

# Powering India's Future



# Powering India's Future:

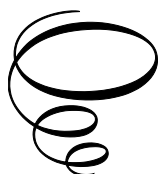
*The Evolution of Electricity from  
Colonial Roots to Net Zero*

By

Atanu Mukhopadhyay and

Dr Papri Mukhopadhyay

**Cambridge  
Scholars  
Publishing**



Powering India's Future: The Evolution of Electricity  
from Colonial Roots to Net Zero

By Atanu Mukhopadhyay and Dr Papri Mukhopadhyay

This book first published 2026

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

Copyright © 2026 by Atanu Mukhopadhyay and Dr Papri Mukhopadhyay

All rights for this book reserved. No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the copyright owner.

ISBN: 978-1-0364-6592-6

ISBN (Ebook): 978-1-0364-6593-3

# TABLE OF CONTENTS

Author Biography .....	viii
List of Figures.....	ix
List of Tables.....	x
List of Abbreviations .....	xi
Preface.....	xvii
Chapter 1 .....	1
Colonial Electrification – The Birth of India’s Power System	
Chapter 2 .....	18
Electrifying Rural India: Demand Patterns, 1900–1950	
Chapter 3 .....	47
Early Sector Dynamics – Institutions, Irrigation & Energy	
Chapter 4 .....	66
From Colonial Sparks to National Grid – Power System Integration, 1930–1950	
Chapter 5 .....	87
Electrifying India – Five-Year Plans, Hydropower, and the Transformation of the Power Sector (1951–2017)	
Chapter 6 .....	106
BHEL’s Role: Public-Sector Leadership in Power Technology	
Chapter 7 .....	135
State-Wise Electricity Consumption Trends since 1947	
Chapter 8 .....	153
1991 Liberalisation – Recharging India’s Electricity Economy	

Chapter 9 .....	159
Privatization Crossroads: Constraints, Controversies, and State-Level Lessons, 1991–2003	
Chapter 10 .....	176
Federal Fault Lines and Reform Frontiers (Post-2003)	
Chapter 11 .....	198
Evolution of Electricity Subsidies and Tariffs in India (1947–2025)	
Chapter 12 .....	235
Reforming and Modernizing India’s Power Distribution Sector	
Chapter 13 .....	255
Electrification and Society – Access, Equity, and Socio-Economic Impacts	
Chapter 14 .....	289
From Biomass to Coal and Beyond – Evolution of India’s Power Generation	
Chapter 15 .....	317
India’s Clean-Energy Decade (2014–2025) – Development Dividends	
Chapter 16 .....	333
Financing Green Energy	
Chapter 17 .....	358
Emerging Renewable Energy Technologies and Future Pathways for India	
Chapter 18 .....	373
Hydropower’s Evolving Role in India’s Renewable Transition	
Chapter 19 .....	384
Modern Grid Segments: HVDC, UHVAC & Synchronous Integration	
Chapter 20 .....	393
Securing the Digital Grid	
Chapter 21 .....	399
Global Trends and the Road Ahead for India’s Power Sector Transformation	

Chapter 22 .....	430
Energy Security Toolkit – PLI, SPR & LNG Initiatives	
Chapter 23 .....	440
India's Net-Zero Pathways – Integrating National Strategy with State Roadmaps	
Chapter 24 .....	459
Transforming India's Power Market for a Clean Energy Future	
Annexure .....	502
List of References.....	509
Index.....	533

## AUTHOR BIOGRAPHY

### **ATANU MUKHOPADHYAY**

Atanu Mukhopadhyay, an Electrical Engineer (BE) with an MA in Economics and a PG Diploma in Urban Development and Planning, has accumulated 35 years of extensive experience in state government electricity utilities. His professional journey began with the Madhya Pradesh Electricity Board in 1990, and he currently holds the position of Superintendent Engineer in Chhattisgarh State Power Generation Co. Ltd. His areas of expertise include operations, maintenance, IT implementation, coal handling, project planning, plant commissioning, and policy formulation. In his current role at Chhattisgarh State Power Generation Co. Ltd., he actively engages in updating himself on the latest developments in electricity systems, showcasing his commitment to continuous learning. This dedication to staying updated in his field is a testament to his adaptability and professional growth.

### **DR. PAPRI MUKHOPADHYAY**

Dr. Papri Mukhopadhyay, with over fifteen years of teaching experience, holds a Ph.D. in English, along with an M.Phil. and an M.A. in English Literature. Her passion for literature, research, and academic publishing is evident in her extensive contributions to peer-reviewed journals and edited volumes. Her scholarly interests encompass postcolonial studies, gender studies. Her publications explore the social and environmental impacts of large-scale infrastructure projects, bringing a critical humanities perspective to the technical and economic history of India's electrification. She is currently serving as Assistant Professor of English at Kalinga University, Raipur, Chhattisgarh, India.

## LIST OF FIGURES

**Fig. 2-1:** Public vs. Private Share in Electricity Generation, circa 1940s.

**Fig. 2-2:** A stark bar chart would show the near-total absence of electricity access in rural India circa 1950.

**Fig. 2-3:** Rural Electrification Comparison (Circa 1950)

**Fig. 4-1:** India's Installed Electricity Capacity Growth (1935-1945)

**Fig. 4-2:** The sectoral distribution of electricity sales in Bombay and Calcutta in 1947.

**Fig. 5-1:** This figure illustrates how ownership of generation shifted during this era.

**Fig. 5-2:** This figure vividly illustrates the post-Independence transition from a predominantly private power supply to one dominated by public entities.

