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Axes of Sustainable Development and Growth in India

Essays in Honour of Professor Jyoti K. Parikh

Edited by
Piyush Tiwari · Kirit Parikh

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ABOUT THIS BOOK

This is a collection of essays in honour of Professor Jyoti K. Parikh. Chapters in this book are written by her students and colleagues, prominent academics and practitioners who have had a professional connection with Professor Parikh during her long and distinguished career. The overarching themes running throughout the book are energy access and policy, climate change and sustainable development. All the essays are shaped by the role that Professor Parikh has played over the last 60 years in the academic and policy arena nationally and internationally.

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A Many Faceted History—Story of Professor Jyoti Parikh's life

Kirit Parikh

Dr. Jyoti Parikh, a multi-faceted personality, completed 80 years on March 20, 2021.

Professor Jyoti K. Parikh is the Executive Director of Integrated Research and Action for Development (IRADe), New Delhi. She was a **Member of the Prime Minister's Council on Climate Change—India and is a recipient of Nobel Peace Prize awarded to IPCC authors in 2007**. She was a Senior Professor at the Indira Gandhi Institute of Development Research (IGIDR), Mumbai. She also worked at the International Institute for Applied Systems Analysis (IIASA), Austria and served as a senior energy consultant at the Planning Commission, New Delhi (1978–1980). She was a Visiting Professor at the Institute of Advanced Studies (IAS) of UNU, Tokyo 1995–1996. She was the Acting Director of IGIDR from 1997 to 1998.

She founded IRADe as a non-profit non-governmental think tank in 2002 and as has nurtured it over the last 20 years. IRADe is regarded as a premier think tank in the country today with several high-profile projects and has 45 staff members and has a building of its own.

The wide diversity of her interests and talents was visible early.

- She stood first among 45,000 students in the SSCE examination of the Gujarat State and won 6 different prizes.
- Sangeet Visharad in Hindustani classical vocal music from the Gandharva Mahavidyalaya,
- Kovid in Hindi from the Rastrabhasha Prachaar Samiti,
- Bhushan in Sanskrit from Gujarat Sanskrit Parishad standing first in the state and
- She also learnt Bharat Natyam.

After getting her M.A. in physics from Berkeley, she followed her supervisor and obtained her Ph.D. in theoretical Nuclear Physics from the University of Maryland. She worked as a physicist for a number of years at TIFR and BARC and published several papers in prestigious international journals such as *Physical Review* and *Physics letters*. In 1976 she moved to IIASA and started her career in energy-related research. Over the last 45 years, she has covered practically every facet of energy and has published over 200 research publications and 25 books. Among these are **energy economics, climate change and modelling, energy technology assessment, rural energy, power sector, environment economics, natural resource management, gender in energy and climate change policy**. She was one of the first to emphasise the importance of **energy access** through a large integrated survey of 80,000 persons that quantified the health costs of indoor air pollution.

The significance of her achievements is reflected in the many honours she has received.

Honours, Awards and Recognition

- **Boutros Ghali Award** for 1995 instituted by the Japan Foundation for United Nations given at the United Nations University (UNU).
- Recipient of **Zayed Prize** convening lead author of Millennium Ecosystem Assessment Report 2006.
- **Special energy award** by IBPL Urja Research Foundation on the occasion of 50 years of independence of India (1998).
- Golden Jubilee for India's independence **award for energy efficiency**—1997.
- **Second prize IFORS** in "Operations Research for development" (1996).
- **Bhasin Award** for Energy and Environment—1995.
- **Gold Medal** from the Systems Society of India for energy and environment—1988.
- **Fellow, National Academy of Sciences.**
- Member of the **Scientific and Technical Advisory Panel (STAP)**—a small group of experts to advise World Bank, UNDP and UNEP to develop technical programmes for Global Environment Facility (GEF), 1996–1999.
- Member of **Global Agenda Council** for decarbonising energy system, World Economic Forum.
- Member Research Advisory Committee of the **Institute for Global Environmental Strategies (IGES)** Japan, 2002–2005, **Tyndall Center for Climate Change**, University of East Angela, UK, 2001–2004, Governing Board **North–South Institute Ottawa, Canada.**
- Convening Lead Author for the chapter on "Carbon Regulation for **Millennium Ecosystem Assessment**"—2002–2005.
- **Technical Advisory Committee (TAG)** for Energy Trust Funds Programmes of the **World Bank,** 2002–2004.
- International Steering Committee of **ENERGIA**, Network on Gender and Environment, Nederland, 2002–2004.
- Member of **the Advisory Panel on Biodiversity** for **Executive Director, UNEP**.

Many International Recognitions

- Review panels of World Bank of its ESMAP, ASTAE and AFREN programmes.

- Scientific and Technical Advisory Panel (STAP) of global environment facility (GEF).
- Member of the Review committee of National Environmental Research Council (NERC) of the UK.
- Research advisory committee of IGES, Japan.
- Board Member Tyndall Centre, UK and North–South Institute, Canada.
- Convening lead author for the Second Assessment of IPCC with Kenneth Arrow (1993–1995).
- Editorial boards of multiple energy journals.

Many National Recognitions

- Member of Prime Minister's Council on Climate Change.
- Fellow of the National Academy of Sciences.
- Member of many government committees.
- Board of Directors of National Institute of Urban Affairs (NIUA).
- Research advisory panel of NEERI.

Created Capacity for Multi-disciplinary Research and Analysis Integrating Energy, Environment and Economics Through

- Setting up and leading IGIDR's energy and environment group.
- Guiding 14 Ph.D. students.
- As Chairperson of EERC (Environmental Economics Research Committee) of EMCaB Project of the World Bank, 1997–2003 distributing US$ 1.5 million for 56 projects across India in Universities, NGO and Research Institutes and ensuring quality output.

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Dr. P. G. Babu is the Director of Madras Institute of Development Studies (MIDS) and is on leave from the Indira Gandhi Institute of Development Research (IGIDR), Mumbai. Since 2015, he is the Managing Editor of Journal of Quantitative Economics, Official Journal of The Indian Econometric Society (TIES) published by Springer Nature, and for two years prior to that he was Joint Managing Editor of the same journal. He is Editor-in-Chief of Review of Development and Change, a journal published by Sage since 2019.

Pankaj Batra did his B. Tech in Electrical Engineering, Diploma in Systems Management, Diploma in Financial Management and Diploma in Public Speaking. He is currently the Project Director, USAID's SARI/EI programme being implemented by IRADe, a reputed think tank in Asia, dealing in all aspects of promoting cross-border trading in energy in South Asia. He was earlier Chairperson and CEO of the Central Electricity Authority (CEA), Government of India, responsible for overall development of the Indian power system. He was also the Member (Planning) of CEA, dealing with various policy and planning functions in the power sector. He has worked in the Western Regional Load Despatch Centre as a System Operator. He was also responsible for operation and maintenance of Power House, Switchyard and Dam in Chukha Hydro Power Corporation in Bhutan and later for the transmission and distribution system of Bhutan. He has worked as Chief (Engineering) in Central Electricity Regulatory Commission, formulating various Regulations.

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Dr. Shikha Jha has published extensively in the fields of public sector and development economics. Most recently she was a principal economist at the Asian Development Bank in Manila where she managed and led economic research for the annual flagship publication Asian Development Outlook. Before that she led country teams in the Central and West Asia Departments to design country-partnership strategies for ADB in close coordination with the governments and development partners. Prior to this she was a professor at the Indira Gandhi Institute of Development Research in Mumbai, a long-term consultant to the World Bank in Washington D.C. and an economist at the National Institute of Public Finance and Policy in Delhi.

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She has a large number of research publications, which include research papers in peer-reviewed journals, books and policy reports.

Dr. Kirit Parikh is the Chairman, Integrated Research and Action for Development (IRADe), New Delhi and former Member, Planning Commission, Government of India. He is Former (Founder) Director (Vice Chancellor), Indira Gandhi Institute of Development Research (IGIDR), Mumbai—An Advanced Research Institute. He was honoured with Padma Bushan (third-highest Civilian Award) by the President of India in March 2009. And he has a Doctor of Science in Civil Engineering and a Master's Degree Economics from MIT, USA.

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CHAPTER 1

Introduction

Piyush Tiwari and Kirit Parikh

This is a collection of essays in honour of Professor Jyoti K. Parikh. Chapters in this book are written by prominent academics and practitioners who have had a professional connection with Professor Parikh during her long and distinguished career. The book engages with different dimensions of sustainable development and growth and presents a scholarly debate that is relevant to policy and research. The definition of sustainability has evolved considerably. An early definition of sustainable development was presented in the Brundtland Report in 1987, which defined sustainable development as the "development that meets the needs of the present generation without compromising the ability

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of future generations to meet their own needs". In 2015, the United Nations General Assembly adopted the sustainable development goals (SDGs) and explained how addressing global challenges such as poverty, inequality, climate change, justice and peace are integrated with sustainable development. There are a number of cross-cutting themes in the SDGs. These include gender equality, education, culture and health. Besides the focus on physical environment, clean technologies, production and consumption, the recent debate on sustainable development has brought the focus on the stock and quality of human capital as well. The overarching themes running throughout the book are energy access and policy, energy efficiency, climate change and sustainable development, quality of growth and human capital. All the essays are shaped by the role that Professor Parikh has played over the last 45 years in the academic and policy arena nationally and internationally. These essays explore problems and opportunities in different aspects of sustainable growth. Hence the title of this collection. The essays are grouped in different areas that reflect the axes of sustainable development and growth.

Part I of the book includes five chapters that deal with various aspects of energy transition and security.

Energy transition from fossil to renewable sources has become an important agenda for sustainable growth. However, Saumen Majumdar and Debabrata Chattopadhyay point out the need for a more balanced and market-oriented approach to energy transition. While the energy policy regime in India has been successful in amassing 77 GW of solar and wind in a short space of time, it has led to financial stress on the thermal sector and distribution companies/customers. Even then the policy target of 175 GW of renewable capacity may not be fully met by 2022. Arguing that the more ambitious target of 450 GW renewable by 2030 may call for at least half a trillion dollars in new investment, mostly in solar and wind projects, it will dry up investment in other forms of generation and distribution system upgrades. It will also almost inevitably deepen the crisis in the thermal sector and may potentially drive several state distribution companies to bankruptcy. It is important to objectively assess these issues and explore an alternative market-driven path to induce renewables on their merit and let coal and other thermal projects also exist. They suggest a balanced measure that promotes a broad mix of renewables including hydro but not at the expense of creating a financial disaster for the thermal sector. Also a market design to price storage is suggested.

Energy availability, choice and access cannot be examined in isolation. Probal Ghosh explores the energy, food and water nexus using a macroeconomic consistency framework. With economic growth and growing urbanisation and population, demand for energy and water would increase. Also as the pattern of consumer demand changes, more food and different products would be required. Thus water demand for agriculture, households, urbanisation and industry will increase. How could this be met given that climate change is likely to change the hydrological pattern and cause an increase in the variability of rainfall? After projecting water demands for various sectors, Ghosh uses IRADe's integrated assessment model to explore alternative technologies and policies. The model is an activity analysis optimisation framework with 25 commodities and services that define the economy and many alternative activities producing different goods. It differentiates twenty consumer expenditure classes whose demand systems have been empirically estimated. His results indicate that the water demand projected to be consistent with economic and demographic scenarios is higher than other projections. It also underlines the importance of water conservation policies of the Ministry of Water Resources and particularly the need for water conservation in the power sector.

A country may not have resources to achieve sustainable development on its own. Efficiencies in production and consumption of resources could be achieved through international trade. Pankaj Batra explores opportunities for greener future through regional cooperation in the energy sector. The South Asian counties of Bangladesh, Bhutan, India and Nepal have different power generation resources and some diversity in their peak demand. These provide an opportunity to gain mutually from power trade and cooperation in developing power systems. Till recently power supply in these countries was not universal, and had frequent interruptions and unstable voltage. With the growing exchange of power among these countries the situation has improved. Batra traces the growth of power exchange among them. Since renewable sources such as solar and wind power have to play a large role to contain greenhouse gas emissions and since they generate power intermittently, they need to have balancing power. Using coal plants to operate at varying loads reduces their life, increases maintenance costs and increases GHG emissions per unit of power generated. Thus hydropower is the best balancing power and power trade among South Asian countries with large hydro resources can lead to greener development.

Examining the role of international power trade, Rajiv Ratna Panda explores how a larger regional energy trade covering the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) countries (Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka and Thailand) can facilitate clean energy transition and sustainability. Though these countries have low per capita CO2 emissions and energy use, they have made commitments to measures to deal with climate change. Their ranking in the achievement of sustainable development goals is very poor. With the varying potential of energy resources in BIMSTEC countries significant scope exists for energy trade to facilitate energy transition. He emphasises the importance of improving cross-border physical transmission infrastructure development and required complementary regulatory, policy, pricing and market mechanisms.

Geopolitical risk is a major hindrance for international cooperation and causes uncertainty to energy security and path to sustainable development. Barnali Nag explores India's options to increase its energy security in the context of uncertainties of highly volatile world oil prices and geopolitical conflict between oil-exporting countries, and India's large dependence on import of oil and petroleum products. She focuses on understanding the nature of and changes in the world oil market and its relevance to India. She suggests actions in two critical dimensions to increase India's oil security. She suggests the deregulation of oil product prices to promote efficient use, competition in the retail market and to give adequate returns to public sector refiners. A domestic price above world prices can help build a more resilient economy in the long run that falters less during spikes in international oil prices and achieves energy security in the long run. She also suggests attracting FDI in oil exploration and the development of a futures market for oil. In the geopolitical areas, she suggests that China and India leverage their positions jointly as major oil-consuming giants in Asia and collaborate on building a central strategic oil reserve. Overall, for India, longer-term strategies to ensure energy security need to involve exploration and increased production and innovation and adoption of new technologies like fracking, improvement in efficiency and gradual shift towards renewables as alternate sources of energy.

Part II of the book discusses some mitigation measures for climate change.

Climate change mitigation also requires that renewable power must grow and it requires balancing power due to intermittent nature of renewable power. Vinod Kumar Agrawal and Mohnish Makwana examine the importance and potential of pumped hydro energy storage (PHES) systems for integration of India's ambitious target of renewable energy. The existing 161,000 megawatts (MW) of PHES accounts for over 94% of installed global energy storage capacity. It retains several advantages such as lifetime cost, levels of sustainability, scale of operation, power grid stability reducing overall system costs and sector emissions. They note that India has 4.8 GW of installed PHES capacity and a target of 10.6 GW. However, 2.6 GW of installed capacity is not in operation. The authors examine the financial implication of managing renewable generation in Tamil Nadu and Gujarat and arrive at the cost of it to be around Rs. 1.5 per kWh. PHES can be economical if there is a difference of around 33% in peak and off-peak power tariffs. They observe that closed-loop off-grid PHES systems are more efficient and economical and, due to the relatively lower degree of civil work involved, invite lesser opposition from the environmentalists.

Women empowerment through access to clean energy for household use and land ownership rights can have benefits that result in better household outcomes. Part III of the book includes two chapters that explore women empowerment through landownership and access to energy.

Gender equality is important to achieve sustainable outcomes. Women's land ownership and agency in household decisions improve child health and family welfare. Koustuv Saha, Vijay Laxmi Pandey and S. Mahendra Dev examine the role of land ownership in economic empowerment of women. In India, while 80% of farm work is undertaken by women, the women landownership is merely 16%. Ownership of land by a woman will improve their bargaining position within the household and increase her intra-household decision-making powers that subsequently can improve her own and her children's nutritional status. Their study demonstrates that for the empowerment of women, single ownership of land is necessary. The joint ownership of land is insufficient for women's autonomy and decision-making.

Access to clean cooking energy is vital for improving women's well-being and empowerment. Ashutosh Sharma and Chandrashekhar Singh examine the evidence from Chhattisgarh and Jharkhand to understand women's choice of cooking fuel, its changing pattern over time for different income classes and impact of Pradhan Mantri Ujjwala Yojana (PMUY). Continued use of biomass is related to the abundance of local availability. More than 75% of the households in rural areas in both Jharkhand and Chhattisgarh use fuelwood. While the number of households using LPG has increased and women recognize LPG use benefits through reduced cooking and utensils cleaning time, reduced drudgery and hardship associated with biomass collection and processing, the benefits of it are restricted as subsidy for refilling cylinders is not available.

