Green Energy and Technology

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# Sustainable Energy Technology and Policies

## A Transformational Journey, Volume 1

Springer

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# Foreword

The 2017 Energy Conclave of the Bengal Chamber of Commerce and Industry focused on the "Transforming Face of Energy", and the discussions at the Conclave, including the papers in the two volumes, address various aspects (technological, financial, policy, and institutional) of the paradoxes associated with high greenhouse gas emissions cohabiting with development goals. This leads to many debates, including that of the comparative economics of renewable energy from new installations and of coal-based power generation from existing plants. It also tells us that this is a longer-term transition, with many challenges along the way and with public policy priorities that also change over time. During the past couple of years, climate change has risen to the top of public policy concerns, which have traditionally included energy security, energy access, business competitiveness, and air quality.

## Low Carbon Energy Growth is Steadily Increasing in India

In 2015, on Gandhi Jayanti, India submitted its Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). We pledged that in the energy sector, at least 40% of our electricity generation capacity would not be based on fossil fuels (and on renewables, hydro, and nuclear) and that the carbon intensity of our economy (i.e., total greenhouse gas emissions divided by the GDP) would be 33–35% less in 2030 as compared to 2005.[1] For the sake of comparison, in 2015, ~30% of electricity generation capacity did not depend on fossil fuels and our carbon intensity was 13% less than the level prevailing in 2005.

[1] India's Intended Nationally Determined Contributions http://www4.unfccc.int/submissions/INDC/Published%20Documents/India/1/INDIA%20INDC%20TO%20UNFCCC.pdf

If we draw a straight line from 2005 to 2014 and onto 2030, it seems that we are on target to meet these goals. The recent success in the growth of renewables and of energy efficiency, largely driven by business models which have also led to sharp decline in the price of energy-efficient and renewable energy products (such as LED bulbs and the solar photovoltaic modules), also suggests a similar trend. Yet, at the same time, coal-based power-generating stations in India are operating at historically low plant load factors and are able to sell, on an average, no more than two-thirds of the electricity that they are designed to produce. And, it is also true that while the cost of electricity from solar photovoltaic is now less than that from coal power stations, it is available only when the sun shines—whereas nowadays the demand for electricity in summer months in cities like Delhi occurs at midnight, when all households who have air conditioners switch them on as they go to sleep.

These trends present competing visions. On the one hand, solar energy is becoming cheaper and the demand for energy is rising more slowly than in the past. On the other hand, our existing fleet of coal power stations is thirsting to sell more electricity in order to be able to pay back the loans that they have taken from our banking systems, and a large amount of our energy use occurs at times of the day when solar energy cannot meet that demand.

## The Transformation is Turbulent … and is not Inevitable

This suggests that the Indian electricity sector is presently going through a major transformation. The accelerated pace of generation capacity added over the past few years has led to a situation where the electricity supply potential is greater than the economic demand, a scenario which has never before existed in the history of the Indian electricity sector. At the same time, we have also been witnessing changes in the energy mix due to enhanced policy focus on climate change, energy security concerns, etc., due to which the penetration of renewable electricity, especially from wind and solar energy, has been increasing steadily and is projected to grow much faster in the coming years. The demand for electricity is increasing, primarily due to increased space conditioning loads, but the growth in demand is slower than expected, in part due to the adoption of energy efficiency (EE) initiatives. As India's energy mix and demand patterns change, due to significant addition of RE in the grid and new EE measures, it is important that the policy and regulatory environment in the power sector rapidly adapts itself to the changing landscape so that new technologies, and more significantly new business models (in addition to the current business model of a distribution company supplying electricity to all consumers within its geographical jurisdiction, while sourcing electricity from power generation companies on the wires of electricity transmission companies), come into place which provide space for newer low carbon technologies, as well as newer ways for local electricity generation and the distribution and sales of this electricity to nearby neighbors and other consumers.