**Fig. 5-3:** Traces of the changing mix of generation sources during the planning era.

**Fig. 11-1:** State tariff subsidy to electricity consumers (booked by DISCOMs), FY2014–FY2024.

**Fig. 14-1:** Decline of Oil-Based Power Capacity in India.

## LIST OF TABLES

**Table 2-1:** This table illustrates that while India's electricity demand did grow, its growth rate consistently lagged global trends in every period.

**Table 2-2:** This table summarizes the core policy and institutional reasons for India's lag.

**Table 2-3:** This table provides a clear, concise comparison of the war's divergent effects.

**Table 2-4:** Rural Electrification Data (~1950).

**Table 2-5:** Electric Grid Benchmarks (1950).

**Table 2-6:** Key Electrification Metrics, c.1950 (India vs. U.S.).

**Table 2-7:** Key Electrification Indicators, circa 1950.

**Table 3-1: Electricity Tariffs vs Average Daily Wages in India (1930s)**

**Table 5-1:** Period and Key Development in Ownership.

**Table 5-2:** Summary of power sector-related outcomes of each Five-Year Plan from 1951 to 2017.

**Table 5-3:** Key Electricity Sector Metrics for 1951, 1986, and 2017

## LIST OF ABBREVIATIONS

- **AC:** Alternating Current
- **ACS:** Average Cost of Supply
- **ADB:** Asian Development Bank
- **ADNOC:** Abu Dhabi National Oil Company
- **AI:** Artificial Intelligence
- **AIADMK:** All India Anna Dravida Munnetra Kazhagam
- **AIIB:** Asian Infrastructure Investment Bank
- **APDRP:** Accelerated Power Development and Reform Programme
- **APTEL:** Appellate Tribunal for Electricity
- **ARR:** Average Revenue Realized
- **AT&C:** Aggregate Technical and Commercial
- **AUSC:** Advanced Ultra-Supercritical
- **BESS:** Battery Energy Storage Systems
- **BHEL:** Bharat Heavy Electricals Limited
- **BPL:** Below Poverty Line
- **BPO:** Business Process Outsourcing
- **BSEB:** Bihar State Electricity Board
- **BSES:** Bombay Suburban Electric Supply
- **CEA:** Central Electricity Authority
- **CEB:** Central Electricity Board
- **CERC:** Central Electricity Regulatory Commission
- **CESC:** Calcutta Electric Supply Corporation
- **Cfd:** Contracts for Difference
- **CGPL:** Coastal Gujarat Power Limited
- **CISF:** Central Industrial Security Force
- **COP:** Conference of the Parties
- **CPPIB:** Canada Pension Plan Investment Board
- **CRRSA:** Coronavirus Response and Relief Supplemental Appropriations
- **CSCs:** Common Service Centres
- **CSIRT-Power:** Computer Security Incident Response Team for the Power sector
- **CTPB:** Central Technical Power Board
- **DAM:** Day-Ahead Market

- **DBT:** Direct Benefit Transfer
- **DC:** Direct Current
- **DDUGJY:** Deen Dayal Upadhyaya Gram Jyoti Yojana
- **DERs:** Distributed Energy Resources
- **DERMS:** Distributed Energy Resource Management Systems
- **DFIs:** Development Finance Institutions
- **DGM:** Deputy General Manager
- **DISCOMs:** Distribution Companies
- **DMRC:** Delhi Metro Rail Corporation
- **DMK:** Dravida Munnetra Kazhagam
- **DPR:** Detailed Project Report
- **DRAP:** Distribution Reform Action Plan
- **DSM:** Demand-Side Management
- **DVC:** Damodar Valley Corporation
- **DVB:** Delhi Vidyt Board
- **EA:** Electricity Act
- **EBRD:** European Bank for Reconstruction and Development
- **EDF:** Électricité de France
- **EE:** Energy Efficiency
- **EMS:** Energy Management Systems
- **EPC:** Engineering, Procurement & Construction
- **EPPs:** Educator Preparation Programs
- **ERCOT:** Electric Reliability Council of Texas
- **ESG:** Environmental, Social, Governance
- **ESL:** English as a Second Language
- **ESSER:** Elementary and Secondary School Emergency Relief
- **EU ETS:** European Union Emissions Trading System
- **EV:** Electric Vehicle
- **EV30@30:** Electric Vehicle 30% by 2030
- **FACÉ:** Fonds d'Amortissement des Charges d'Électrification
- **FACTS:** Flexible AC Transmission Systems
- **FAME:** Faster Adoption and Manufacturing of Electric Vehicles
- **FDI:** Foreign Direct Investment
- **FERC:** Federal Energy Regulatory Commission
- **FY:** Fiscal Year
- **GAIL:** Gas Authority of India Limited
- **GDP:** Gross Domestic Product
- **GEC:** Green Energy Corridor
- **GGEF:** Green Growth Equity Fund