Part IV of the book has a paper by Deepak Sharma and Haripriya G. that examines the efficiency of the Indian petroleum sector and proposes restructuring options for national oil companies. National oil companies have dominated petroleum sector in India, which are specialized companies. Internationally oil companies have become vertically integrated which allows them to withstand oil price volatility and operate efficiently. Sharma and Haripriya find that major oil companies such as ONGC are scale and technically inefficient. They propose that vertical integration as the best restructuring option to improve efficiency.

Part V of the book looks into the questions related to sustainable development in urban India. Cities are the drivers of socio-economic change and the current pattern of urbanization pose questions for urban sustainability. B. Sudhakara Reddy and P. Balachandra examine whether present patterns of urbanization in India in creating megacities are sustainable? Using index approach, they find that indian cities, Bangalore and Mumbai fare poorly compared to international cities such as London, Shanghai and Singapore on economic sustainability but are relatively better off on social and environmental sustainability. These indices are important tools for the identification of gaps in development and could assist policymakers in designing appropriate interventions that address the challenge of sustainable urban development.

Another emphasis to address climate change is through the development of green infrastructure. India has committed to reduce its emissions by 33–35% from 2005 levels by 2030. With a growing economy, there is also huge unmet demand for infrastructure investment. With a national infrastructure investment pipeline of USD 1.5 trillion for the next five years, there is a substantial opportunity to contribute to green infrastructure agenda. A third of this investment will come from private sector through public–private partnership. Raghu Dharampuri Tirumala and Piyush Tiwari examine the challenges that PPP projects face in developing green infrastructure. Most of these PPP green infrastructure projects are in economically weaker states. There are challenges associated with structuring PPP projects and also in the engagement of public and private sectors. These would need to be addressed to improve infrastructure development in an environmentally sustainable manner. The chapter also proposes pathways for evolving PPP mechanisms.

The final section of the book examines questions related to the quality of growth, human development and raising resources.

Development literature recognises the limitation of GDP as a measure of country's economic well-being. Even though there have been progress and some countries have transitioned from low-income to middle-income status, the problems such as poverty, inequality, gender disparities and environmental degradation persist. Social development goals aim to address these challenges. Inadequate social protection systems and poor quality infrastructure further constrain development. Shikha Jha and P.V. Srinivasan examine the factors that can improve the quality of growth. They propose a new metric—the Inclusive Green Growth Index for measuring the quality of growth. Economic growth and institutional factors are important to sustain the quality of growth. Their results highlight the importance of sound public financial management systems to enlarge fiscal space and provide efficient public services. Legislation and sound implementation mechanisms are necessary for environmental management.

The stock and quality of human capital is important for sustainable development and growth. Human Development Index (HDI) is used as an aggregate measure of human development and ranks countries in four tiers. The index is based on three factors: income, education and health. Bibhas Saha argues that India has progressed upwards on HDI index largely due to a rise in income. Quality of human capital is affected by the educational achievement and progress in health outcomes. Education has performed moderately and health has been worst performing component of the index. Given the importance of education for human development, Saha examines the New Education Policy of the government which puts child's learning at the top of the agenda. He argues that with proper allocation of resources to the New Education Policy, the learning situation and access to education will get serious attention.

The final paper in this book is by P.G. Babu and Vikas Kumar where they look at how resources can be allocated. Examining auctions in *Kautiliya Arthasastra*, they highlight that Kautilya's auction of goods are Pareto-efficient but do not maximize seller's profits. However, auction of land in Kautilya's auction is neither Pareto-efficient nor profit maximizing for sellers. They also discuss differences in the design of auctions, degree of competition and what constitutes the idea of just price in Kautilya's treatise and modern auction theory. The chapter highlights the importance of examining pre-modern economics treatise as these can provide insights into modern questions related to resource allocation, business viability, implementation of customs and laws and mechanisms for their enforcement.

PART I

Energy Transition and Security

CHAPTER 2

Indian Energy Transition: Need for a More Balanced and Market-Oriented Approach

Saumen Majumdar and Debabrata Chattopadhyay

2.1 Prelude: Questions

Speaking at the India Energy Forum on October 20, 2020, the Prime Minister of India, Shri Narendra Modi, sketched India's future map of energy as seven "pivots", likening them to the seven horses driving the Sun God's chariot (Times of India, 2020). These "pivots" include *among other things*, an aspirational target of 450 GW of renewable energy (RE)—primarily in the form of solar and wind—that will need to be met by 2030. The other six pivots include gas, cleaner use of petroleum and coal, biofuels, electric mobility, hydrogen and digitalization of the energy

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supply chain. While these are all important areas, there is a need to scrutinize and prioritize them, keeping in view the current energy supply infrastructure, the pace at which the proposed changes can realistically be made to the existing system, investment requirements and a myriad of complex social and environmental issues that must be addressed to ensure the energy transition is done smoothly. Clearly, energy choices are interlinked to economic, environmental and ecological aspects of India's growth, and therefore energy choices must be made in conjunction with other aspects of growth.

In this chapter, we will discuss the ramification of the proposed set of policies on the power sector, primarily focusing on the 450 GW RE target. Undeniably, this is the centrepiece of the most impactful policy as the RE target is very significant both in terms of the new capital that needs to be mobilized in a short space of time and what it entails for the existing assets. The Indian power system has a total installed capacity of 375 GW (in January 2021). Existing renewables (excluding hydro) are 92.5 GW, including 38 GW of solar and 39 GW of wind. There is a RE policy goal to first get to 175 GW of renewable by 2022, including 100 GW of solar and 60 GW of wind. The 450 GW target, together with some of the other *pivots,* hover around the issue of displacement of coal with cleaner energy resources. This is a laudable initiative. However, we must also recognize the current reality, including the fact that the existing 206 GW coal capacity (including lignite) forms the core of the power supply. A significant part of this capacity has come about quite recently—consider, for example, the following facts:

1. During the first 50 years since independence till 1997, India had developed 54 GW of coal-based capacity. At the turn of the century, it stood at ~60 GW;
2. Over the last decade, coal capacity has nearly doubled to add 100+ GW to reach the current level. In other words, the country added more or less the same quantum of coal capacity in the last ten years as it did in the previous 64 years since independence;
3. Solar and wind capacity saw a phenomenal increase over the last decade, albeit on a low base, and added a substantially lower capacity of 65 GW than coal. The Renewable Energy Source (RES) capacity stood at 92.5 GW at the end of 2020, which is likely to fall well short of the 175 GW target set for the next year and
4. There is still another 50 GW of coal capacity under various stages of construction at present.

The confusion over energy transition away from coal is not unique to India. The global installed coal-fired capacity has doubled from 1066 GW in 2000 to 2125 GW in 2020 (Carbon Brief, 2020), through a period of intense debate over climate change during which the cost of wind, followed by solar and battery storage, kept falling. An additional 200 GW of coal capacity is being constructed and another 300 GW is in the planning stage. The number of countries where coal capacity expanded over the years to 80, and there are still as many as 13 new countries added to the list. On the bright side, global coal generation plateaued over the last five years. It even decreased for the first time in 2020, albeit a serious contraction in demand for a significant part of the year due to COVID-19 contributed to it.[1] More importantly, the retirement of an older fleet has accelerated, and nearly 300 GW of coal capacity has shut down over the past five years. India has also seen the retirement of 6.2 GW capacity over FY18–20. There was also an announcement by the Indian Power Minister in October 2020 that 29 additional coal plants will be retired to create space for renewable power (Reuters, 2020). The Powering Past Coal initiative led by the UK and Canada promises to phase out coal from 19 countries. This, however, accounts for less than 5% of the installed 2125 GW capacity. Some analysts suggest a large share—somewhere in the range of 65%–80+% will be needed by 2030 to contain the global temperature increase to 2 °C or below it (e.g., 1.5 °C). This is a case where India and the rest of the world did not act on time, and now time is running out to get to a 2°C outcome and is probably too late for 1.5 °C (Roberts, 2020). This is the classic dilemma between economic development to power the economy, including giving electricity to hundreds of millions who do not have access, relying doggedly on tried and tested fuel/technology that was easy to expand, and environmental costs that kept mounting. The tension between these two goals has never been stronger, and the sharp policy reactions in the developed world are beginning to show.

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[1] Bertram et al. (2021) present several illuminating findings on the trend of power generation during the pandemic: (a) Global power demand declined due to global economic downturn and (b) drop in carbon intensity of power generation was even greater as the drop in share of coal generation was even greater.

There is, however, a cost to do a rapid turnaround, and we must ask some questions to make doubly sure the current swath of well-meaning policies is feasible, timely, balanced, economical and does not have unwarranted impacts:

1. **Where does the economics of coal stand today relative to solar/wind?** Since the debate in some shape and form always comes down to coal vs. renewables, this is a pertinent question to see if coal is indeed "dead" economically, as claimed in some of the analyses (e.g., Benn et al., 2018).
2. **Is the 450 GW renewable energy target (mostly solar and wind) by 2030 too much and too fast for India?** This will require a massive level of investment that will be needed—a relatively optimistic estimate of $500 billion has recently been provided by Buckley and Trivedi (2021). This is already an order of magnitude higher than the $42 billion received in the renewable sector in India since 2014. The estimate of $500 billion does not consider the generation investment needed to provide spinning reserve or the upgrades needed to the distribution system and hence is probably an underestimate. Nevertheless, as capital competes in India for energy, other non-agricultural sector and the agricultural sector—there is a high opportunity cost for limited capital that also needs to be factored in (Majumdar & Parikh, 1996). As India is already lagging behind the 175 GW target by 2022, it also raises a question on the feasibility of getting close to 400 GW additional capacity in approximately nine years. Then there are questions around the economics of the target, which relates to the first question we have posed, plus the difficult issue of the massive amount of stranded assets (Mercure, 2018).
3. **Would market-driven entry of renewables be a better way to pave the way for a broader mix of renewables, including cross-border hydro *and* allow exit of coal?** Finally, we pose some solutions to minimize the ill effects of the proposed energy transition policy and leave the entry of RE and exit of coal to the market forces. After all, significant efforts that went into setting up a wholesale electricity market were made to ensure new generation capacity comes through a market-based mechanism, and as RE costs have dropped sufficiently, we should let the market drive the selection of the right type, volume and time for these.

Through this lens, this paper attempts to scrutinize the energy choices as proposed by Prime Minister Modi for India. The next section elaborates on some of the economic and technical choices surrounding renewables and fossil-based electricity generation. In contrast, subsequent sections evaluate them in the context of the Indian power grid based on a holistic framework of environmental, technical and economic considerations. Instead of a conclusion, the last section outlines a way forward from this conundrum, highlighting the need for more rational exuberance towards the impending energy transition underway.

2.2 Where Does the Economics of Coal Stand Today Relative to Solar and Wind?

Coal capacity is expected to decline as solar and wind have reached grid parity (Ma et al., 2015). This process is expected to accelerate with 42% of the global capacity already making a loss four years ago according to Bennet et al. (2018). There are however alternative views. Rosenbaum and Gao (2016) noted that a simple comparison of levelized costs across the board hides important nuances that may the case for renewable challenging and competitiveness of renewables is likely to happen on a more case-by-case basis in specific locations. The fact that coal generation increase has largely continued unabated, it is therefore worth taking a closer look at the competitiveness of coal in India. We have drawn from an analysis at the World Bank (Huang et al., 2021) that compares the short-run marginal cost of coal plants for several countries worldwide with the levelized cost of electricity (LCOE) of solar PV and wind for 2019/20. Figure 2.1 reproduced from the World Bank work shows the cumulative coal capacity (organized by power plants) and LCOE and PPA prices for India using data from IRENA (2020) for the latter.[2] The underlying argument is that coal plants will probably continue to be in operation as long as they can recover their short-run costs (including maintaining the asset).

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[2] The definition of SRMC adopted for the World Bank study includes fuel costs, variable operation and maintenance costs as well as levelized cost of recurring (annual) fixed operation and maintenance costs. The last component is included to reflect the fact that these are also linked to usage of the plant and a component that is particularly relevant for ageing coal plants.

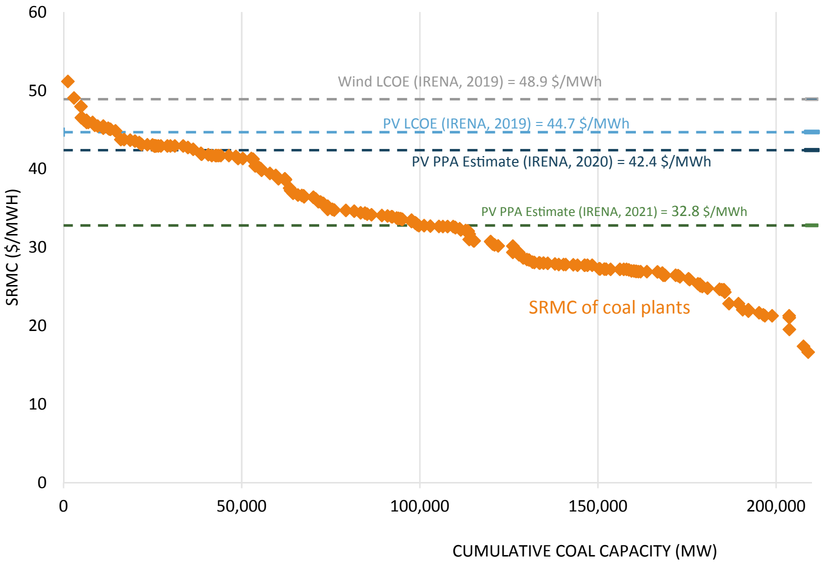

Fig. 2.1 Cumulative coal capacity in India (2020) vs. Short-Run Marginal Cost of coal generation (*Source* World Bank [2021])

This comparison is highly relevant because India is surging ahead with renewable power with the third fastest capacity additions around the globe in recent years (IEA, 2020). Although coal continues to be dominant both in capacity (204 GW out of 402 GW in 2022) and energy terms (close to 1100 TWh out of 1491 TWh in FY 2022). As the cost of renewables falls and the older coal fleet becomes more inefficient and hence more expensive, the balance will change over the coming years.

Huang et al. (2021)reported an average LCOE of wind ($49/MWh) and PV ($45/MWh) in 2019 as benchmarks, and that rendered 14 GW coal plants in India already unprofitable. Put differently, 6% of the operating coal capacity has a short-run marginal cost (SRMC) higher than the LCOE of PV. If a comparison is made with the solar power purchase agreement (PPA) price estimates, $42/MWh in 2020 and $33/MWh in 2021, a significantly higher share of coal, 16% and 43%, respectively, will be rendered uneconomic (Fig. 2.1).

If the average LCOE of renewable generation drops to about $30/MWh (3 c/kWh), more than 50% of the existing coal plants, or

110 GW, will be no longer economic in power generation, especially the plants running on expensive imported coals. Nearly 50% of these plants were commissioned after 2010 and hence are relatively new.

Coal plant utilization has been dropping relatively steadily from a healthy 78% in FY 2010 to close to 58% in FY 2022 including state-owned plants that saw average utilization of only 45% in FY 2021. While several GWs of coal capacity have shut down already in response, the cost comparison tells us why we have not yet seen significant coal retirement to date. The competition from renewables is however getting intense and a further drop in solar/wind prices may start an avalanche of coal retirement before too long *if a rudimentary economic test we applied were the sole criterion that would determine the exit of coal*.

As Huang et al. (2021) and Tongia (2020), among others, have noted, the choice between coal and renewables anywhere is far more complex than a simple comparison cost. The cost of integrating renewable is an issue especially as the penetration increases requiring mega green transmission corridors each of which can cost a billion dollar. Variability of solar and wind has a cost with the timescale of such variability ranging from a milli-second scale that requires spinning reserve to be carried by other generators/storage to longer-term variability over days and weeks that largely requires the thermal backup capacity to be in place. Extended periods of low wind below five m/s can stretch over 100 days that would essentially render a substantial part of wind capacity to be ineffectual (Chattopadhyay & Chattopadhyay, 2020). Even at a relatively low renewable penetration around 10% (FY 2020), it was estimated (in July 2020) that the cost of integrating renewable is around $15/MWh (Rs. 1110/MWh) (Singh, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i, 2020j) which considers the additional transmission and balancing costs, but not storage costs. This cost is expected to go up significantly as the penetration of variable renewables increases over the years.