The Government of India's (GoI) resolve to combat climate change and de-carbonize India's energy systems is clearly spelled out in India's Nationally Determined Contributions (INDCs). To enable the goals, a range of policies and programs to promote RE is in place at the central and state levels in India, which suggests the possibility of an early initiation of de-carbonization of India's electricity sector. There is a high probability that if the costs of storage technologies continue to decline at the same rate as in the past ten years, then it is quite possible that, by 2025, all new electricity generation capacity that is added—and a lot of generating capacity still needs to be added to ensure that there is an adequate provision of energy services in the country so that all citizens have a high quality of life—comes from renewable energy, with storage providing the means to ensure that the electricity from the sun harnessed during the day by solar cells is available for use even when the sun does not shine.

In the interim (till storage costs become economically viable), a recent study carried out by the Power System Operation Corporation India (POSOSO), NREL, and LBNL has demonstrated that India's electricity grid can manage the variability and uncertainty of adding large amounts of renewable energy into the grid. The studies demonstrate that balancing the Indian power system in 2022 with 100 GW solar cell and 60 GW wind is achievable with minimal curtailment of renewable energy output.[2] However, economically viable electricity from solar cell and storage means that we will need to continue to expand the competitive procurement of solar electricity and, in addition, start the procurement of storage capacity as well. Only this will ensure that prices of electricity from renewables and storage keep declining —so that when new electricity generation capacity needs to be added (in about 2025), this will be competitive with the price of electricity from new coal-based generation capacity.

The tension in enhancing renewables at present, when the coal-based power sector is facing low utilization, was captured in the 16th Darbari Seth Memorial Lecture (http://www.teriin.org/themes/teriday/darbariseth2017.php) that Dr. Arvind Subramanian, the Chief Economic Adviser, delivered at TERI on August 17, 2017. His analyses suggested that the social cost of electricity from renewables is more than the social cost of electricity from coal and that the country could not both provide relief to the coal power plants operating at low plant load factors (and to the banks whose NPAs are increasing as a result) and subsidize renewable electricity. This suggests that the straight-line movement to 40% non-fossil fuel generation capacity in 2030 is not preordained. It also means that several ancillary goals will have to be achieved in order that we meet our INDC pledges.

All these changes are occurring while we, as a country, will have to make adequate and affordable energy, including electricity, available to all citizens. Current estimate suggests that more than 40 million households still do not have an electricity connection and that of those that are connected, more than half gets

[2] GREENING THE GRID: Pathways to Integrate 175 Gigawatts of Renewable Energy into India's Electric Grid, Vol. I—National Studyhttps://www.nrel.gov/docs/fy17osti/68530.pdf

electricity for less than some 16 h per day. The recently announced Saubhagya program[3] promises to ensure connectivity to all households by the end of 2018, but the challenge to provide 24x7 electricity supply to all of them will need new initiatives. We also note that the average electricity consumption in India is still only about 1075 kWh[4] per person per year—which is way below that needed for ensuring a good quality of life. And, there is no country in the world with a standard of living—with a Human Development Index (HDI) of 0.9 or more—with electricity consumption of at least 5000 kWh per person per year. Consequently, electricity demand growth is both inevitable and essential. At the same time, the ability of most of the newly connected electricity households to purchase electricity is limited; affordable and adequate electricity supply is a necessary prerequisite for development.

## The Next Steps

In view of the uncertainties associated with the transition, and the changing comparative economics of coal- and renewables-based electricity for the next decade or so, it is difficult to suggest next steps. What is clearer is that we will pass through at least three phases during this period during each of which a different set of strategies will need to be followed.

## To Add From Letter to Foundations (of August 2017) About the Three Phases of the Transformation

In the short term, the primary goal is to ensure that renewable electricity continues to have breathing space, while the coal plants are also able to survive. In the short and medium term, the bulk of electricity would continue to be provided from the coal-based power stations. This is both because the majority of our current electricity capacity is based on coal power and also goes on a full cost basis (which includes the need to provide electricity when the sun does not shine and wind does not blow).

