT	Direct Benefit Transfer
DDG	Decentralised Distributed Generation
DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana
DERs	Distributed Energy Resources
DF	Distribution Franchisee
DFIs	Development Finance Institutions
DG&S	Decentralised Generation and Supply
DISCOM	Distribution Company
DNO	Distribution Network Operator
DSO	Distribution System Operators
EA	The Electricity Act, 2003
ECoF	Electricity Company of the Future
ECOWAS	Economic Community of West African States
ESCOs	Energy Service Companies
ESMAP	Energy Sector Management Assistance Program
FAC	First Action Countries
FEDCO	Feedback Energy Distribution Company Limited
FiT	Feed-in-tariff
FYP	Five-Year Plans
GCEEP	Global Commission to End Energy Poverty
GEC	Global Energy and Climate
GIS	Geographic Information System
GNESD	Global Network on Energy for Sustainable Development

IBF-IRS	Input-based Franchisee with Incremental Revenue Sharing
IDC	Integrated Distribution Company
IDF	Integrated Distribution Framework
IEA	International Energy Agency
IGAs	Income Generating Activities
IPD	Independent Power Distribution
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
JREDA	Jharkhand Renewable Energy Development Agency
KPI	Key Performance Indicator
LCOE	Levelized Cost of Electricity
MDGs	Millennium Development Goals
MGO	Mini-grid Operator
MITEI	MIT Energy Initiative
MMAR	Mixed Methods Action Research
MMR	Mixed Methods Research
MNP	Minimum Needs Program
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
MP	Madhya Pradesh
MPERC	MP Electricity Regulatory Commission
NDCs	Nationally Determined Contributions
NEDCL	National Electricity Distribution Company Limited
NEP	National Energy Policy
NGOs	Non-Governmental Organisations

NOC	No Objection Certificate
NPCL	Noida Power Company Limited
NTPC	National Thermal Power Corporation Limited
NZE	Net Zero Emissions
O&M	Operation and Maintenance
OERC	Odisha Electricity Regulatory Commission
PDN	Public Distribution Network
PEO	Program Evaluation Organisation
PGCIL	Power Grid Corporation of India Limited
PHEC	Per Hour Energy Consumption
POLR	Provider of Last Resort
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
4P	People-PPPs
5P	Pro-Poor PPPs
PSP	Private Sector Participation
PUE	Productive-uses-of-energy
RDF	Rural Distribution Franchisee
REC	Rural Electrification Corporation
REP	Rural Electrification Plan
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RPO	Renewable Purchase Obligation
RTI	Right to Information
RVGs	Renewable energy-based village grids
Saubhagya	Pradhan Mantri Sahaj Bijli Har Ghar Yojana

SD	System Dynamics
SDGs	Sustainable Development Goals
SEB	State Electricity Boards
SERCs	State Electricity Regulatory Commissions
SFD	Stock and Flow Diagram
SLDC	State Load Dispatch Centres
SoP	Standard of Performance
SPI	Smart Power India
SPRD	Smart Power for Rural Development
SPV	Special Purpose Vehicle
STEPS	Stated Policy Scenarios
T&D	Transmission and Distribution
TERI	The Energy and Resources Institute
TPDDL	Tata Power Delhi Distribution Limited
TPRMG	TATA Power Renewable Microgrid
UEA	Universal Energy Access
UNDP	United Nations Development Program
UNSD	United Nations Statistics Division
UP	Uttar Pradesh
UPPCL	Uttar Pradesh Power Corporation Limited
USAID	United States Agency for International Development
USO	Universal Service Obligation
VGF	Viability Gap Funding
WHO	World Health Organisation
WTP	Willingness to Pay