On the other hand, there are hidden costs of coal that would partially offset some of these costs. Most of the incumbent coal power purchase agreements (PPA) have a "fixed cost" component that is akin to capital cost and can be in the range of $10–26/MWh. This is a significant component of the cost from a buyer perspective in part because these costs have to be paid regardless of whether they need generation from these plants as long as they are available to deliver 85% of the contracted capacity. Tripathi (2020) showed that shutting down 54 coal plants that are older than 20 years would save the distribution companies a massive \$7.2 billion (Rs. 530 billion). However, Tongia (2020), aptly notes that a more holistic comparison of the options needs to be made to account for integration, including storage costs that might make a case for a combination of renewable and coal to be economical.

If coal capacity does not retire rapidly—and so far, we do not see an overwhelming economic reason for it—this raises the obvious question: is there going to be room for both? India recorded its highest peak demand to date on January 22, 2022, at 187.3 GW, roughly half of its installed capacity. The Load Generation Balance Report from the Central Electricity Authority for 2020/21 noted that the growth in energy requirement between FY 2019 and FY 2020 (i.e., just before COVID broke out in India) was only 1.3%.[3] There is, therefore, no reason *prima facie* that an additional 400 GW of RE is needed to meet demand per se.

2.3 450 GW RENEWABLES BY 2030: TOO MUCH, TOO FAST FOR INDIA?

This brings us to the next question on the 450 GW RE target being overly aggressive. Energy transition to move from a fossil fuel-centric power system to one with solar, wind, hydro, renewable and biomass accounting for the major share of generation is inevitable to meet the carbon reduction pledge. As the fourth-largest emitter of (total) CO_2 globally and with ~5% of its generation still coming from fossil fuels—the power generation mix will continue to be under pressure to switchgear and other sectors, especially for transport with its e-Mobility drive will count on it too (Slater, 2020).

India has made remarkable strides on the renewable front, especially on solar and wind, over the past decade. Although there was a less than auspicious beginning with the wind in Tamil Nadu marred with high tariff and transmission constraints that made the effective power production to be expensive, India did quite well with subsequent development, especially on solar to reach 92.5 GW installed RE capacity (in January 2021) or almost a quarter of the country's generation capacity. The good

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[3] CEA, LGBR report: https://cea.nic.in/ page, 14.

thing about this development was that, unlike most developing countries, India shook off the initial high feed-in-tariff quickly and moved to auctions that took advantage of the global reduction in solar and wind project costs. The not-so-good aspect of this development was that at least for the first several years until 2018 when the cost of solar/wind sufficiently came down; these costs were still high relative to coal and the Renewable Purchase Obligation (RPO) made life difficult for the DISCOMs. The 175 GW RE target, just like the 450 GW RE target, was announced without much scientific analysis behind it. The 175 GW RE target (including 100 GW solar and 60 GW wind—together, they account for 91.4% of the mix) by 2022 was announced in 2014. There were indeed reasons to apply some caution raised back in 2014 (e.g., Tongia, 2014). Given the cost of wind and solar when the policy was formed and significant uncertainties around its future cost—it was a very substantial amount of investment that could have gone wrong. Some aspects of that policy have indeed gone wrong:

1. It imposed high costs on DISCOMs, who continued to pay the fixed costs associated with the thermal PPAs and purchase renewables. The average power purchase cost for DISCOMs kept rising over the years (Singh, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i, 2020j) and DISCOMs mounted unprecedented financial losses;
2. There was not a great deal of planning involved that meant renewable power rejection continued to happen although India has a robust HV transmission network;
3. There are significant "Variable Renewable Energy (VRE) integration costs" including transmission charges, cost of generation needed to balance variability of solar and wind, including investments needed in fast ramping generation resources, demand response measures and energy storage. Even if we disregard the last component on new investments, which may be the most significant one as the VRE penetration level increases, the remaining costs are estimated at Rs. 1.1/kWh or US 1.5 c/kWh (Singh, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2020g, 2020h, 2020i, 2020j). This is a significant adder and may further increase steeply as new investments, including storage, are needed to counter variability;

4. There were also conflicting policies developed around gas that led to significant (14+ GW) of almost new gas capacity being stranded (Standing Committee on Energy, 2019);
5. As we have noted before, coal plant utilization (plant load factor) fell rapidly over the years. This is particularly true for the state-owned coal plants. The utilization of these plants was always lower than the central sector counterparts. However, the average utilization of state-based plants over the last eight years has dropped from 66 to 42% in 2020/21. This has virtually stranded several plants in the states causing financial stress on several generating companies (gencos) notwithstanding the fixed costs these plants earn. Newer coal plants also feel the financial stress, and there are also 40 GW of "stressed" thermal capacity (Sinha, 2018);
6. Investments in other forms of cleaner generation, including hydro, have been neglected—hydro capacity has grown only 7 GW over the last decade. Although there has been some welcome development in cross-border transmission and hydro development in Bhutan, these have also taken a backseat due to solar and wind developments. It has not been possible to raise financing for a significant part of the solar and wind target—as of January 2021, 38% of the solar and 63% of the wind target have been fulfilled with only around a year left. There have been significant difficulties associated with all aspects of the capacity auction, power purchase agreements and payment delays (PTI, 2020) and
7. Despite all the fanfare on variable RE development, they still account for just over 9% of total generation, and CO_2 emissions from the sector continued to rise over the years and account for close to a billion tonne and the largest share (41%) of total emissions barring a few months due to COVID-19 related contraction in demand. It has stabilized the emissions to some extent. Still, the cost-effectiveness of solar/wind to reduce emissions during a period where these costs were relatively high has been questioned in other parts of the world (Greenstone & Nath, 2019). There has not been an adequate level of scrutiny on the policy objectives, and transparent economic analysis of carbon reduction policy is lacking. It is worth noting that an efficient CO_2 emissions reduction policy will typically need to consider a wider range of options that may include a switch to renewables and other forms of cleaner generation such as nuclear, gas and optimized dispatch and power exchanges with

> other systems. Chattopadhyay and Parikh (1993) had, for example, demonstrated in the early nineties that an integrated operation of a national grid could lead to a win–win situation to reduce cost as well as emissions.

Although the achievements in absolute terms are phenomenal and highly laudable, the target was never achievable and created a level of stress on competing generation alternatives and DISCOMs/customers and led to a sense of failure that is unwarranted. Solar and wind development will and should continue as the drop in solar/wind costs has created a strong impetus, as long as it is economically and financially viable. A tariff order issued by the Central Electricity Regulatory Commission (CERC) in February 2020, for instance, had approved a PPA price of Rs. 2.76/kWh (or around four c/kWh including approved trading margin) for a hybrid solar–wind project (840 MW).[4] This price marks a *significant* improvement over solar/wind projects in the past, and prices going forward are projected to drop further. For instance, just over a year ago, a TERI study in February 2019 had estimated that "*By 2030, we project that the cost of wind and solar will be between Rs. 2.3–2.6 per Kilowatt hour (kWh) and Rs. 1.9–2.3 per kWh, respectively, while the cost of storage will have fallen by about 70%*".[5] We see average project costs already in the vicinity of these ranges for both solar and wind. The cost reduction has been most prominent in the last three years and has been key to solar and wind capacity growth.

Even if the target is met and even if we assume solar/wind at less than Rs. 3/kWh are competitively procured, it will require concomitant policies, including market orientation—areas that have received very little attention. There would, for instance, be a need to address stranded gas/coal capacity, the financial burden on DISCOMs who are locked into long-term PPAs, how RE rejection is to be managed, massive increase in transmission, especially *intra*-state transmission network that would cost tens of billion dollars, in addition to tens of billions of dollars that will be needed to upgrade dilapidated distribution networks in many states,

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[4] CERC, Petition No. 56/AT/2020, 28 February, 2020. Available online: http://www.cercind.gov.in/2020/orders/56-AT-2020.pdf.

[5] TERI, Accelerating India's transition to renewables: Key findings from Energy Transitions Commission India, February 13, 2019, Available online: https://www.teriin.org/report/accelerating-indias-transition-renewables-key-messages-and-results-etc-india-project.

supporting investments in flexibility (e.g., pumped storage hydro, battery storage)—to name a few of the major concerns. Yet, the government has announced a much higher 450 GW target by 2030 that would *seriously* exacerbate all of the issues just noted (PTI, 2020).

It is time to pause and reconsider options. It is undeniable that the energy transition is happening, and its pace needs to pick up in the coming decade. We should, however, also be willing to accept the fact that there are trade-offs. This is not the first time power systems have faced this problem. There is no unilaterally "best" technology in a power system, so it remains a mix of many good options. The race of higher voltage for transmission and larger generating units and competing technologies (e.g., DC vs. AC) all ended up hitting some extreme on the many trade-offs among cost, reliability, security and other factors. The significant economies of scale and smaller footprints for higher voltage and bigger generating units both proved to be a contingency that elevated the risk of outage too high that costs too much to fix. For instance, it is now possible to build 1200 kV transmission lines capable of carrying 6 GW or more on a single line. However, it also means that the failure of a single line might lead to a significant dip in system frequency that may lead to a grid failure. Therefore, it will require the rest of the system to be operated so that it imposed additional cost. It is, therefore, unlikely that a substantial part of a system will comprise 1200 kV lines even if these lines are highly scale-efficient. This is why we do *not* find small power systems with a disproportionately large share of ultra HV lines or super large generating units to serve them. All systems generally go to a higher voltage for transmission in an orderly manner as they grow in size.

Renewable power also presents a very similar case that should help us to systematically analyse the trade-off. As developing countries are rapidly adopting higher and higher targets, it would appear that more the better is the norm ignoring the fact that there has to be a cap that will be hit either in terms of economics, and/or practicability, and/or system security or wider impacts on other competing alternatives. However, even if problems like RE rejection on power system contingencies arising from high penetration of renewable are surfacing in reality, they are being patched up through ad-hoc rules, including limiting the VRE generation only up to a certain share of the load and rejecting the rest, or worse leading to grid failures. The innovations around VRE, including the massive cost reduction, are probably the best development for the power system over the last several decades. The part of the energy community that truly cares for it should be very objective and scientific about defining how meaningful targets are set, and how it is adopted for them to be put to the best use—a balanced approach to the transition to date is a missing element that should be embraced to meet this end. In the remainder of this paper, we discuss some measures that can help to achieve this end.

There are three key measures to alleviate the current state, namely:

- An objective and holistic assessment of the 450 GW target that covers the core issues we have alluded to in the preceding discussion, including its impact on the power system and investment requirements, financial stress on coal generators and DISCOMs, and if this is indeed the most efficient means to reduce carbon emissions;
- Other options can complement variable RE that should receive more attention, including
    - o Other forms of renewables including hydro and biomass;
    - o Energy efficiency to reduce power consumption and demand response to manage sharp peaks and manage the variability of demand/generation;
    - o Cross-border hydropower import from Bhutan and increasingly from Nepal through joint ventures and
    - o Intelligent pricing to take advantage of high renewable periods, reduce consumption in other periods, etc.
- Active market orientation of renewable power and all of the other resources so that there is a transparent price discovery process that dictates how much RE is needed in the system, with the policy playing the role of setting an aspirational target only. Although India has wholesale electricity market in operation for more than a decade, renewable power is not traded in the market, leaving it to PPAs and imposed on the DISCOMs through RE purchase obligations (RPO). It becomes an obligation to the system operators to find ad-hoc measures to manage the variability. While this was essential to facilitate the entry of solar and wind, they are becoming subsidy-free and competitive to be part of the market mechanism to decide how much of it ought to be developed, including how the variability will be managed ancillary services market. In the next section, we provide a commentary on why the timing is right to adopt a market-oriented adoption of renewables (including cross-border hydro) and storage options.

2.4 Market Orientation of Renewable Power

2.4.1 Wholesale Spot Prices Already Support Solar and Wind Projects

As both wind and solar PPA prices dipped *below Rs. 3/kWh (US 4.5 c/kWh)*, it already opens up a possibility for this energy to be traded in the wholesale electricity market in India, namely, the Indian Energy Exchange (IEX), which accounts for 90% of the wholesale market trade volume, and Power Exchange of India Limited (PXIL). IEX has recently announced its plan to launch a renewable energy trading platform.[6] There are several reasons why some exposure to the spot market may be a useful avenue to explore, including enhancing revenue prospects for the RE generators, reducing the cost of wholesale energy for the DISCOMs, the flexibility a market regime offers for both generators and DISCOMs,[7] the current state of non-payment on many of the existing PPAs,[8] very low liquidity on IEX/PXIL of just 4%, that may be boosted by the participation of RE generators, to name a few. Figure 2.2 shows IEX all-India monthly average prices over Sep'14–Sep'19, and Fig. 2.3 shows a cumulative distribution of 15-minute prices over FY 2012–2020. As Fig. 2.3 shows, spot prices were above Rs. 3/kWh for 35–73% of the time over the last five years.[9]

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[6] Energy World, April 6, 2020, Indian Energy Exchange (IEX): We plan to launch a platform for renewable energy trading soon: Rohit Bajaj, IEX, Energy News, ET EnergyWorld, Available online: https://energy.economictimes.indiatimes.com/news/power/we-plan-to-launch-a-platform-for-renewable-energy-trading-soon-rohit-bajaj-iex/74999746.

[7] A Real-Time Market (RTM) slated to open on June 1, 2020 will further enhance this flexibility to change availability within 30-minutes of actual trading. This will help solar and wind generators immensely.

[8] G. Seetharaman, *Why India may not achieve the 2022 clean energy target,* The Economic Times, November 3, 2019, The article noted that as of July, 2019, DISCOMs in India accumulated non-payment of Rs. 97 billion ($1.4 billion) to renewable producers. Available online: https://economictimes.indiatimes.com/industry/energy/power/why-india-may-not-achieve-its-2022-clean-energy-target/articleshow/71869684.cms.

[9] Prices post-March 2020 has been even lower but this largely represents demand contraction due to COVID-19.

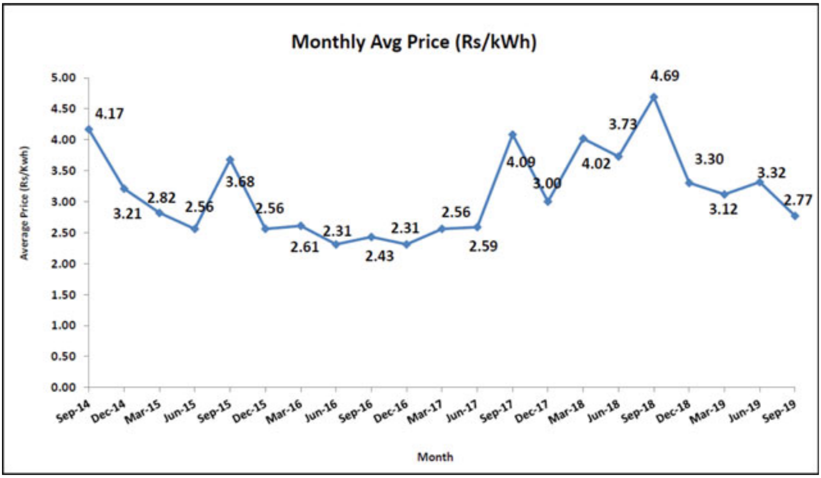

Fig. 2.2 Indian Energy Exchange historical spot prices: monthly average prices (Rs/kWh) (*Source* IEX, https://www.iexindia.com/Uploads/Presentation/18_11_2019Presentation_Nov_2019.pdf)

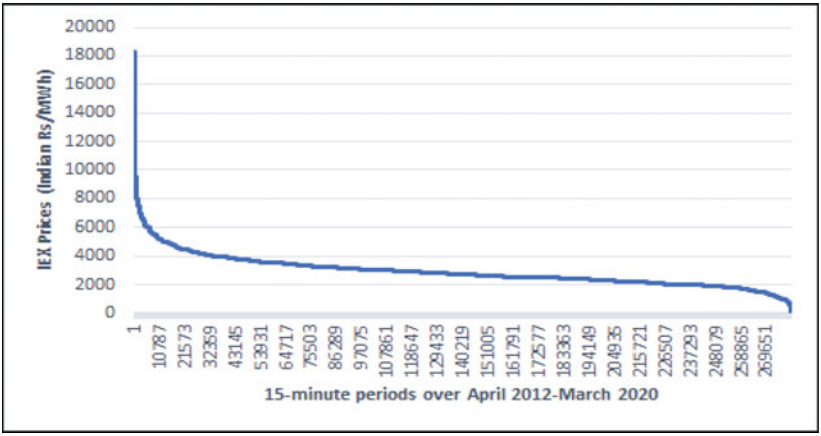

Fig. 2.3 Price duration curve for 1 April 2012 to 31 March 2020 (8 years of 15-min price data)

2.5 Hydropower with Some Storage Can Earn a Premium

Hydro, including cross-border regional hydro projects in Nepal and Bhutan, has two major attractions:

1. These plants have a better chance of holding their generation and supporting evening peaks that attract average Rs. 1/kWh (or 30%) higher prices than the average price in the last five years. As Fig. 2.3 shows, prices can range from close to zero to Rs. 18,000/MWh or beyond. Over the last eight years, prices exceeded R3.5/kWh (around US 5c/kWh)[10] for 37% of the time (or 103,789 15-minute periods out of 280,512 periods). If an MW could selectively run for those 103,789 periods, it would have earned a *net* benefit of Rs. 103 million (or $1.47 million) that could recover a significant part of the capital cost over a fraction of the life of the asset.[11] Therefore, even with limited bondage storage that can store energy for a few hours, hydro plants can earn a premium over solar/wind, albeit their levelized cost may also be typically higher. A "peaking run-of-the-river" project with a storage capacity of only 4–8 hours can be immensely useful in a high solar PV scenario because it can use the storage to manage variability during the day, or simply hold it as a contingency reserve and use the balance storage to support the evening peak and
2. Hydro plants can also earn revenue from Frequency Control Ancillary Services (FCAS), the demand for which is rising quickly as the share of solar/wind increases over the years. Hydro can offer significant flexibility in managing this variability through stored water, and the bulk of the storage volume held through a day can earn FCAS revenue. Although the price for such services may be a fraction of the energy price, this is paid for a MWh in storage until it is dispatched to earn energy revenue. For instance, a MWh in storage may earn only Rs. 150–300/MW-hour but over, say, a period of 12

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[10] This is a typical average estimate of LCOE of a hydro project (see, for example, https://www.irena.org/costs/Power-Generation-Costs/Hydropower).