Consequently, in the short term coal plants are able to survive the financial stress that they are currently undergoing. The TERI analyses, "Transitions in Indian

[3] Government of India notification for Pradhan Mantri Sahaj Bijli Har Ghar Yojanahttp://powermin.nic.in/sites/default/files/webform/notices/OM_SAUBHAGYA_SIGNED_COPY_0.pdf

[4] CEA executive summary, Page 11http://www.cea.nic.in/reports/monthly/executivesummary/2017/exe_summary-09.pdf

Electricity Sector 2017–2030[5]," showed that the coal-based capacity (the current capacity that is already installed and that which is currently under installation) would reach an average plant load factor of at least 60% by 2023, or so. This PLF level of utilization is significant since most plants would be able to operate profitably at this level of utilization. Beyond 2023, the PLFs would increase further and the coexistence of electricity from renewables and from coal would be easier.

However, electricity demand would continue to increase, and the existing coal capacity and the renewable capacity that is added would no longer be adequate to meet the demand somewhere around 2026 or 2027.

The comparative economics of coal and renewable electricity in the 2025–2027 time period is of crucial importance in meeting our pledges. If, at this time, the price of electricity from renewables, including the additional cost of setting up balancing capacity (to take care of the demand when the sun and wind are not available) is less than that from new coal capacity addition, then all new electricity generation capacity that is needed to be added from that time onward would be based on renewables and storage. In this scenario, we will not only need our pledge to ensure that at least 40% of our electricity generation capacity is on non-fossil fuel, but will exceed it. On the other hand, if electricity from coal continues to be less expensive, it would be difficult to sustain a future in which the larger additional costs of renewable energy are borne by the economy and paid for by recently electrified households. In such a case, the share of renewables would probably be similar to that which exists today and which seems to be the upper limit of what can be absorbed by the grid and by the economy.

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[5] Transitions in Indian Electricity Sector- A Report by TERIhttp://www.teriin.org/files/transition-report/files/downloads/Transitions-in-Indian-Electricity-Sector_Report.pdf

# Preface

With the growing concern for environmental degradation and specifically climate change problem, energy sector all over the world is facing the difficult challenge to meet the ever-increasing energy demand with minimum/no degrading effects on the environment in an economic way. Energy is a vital component for modern civilization, and often per capita consumption of energy is considered as the index of life standard of people of a country. Supplying energy for a decent living at an affordable price and in an environment-friendly way is the critical challenge.

Sustainability is the concept of meeting the present demand without compromising the needs of the future generation. Optimum planning of use of natural resources to meet the need of the present as well as future generations is very critical for sustainability. Solutions must be socially and environmentally acceptable as well as economically feasible. For a long period, fossil fuels were the main source of useful energy for rapid development of human civilization. Technologies for using these fuels have matured over a long period and are available at an affordable cost all over the world. However, limited remaining reserves of these fuels have forced energy technologists to explore alternative options. On top of that, climate change problem may force us to 'leave fossil fuels before they leave us.' Renewable resources are considered to be only future options of energy in a longer time frame as these are virtually inexhaustible. However, technologies for using different renewable resources are widely varying and most of them are still developing. Economic feasibility as well as social acceptance of these new options has to be checked thoroughly before they can emerge as reliable options for future. Intermittency of most of these resources is another problem. These are to be used when 'these are available rather than when we need these for our use.' Different ways of addressing this challenge are under active investigation, including suitable technology development for energy storage and 'hybridization' of different resources available locally. Thus, solutions may be site specific and no unique solution may be available for the whole world. Removing fossil fuels immediately may not be a feasible solution too as other options are neither capable to meet the huge demand nor their reliability is assured under all possible adverse situations. Also, a large capital is already 'locked' in fossil fuel-based technologies. A planned

smooth phasing out of these technologies is required with the development of alternative ones within a specified time frame. This needs proper energy policy with multilevel governance. Moreover, suitable change of existing fossil fuel-based technologies during this transition is critical, most specifically due to climate change problem. Energy sustainability is a global challenge, though many issues of it are site specific. Addressing energy sustainability is thus a global issue as well as local one—starting from a country even up to a small village of that country.