- **GIS:** Geographic Information System
- **GNA:** General Network Access
- **GOELRO:** State Commission for the Electrification of Russia
- **GSDP:** Gross State Domestic Product
- **GW:** Gigawatt
- **GWh:** Gigawatt-hour
- **HE(I)L:** Heavy Electricals (India) Ltd.
- **HPO:** Hydropower Purchase Obligation
- **HPX:** Hindustan Power Exchange
- **HVAC:** High-Voltage Alternating Current
- **HVDC:** High-Voltage Direct Current
- **HVDS:** High Voltage Distribution Systems
- **IEA:** International Energy Agency
- **IEEFA:** Institute for Energy Economics and Financial Analysis
- **IEX:** Indian Energy Exchange
- **IFC:** International Finance Corporation
- **IGFF:** India Green Finance Facility
- **IHA:** International Hydropower Association
- **IITs:** Indian Institutes of Technology
- **IMR:** Infant Mortality Rates
- **IOC:** Indian Oil Corporation
- **IoT:** Internet of Things
- **IPDS:** Integrated Power Development Scheme
- **IPP:** Independent Power Producer
- **IPT:** Incentivizing Pathways to Teaching
- **IREDA:** Indian Renewable Energy Development Agency
- **ISI:** Indian Standards Institution
- **ISO:** International Organization for Standardization
- **ISPRL:** Indian Strategic Petroleum Reserves Ltd.
- **ISTS:** Inter-State Transmission System
- **IT:** Information Technology
- **JETP:** Just Energy Transition Partnership
- **KUSUM:** Kisan Urja Suraksha evam Utthaan Mahabhiyan
- **kWh:** Kilowatt-hour
- **LC:** Letter of Credit
- **LED:** Light Emitting Diode
- **LiFE:** Lifestyle for Environment
- **LNG:** Liquefied Natural Gas
- **LPS:** Late Payment Surcharge

- **LT-LEDS:** Long-Term Low-Emission Development Strategy
- **LVRT:** Low-Voltage Ride Through
- **MAPS:** Madras Atomic Power Station
- **MBAS:** Market-Based Ancillary Services
- **MBED:** Market-Based Economic Dispatch
- **MIGA:** Multilateral Investment Guarantee Agency
- **MISO:** Midcontinent Independent System Operator
- **MMT:** Million Metric Tonnes
- **MNRE:** Ministry of New and Renewable Energy
- **MoEFCC:** Ministry of Environment, Forest and Climate Change
- **MoU:** Memorandum of Understanding
- **MSEB:** Maharashtra State Electricity Board
- **MW:** Megawatt
- **NAPCC:** National Action Plan on Climate Change
- **NASDAQ:** National Association of Securities Dealers Automated Quotations
- **NBFCs:** Non-Banking Financial Companies
- **NDC:** Nationally Determined Contribution
- **NEM:** National Electricity Market
- **NEPF:** Nevada Educator Performance Framework
- **NHPC:** National Hydroelectric Power Corporation
- **NIIF:** National Investment and Infrastructure Fund
- **NIWE:** National Institute of Wind Energy
- **NOx:** Nitrogen Oxides
- **NPCIL:** Nuclear Power Corporation of India Ltd
- **NTAS:** Nevada Teacher Advancement Scholarship
- **NTPC:** National Thermal Power Corporation
- **O&M:** Operations and Maintenance
- **OAPEC:** Organization of Arab Petroleum Exporting Countries
- **OECD:** Organisation for Economic Co-operation and Development
- **OEEC:** Organisation of European Economic Co-operation
- **OERC:** Orissa Electricity Regulatory Commission
- **ONGC:** Oil and Natural Gas Commission
- **OSOWOG:** One Sun, One World, One Grid
- **OT:** Operational Technology
- **OTPP:** Ontario Teachers' Pension Plan
- **PAT:** Perform, Achieve & Trade
- **PFC:** Power Finance Corporation
- **PHCs:** Primary Health Centres

- **PHWR:** Pressurized Heavy Water Reactor
- **PJM:** PJM Interconnection
- **PLI:** Production Linked Incentive
- **PM-JANMAN:** PM Janjatiya Anusandhan Avum Nyaya Mahaabhiyan
- **PM-KUSUM:** Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
- **PMU:** Phasor Measurement Unit
- **PPA:** Power Purchase Agreement
- **PPP:** Public-Private Partnership
- **PRGs:** Partial Risk Guarantees
- **PSBs:** Public-Sector Banks
- **PSH:** Pumped Storage Hydropower
- **PSL:** Priority Sector Lending
- **PSP:** Pumped Storage Project
- **PSU:** Public Sector Undertaking
- **PTC:** Power Trading Corporation
- **PV:** Photovoltaics
- **PXIL:** Power Exchange India Ltd
- **R&D:** Research and Development
- **RAPDRP:** Restructured-APDRP
- **RAPS:** Rajasthan Atomic Power Station
- **RBI:** Reserve Bank of India
- **RDSS:** Revamped Distribution Sector Scheme
- **REA:** Rural Electrification Administration
- **REC:** Rural Electrification Corporation
- **REIPPPP:** Renewable Energy Independent Power Producer Procurement Programme
- **REIT:** Real Estate Investment Trust
- **REMC:** Renewable Energy Management Centre
- **RGVY:** Rajiv Gandhi Grameen Vidyutikaran Yojana
- **RMI:** Rocky Mountain Institute
- **RoW:** Right-of-Way
- **RPO:** Renewable Purchase Obligation
- **RTM:** Real-Time Market
- **RTOS:** Regional Transmission Organizations
- **SAIDI:** System Average Interruption Duration Index
- **SAIFI:** System Average Interruption Frequency Index
- **SAPCC:** State Action Plan on Climate Change
- **SCADA:** Supervisory Control and Data Acquisition