[11] A typical hydro plant may cost $1500–2000/kW depending on the level of storage (say $1700/kW on average). Hence, more than 80% of the initial capital cost could be recovered in just five years.

> hours during the day, it would accumulate Rs. 1800 and be eventually dispatched during a high-price period in the evening. Therefore, the combination of energy and FCAS revenue can further enhance the profitability of hydro. A World Bank study (Curiel & Chattopadhyay, 2020) for cross-border hydro projects estimated that a MW of hydro can support 2–6 MW of variable RE.

As India plans to add close to 300–400 GW of RE by 2030, the FCAS requirement will be *extremely* high. Operating reserve requirement (especially "flexibility" reserve) would typically increase as a % of VRE generation. If we assume every GW of VRE generation at a given point in time would require 10% or 0.1 GW to cover for variability, the additional requirement for operating reserve for 300 GW of VRE would be a massive 30 GW.[12] In other words, up to 30 GW of additional flexible capacity will essentially need to be available for all the hours wind/solar generation occurs. There is already a scarcity of fast FCAS providers in the system, and there are major challenges in developing large-scale hydro projects within the country. Cross-border hydro potential in Nepal (at least 43 GW) and Bhutan (at least 24 GW) therefore assumes a special significance to complement the VRE development in India.

2.6 Role of Battery Energy Storage System (BESS)—Indicative Complementarities with Hydropower

BESS has become synonymous with VRE as BESS of all technologies and a wide range of use cases being piloted, tested and now commercialized to support VRE development.[13] They are, however, still relatively expensive, with a levelized cost of storage for wholesale energy purposes estimated

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[12] The exact fraction of operating reserve requirement would depend on the degree of variability. We use 10% as a total increase in reserve requirement for all types (regulation, spinning and flexibility) following, W. Cole et al., *Operating Reserve in Long Term Planning Models*, NREL, January 2018. Available online: https://www.nrel.gov/docs/fy18osti/71148.pdf.

[13] Central Electricity authority of India has recently concluded an economic potential of 34 GW/136 GWh of BESS to support 440 GW of RE in 2030 (Mukhopadhyay et al., 2020).

in the range of Rs. 11–22/kWh (US 15–30 c/kW).[14] It is, therefore, an interesting question if BESS is economical to do energy arbitrage in IEX *and* complement hydro in supporting VRE through FCAS provision.

There is a potent combination of large-scale RE (predominantly solar and wind) planned to go from 92 to 450 GW in a decade, 67 GW of hydro-economic potential in neighbouring Nepal and Bhutan, and BESS with its falling cost.[15] These options should be considered together in a market environment to see a market-led sustainable development path for these clean options to mutually support each other.

In summary, we note that:

1. The presence of a mature wholesale electricity market in India makes an eminent case for the adoption of solar and wind projects through a market-based mechanism and bring in as much of it as is supported by the forces of demand and supply. Wholesale prices demonstrably already support solar/wind projects that cost less than Rs. 3/kWh today. This is not to suggest these generators need to rely solely on a spot market, and long-term contracts will need to be in place to manage risk and ensure capital recovery. The intent is, however, that (a) these projects can have some spot price exposure and (b) this will, in turn, ensure that long-term PPA prices are closely linked to spot prices over the years;
2. Hydro projects, especially cheaper cross-border hydro projects in Nepal/Bhutan, can also benefit from a market-oriented development. These projects can already be competitive in the wholesale markets in India. Since these projects will typically have storage, even if it is for a few hours, they offer flexibility that will enable them to earn a premium over VRE projects. They can also earn revenue in

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[14] According to Lazard Levelized Cost of Storage version 5 analysis, November 2019. Wholesale services are defined as Large-scale energy storage system designed for rapid start and precise following of dispatch signal. Variations in system discharge duration are designed to meet varying system needs (i.e., short duration frequency regulation, longer duration energy arbitrage or capacity, etc.). Cost estimates are reported in Lazard as \$165–325/MWh converted into Indian Rs. using an exchange rate of 1 USD = Rs. 70. https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf.

[15] See for instance, Lazard's BESS Levelized Cost of Storage (LCOS) estimates that have dropped to \$188–329/MWh: https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/.

an ancillary services market that is under active consideration. Hydro and solar/wind can complement each other, and therefore a policy impetus not merely on VRE but also on hydro is very much needed. If we go with a rule-of-thumb that each GW of hydro can support around 5 GW of VRE, it suggests ~ 350–400 GW of VRE by 2030 would benefit immensely from 70 to 80 GW of new hydro. It practically means using a bulk of the economic potential for hydro that exists in Bhutan and Nepal and

3. Finally, battery storage has been discussed extensively as an option in India, and one of the studies by the national planning body has shown a need for 34 GW of it to support the 450 GW target by 2030. Since BESS is still a relatively expensive option at a minimum levelized cost of $188/MWh for 4-hour storage (Lazard, 2020), it should ideally complement hydro, especially cross-border hydro cheaper means to provide storage. However, BESS has several advantages, including its modular nature, fast development time, ability to install it in substations close to load centres or co-locate it with VRE projects and ability to provide the fastest form of frequency control response. It is expected that this will be a useful complement to hydro in supporting the large-scale development of solar and wind in India. The market must also drive such developments. Spot markets for energy to support energy arbitrage by BESS and that for FCAS will be an extremely useful way to signal the need for BESS.

2.7 In LIEU of a Conclusion

The meteoric rise in wind followed by solar power generation capacity development in India over the last few years, coupled with the media spotlight firmly on such developments, might give the impression that there has not been much else happening in the power sector. It is easy to miss the fact that India was, in fact, quietly adding an even greater quantum of coal capacity over the last decade, which remains its mainstay for power generation, albeit with an increasingly ageing fleet, part of which is rapidly losing dispatch. Solar and wind capacity boom came initially on the back of the 175 GW renewable target by 2022, probably not going to be met. This has nevertheless helped India to amass 92 GW of renewable capacity, including 39 GW of wind and 38 GW of solar, at a rapid pace. RES generation accounts for 9% of the total generation today.

It has helped to contain growth in CO_2 emissions, although power sector emissions have risen significantly to get close to a billion tonne. There are also several downsides to the development, not the least of which is financial stress on the distribution companies, the rising cost of integrating solar and wind in the grid and a direct conflict with simultaneous measures to promote coal and gas capacity. The last issue is pertinent. It has contributed to the rapidly falling utilization of coal generators, 40 GW of stressed thermal assets and at least 14 GW of the practically stranded gas asset. This also has contributed to the financial stress on DISCOMs generators because of the tariff policy that, in a majority of the cases, obligates them to pay for the fixed charges associated with the thermal PPAs. To put it bluntly, a well-meaning development of renewables was not planned well, was imposed in an ad-hoc way and has had its unwarranted impacts that received far less attention than its success.

Late last year, a far more ambitious 450 GW RE target by 2030 was announced as part of a seven-part energy strategy. While this can be a serious way to drive the decarbonization plan, it can also deepen some of the ill effects to the point of a potential crisis in the sector. If RES generation share increases from under 9% to 40+% in the space of nine years, it will put enormous pressure on the thermal assets. Absent a concomitant change in tariff policy that still obligates the distribution companies (DISCOMs) to pay for the fixed charges, deepening their financial problems. The stress would also be felt by thermal generators, which would disproportionately lose dispatch and revenue on the variable component, including many relatively new assets. A simple comparison of the short-run marginal cost of coal and levelized cost of renewables demonstrates that at least half of the existing coal assets are still competitive to the lowest cost solar PPAs. An explosion in the stranding of economic coal assets is not warranted, at least not without a judicious strategy. Absent a proper stranded asset compensation policy and exit for coal/gas generators, it might be a recipe for disaster for the power sector. The investment needed to finance the renewable generation is estimated at $500 billion, although this excludes some important components that would further increase this amount. Even at half a trillion, this is an order of magnitude increase from the previous wave of renewable investment that will almost certainly dry up the capital flow in other forms of generation and possibly from other sectors. We, therefore, believe that the 450 GW renewable target may well be “too much and too fast” that, at the very least, requires closer scrutiny to identify policy areas that need immediate attention to minimize unwarranted impacts.

As the cost of solar and wind projects has fallen drastically over the last five years for these to be eminently competitive, we also consider that the market forces should directly decide how much of these is needed rather than being dictated by a technology-specific policy measure. This is particularly relevant in India with a wholesale electricity spot market in operation for more than a decade, and renewable power is yet to participate in it. A simple analysis of Indian Energy Exchange (IEX) historic prices demonstrates that both solar and wind projects should already be competitive with a reasonable return they could have already earned in the spot market. Put differently, if solar and wind generators could participate in the market and at least have part of their (uncontracted) capacity in the market, it could provide a highly transparent dynamic way of guiding the future development of renewable projects. In fact, in the same token, we find that hydro projects, including cross-border hydro projects in Bhutan and Nepal, could also be competitive in the Indian market. They could also be an excellent complement to the solar/wind project in managing their variability.

In summary, there is a need to recognize that well-meaning but abrupt changes to the power sector still very reliant on coal should be avoided. The policy measure needs to be "balanced" to ensure it encourages renewables but not at the expense of creating a financial disaster in the thermal sector. A meaningful way to achieve this end would be through a market-oriented introduction of renewables—ideally, a broader mix of renewables including hydro that complement solar and wind coupled with innovations around the wholesale market design to price storage options.

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CHAPTER 3

Projection of Water Demand in India in a Macroeconomic Consistency Framework Incorporating the Food, Water and Energy Nexus

Probal Pratap Ghosh

3.1 Introduction

There are four major sources of water demand in India viz. (1) Agriculture, (2) Residential, (3) Industry, (4) Power Generation. Agriculture and Power are major water-consuming sectors. Higher economic growth would result in changing agricultural consumption patterns which in turn would imply a change in cropping pattern. This coupled with increasing population would impact the amount of water required by agriculture sector. At the same time higher economic growth would imply

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increasing power generation leading to an increase in water demand for cooling requirements. Economic growth would also result in higher water demand due to increasing urbanisation through expanding cities and increasing manufacturing bases to support such an economic growth. Climate change is expected to affect rainwater frequency, intensity and distribution as well as flows in rivers fed by glacier melts. This may lead to reduced water availability for irrigation and also lower groundwater levels. The decreased levels of precipitation and lower groundwater levels would imply an increase in use of groundwater pumps which would increase the demand for power. There exists a food energy water nexus (FEW nexus) which needs to be accounted for a sustainable economic growth path through a sustainable use of water resources across sectors and by private households. To understand the constraints that water demand can impose on economic growth and the water deficit that may appear in the future it is important to project future water demand from all sources by accounting for the FEW nexus. The issues highlighted above are analysed in this paper through the following research questions.

1. To assess the nexus between food energy and water and provide the most optimal strategy for energy sector growth through water conservation and water use efficiency
2. To project the water demand up to 2050 due to
    a. Irrigation accounting for changing cropping patterns due to changing food consumption patterns
    b. Population increase and urbanisation
    c. Industry and power sector
3. To assess the reduction in water use due to water conservation policies for the power generation sectors.

3.2 Methodology

The major usage of water is from, agriculture for irrigation purposes, residential sector for domestic consumption, power sector for cooling and ash cleaning purposes and Industry for Industrial purposes. However, each of these sectors is a part of the larger economy and their growth has common macroeconomic drivers and intersectoral linkages with other economic sectors. Therefore to assess the competing demands for water from each of this sector, a consistent projection of outputs of each sector with respect to the economy-wide growth is needed. This is achieved through input–output-based models which ensure intersectoral consistency in computing production levels of each industry. We use an input–output dynamic optimisation model, The IRADe–Integrated Assessment model (IRADe–IAM), based on input–output framework to make consistent projections of outputs of all sectors. The input–output framework ensures intersectoral consistency and the macroeconomic relations imposed as constraints in the model ensures that the model solution is feasible and macroeconomically consistent. The IRADe–IAM model is an economy-wide model in activity analysis framework and covers all sectors of the economy. It is a top–down model with bottom-up specifications of technologies. In this sense the model is an integrated model that combines top-down macroeconomic structure and intersectoral linkages with bottom-up technological specifications. A brief description of the IRADe–IAM model is provided in Annexure 1.

The 78 × 78 sector Social Accounting Matrix for 2007 (Pradhan et al., 2013) forms the reference for the base year data of the model. The base year of the model is 2007–2008 and the sectors from the 78 × 78 sector Social Accounting Matrix for 2007–2008 are aggregated to 25 × 41 sectors for the most appropriate representation of energy sector and its linkages with the overall economy. There are 7 agricultural sectors, 10 industrial sectors (excluding energy sectors) and 3 services sectors. There are three primary energy sectors and two secondary energy sectors. The detailed sectoral structure is shown in Annexure 2.

Generally, energy and climate change models are long-term models which project for long time periods of 50–100 years using a benchmark base year data despite economy and energy systems changing substantially in 50 or 100 years. Structural changes occurring over such a long period of 50–100 years is addressed by the inclusion of futuristic technologies, sector-wise energy efficiency trends, factor productivity trends and change in consumer demand pattern. The model used assumes all these structural changes. Since 2007, the major change in the energy sector in India is adoption of new renewable power generation technologies. The model considers 16 current and future power generation technologies (Table 3.20, Annexure 2) with prescribed market penetration rates based on current trends (Table 3.6). In all other sectors, the changes since 2007–2008 have been in terms of energy efficiency and factor productivity growth. Time trends in both these factors have been assumed and specified in Table 3.5. The most important factor that contributes to structural change in production over a long period of 50 years is the structural change in household consumer demand. The model combines a nonlinear demand system with endogenously changing income distribution (explained in Annexure 1). This helps the model compute changing demand structure in a realistic manner due to changing tastes with increasing income and due to upward economic mobility through growth. Thus the model manages to address all changes in the economy from 2007–2008 till today.

The choice of base year 2007–2008 is partly due to the non-availability of a SAM of more recent years that is suitable for the disaggregation required in the analysis. Besides many years in the recent past have been years of economic shock and intervention like oil price rise in early 2011–2012, demonetisation in 2016, GST in 2017 and COVID in 2020. Using 2007–2008 as base year is also helpful in estimating the impact of low carbon pathways on water demand as is one of the objectives in the paper. Selecting a more recent base year would not help in assessing the impact of low carbon transitions already achieved.

Water consumption in each sector is directly proportional to the output of these sectors in 2007–2008. These are technological coefficients and there is no reason to assume a change in them over time except for technological improvement which is a policy scenario considered in this paper. The calculation of sector-wise water consumption coefficients and model parameters and policy assumptions is presented in the section below.