Sustainability of Indian energy sector needs thorough introspection. Presently, coal dominates with 54% of installed generation capacity and ~69% in terms of actual power generation. Also, most of these coal-based power plants are of conventional PF fired with low efficiency. Large transmission and distribution losses with minimum environmental regulation are other limitations of these plants. Hydropower has the next largest share (21% of total installed). Other renewable and nuclear power have steady growth but with some constraints—technological, social, economical, and even political. Transport sector is mostly dependent on imported oil with large uncertainty, economical as well as political. Traditional sources of energy also have a good share, though decreasing. To have a sustainable plan for the Indian energy sector, assessment of the present scenario and future planning based on this assessment is very urgent.

In two volumes of this book, experts from all over the world have addressed energy sustainability from different viewpoints in several articles. Specifically, Indian energy sustainability is also explored with a background of this global perspective.

In the introductory chapter, Sikdar has reported his perception about the different terminologies, say, clean, green, and sustainable energy. Solar photovoltaic technology is considered to be one of the most widely used renewable technologies worldwide as an alternative to fossil fuel-based electricity. Roy discussed this technology starting from the very basic fundamentals up to the most advanced research findings in this field. Integration of intermittent renewable electricity to the conventional grid is a real challenge. Microgrids are considered to be emerging solutions for utilizing different distributed intermittent renewable energies. N. K. Kishore et al. have presented an overview of the present status of microgrids. Transmission and distribution losses affect the overall energy efficiency. Lakshmi and Ganguly presented a state-of-the-art review of transition of power distribution systems. Distributed generation is emerging as a sustainable solution in place of large-scale fossil fuel-based energy systems. Iaria et al. have reported such a system using solar energy. Design of this system has been developed up to the full-scale implementation. Unexplored potential of distributed generation in India has been reported by Jana and De. Full utilization of this potential may make a paradigm shift of energy sustainability of India. Delivery of multiple utility with single or multiple inputs is called polygeneration. It increases the overall energy efficiency with optimal design. A mathematical optimization process using linear programming for such systems has been discussed by Tan and Aviso. Though increasing renewable share is always desired, fossil fuel-based electricity will continue to remain as the major source of electricity. Detoxification technology during

processing of crude oil has been reported by Jarullah et al. $CO_2$ capture is required to use fossil fuels in power plants in a longer time frame. Different technologies are being developed for this purpose. An overview of state of the art of this technology has been discussed by Maria et al. Prospects of use of algae specifically for this purpose have been discussed by Chowdhury et al. In spite of all challenges, coal plays a critical role in energy sustainability of India. This complex issue is addressed by Bhattacharyya, former chairman of the largest coal producing company of India. Finding new fuels and to use those in innovative ways also add to future energy sustainability. A chapter on use of gas hydrates has been contributed by Nair et al. Biofuel is undoubtedly one important option to substitute fossil fuels in future, specifically in transport sector. Several chapters discuss this important issue both from global perspectives as well as in Indian context. Two chapters by Verma and Kishore and other two by Chowdhury et al.; Yadav and Sen discussed different aspects of biofuels. Energy sustainability cannot be achieved without improving energy efficiency. Building energy efficiency is considered to be a very important issue for future energy sustainability. Two chapters by Azad and Rakshit; Saikia et al. discussed this important issue including Indian context. In the concluding chapter, possible energy efficiency measures in a milk plant of India have been discussed by Srinivasan et al.

Editors thankfully acknowledge the support of experts in different disciplines as both authors and reviewers. The book is the outcome of one of the collaborations (INCP-2014-10086) under the Indo-Norwegian Cooperation Program between the Jadavpur University, India, and the University of Stavanger, Norway. Both coordinators from India and Norway of this collaboration are two editors of this book. Support from industry is specifically acknowledged. The Bengal Chamber of Commerce and Industry (BCC&I), the oldest industry chamber of India, was very much supportive to this effort of joint activity by academia and industry. Chamber is also represented by its Vice President as one of the editors of this book. Department of Energy Science and Engineering of the Indian Institute of Technology (IIT), Bombay, is one of the pioneering groups of India for higher studies and research of interdisciplinary sustainable energy. A Chair Professor of this department is also another editor of this book.