- **SEB:** State Electricity Board
- **SEBI:** Securities and Exchange Board of India
- **SECC:** Socio-Economic Caste Census
- **SECI:** Solar Energy Corporation of India
- **SERC:** State Electricity Regulatory Commission
- **SHGs:** Self-Help Groups <sup>1</sup>
- **SHIP:** Strategic Hydrogen Innovation Partnership
- **SOCs:** Security Operations Centres
- **SPR:** Strategic Petroleum Reserves
- **STG:** Steam-Turbine-Generator
- **T&D:** Transmission and Distribution
- **TDS:** Tax Deducted at Source
- **THDC:** Tehri Hydro Development Corporation
- **TNS:** Teach Nevada Scholarship
- **ToD:** Time-of-Day
- **ToU:** Time-of-Use
- **TPA:** Tripartite Agreement
- **TVA:** Tennessee Valley Authority
- **TWh:** Terawatt-hour
- **UDAY:** Ujwal DISCOM Assurance Yojana
- **UHV:** Ultra-High Voltage
- **UHVAC:** Ultra-High Voltage Alternating Current
- **UJALA:** Unnat Jyoti by Affordable LEDs for All
- **UMPPs:** Ultra Mega Power Projects
- **UN:** United Nations
- **UNDP:** United Nations Development Programme
- **USD:** United States Dollar
- **USDA:** United States Department of Agriculture
- **USICEF:** U.S.–India Clean Energy Finance
- **USSR:** Union of Soviet Socialist Republics
- **UTs:** Union Territories
- **V2G:** Vehicle-to-Grid
- **VGf:** Viability Gap Funding
- **VPP:** Virtual Power Plant
- **VSC:** Voltage-Source Converter
- **WAMS:** Wide-Area Monitoring Systems
- **WWI:** World War I
- **WWII:** World War II

## PREFACE

India's goal of having a sustainable energy future is one of the most important things to happen in the 21st century. India is one of the world's greatest rising economies and the third-largest source of greenhouse gases. It has promised to cut its carbon emissions to zero by 2070. This ambitious pledge, made by Prime Minister Narendra Modi at the COP26 climate meeting in 2021, puts India in line with global efforts to slow climate change. However, India confronts the dual task of cutting emissions and pulling millions out of poverty. Not only is the country's route to "Net Zero" good for the environment, but it is also closely tied to India's development, energy security, and the health of its 1.4 billion people. This book is all about that journey, going into detail about the many things India has already done to deal with climate change and make its energy system more sustainable. In doing so, it brings to light the main projects, policy changes, new institutions, and structural problems that have shaped India's energy transformation so far.

India has made major changes to its power sector and pushed for clean energy over the past few decades. This shows a strong commitment to balancing economic progress with environmental responsibility. These efforts cover a wide range of areas, from ambitious plans to expand renewable energy and make it more efficient to major changes in how energy is governed. India has established one of the fastest-growing clean energy programs in the world. It has also added renewable capacity at the quickest rate of all major economies. The government has already reached a major goal of getting 40% of its installed electric generating capacity from sources other than fossil fuels. This goal was met far before the initial 2030 date set by the Paris Agreement. The National Solar Mission and other big projects have pushed the use of solar power to new heights, adding to the hundreds of gigawatts of renewable energy capacity we have presently. India's work on energy efficiency and access is just as impressive. For example, the UJALA program has given out hundreds of millions of high-efficiency LED bulbs across the country. This means that India will be the first country to use LEDs for all its lighting needs, which is expected to save over \$6 billion a year in energy costs. At the same time, coordinated efforts to bring power to rural areas have made it almost universally available. India had linked almost all its ~600,000 villages to the electrical grid by

2018. It connected almost 21 million homes that had never had power before. This was a huge social and infrastructure success that turned electricity from a luxury for a few into a basic service for everyone. These examples show that India's climate goals and development goals often go hand in hand. For instance, increasing access to clean energy and clean energy itself may both help each other.

India's search for sustainable energy has been supported by major changes to policies and institutions. The Electricity Act of 2003 and other major improvements to the power industry changed the structure of electricity markets and made it easier for private companies to invest. This set the stage for a more efficient and varied energy supply. India has also included climate issues in its national planning. For example, it created a National Action Plan on Climate Change with specific goals for solar energy, energy efficiency, sustainable habitat, and other areas. It also set ambitious Nationally Determined Contributions (NDCs) under the Paris Agreement. The government's Panchamrit strategy, which was announced in Glasgow, sets clear mid-term goals: by 2030, they want to install 500 GW of non-fossil capacity, meet 50% of electricity demand from renewables, cut projected carbon emissions by a billion tonnes, and cut the carbon intensity of the economy by 45%. All these goals are in service of the 2070 Net Zero vision. New institutions and coalitions have formed as new ways to govern to make these aims happen. India has been a leader in international alliances like the International Solar Alliance, which is a treaty-based group of solar-rich countries that started in 2015 to get people throughout the world to support solar energy. This shows India's commitment to being a leader in global climate action. The Bureau of Energy Efficiency, the Solar Energy Corporation of India, and state-level renewable agencies are examples of how the government is working to put clean energy policies into action in India. The country has also tried out new ways to make people more environmentally friendly, like trading renewable energy certificates and energy-saving certificates. India has been able to overcome long-standing problems with its infrastructure, such as power shortages and financial problems at electricity providers, as well as the technological problems of adding intermittent renewable power to the grid. There are still a lot of problems to solve, but the progress that has been made so far shows that policies can change and institutions can evolve to reach sustainable development.