3.2.1 Model Assumptions

The key parameters and assumptions that drive model results are provided below while the remaining details are provided in the Annexure.

a. Population

All the scenarios use the UN medium variant population for India. The population of rural and urban areas is assumed based on the UN medium variant population for India and is given in Table 3.1.

Table 3.1 Total, rural and urban population projection

Population[a] *(in millions)*

Year	*Total*	*Rural*	*Urban*	*Urbanisation (in %)*
2007	1158	812	346	30
2010	1206	833	373	31
2020	1353	883	471	35
2030	1476	893	583	39
2040	1566	864	701	45
2050	1620	806	814	50

[a] Population UN Medium Variant

Table 3.2 Resource growth assumptions

Resource	*Reserves in 2007*	*Growth Rate in reserves (%)*
Coal and lignite (million tonnes)	153,103	1.0
Crude petroleum (million tonnes)	725	0.0
Natural gas (billion cubic metre)	1055	1.1

Source http://www.coal.nic.in/content/coal-reserves

b. Resource Reserves and Growth Assumptions

The growth rate and stock of proven reserves of fossil fuel such as coal and lignite, crude oil and natural gas are provided in Table 3.2.

c. Macroeconomic Assumptions

The other major macroeconomic assumptions that drive the model include assumptions on discount rate, post-terminal growth rate, government consumption rate, maximum savings rate, bounds on per capita consumption growth rates and export and import bounds. The export bounds are provided as % share of total output and import bounds are provided as % share of total availability (output + imports). These assumptions are provided in Tables 3.3 and 3.4.

Table 3.3 Macroeconomic assumptions

Parameter	*Assumption (%)*
Maximum growth rate of per capita consumption	8
Government consumption growth rate	7
Maximum savings rate	40
Discount rate	4
Post-terminal growth rate	3

Table 3.4 Trade, exports and imports bound (%) assumptions

	Commodity	*Export upper bound*	*Import upper bound*	*Import lower bound*
1	Food grains	10	10	0
2	Sugarcane	10	10	0
3	Oil seeds	10	10	0
4	Other crops	10	10	0
5	Animal husbandry	10	10	0
6	Forestry	10	10	0
7	Fishing	10	6	0
8	Coal and lignite	1	30	20
9	Crude petroleum	2	98	80
10	Mining and quarrying	99	45	0
11	Agro-processing	10	20	1
12	Textiles	50	30	0
13	Petroleum Products	20	20	5
14	Fertiliser	20	33	20
15	Cement	10	0.6	0.3
16	Non-metallic minerals	10	10	1
17	Steel	20	10	1
18	Manufacturing	40	30	1.5
19	Construction	0	0	0
20	Electricity[a]	0	0	0
21	Water supply and gas	0	0	0
22	Railway transport services	30	0	0
23	Other transport	30	20	3
24	Other services	20	10	6
25	Natural gas	0	80	20

[a] Imports and Exports of Electricity specification are explained in the methodology sections

d. Energy Sector Policies

The assumptions and policies that directly relate to the energy sector are, autonomous energy efficiency improvement, cost reduction for renewables (solar PV and wind) due to the efficient use of production factors and market penetration rates of various technologies based on announced plans of the Government of India. India has announced its intended nationally determined contributions (INDCs) and commitment towards low carbon growth. The government has announced various low carbon measures through support schemes and programme targets and these announced plans in power, energy efficiency, buildings and transport sector have been incorporated in the model scenarios. The details of these assumptions of AEEI, cost reduction and market penetration rates and low carbon policies are provided in Tables 3.5, 3.6 and 3.7.

3.2.2 Calculation of Water Demand Coefficients

Water demand is calculated for four categories—(1) irrigation (2) Domestic (3) Industry (4) Power generation using estimated coefficients. The calculation of water consumption coefficient for each category is provided below.

Agriculture: Water is required for irrigation and depends on the area under irrigation coverage and the type of crops grown. The model projects output of each agricultural sector including food and non-food crops from irrigated and unirrigated areas. We use data from land use statistics at a glance from 2000–2001 to 2009–2010 to compute area under irrigation for each crops for the year 2007–2008, which is the base year for the model. The Gross Irrigated Area and Gross Cropped Area for each crop sector for the model base year 2007–2008 are provided in Table 3.8.

For each crop, the ratio of area under irrigation to the output of that crop from irrigated area for the year 2007–2008 is computed and used to project irrigated area based on irrigated production level for each crop for subsequent years up to 2050.

Crop-wise water requirement data in mm per growing period is collected from the website of Food and Agriculture Organisation and shown in Table 3.9. This crop-wise water requirement in mm/hectare of irrigated area for entire growing period of each crop multiplied by the total irrigated area is used to project total water demand aggregated over

Table 3.5 Assumptions of exogenous parameters for DAU scenario

Parameter	*Sectors*	
TFPG	Agriculture and power	1%
	Rest of the economy	1.5% for all except new technologies in power sector
AEEI for non-power sectors	Coal	1.5% per year
	Petroleum products	1.5% per year
	Natural gas	1.5% per year
	Electricity	1.5% per year
AEEI for power sectors	Coal	No AEEI for coal use in power sector technologies assumed
	Petroleum products	No AEEI for diesel use in power sector technologies assumed
	Natural gas	No AEEI for gas use in power sector technologies assumed
	Electricity	Reduction in transmission and distribution losses assumed
Reduction in energy use by government and households	Petroleum Products	1% reduction in marginal budget share of expenditure on petroleum products by households due to the use of more efficient vehicles
	Electricity	1.5% reduction in marginal budget share of expenditure on electricity by households due to the use of efficient appliances

all crops for each period. This calculation for 2007–2008 is shown in Table 3.10. The water demand for the subsequent years is also calculated similarly based on the model projection of crop-wise irrigate area.

Domestic: Water demand from the domestic sector is on account of drinking, cleaning and bathing purposes. In the IRADe–IAM model, the household residential sector is disaggregated into 10 expenditure classes each for rural and urban areas. Water consumption depends on the household's living standards which are captured by the expenditure levels of the household classes projected by the IRADe–IAM model. Water demand for each expenditure class is estimated using water consumption per capita

Table 3.6 Power sector policies scenario

Power sector policies	
Costs for renewable	Chapter 1 Cost reduction due to recent fall in solar and wind energy prices
Growth of renewable	Chapter 2 A minimum share for renewable of 8% by 2030 and 10% by 2050 is prescribed
Minimum share of solar	Chapter 3 A minimum penetration rate for solar power is prescribed to allow for minimum share of 1.4% in 2030 and increases to 1.6% in 2050
Nuclear power	Chapter 4 Nuclear generation capacity is projected to reach up to 8 GW by 2050
Thermal coal	Chapter 5 No investment in capacity and no fall in costs due to factor productivity for subcritical coal assumed from 2017
Hydropower	Chapter 6 Constrained to grow by 1% in keeping with the government plans
Gas-based power generation	Chapter 7 Maximum of 40% of domestic production of Gas is used for Power Generation
Minimum penetration rate for ECBC buildings	Chapter 8 The share of ECBC is specified to increase by 1%

Table 3.7 Transport sector policies in DAU scenario

Transport sectors policies	
Share of railways in total freight movement	Stipulated to increase by 1.5% per year, from around one-third in 2015 to almost two-thirds by 2050
Greater use of public and non-motorised transport	Reducing marginal budget shares for petroleum products by 0.2% per year beginning in 2015
Change in the fuel mix in road transportation sector	Reducing petroleum product inputs in the transport sector by 0.5% per year, and replacing them by increasing inputs of natural gas and electricity in the ratio 60:40, respectively, from 2015

Table 3.8 Crop-wise area under cultivation and irrigation (000 Hectares) for the year 2007–2008

	Crop	*Gross cropped area*	*Gross irrigated area*
1	Paddy	43,623	25,199
2	Wheat	28,596	26,101
3	Coarse Cereals	28,669	4227
4	Grams and Pulses	24,820	3925
5	Sugarcane	5151	4844
6	Oilseeds	28,686	7811
7	Fibres	10,431	3487
8	Plantations	1352	196
9	Fruits	4151	2560
10	Vegetables	5944	3666
11	Other Crops	13,711	5968

Source Land use statistics at a glance 2000–2001 to 2009–2010 Directorate of Economics and Statistics, Department of Agriculture and Cooperation Ministry of Agriculture, Government of India

per day coefficients from Shaban and Sharma (2007). The estimated coefficients used are presented in Table 3.11.

With economic growth and prosperity, per capita consumption increases and people shift from lower expenditure classes to higher expenditure classes. The model captures this using a non-linear demand system and a log-normal income distribution function to endogenously project the per capita household consumption expenditure for each expenditure class and number of people in each expenditure class in each year. With increasing economic prosperity, the household's water consumption patterns become similar to the patterns of high-income groups. The household water consumption coefficients (as mapped for each expenditure class in Table 3.11) per person per day are multiplied by the number of people in each expenditure class and aggregated to get the total water demand from domestic sector for each year from 2007–2008 to 2050.

Industry: Water is consumed by Industry in various production processes. The Centre for Science and Environment (CSE, 2004) report that estimates water demand for the year 2004 from major industrial sectors is used to calculate water demand in Industry. The report found that water is in optimally priced as it is provided either by municipalities or through extraction from ground using subsidised energy. This leads to

Table 3.9 Crop-wise water needs for irrigation

Crop	*Crop water need (mm/total growing period)*	*Average*
Alfalfa	800–1600	1200
Banana	1200–2200	1700
Barley/Oats/Wheat	450–650	550
Bean	300–500	400
Cabbage	350–500	400
Citrus	900–1200	1050
Cotton	700–1300	1000
Maize	500–800	650
Melon	400–600	500
Onion	350–550	450
Peanut	500–700	600
Pea	350–500	425
Pepper	600–900	750
Potato	500–700	600
Rice (paddy)	450–700	575
Sorghum/Millet	450–650	550
Soybean	450–700	575
Sugar beet	550–750	650
Sugarcane	1500–2500	2000
Sunflower	600–1000	800
Tomato	400–800	600
Tobacco[a]	400–600	500

Source http://www.fao.org/docrep/s2022e/s2022e02.htm#TopOfPage

[a] https://agriculturalinformation4u.blogspot.in/2016/02/irrigation-water-requirement-for.html

inefficient use of water and so the industrial water productivity which is represented by the ratio of Industrial GDP to water consumption is one of the lowest for India among major industrialised countries. The Industry sector-wise water demand from the report (CSE, 2004) is presented in Table 3.12. Each of the industry sectors covered by the report is considered in the IRADe–IAM model either explicitly or as a part of a larger aggregated sector. We compute the ratio of water consumed to output in 2004 and multiply the ratio to output growth of the sectors for all the years from 2007–2008 to 2050.

Table 3.10 Crop-wise irrigation water demand (BCM) in 2007–2008

Model cropping sectors	*Irrigated area (IA)* (000 hectares)	*Water consumption (WC)* (mm/hectare)	*Water demand for total irrigated area (IA) of the crop* (BCM)
Paddy	25,199	575	145
Wheat	26,101	550	144
Coarse Cereals	4227	583	25
Grams and Pulses	3925	400	16
Sugarcane	4844	2000	97
Oilseeds	7811	600	47
Fibres	3487	1000	35
Plantations	196	500	1
Fruits	2560	1083	28
Vegetables	3666	521	19
Other Crops	5968	831	50

Table 3.11 Area-wise consumption of water per capita per day (in litres)

Resident household status	*Model expenditure class in rural and urban areas mapped to*	*Mean*
High-income group (HIG) areas with well planned building	H10, H9	99.9
Middle-income group (MIG) areas with well planned building	H8, H7, H8	94.2
Low-income group (LIG) areas with well planned building	H3, H4, H5	90.2
Slum areas	H2 and H1	81.9
Others (mixed areas)		91.3
Total		91.6

Source Shaban and Sharma (2007) H1, H2,…, H10 refer to households in different expenditure classes in rural and urban areas

3.2.2.1 *Power Generation*

Thermal power generation technologies require water for cooling purposes. Coal-based thermal power generation in addition requires water for ash cleaning. The power sector in the IRADe–IAM model is disaggregated into 13 technologies as shown in Annexure 2. The models

Table 3.12 Wastewater generation and water use by different industries in India, 2004

Industrial sector	*Annual consumption (million cubic metres)*
Engineering	2019.9
Pulp and paper	905.8
Textiles	829.8
Steel	516.6
Sugar	194.9
Fertiliser	73.5
Others	314.2

Source CSE (2004)

provide output for each power generation technology in value and physical terms. The thermal power generation technologies included are subcritical coal, supercritical coal, ultra-supercritical coal, IGCC coal, Gas, Nuclear, biomass, solar PV and solar thermal with and without storage. We use India-specific water use coefficients of power generation technologies from CEEW (2017) to project water withdrawal and consumption from the power sector. The CEEW (2017) provides fuel technology-wise water coefficients for cooling tower (CT) and once-through cooling (OTC) technology separately. The IRADe–IAM model does not consider power generation technologies differentiated by cooling technique use and hence a weighted average of the water coefficients of CT and OTC for each fuel technology is assumed. The weights are the installed capacity with CT and OTC cooling technology under each power generation technology. The average water use coefficients considered for each technology are reported in Table 3.13. Water consumption in power sector is projected by multiplying the technology-wise water coefficients with technology-wise power generation from the model.

3.2.3 Scenarios

In trying to assess the future demand for water and the factors and policies that may impact it, we address the following three questions (1) Impact of Economic Growth on water demand (2) Impact of water conservation policies and low carbon policies in power sector on water demand (3) impact of implementing government schemes and climate targets on water demand. The first question is answered using a set of three scenarios—each representing a different rate of GDP growth rate.

Table 3.13 Technology-wise water withdrawal per unit generation

Technologies	*Water withdrawal (m^3/Mwh)*			
	2015	*2016*	*2017*	*2018*
Coal	41.87342	22.69972	3.5	3.5
Gas	1.62	1.62	1.62	1.62
Nuclear	152.7726	78.58846	3.5	3.5
Refined liquids	68.3	68.3	68.3	68.3
CSP	2.845	2.845	2.845	2.845
PV	0.1	0.1	0.1	0.1
Biomass	4.35	3.925	3.5	3.5

Source Weighted average from CEEW (2017)

Low Growth rate scenario: GDP growth rate is simulated to 5.88% from 2011–2012 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.
Medium Growth rate scenario: GDP growth rate is simulated to 6.70% from 2011–2012 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.
High Growth rate scenario: GDP growth rate is simulated to 7.40% from 2011–2012 to 2047 by appropriately adjusting parameters and assuming MOEFCC guidelines on water conservation policies in power plants.

The second question of the impact of power sector policies on water demand and power sector water conservation policies is answered by another set of two scenarios.

Reference Scenario (REF): We use the Medium Growth rate scenario with MOEFCC guidelines on water conservation in power plants.
Water Conservation Policy Failure (WCF): The scenario assumes a Medium Growth rate scenario without MOEFCC guidelines on water conservation in power plants.

The Water Conservation Policy Failure scenario shows the additional water demand in the power sector if the MOEFCC guidelines are not adhered to.

The third question of the impact of government's announced power sector plans and capacity build-up and NDC commitments made in Paris is addressed by comparing the REF scenario with two additional scenario.

> **INDC Scenario (INDC)**: The scenario considers announced government policies of 175 GW of renewable power capacity, Nuclear and Hydro plans and attainment of the INDC targets.
>
> **AMBLC Scenario (AMBLC)**: The scenario considers announced government policies of 175 GW of renewable power capacity, Nuclear and Hydro plans and attainment of more ambitious targets of nearly 60% non-fossil fuel capacity by 2030.

3.3 Impact of Growth on Water Demand

GDP growth stimulates economic activity and increases the drivers of water demand leading to competing demand for water. The model accounts for this competing demands or the FEW nexus and projects demand for water under each scenario. To assess the impact of GDP growth on water demand we consider three scenarios (1) Low Growth rate scenario with a CAGR growth of 5.88% from 2011–2012 to 2047, (2) Medium Growth rate scenario with a CAGR growth of 6.70% from 2011–2012 to 2047 and (3) High Growth rate scenario with a CAGR growth of 7.40% from 2011–2012 to 2047.