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Mumbai, India — Santanu Bandyopadhyay
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# About the Editors

**Sudipta De** is currently a Professor at the Mechanical Engineering Department, Jadavpur University, Kolkata. He received his Ph.D. from IIT, Kharagpur, and was a guest researcher at the Department of Energy Sciences, Lund University, Sweden. He was an INSA (New Delhi) visiting scientist to Germany, selected faculty of Erasmus Mundus External Cooperation Window of the EU in sustainable energy. He delivered invited lectures in many programs/institutes including Indian National Clean Coal Technology Mission meeting, TU of Berlin and Munich, KTH, Stockholm, University of Stavanger, Norway, etc. He received his research funding from UGC, DST of India, EU, German Research Foundation, Swedish Research Council, Research Council, Norway, etc. Presently, he is the Coordinator/ Coinvestigator of two EU projects. He is also closely associated with industry chambers.

**Santanu Bandyopadhyay** is currently an Institute Chair Professor, Department of Energy Science and Engineering, at the Indian Institute of Technology Bombay (IIT Bombay). He obtained his B.Tech. (Hons.) in Energy Engineering from IIT Kharagpur in 1992 and M.Tech. and Ph.D. in Energy Systems Engineering from IIT Bombay in 1995 and 1999, respectively. His research interest includes process integration, pinch analysis, industrial energy conservation, modeling and simulation of energy systems, design and optimization of renewable energy systems, etc. Since 1994, he has been associated with and contributed toward various developmental, industrial, and research activities involving different structured approaches to process design, energy integration, and conservation as well as renewable energy systems design. Prior to joining IIT Bombay, he worked for M/s Engineers India Limited, New Delhi. He is currently one of the Editor in Chiefs for Process Integration and Optimization for Sustainability (Springer Nature) as well as Associate Editor for Clean Technologies and Environmental Policy (Springer Nature), International Journal of Energy Technology and Policy (Inderscience), and INAE Letters (Springer Nature).

**Mohsen Assadi** is a Professor at Faculty of Science and Technology, University of Stavanger (UiS), Norway, Head of energy efficiency group for clean energy network at UiS, Head of monitoring and maintenance hub at CIAM, UiS, Visiting Professor at Sheffield University and London City university. Developing methods and tools for identification of optimized instrumentation for cost-effective monitoring and control of various types of power plants has been one of the focus areas for the conducted R&D activities during the past years. He has been a project leader for several national- and European-funded projects, dealing with performance monitoring and concept evaluation for conventional combined cycle plants using industrial gas turbines from various OEMs; a hybrid plant using a combination of biomass-fueled steam cycle and natural gas-fired gas turbine with HRSG delivering steam to a common steam turbine; an innovative cycle utilizing the humid air turbine concept, small-scale combined heat and power (CHP) units using mixtures of various gas fuels; an integrated gasification combined cycle plant, etc.

**Deb A Mukherjee** is an entrepreneur, professionally qualified as a lawyer, with over 33 years of work experience in diverse business domains, engineering systems, information technology solutions, and later in energy services for the last 15 years. He was the Executive Chairman of Eaga Energy India Pvt Ltd (subsidiary of Eaga plc UK FTSE 250 company) until 2012. Currently, he is an Investor and Country Director for Big Solar Ltd UK and also Managing Director of Cenergist Ltd UK, India Operations, an energy services business with operations in the UK, Spain, Germany, Italy, and now in India. He is also incubating an IT start-up Teknowlegion Ltd in Kolkata, India. He has served on various trade committees in India and the UK and spoken at several international seminars on sustainability issues, energy efficiency, renewables, water management, and business strategies. Currently, he serves as the Vice President and Chairperson of the Energy and Environment Committee and is also the Member of the Managing Committee/Board of the Bengal Chamber of Commerce & Industry, Kolkata, India.