It's crucial to know that India's path hasn't been easy or straight. Historical legacies and structural problems have sometimes made change happen more slowly, which has required constant work and creativity. India became

independent in 1947 and inherited a power grid that was small and unequal. By 1950, less than 3% of Indian villages had electricity, and per-capita electricity use in India was just 1% of what it was in industrialised countries. For the next few decades, addressing this huge disparity became a project to create the nation. India's tale of energy evolution is also a story of overcoming obstacles, such as bringing electricity to every part of the country and revamping institutions that were made for a different time. India's history indicates that dealing with climate change in a developing country is a tricky balancing act. The country must lower emissions by a lot while still pulling a large part of its population out of poverty. India's approach to finding this balance—through incremental and calibrated regulations, trial projects that grow into huge programs, and ongoing negotiation between developmental and environmental priorities—can teach other countries who are at similar crossroads a lot. This book tries to show how India is trying to find a low-carbon growth path without giving up energy security or equitable development by writing down important projects and their results.

**The Book's Scope and Structure:** This book is set up so that readers can get a big picture view of India's energy transition in the context of its Net Zero goals, as well as a more in-depth look at it. The chapters are set out to explore five main ideas:

The first few chapters look at how India's power sector has changed over time, starting with its colonial roots and ending with the present day. This historical overview shows how India's electricity system has changed over time, starting with the first electric utilities set up by the British, moving on to the push for industrialisation and rural electrification after independence, and finally to the era of renewable energy in the 21st century. Readers can learn about the legacy difficulties and breakthroughs that have impacted today's energy situation by looking at this path. The story shows how early policies and investments (or the lack of them) caused fundamental problems that India had to deal with later. This sets the framework for the current efforts to shift to cleaner energy.

**Detailed Case Studies:** This book has in-depth case studies that show important events and lessons in India's energy journey. These case studies look at certain projects, initiatives, or time periods in more detail. For example, they look at the rapid growth of the national grid, major renewable energy projects like big solar parks, new ways to bring electricity to rural areas, or important policy experiments like the deregulation of the power market. These sections make the problems that people faced on the ground

come to life by presenting real-world instances and showing how they were solved (or in some cases, why they didn't work). The case studies give us a more detailed picture of what it looks like to put big plans into action, looking at the reasons for both triumphs and failures. They also help to make the bigger trends more personal by focussing on localised experiences or institutional case histories that are full of useful information.

**Sector-Wise Policy Analysis:** A big part of the book is about looking at energy and climate policies by sector. Different chapters look at important areas like transportation, power generation, industry, and buildings to see how legislative changes have helped each one move towards a lower-carbon path. This includes looking at changes to the power sector and policies for renewable energy in the electricity sector, the push for electric vehicles and cleaner fuels in transportation, requirements for energy efficiency and emissions in industry, and planning and building cities in a way that is good for the environment in the buildings sector. By breaking the shift down into several areas, the book shows how complicated India's climate action is, since each sector has its own problems and chances. Readers will learn about how rules, economic incentives, and technology options have changed in each area, as well as how these sectoral efforts work together to help India reach its climate goals.

**Changes and New Ideas in Institutions:** Another main topic is how India's energy transition has been supported by changes in institutions and governance systems. The book talks about how government agencies, public-sector companies, and regulatory bodies have changed over time. It starts with the creation of central electricity authorities and state electricity boards in the middle of the 20th century. It then goes on to talk about the establishment of independent regulators and energy ministries, and finally, the more recent creation of specialised agencies and missions to focus on renewables and efficiency. It also looks at new ways of doing things in institutions, like public-private partnerships in infrastructure, international partnerships (like India's engagement in global climate conferences and alliances like the International Solar Alliance), and community-level projects for decentralised renewable energy. It's important to understand these institutional aspects since they often decide how well policies are put into action. These chapters look at how better institutional capacity and coordination have helped (or sometimes hurt) the rollout of new technologies and programs. They also talk about ongoing governance issues, like the need for stronger enforcement of environmental rules or the financial stability of power distribution companies.

**Technology Progress and Future Outlook:** Finally, the book looks at the technology progress that is making India's clean energy future possible and what the future holds on the way to Net Zero. This includes the growth of renewable energy technologies (such solar and wind), the electric grid, and energy storage options, as well as the development of nuclear and bioenergy. It also includes the potential of future technologies like green hydrogen and carbon capture. The conversation shows how indigenous innovation and technology adoption have made things cheaper and more reliable. For instance, solar power costs have dropped dramatically, battery storage breakthroughs have made it easier to integrate solar power into the grid, and India's skills are growing in areas like electric vehicles and advanced biofuels. The book uses a map of the technology trajectory to show which new technologies are likely to transform the game in the next few decades and what gaps still exist. This research looks ahead and ties to policy and institutional preparation. It asks issues like, "How will India handle the change in sectors that are hard to change?" What are the most important research and development goals for reaching deep decarbonisation? The latter chapters give a strategic view on how India may get beyond the last obstacles on the way to its 2070 Net Zero target. They stress the connections between technology, politics, and society in creating a sustainable energy future.

The book gives a full look at India's energy transformation journey by using a structured approach that goes from the history to the present to the future and from broad overviews to targeted studies. Each section builds on the ones before it to give a complete picture of how far India has come, how it got there, and what is next. Readers will discover that the mix of historical narrative, empirical case studies, and thematic policy analysis gives both depth and breadth. This is perfect for an academic or policy-oriented audience that wants to comprehend the subtleties of India's response to energy and climate concerns.