The drivers of water demand and their growth rates under the three growth scenario are provided in Table 3.14. Higher GDP growth results in people moving from lower expenditure classes to higher expenditure classes which increases their per capita consumption. This increases the aggregate per capita consumption levels, which is an indicator of the improving levels of standards of living of households. The per capita consumption expenditure increases at a CAGR of 5.53, 6.41 and 7.11% in the Low Growth, Medium Growth and High Growth scenarios, respectively, from 2011–2012 to 2047.

An increase in consumption increases demand for Agricultural commodities including Food, Industrial products and Electricity. The increase in Agricultural GDP results in higher production of food and

Table 3.14 Drivers of water demand under various economic growth scenario

		Year			*CAGR 2011–*	
		2011	*2030*	*2050*	*2030*	*2050*
GDP (Rs. billion)	Low growth	59,577	229,671	496,225	7.36	5.59
	Medium growth	59,475	242,957	632,731	7.69	6.25
	High growth	59,482	242,542	781,130	7.68	6.83
Agriculture GDP (Rs. billion)	Low growth	5438	13,019	15,493	4.70	2.72
	Medium growth	5384	13,854	18,856	5.10	3.27
	High growth	5385	13,982	22,197	5.15	3.70
Aggregate irrigate area (000 Hectares)	Low growth	96,260	139,311	209,585	1.96	2.02
	Medium growth	96,260	139,311	209,587	1.96	2.02
	High growth	96,258	139,312	209,588	1.96	2.02
Industry GDP (Rs. billion)	Low growth	29,473	95,072	239,145	6.36	5.51
	Medium growth	29,459	102,650	286,259	6.79	6.00
	High growth	29,465	102,176	355,229	6.76	6.59
Power generation (billion Kwh)	Low growth	1074	3057	4857	5.66	3.95
	Medium growth	1074	3247	6365	6.00	4.67
	High growth	1074	3242	7746	5.99	5.20
Per capita consumption (Rs./person)	Low growth	23,783	84,608	193,852	6.91	5.53
	Medium growth	23,164	82,408	260,870	6.91	6.41
	High growth	23,179	82,462	337,151	6.91	7.11

non-food crops, requiring an increase in irrigation coverage over time. Agriculture GDP increases at a CAGR of 2.72, 3.27 and 3.70% in the Low Growth, Medium Growth and High Growth scenarios, respectively, from 2011–2012 to 2047. The water requirement for agriculture would depend on the area covered by irrigation. Figure 3.1 gives the crop-wise irrigated area.

Gross irrigated area increase is exogenously prescribed and is same across all scenarios although its distribution across crops varies by production choices. Gross irrigated area increases at a growth rate of 2% from 88 million hectares to 139 million hectares in 2030 and to 209 million hectares in 2050. Paddy, Wheat, Coerce Cereals, Sugar cane, Oilseeds and other crops have a significant share in gross irrigated area. The share of crops in gross irrigated area changes, driven by changing consumption pattern and availability and cost competitiveness of imports. With economic growth, increase in income and urbanisation, diet preferences of households change from cereal based to high-value foods like fruits

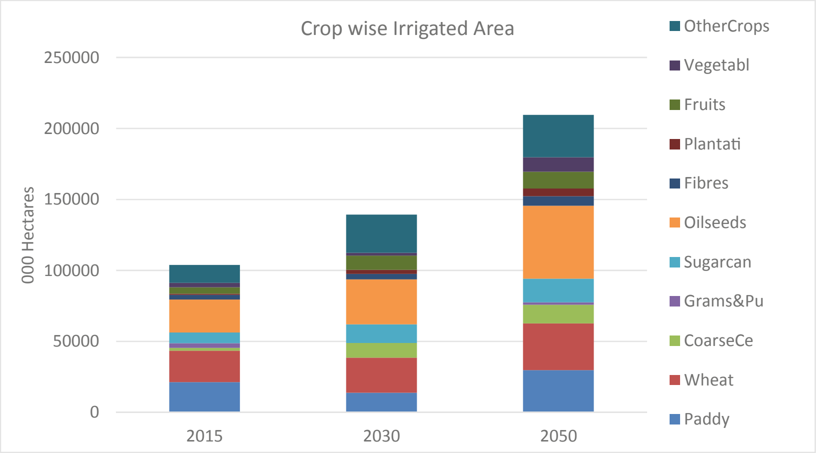

Fig. 3.1 Crop-wise irrigated area in thousand hectares in reference medium growth scenario

vegetables, fibres, etc. Even within cereals, food pattern may change from rice eating to wheat, jowar and bajra. As shown in Table 3.9, fruits, vegetables, fibres and cereals like wheat, jowar and bajra have high water consumption coefficients and are likely to increase water dependence.

Industry includes sectors like Engineering, pulp and paper, Textiles, Steel, Sugar, Fertilisers and other miscellaneous manufacturing sectors. Higher economic growth and household consumption demand increase industrial GDP. Industrial GDP increases at a CAGR of 5.51, 6.00 and 6.59% in the Low Growth, Medium Growth and High Growth scenarios, respectively, from 2011–2012 to 2047.

Increase in GDP growth, Agriculture, Industry GDP and residential sector expenditure results in higher demand for power and corresponding increases in generation from various technologies. A major share of power generation is from Thermal technologies which require water for cooling requirements and for ash cleaning in coal-based thermal technologies. The technology-wise generation is provided in Figs. 3.2, 3.3 and 3.4.

Power generation is projected to increase from 1074 billion Kwh in 2011–2012 to 4857, 6365 and 7746 billion Kwh by 2050 at a growth rate of 4.18, 4.97 and 5.51% for Low, Medium and High GDP growth scenarios, respectively. Coal-based thermal power generation is the most

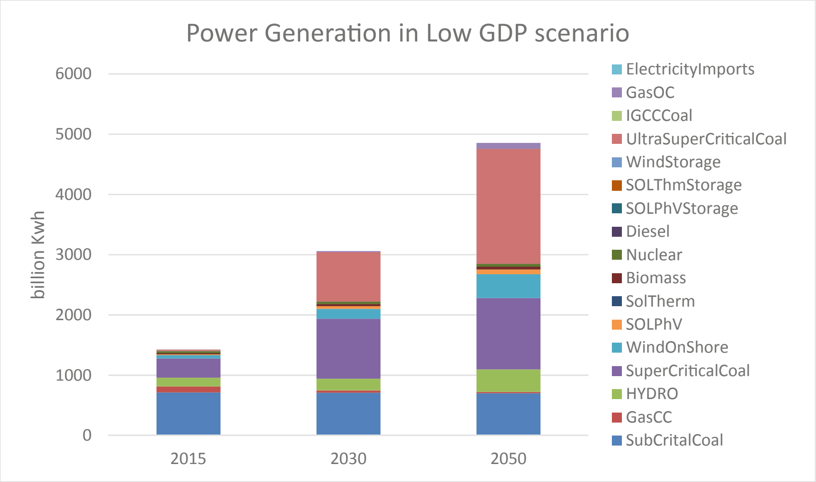

Fig. 3.2 Power generation in low GDP growth scenario

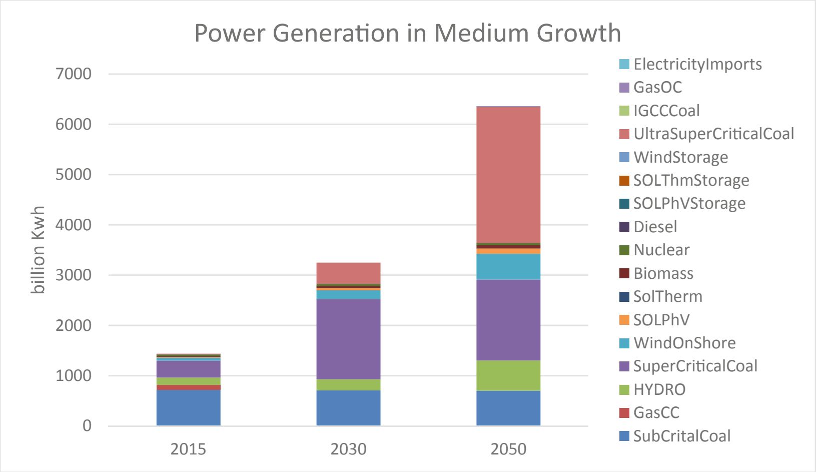

Fig. 3.3 Power generation in medium GDP growth scenario

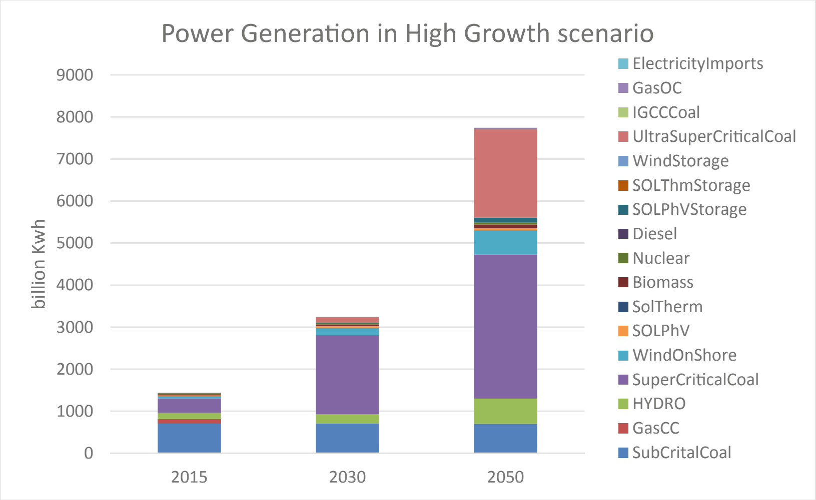

Fig. 3.4 Power generation in high GDP growth scenario

preferred choice of generation. The share of subcritical coal decreases due to the government's stated policy of not having any new subcritical-based plants after 2017. However, coal-based thermal power generation still remains the preferred choice as generation shifts to supercritical coal and ultra-supercritical coal despite its higher capital cost. Thermal power generation will have a major impact on water demand as thermal power generation would require water for cooling purposes and coal-based thermal power generation would require water for ash cleaning.

The water demand by various sectors based on the growth of the above-mentioned drivers for the three GDP growth scenarios are provided in Table 3.15.

Total water demand in 2015 is estimated to be at 868 bcm, of which irrigation demand is about 768 bcm and demand for power is about 50 bcm. Industry has a very small share of 7 bcm and domestic demand is at 43 bcm. The total demand increases to 1145, 1189 and 1203 bcm in 2030 in the Low, Medium and High Growth rate scenarios, respectively. In 2050 the total water demand increases to 1703, 1713 and 1731 bcm for the Low, Medium and High GDP scenarios. Demand from irrigation increases from 768 bcm in 2015 to 1069, 1110 and 1125 bcm in

Table 3.15 Impact of economic growth on water demand (billion cubic metres)

	2015			*2030*			*2050*		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*
Irrigation	764	768	768	1069	1110	1125	1604	1600	1602
Domestic	43	43	43	52	52	52	59	59	60
Industry	7	7	7	16	17	17	27	36	47
Power Generation	50	50	50	9	10	10	14	18	22
Total	864	868	868	1145	1189	1203	1703	1713	1731

2030 and to 1604, 1600 and 1602 bcm for Low, Medium and High GDP growth scenarios. The demand for water from Power of course decreases as we assume MOEFCC guidelines for water conservation in power plants are adhered to from 2017. The demand for water in power sector decreases from 50 bcm to 9, 10, 10 bcm in 2030 and to 14, 18 and 22 bcm in 2050 for the Low, Medium and High GDP Growth rate scenario, respectively.

3.4 IMPACT OF LOW CARBON PATHWAY ON WATER DEMAND

To assess the impact of low carbon pathway and Government of India's proposed power sector policies on water demand we provide a comparative analysis of three scenarios (1) Ref-Medium GDP Growth rate (2) INDC Scenario and (3) AMBLC scenarios as described in Sect. 3.2 for scenarios. The low carbon scenario requires investment in non-fossil power generation capacities like Renewables, Nuclear and Hydro technologies. Coal is the cheapest source of power generation in India and is also confirmed by the choice of supercritical and ultra-supercritical as the preferred technology for Low, Medium and High GDP growth scenarios. A low carbon path would imply a shift in India's power generation from being coal based to other technologies like Gas, Hydro, Solar, Wind, Nuclear and Biomass. Many of the alternative technologies have significant water requirements, though may be much less than coal-based thermal power generation. Thus, low carbon pathways would reduce CO_2 emissions and may also reduce water demand in the power sector. Thus, the net impact on water demand in power sector may be of interest to policymakers. This section deals with the extent to which low carbon pathways reduce the water stress in the economy and secure energy from any likely future water scarcity. The Government of India has come out with many low carbon policies which include no subcritical plants after 2017, 175 GW of renewable energy capacity by 2022, the ambitious Nuclear energy programme and Hydropower plans. In one of the most significant announcements, the Indian Government announced at the Paris COP, its INDCs to reduce emissions intensity by 33–35%, to increase its non-fossil fuel capacity to 40% of its total capacity by 2030. We assess the impact of the announced government plans and policies on water demand in the power sector by comparing the REF scenario with INDC and AMBLC scenario as defined in Sect. 3.2 in the sub-section scenarios.

Table 3.16 shows the impact on various drivers of water demand due to low carbon policies. The results show that impact on GDP is insignificant, but household consumption is lower in the low carbon scenarios.

The power generation decreases in the low carbon scenario due to feedback effect. Power generation increases from 813 BU in 2007 to 3247 BU and 6365 BU, an increase of 4 times and nearly 8 times in 2030 and 2050, respectively, in the Reference Medium GDP growth scenario. The INDC scenario which assumes the 175 GW by 2022 target and the INDC commitments of the Government of India in COP at Paris and the AMBLC scenario which represents a more ambitious low carbon scenario with 60% non-fossil fuel capacity by 2030 brings down power generation. Figures 3.5, 3.6 and 3.7 show the impact on power generation and capacity mix for REF-medium, INDC and AMBLC scenario, respectively.

In the medium growth reference scenario (Fig. 3.5), coal is the dominant source of power generation and has the most major share in capacity. Coal-based thermal power technologies share in generation is 84% (subcritical: 22%, supercritical: 49%, ultra-supercritical: 13%) in 2030 and reduces to 79% in 2050 (subcritical: 11%, supercritical: 25%, ultra-supercritical: 42%). Among non-fossil fuel technologies, share of hydro is 7 and 9%, share of wind onshore is 5 and 8% and solar Phv is 1 and 2% in total generation in 2030 and 2050, respectively. In terms of capacity also Hydro, Wind onshore technologies are major contributors in addition to Solar Photovoltaic. Total capacity increases from 146 GW in 2007 to 575 GW and 1208 GW in 2030 and 2050, respectively. Coal share in total capacity decreased from 68% in 2030 (subcritical: 18%, supercritical:

Table 3.16 Impact of low carbon policies on drivers of water demand

		Year			*CAGR 2011-*	
		2011	*2030*	*2050*	*2030*	*2050*
GDP (Rs. billion)	REF-Medium	59,475	242,957	632,731	7.69	6.25
	INDC	59,361	240,404	635,777	7.64	6.27
	AMBLC	59,368	241,660	645,575	7.67	6.31
Agriculture GDP (Rs. billion)	REF-Medium	5384	13,854	18,856	5.10	3.27
	INDC	5353	13,813	18,849	5.12	3.28
	AMBLC	5365	13,793	19,068	5.10	3.31
Aggregate irrigate area (000 Hectares)	REF-Medium	96,260	139,311	209,587	1.96	2.02
	INDC	96,258	139,313	209,587	1.96	2.02
	AMBLC	96,259	139,311	209,585	1.96	2.02
Industry GDP (Rs. billion)	REF-Medium	29,459	102,650	286,259	6.79	6.00
	INDC	29,382	101,045	328,328	6.72	6.38
	AMBLC	29,391	102,295	471,475	6.78	7.38
Power generation (billion Kwh)	REF-Medium	1074	3247	6365	6.00	4.67
	INDC	1074	3177	6188	5.87	4.59
	AMBLC	1074	3186	6094	5.89	4.55
Per capita consumption (Rs./person)	REF-Medium	23,164	82,408	260,870	6.91	6.41
	INDC	23,024	81,909	260,454	6.91	6.42
	AMBLC	22,877	81,386	258,794	6.91	6.42

40%, ultra-supercritical: 10%) to 59% in 2050 (subcritical: 8%, supercritical: 19%, ultra-supercritical: 32%). Share of hydro increases to 12 and 16%, share of wind onshore to 13 and 18% and solar Phv is 4% in 2030 and 2050, respectively. The share of Solar Photovoltaic is insignificant in generation because it has a low PLF.