**For Development That is Fair and Lasting:** A fundamental idea that runs through the full study in the following chapters is national development and policy relevance. India's efforts to reach Net Zero are not happening in a vacuum; they are an important aspect of India's continuous growth story. Making sure that everyone has access to energy and that it is safe has been key to raising living standards and creating jobs for millions of Indians. As the country works to balance these development goals with climate responsibility, the idea of energy justice comes to the forefront. This book stresses that becoming sustainable isn't only about putting up solar panels or wind turbines. It's also about making sure that everyone in society

benefits from the switch to clean energy and that no community is left in the dark. The conversation focusses a lot on issues of affordability, inclusivity, and a fair transition. This is because the move to a low-carbon economy must also support the ideas of social justice. India's leaders have increasingly seen access to clean, reliable energy as a key part of fair progress. This is shown by programs that prioritise electrification and subsidised clean cooking fuel for rural and underprivileged areas. The story here shows again why this strategy is so important: in India, sustainable development requires that climate action be combined with efforts to reduce poverty and empower the economy.

This book wants to encourage educated discussion about the choices and trade-offs that lie ahead by giving a well-researched description of India's energy and climate initiatives. The tone is intentionally serious and professional throughout, encouraging readers—scholars, students, practitioners, and curious citizens alike—to think about the facts and ideas the writers have gathered. The stakes couldn't be higher: how India makes the switch to clean energy will have huge effects not only on its own people, but also on the fight against climate change around the world. India's achievement in creating a sustainable, low-carbon growth model can serve as an example for other developing countries who want to do the same thing. India is one of the largest and fastest-growing economies in the world. On the other hand, the problems India must deal with, like finding money for green infrastructure and retraining workers for new industries, show how hard it is to change energy systems on a large scale. A nuanced understanding of India's experience is a useful tool for policymakers and stakeholders around the world.

In conclusion, the main goal of this book is to show how India has responded to the energy transition challenge in all its complexity and depth. It does this by applauding the progress made, honestly looking at the challenges faced, and drawing lessons for the future. It is both a record of what has been done so far and a look at what still needs to be done. If you read this introduction and the chapters that come after it, you should understand that India's push towards Net Zero is more than just a change in energy sources; it represents a huge change in the economy and society. It represents a vision of development in which growth is not linked to carbon emissions and sustainable development and energy equity go hand in hand. The goal of this book is to help start a deeper conversation about how India can keep powering its future in a way that is sustainable, open to everyone, and in line with the global effort to safeguard the planet for future generations.

Now that we've set the stage, we welcome readers to read the next chapters, which tell the story of how India is moving from its colonial past to Net Zero and what this journey implies for the country and the world. This work may help people understand and think more about how to make the future greener and fairer for everyone by using informed analysis and evidence.



# CHAPTER 1

## COLONIAL ELECTRIFICATION: THE BIRTH OF INDIA'S POWER SYSTEM

### 1.1 Introduction

Electrification emerged in the late 19th century as both a technological marvel and a broad social project, reshaping industry, transportation, and daily life across the industrializing world. From the first central power stations built almost simultaneously in New York and London in 1882, electricity networks grew exponentially over the next several decades.<sup>1</sup> By 1950, an incipient global grid was in place, supplying roughly 140 GW of generating capacity and 800 TWh of electricity per year – an increase of more than two orders of magnitude in just half a century.<sup>2</sup> This growth, however, was far from uniform. Early leaders such as the United States, Britain, and Germany electrified rapidly with coal-fired steam power and large hydropower projects, while later developers like the Soviet Union and Canada leveraged state planning and abundant resources to catch up after 1920.<sup>3</sup> Crucially, electrification became tied to national development ambitions: governments and firms alike saw electric power as essential for industrial growth, urban modernization, and even geopolitical strength.<sup>4</sup> By the mid-20th century, many industrialized countries had built continent-

---

<sup>1</sup> Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 18-45. Hughes details the launch of the Pearl Street Station in New York and the Holborn Viaduct station in London.

<sup>2</sup> Vaclav Smil, *Energy in World History* (Boulder, CO: Westview Press, 1994), 178. Smil provides figures on the growth of global electricity generation.

<sup>3</sup> Hughes, *Networks of Power*, 227-285, 365-404. Hughes contrasts the development models in Germany, the US, and Britain. For the state-led model, see also David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990), which discusses government involvement in projects like the Tennessee Valley Authority.

<sup>4</sup> Nye, *Electrifying America*, 287-348. Nye explores how electricity became intertwined with ideas of progress, modernity, and national identity.

spanning grids and begun to view universal electric service as a public good. Yet vast portions of the world – including most of colonial Asia and Africa – remained barely touched by this electric revolution.

Against this backdrop, this chapter charts the **global chronology of electrification up to 1950**, highlighting pivotal technological breakthroughs, infrastructure buildouts, and policy shifts that enabled electricity's spread. It contrasts divergent national pathways – from state-driven programs in some countries to laissez-faire, profit-led models in others – and quantifies the uneven progress of early electrification.<sup>5</sup> In doing so, it distils the lessons of the pre-1950 era (e.g. the benefits of technical standardization, public-private collaboration, and treating electrification as nation-building) as a historical baseline.<sup>6</sup> These themes set the stage for the post-World War II expansion and for contemporary debates on energy access and transitions. Importantly, the chapter also frames **India's colonial electrification experience** within this global context. By 1950, countries like the U.S. and U.K. had made electricity an everyday utility for most citizens, whereas India's per-capita electricity use was **minuscule** – barely 1% of the U.S. level – and only a tiny fraction of its villages had any power supply.<sup>7</sup> Understanding how and why India was left behind in the early electric era is crucial for appreciating the challenges and choices that defined its post-independence power sector trajectory.