Figure 3.6 shows the technology-wise generation and capacity in the INDC scenario. INDC scenario reduces power generation in 2030 to 3177 BU and in 2050 to 6188 BU. The share of non-fossil fuel in power generation and capacity increases mostly because of Solar Photovoltaic without storage. The share of supercritical coal in total generation decreases to 39 and 21% in 2030 and 2050, respectively. Solar Photovoltaic increase its share to 6 and 4% and Nuclear to 3 and 2%, respectively in 2030 and 2050. The total capacity requirement increases to 609 GW and 1237 GW in 2030 and 2050, respectively. The share of supercritical coal in total capacity decreases to 29 and 15%. Solar Photovoltaic share increases to 16 and 10% in 2030 and 2050, respectively.

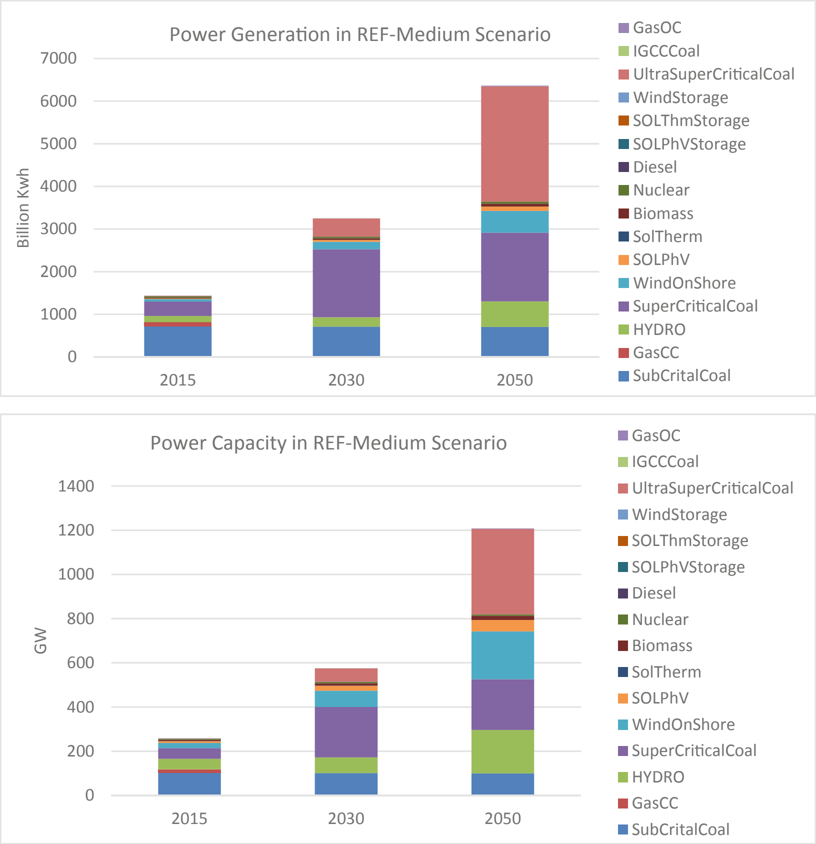

Fig. 3.5 Power generation and capacity in reference medium scenario

In AMBLC scenario the power generation in 2030 is 3186 BU and in 2050 it is 6094 BU. The share of supercritical coal in 2030 and 2050 decreases to 32 and 2%, ultra-supercritical also decreases to 4 and 16%, share of solar Phv is 4 and 2%, wind onshore increases to 7 and 11%, nuclear increases to 14 and 10% and solar Phv with storage increases to 4 and 33%, respectively. Total capacity requirement increases to 660 GW and 1936 GW in 2030 and 2050, respectively. The share of supercritical decreases to 22 and 1% and share of ultra-supercritical coal decreases to 3 and 7% in 2030 and 2050, respectively. The share of wind onshore

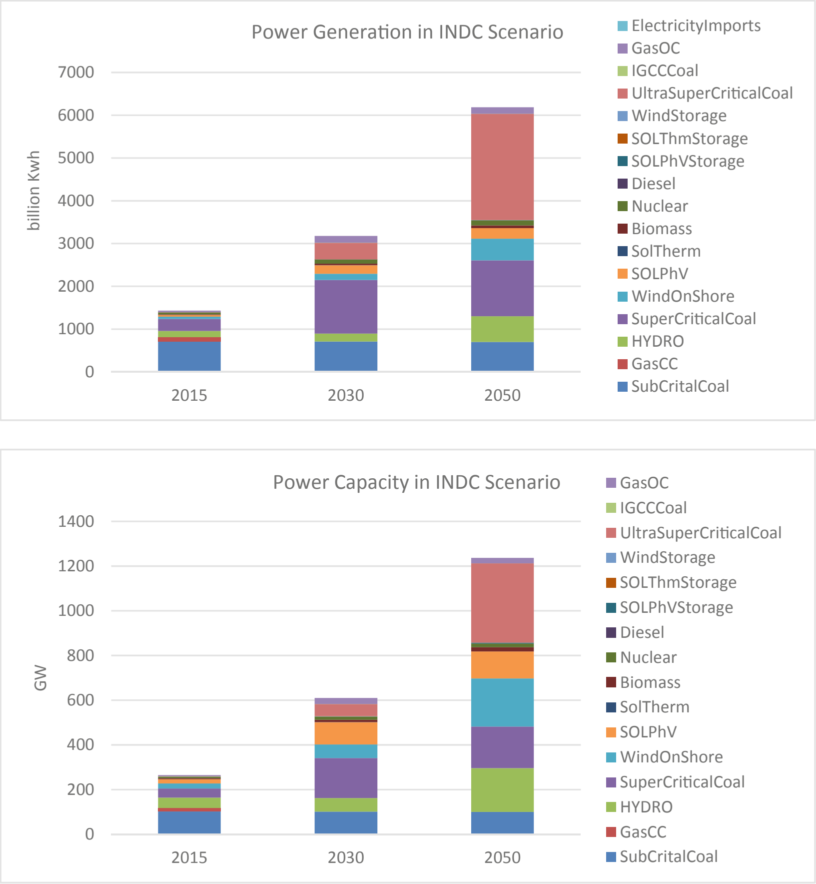

Fig. 3.6 Power generation and capacity in INDC scenario

increases 14 and 15%, nuclear increases to 10 and 5% and solar Phv with storage increases to 9 and 51%, respectively in 2030 and 2050.

Thus, low carbon pathways and government's announced policy and programmes would shift power generation from coal-based thermal power technologies to more wind onshore, solar photovoltaic, solar photovoltaic with storage and nuclear technologies all which have much less water requirements and hence is likely to reduce water demand in power sector. However, low carbon pathways are expected to increase

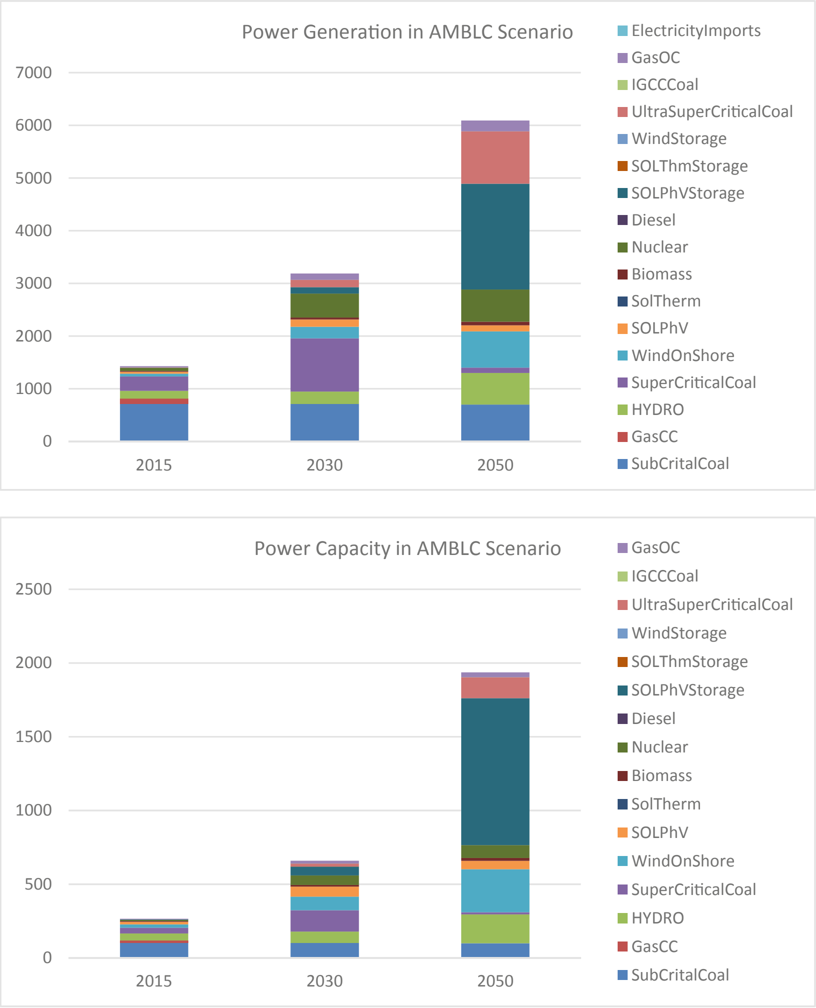

Fig. 3.7 Power generation and capacity in AMBLC scenario

Table 3.17 Impact of low carbon pathway on water demand (billion cubic metres)

	2015			*2030*			*2050*		
	REF-Medium	*INDC*	*AMBLC*	*REF-Medium*	*INDC*	*AMBLC*	*REF-Medium*	*INDC*	*AMBLC*
Irrigation	768	768	769	1110	1109	1108	1600	1600	1600
Domestic	43	43	43	52	52	52	59	59	59
Industry	7	7	7	17	17	17	36	36	38
Power generation	50	49	50	10	9	8	18	17	9
Total	868	867	869	1189	1186	1186	1713	1712	1706

industrial demand due to higher investment requirement of low carbon technologies. Higher industrial demand may increase water demand from the industrial sector.

The impact on water demand for each sector is shown in Table 3.17. The water demand from irrigation and domestic residential households is not affected. Water demand by the Industry too is not much affected except for 2 bcm increase in the case of AMBLC scenario in 2050. Water demand from the power sector is in general decreasing however INDC reduces it by 1 bcm in 2030 and 2050, while AMBLC decreases water demand in power sector by 2 bcm in 2030 and by 9 bcm in 2050.

Thus, low carbon policies are likely to reduce the dependence on water for the power sector and are likely to make the sector less susceptible to water scarcity in future.

3.5 Impact of Water Conservation Policies in Power Sector on Water Demand

Till now all scenarios discussed assumed that water conservation policy announced by the ministry of environment, forests and climate change (MOEFCC) are implemented. In this section we analyse the impact of policy failure of not being able to implement MOEFCC guidelines on power sector water conservation policies. The MOEFCC guidelines issued in 2015 are briefly mentioned Box 3.1.

Box 3.1: MOEFCC Guidelines on water conservation policies in power sector

Standards for Water Consumption vide Notification No. S.O. 3305(E) dated 07.12.2015

1. All plants with Once Through Cooling (OTC) shall install Cooling Tower (CT) and achieve specific water consumption up to maximum of 3.5m3/MWh by 07/12/2017.
2. All existing CT-based plants reduce specific water consumption up to maximum of 3.5m3/MWh by 07/12/2017.

3. New plants to be installed after 1 January 2017 shall have to meet specific water consumption up to maximum of 2.5 m3/MWh and achieve zero waste water discharged.

Policy failure for water conservation would imply continuation of water use technologies as existing in 2015. Hence referring to Table 3.13, to model a policy failure scenario we assume the water withdrawal coefficients in 2015 continue subsequently for all years. Since policy failure of implementing water conservation policies in power sector will only impact the power sector alone hence we restrict the discussions here only to the power sector. We analyse the impact of policy failure here by comparing the Reference medium growth rate with water conservation policy (Ref-Medium) with Reference medium growth rate without water conservation policy (WCF).

Figure 3.8 shows the impact on water demand if water conservation policies of MOEF are not implemented. The comparison of water withdrawal under the two policies from power sector shows that water withdrawal demand from power sector would be nearly 12 times in 2030 and nearly 20 times in 2050. Implementation of water conservation policies in power sector is essential to make the power sector growth secure from uncertainties of water availability in future. This will also make power generation more sustainable.

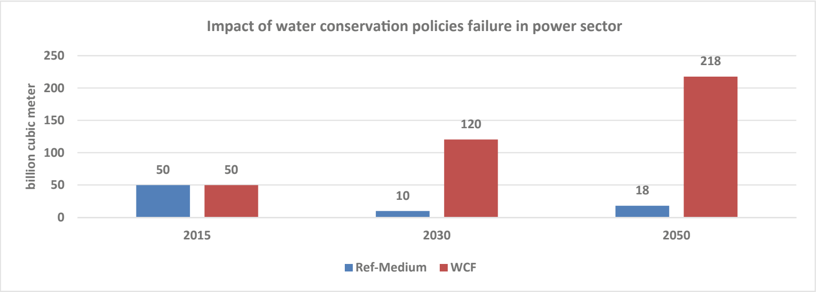

Fig. 3.8 Impact of water conservation policies failure in power sector in the medium scenario

3.6 Conclusions

Water demand for the entire economy is projected in a consistent manner using a macroeconomic model that takes care of macroeconomic relationships, intersectoral linkages and competing demands for water through the FEW nexus. The water demand calculated is consistent with the overall economic growth projected and the structural change that accompanies such a growth. There have been other researchers' and official estimations of water demand in India. Table 3.18 provides two such official projections of sectoral and total water demand.

The official projections from Table 3.18, if compared to the projections in this paper under various scenarios provided in Table 3.19, we can conclude that the total demand projection using the IRADe–IAM model is in the close range of projections by official government agencies for the starting year. The projections in this report in 2015 for irrigation and domestic use are not too far from the projections for 2010. However, there are differences in estimates between the projections by the Ministry of water resources (MOWR) and the National commission on integrated water resources (NCIWRD).

Table 3.18 Government of India agency's projection of water demand

Projected Water Demand in India in BCM (Billion Cubic Metre)

	Standing Sub-Committee of MOWR			*NCIWRD*					
Sectors	*2010*	*2025*	*2050*	*2010*		*2025*		*2050*	
				Low	*High*	*Low*	*High*	*Low*	*High*
Irrigation	688	910	1072	543	557	561	611	628	807
Drinking Water	56	73	102	42	43	55	62	90	111
Industry	12	23	63	37	37	67	67	81	81
Energy	5	15	130	18	19	31	33	63	70
Other	52	72	80	54	54	70	70	111	111
Total	813	1093	1447	694	710	784	843	973	1180

Source Basin Planning Directorate, CWC, XI Plan Document., Report of the Standing Sub-Committee on 'Assessment of Availability & requirement of Water for Diverse uses-2000'

Note NCIWRD (1999): National Commission on Integrated Water Resources Development, BCM: Billion Cubic Metres, MOWR: Ministry of Water Recourses

Table 3.19 Summary projection of water demand from various scenarios analysed

	2015			*2030*			*2050*		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*
Irrigation	764	768	768	1069	1110	1125	1604	1600	1602
Domestic	43	43	43	52	52	52	59	59	60
Industry	7	7	7	16	17	17	27	36	47
Power generation	50	50	50	9	10	10	14	18	22
Total	864	868	868	1145	1189	1203	1703	1713	1731
	INDC	AMBLC	WCF	INDC	AMBLC	WCF	INDC	AMBLC	WCF
Irrigation	768	769	768	1109	1108	1110	1600	1600	1600
Domestic	43	43	43	52	52	52	59	59	59
Industry	7	7	7	17	17	17	36	38	36
Power generation	49	50	50	9	8	120	17	9	218
Total	867	869	868	1186	1186	1299	1712	1706	1913

In 2030 and 2050, the IRADe model estimates of water demand are higher than those of either MOWR or NCIWRD. The highest projection of water demand in 2050 is 1447 bcm by MOWR. This is still lower than the lowest projection among all scenarios of 1703 bcm for Low GDP growth scenario. This could be due to two factors. First, this paper assumed water conservation policies only for the power sector and not for other sectors like irrigation and industry. Secondly, the paper assumed 100% irrigation coverage by 2050 on the basis of the government's slogan of '*har khetme paani*' (water in every field), which increases water requirement for irrigation. Also if one were to assume that sprinkler and drip irrigation would be widely used, the water requirement for irrigation can be reduced by 30%, in which case in 2050, IRADe–IAM model-based projection of water needed for irrigation will be around 1120 BCM close to MOWR projection of 1060 BCM.