---

<sup>5</sup> Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983). Hughes's work is the foundational text for comparing these divergent pathways, contrasting the fragmented, market-driven system of London with the more integrated, technically driven systems in Berlin and Chicago.

<sup>6</sup> David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990). Nye extensively analyses how electrification in the U.S. was framed as a project of national modernization and social progress, particularly through large-scale federal projects like the Tennessee Valley Authority.

<sup>7</sup> B. R. Tomlinson, *The Economy of Modern India, 1860-1970* (Cambridge: Cambridge University Press, 1993), 96-98, 151. Tomlinson discusses the severely limited nature of industrial and infrastructural development in colonial India. While exact figures vary, sources confirm the scale of the disparity: India's per capita consumption in 1950 was approximately 14 kWh, compared to over 2,000 kWh in the U.S. Furthermore, official government data indicates that only about 3,000 of India's 560,000 villages were electrified by 1951.

## 1.2 Early Innovations and the Rise of Electric Power (1880s–1910s)

The roots of electrification lie in 19th-century scientific discoveries that made electricity a practical source of light and power. A series of breakthroughs – **Alessandro Volta’s battery (1800)** providing a steady current, **Michael Faraday’s electromagnetic induction (1831)** showing how to generate electricity mechanically, and **Humphry Davy’s arc lamp (1808)** demonstrating electric lighting – paved the way for later inventions.<sup>8</sup> By the 1870s, electricity was ready to leave the laboratory. Lighting was the first killer application: arc lamps, which produce a brilliant light between carbon electrodes, were used in the 1870s to illuminate streets and public squares in cities from Paris to New York. However, arc lamps were too bright and high maintenance for homes. The solution came with the **incandescent light bulb**, invented independently by Britain’s *Joseph Swan* and America’s *Thomas Edison* in 1878–79. Edison’s bulb, coupled with his vision of an integrated generation and distribution system, led to the opening of **Pearl Street Station in New York City in 1882**, the world’s first central electric power plant. This coal-fired station delivered direct-current (DC) electricity through underground cables to dozens of customers, proving that a citywide electric lighting utility was feasible. Almost simultaneously, London’s Holborn Viaduct station began service in 1882, and within a few years many major cities had small central stations powering streetlights, theatres, and wealthy homes.<sup>9</sup>

These early systems were **rudimentary and localized** – they generated only a few hundred kilowatts and could serve just a compact urban area. Two innovations around the turn of the 20th century broke those limitations. First was the introduction of **alternating current (AC)** for power transmission. In the late 1880s, inventors like *Nikola Tesla* and entrepreneurs like *George Westinghouse* championed AC systems that could use transformers to boost voltage for long-distance transmission and then step it down for safe indoor use. This resolved the distance and efficiency problems of Edison’s low-

---

<sup>8</sup> W. Bernard Carlson, *Tesla: Inventor of the Electrical Age* (Princeton, NJ: Princeton University Press, 2013), 15-25. Carlson provides a concise overview of the foundational scientific work by Volta, Faraday, Davy, and others that preceded the age of commercial electricity.

<sup>9</sup> Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 18-46. This section of Hughes's work provides the definitive account of Edison's system-based approach and the establishment of the Pearl Street and Holborn Viaduct stations.

voltage DC networks.<sup>10</sup> By 1895, the huge generators at **Niagara Falls**, harnessed by Tesla and Westinghouse, were transmitting AC power over 20 miles to Buffalo – a dramatic validation of the AC paradigm. High-voltage lines quickly spread by 1900, transmission lines of 20–50 kV were connecting remote hydropower plants to cities.<sup>11</sup> The second innovation was simply **scale**. Generators grew from the kilowatt scale to the multi-megawatt scale in just two decades. For example, the Niagara Falls plant's initial units (1895) were 5,000 HP each (~3.7 MW), an unprecedented size at the time. By the 1910s, large steam turbogenerators and hydro turbines allowed utilities to serve entire cities and regions from centralized stations.<sup>12</sup> These technical advances meant electricity was no longer a curiosity – it was becoming a backbone of modern infrastructure.

With technology maturing, **investment and institutions** began to catch up. The earliest electric utilities were typically private entrepreneurs or local companies, operating under minimal regulation. Cities like New York, London, and Paris saw fierce competition in the 1880s as multiple firms set up power stations and ran tangles of wires, much like the early days of telephones. This chaos led to the first attempts at oversight. In Britain, for instance, the *Electric Lighting Act of 1882* required that any electric supply company obtain permission from local authorities, implicitly recognizing that electricity was a public-service concern.<sup>13</sup> Over the 1890s, many cities transitioned from competing private lighting companies to **municipal ownership or franchises** to impose order and ensure wider access. In the United States, city governments also began granting exclusive franchises to

---

<sup>10</sup> Hughes, *Networks of Power*, 87-139. Hughes masterfully details the "war of the systems" (AC vs. DC), outlining the technical advantages of AC for transmission and the roles of Tesla and Westinghouse in its promotion.

<sup>11</sup> David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990), 123-134. Nye describes the Niagara Falls project as a symbol of the new era of large-scale, long-distance AC power.

<sup>12</sup> Vaclav Smil, *Creating the Twentieth Century: Technical Innovations of 1867-1914 and Their Lasting Impact* (New York: Oxford University Press, 2005), 65-72. Smil documents the rapid and massive increase in the scale of prime movers, particularly steam turbines and hydro turbines, which made large central power stations possible.

<sup>13</sup> Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 227-235. Hughes describes the initial "chaotic" phase of competition and discusses the significance of the 1882 Act in establishing a framework for public oversight in Britain.

utility companies in exchange for service obligations.<sup>14</sup> Meanwhile, countries rich in hydropower, such as **Canada** and parts of **Scandinavia**, saw early moves toward public development of electricity. In Canada, the province of Ontario created a publicly owned utility (Ontario Hydro in 1906) to develop cheap hydroelectric power for cities and farms.<sup>15</sup> By the 1910s, the basic institutional models that would dominate much of the 20th century were set: a mix of **private utilities (often regulated by the state)** and **publicly owned utilities**, each expanding generation and networks to meet the exploding demand for electric light and power.

By the eve of World War, I (1914), electrification had taken root in all industrialized countries, though its **extent varied widely**. The United States was already the world leader – its installed capacity had grown to roughly several thousand megawatts, and electric lights and tramways were common in its cities.<sup>16</sup> Much of Europe was not far behind: by 1913, for example, **Russia** had about 1,000 MW of capacity installed (mostly in Moscow, St. Petersburg, and a few industrial areas), which was lagging Germany or the U.S., but still a significant base.<sup>17</sup> In **Japan**, urban electrification began in the 1890s (Tokyo's first power company launched in 1887), and by the 1910s Japan too had a nascent grid cantered on cities and industrial corridors.<sup>18</sup> In contrast, **colonial India** at this time had only scattered beginnings of electric supply – the first utility in India opened in 1897 in Calcutta, followed by others in Bombay and Madras in the early 1900s. These were isolated systems serving Europeans, businesses, and a handful of well-to-do consumers. No more than a few tens of megawatts were in

---

<sup>14</sup> David E. Nye, *Electrifying America: Social Meanings of a New Technology, 1880-1940* (Cambridge, MA: MIT Press, 1990), 185-224. Nye discusses the rise of the regulated monopoly model in the U.S., where cities granted franchises to private utilities.

<sup>15</sup> H. V. Nelles, *The Politics of Development: Forests, Mines, and Hydro-Electric Power in Ontario, 1849-1941* (Montreal: McGill-Queen's University Press, 1974), 215-308. Nelles provides the authoritative account of the political movement that led to the creation of the publicly owned Ontario Hydro.

<sup>16</sup> Nye, *Electrifying America*, 141. Nye states that by 1912, the U.S. had an installed capacity of 5,200 MW, far exceeding other nations.

<sup>17</sup> Jonathan Coopersmith, *The Electrification of Russia, 1880-1926* (Ithaca, NY: Cornell University Press, 1992), 48-51. Coopersmith provides detailed statistics on the state of Russian electrification before the revolution, noting its concentration in a few urban and industrial centres.

<sup>18</sup> Richard J. Samuels, *The Business of the Japanese State: Energy Markets in Comparative and Historical Perspective* (Ithaca, NY: Cornell University Press, 1987), 60-65. Samuels outlines the beginnings of Japan's electric power industry, noting the establishment of the Tokyo Electric Light Company in 1887.

operation across all of India prior to WWI, highlighting a gap that would only widen in the coming decades.<sup>19</sup>

### 1.3 The Interwar Electrification Drive and State Intervention (1920s–1930s)

The period between the two World Wars (1920s and 1930s) marked a decisive shift in electrification's **scale and governance**. In many countries, what had been a patchwork of small private or municipal providers evolved into more coordinated, often nationwide, systems during this time.<sup>20</sup> Several key trends defined this interwar electrification drive:

- **Formation of National Grids:** Governments and engineers increasingly pursued the integration of local networks into broader grids for reliability and efficiency. A landmark example was **Great Britain's National Grid**, built in the 1920s–1930s. The *Electricity (Supply) Act of 1926* created the Central Electricity Board, which oversaw constructing a 132 kV national transmission network linking the most efficient regional power stations.<sup>21</sup> Completed in 1933, this grid enabled power sharing across regions and reduced costs by using larger, centralized stations.<sup>22</sup> Other countries followed similar paths: **Germany** and **Italy** both expanded interconnections in the 1920s, and **Japan** grew two sizable regional grids (though with an east–west frequency divide).<sup>23</sup> Importantly, **no such integrated grid was developed in colonial India** – power networks there remained fragmented by province and princely state, with only local

---

<sup>19</sup> B. R. Tomlinson, *The New Cambridge History of India, III.3: The Economy of Modern India, 1860-1970* (Cambridge: Cambridge University Press, 1993), 97. Tomlinson notes the extremely limited scope of electrification in colonial India, describing it as "an urban and industrial phenomenon" that had "hardly touched the countryside." Official reports from the period confirm that total installed capacity was less than 100 MW before 1920.

<sup>20</sup> Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 1-13.

<sup>21</sup> Leslie Hannah, *Electricity Before Nationalisation: A Study of the Development of the Electricity Supply Industry in Britain to 1948* (London: Macmillan, 1979), 88-125.

<sup>22</sup> Hughes, *Networks of Power*, 365-368.

<sup>23</sup> On Germany, see Hughes, *Networks of Power*, 319-361. For Japan, see Ryoshin Minami, *The Economic Development of Japan: A Quantitative Study* (London: Palgrave Macmillan, 1986), 134-137.