The estimate of domestic water in this paper is also much smaller than those by MOWR and NCIWRD. The current norm for supplying water to urban households is 140 litres/day/person, which is higher than the norm of around 90 litres/day/person taken here. Given the severe water crisis faced by Cape Town and similar ones staring in the face of other cities, such as Bengaluru, underscores the need for water conservation in households. India where much of the housing is yet to be built has an opportunity to make them water efficient and build in as much of recycling as possible.

Official estimates (water and related statistics 2010) suggest that India's estimated annual precipitation including snowfall is 4000 bcm. The estimated annual average potential in rivers is 1869 bcm. The utilisable water is estimated to be around 1123 bcm. Climate change is likely to further reduce the utilisable water availability. Both MOWR (1447 bcm) and the scenarios in this paper report higher water demand (around 1700 bcm) than the estimated utilisable water. This further highlights the importance of water conservation in major sectors like irrigation and industry.

The lowest total water demand is of 1703 bcm for Low GDP growth scenario and the highest water demand is of 1913 bcm for water conservation policy failure in power sector scenario. The result underscores the importance of water conservation in power sector. If water conservation policies suggested by the MOEFCC are not implemented, then it can increase water demand in the power sector by almost 200 bcm. Implementing MOEFCC guidelines for water conservation would secure future power generation from uncertainties related to water availability. The scarcity of water is far more serious than indicated by these projections that exceed the estimate of utilisable water as water is distributed unevenly in space and time. Thus not only conservation and efficiency but also storage and transport of water need highest priority.

Annexure 1

Structure of the Model

The IRADe–IAM model is a multi-sectoral, inter-temporal dynamic optimisation model that is bottom-up in the sense that it includes alternative technology options, and top-down in the sense that it covers the whole macroeconomy (similar to Parikh & Ghosh, 2009) and captures the characteristics considered essential by Urban et al. (2007) for models of developing countries. The model is set up in an activity analysis framework and is solved as a linear programming problem using the GAMS programme (Brooke et al., 1998).

The model maximises present discounted value of the total sum of private consumption over the planning period using a real discount rate of 4% subject to various macroeconomic, technological and resource constraints. It uses the Social Accounting Matrix (SAM) for the year 2007–2008 (estimated by Pradhan et al. [2013]) to represent the whole economy and the sectoral interlinkages. The SAM used in the model is aggregated into 25 commodities and 38 production activities. The model ensures that demand and supply balance in the optimal path for each commodity for each period.

$$C_{it} + G_{it} + Z_{it} + IO_{it} + E_{it} \leq Y_{it} + M_{it} \quad \text{for each } i \text{ and } t \tag{3.1}$$

where, $\Upsilon_{i,t}$ denotes output and $M_{i,t}$ denotes imports, $C_{i,t}$ denotes Private consumption, $G_{i,t}$ denotes Government consumption, Z_{it} is vector of investment goods, $IO_{i,t}$ denotes Intermediate demand and exports are denoted by $E_{i,t}$. Intermediate demand $(IO_{i,t})$ is determined using the Input–output coefficients from the SAM.

The private household consumption is disaggregated into ten expenditure classes each for urban and rural areas. The per capita household demand function of each commodity by each consumer class is empirically estimated as a Linear Expenditure System (Stone, 1954) based on an underlying common nonlinear expenditure system (Swamy et al., 1983).

$$C_{iht} = \alpha_{ih} + \beta_{ih0}\left(E_{ht} - \sum_{i} \alpha_{ih}\right) \quad \text{for each } i, h \text{ and } t \tag{3.2}$$

where, C_{iht} = per capita consumption of the ith commodity by the hth household group in tth time period,
α_{ih} = minimum per capita consumption of the ith commodity by the hth household,
$\beta_{ih\ ih}$ = share of the ith commodity in the supernumerary expenditure (total per capita expenditure less the expenditure for minimum consumption) of the hth household and
E_{ht} = Total per capita consumption expenditure of the hth household.

The total number of people in each expenditure class is projected using an estimated log-normal distribution for a given level of total per capita consumption. As incomes rise, per capita consumption increases, which results in people moving from lower expenditure classes to higher classes and adopting the consumption patterns of the higher expenditure classes. This is particularly relevant for energy commodities as with higher income levels people adopt more energy-intensive lifestyles for mobility, electricity and petroleum products. The Linear Expenditure System and the log-normal distribution together provide the estimate of $C_{i,t.}$

The output of any production activity $X_{j,t}$ is constrained by available capital stock in the activity. As incremental capital output ratio, ICOR, changes due to technical progress incremental output is related to incremental capital stock.

$$\left(X_{j,t} - X_{j,t-1}\right) \leq \left(K_{j,t} - K_{j,t-1}\right)/ICOR_{j,t} \quad \text{for each } j \text{ and } t \tag{3.3}$$

where, $X_{j,t}$ = domestic output of the jth sector at time t, $K_{j,t}$ = capital of the jth sector at time t and
$ICOR_{j,t}$ = incremental capital output ratio of the jth sector in period t.

The total output of a commodity is the sum of the output of all production activities that produce that commodity. Thus $Y_{i,t} = U_{ij}{}^{*}X_{jt}$ where U_{ij} is a matrix with a entry of 1 if jth sector produces the ith commodity and zero otherwise.

Capital stock in sector j at time t depends upon the rate of depreciation, and investment at time t.

$$K_{j,t} = DEL(J) * K_{j,t-1} + I_{j,t} \tag{3.4}$$

where *DEL(J)* is the rate of depreciation in sector j, which is exogenous, and $I_{j,t}$ is the investment in sector j.

Aggregate investment resource available in the economy depends on aggregate domestic investible resources (domestic savings determined by the marginal savings rate) and foreign investments in the economy (net capital inflow).

$$\sum_{i}\sum_{j} P_{i,j} * I_{j,t} \leq Z_0 + S * (VA_t - VA_0) + (FT_t - FT_0) \tag{3.5}$$

Investment goods, are identified separately from other commodities and are also allocated to different sectors as fixed proportions $P_{i,j}$ (which reflect the share of *i*th capital good in the *j*th sector) of the total investment ($I_{i,t}$) in *j*th sector at time *t* subject to the availability of investment goods.

$$\sum_{j}\left(P_{i,j} * I_{j,t}\right) \leq Z_{i,t} \tag{3.6}$$

where, $Z_{i,t}$ = demand of commodity i for investment at time *t*, VA_t = value added at time *t*, S = exogenously specified maximum marginal savings ratio, Z_0 = investment in the base year (2007–2008).

The foreign investments in the economy (net capital inflow) are modelled as a positive but decreasing function of GDP (value added) to allow for developing economies to reduce their reliance on foreign investments over time with development as shown in Eq. 3.7.

$$FT_t = (a - b * t) * VA_t \tag{3.7}$$

where FT_t = foreign investment at time *t*.

The balance of payment constraint requires that the foreign exchange earnings through net capital inflows, FT_t and total export earnings are used to meet the foreign exchange requirement from the total import bill. The balance of payment constraint is imposed on the model solution using Eq. 3.8. Trade, exports and imports are endogenous to the model. Upper and lower limits on trade levels are exogenously specified for the model to optimise export and import levels within a reasonable range.

$$\sum_{i}\left(M_{i,t} * MTT_i\right) = \sum_{i} E_{i,t} + FT_t \tag{3.8}$$

The model also imposes monotonicity constraints on outputs and per capita consumption to simulate a smoother pathway. Resource constraints as incorporated for fossil fuel coal, crude oil and natural gas.

Overall, the model's projections for commodity demand and production are sectorally consistent and it satisfies all macroeconomic relationships. This feature helps the model to assess the energy economy and resource linkages in a more consistent manner and hence provides a more consistent assessment of the environmental GHG emissions due to activities in the economy. The IRADe–IAM Model is thus able to give a detailed and comprehensive picture of feasible production levels for each sector given the availability of a scarce resource for which all sectors have a competing demand. In this case the constrained resource is water and the IRADe–IAM model can be used to make an assessment for the feasible levels for agricultural and energy sector growth given the water resources available in India and the kind of water conservation strategy required to optimise growth.

The IRADe–Integrated Assessment Model (IRADe–IAM) was used to assess the water demand for power sector in India and the impact of energy efficiency and water use efficiency measures in power sector.

Table 3.20 Sectoral classifications

	Commodity name	*Production activity name*
Non-energy sectors		
Agriculture		
	Food grains	Food grains
	Sugarcane	Sugarcane
	Oil seeds	Oil seeds
	Other Crops	Other crops
	Animal husbandry	Animal husbandry
	Forestry	Forestry
	Fishing	Fishing
Industry		
	Mining and quarrying	Mining and quarrying
	Agro-processing	Agro-processing
	Textiles	Textiles
	Fertiliser	Fertiliser
	Cement	Cement
	Non-metallic minerals	Non-metallic minerals
	Steel	Steel
	Manufacturing	Manufacturing
	Construction	Construction
	Water supply and gas	Water supply and gas
Services		
	Railway transport services	Railway transport services
	Other transport	Other transport
	Other services	Other services
		Other services with ECBC

(continued)

Table 3.20 (continued)

Commodity name	*Production activity name*
Energy Sectors	
Primary energy sectors	
Coal and lignite	Coal and lignite
Crude petroleum	Crude petroleum
Natural gas	Natural gas
Secondary energy sectors	
Petroleum products	Petroleum products
Electricity	Subcritical coal
	Gas combined cycle
	Hydropower
	Supercritical coal
	Onshore wind
	Solar photovoltaic without storage
	Solar thermal without storage
	Biomass
	Nuclear
	Diesel
	Solar photovoltaic with storage
	Solar thermal with storage
	Offshore wind
	Ultra-supercritical coal
	Integrated gasification combined cycle coal
	Gas open cycle

ANNEXURE 2

See Table 3.20

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CHAPTER 4

Greener Future Through Regional Cooperation

Pankaj Batra

4.1 Introduction

There was a time, in India and likely in all countries, when electrification was started on a large scale for all its citizens. The only issue was to get electricity across to all its citizens, never mind the quality and reliability. Once that step was accomplished, then came the stage of quality and reliability, where the unification of the national grid was started, adequate generation capacity was planned, where redundancy in transmission and distribution system was introduced along with the $n-1$ transmission planning criteria, ring mains for the distribution system, installation of switchable capacitors, etc. This was followed by efficiency in generation, transmission, distribution and utilization. Alongside, countries have also started getting into the optimization of operation of the power system as a

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P. Tiwari and K. Parikh (eds.), *Axes of Sustainable Development and Growth in India*, Sustainable Development Goals Series,
https://doi.org/10.1007/978-981-19-9756-3_4

whole. For example, power trading between States/Distribution companies (control areas) utilizes short or long-term surpluses of power. The granularity of trade was brought down in India to as low as 15 minutes through the power exchange, i.e. an entity could trade (buy or sell power) power for as little a time as 15 minutes. This has resulted in the operating frequency staying in a narrow range of 49.9 and 50.05 Hz. most of the time, thus improving that aspect of power quality. Interruptions at the bulk supply level have become rare. The frequency of large grid disturbances that affect a complete Region has become rare. The last grid disturbance involving a Region happened in 2012, after a gap of 12 years. Access to electricity in India is now 100%. The number of hours of power supply even to villages has increased substantially. According to a study done by Prayas, an NGO based in Pune, India, the number of hours of supply to villages is 17–18 hours in a day, up about 6 hours in 6 years. Because of optimization, the thermal power plants started operating with higher utilization and lower emissions. The tripping of units was reduced because the grid became stable on account of unification.

4.2 History of Cross-Border Trade in South Asia

This optimization of power resources has now crossed over beyond national boundaries. Power started getting exported radially from India to Nepal, in the year 1971, to the border areas of Nepal, which were disconnected from the Nepalese grid. Power export increased substantially to Nepal after the commissioning of the Double Circuit 400 kV Muzzaffarpur Dhalkebar line in February 2016, initially charged at 132 kV, upgraded to 220 kV in August 2018 and further upgraded to 400 kV in November 2020, signifying the increased carrying capacity and plan for greater trade. Now, more such cross-border lines between India and Nepal are in the planning stage.

A bilateral agreement with Bhutan has resulted in hydropower from Bhutan flowing to India, from 1986, from the 336 MW Chukha Hydro Project. The 1020 MW Tala Hydro Project followed this. Multiple hydro projects are now under construction in Bhutan, primarily for agreement for the sale of power to India.

India started exporting power to Bangladesh in December 2013, after commissioning the Baharampur (India)—Bheramara (Bangladesh) 400 kV D/C line and the first 500 MW HVDC back-to-back terminal at Bheramara, through the Western border of Bangladesh. Power export from India to Bangladesh increased by 160 MW, after another 400 kV (operated at 132 kV) cross-border line radial interconnection from Surajmaninagar in Tripura in India to Comilla in Bangladesh, through the Eastern border of Bangladesh, was commissioned in 2016. Power export to Bangladesh was further enhanced from the Western border by adding a second pole to the HVDC link at Bheramara in July 2018.

Both Nepal and Bangladesh have gained substantially from the power import from India. Both have become power cut free, except where the internal transmission and distribution system has not been strengthened within the respective countries. As per the World Bank, Bangladesh GDP growth surged to 8.2% in 2019 to become the fastest growing economy in South Asia due to industries getting more power.

The cross-border flow of power from India to these neighbouring countries has helped in better utilization of the coal-based generation power plants in India, and therefore helped in marginally higher plant load factors, thereby resulting in lower emissions per unit of generation since operating at lower levels of generation decreases the efficiency of the power plant.

There are also now discussions between India and Sri Lanka on connecting the grids of the two nations through an HVDC line. That would result in a further transfer of power between the two nations on a requirement basis. Sri Lanka can immediately benefit from the availability of power from India. Transmission tariff, in general, is about one-tenth the generation tariff, which is a result of the relatively lesser capital cost of transmission vis-à-vis a generation project and the higher period of amortization because of the longer life of the transmission system, as compared to that of a generating plant. The cost of an HVDC system (line plus HVDC stations at either end) is higher than that of an AC system but would still be more economical than setting up generating capacity in Sri Lanka in the long run. A cost–benefit analysis could nudge the project into faster implementation.

Also, what is set to be tapped is the diversities of peak demands between the South Asian countries, daily peak demand and seasonal peak demand for free flow of power compared to fixed long, medium and short-term contracts presently. **The SAARC Framework Agreement for Energy Cooperation (Electricity)** was signed between the SAARC nations in November 2014. Since India is at the centre of the SAARC nations and the largest nation among these countries, both geographical area, population and power demand and generation, India must be involved to cross-border trade in electricity further. The Ministry of Power, Government of India, issued the revised "**Guidelines for Import/Export (Cross Border) of Electricity**" in December 2018 to encourage cross-border trade in electricity. This was followed by the **Cross-Border Trade of Electricity Regulations** made by the Central Electricity Regulator of India, the Central Electricity Regulatory Commission, in March 2019. The Central Electricity Authority has, on 26 February 2021, come out with the **Procedure for approval and facilitating Import/Export (Cross-Border) of Electricity) by the Designated Authority**, a requirement of the Guidelines issued by the Government of India in 2018. This should open the gates for an increase in the trade of power in South Asia and further optimize South Asia's power resources.

4.3 Exploiting Diversities of Peak Demand and Generation Resources in South Asia

Exploiting the diversities of peak demand and generation resources in South Asia is the name of the game of optimization of power resources. The South Asian countries have been blessed with a diversity of natural energy resources. Whereas India has large quantities of coal and renewable energy, Bangladesh has predominantly gas resources, and Bhutan and Nepal have hydropower resources predominantly. Sri Lanka has hydro resources and is largely dependent on fossil fuel imports for other power generation sources. It is exploring some underwater gas resources in its basins, as well as renewable energy.

Bhutan and Nepal have their peak seasonal demand in winter, i.e. December to February when their hydropower generation is the least, whereas the peak seasonal demand in India and Bangladesh is in summer, from May to September. Bhutan and Nepal are generating at their maximum in the summer season, whereas their demand is at its lowest. If Nepal has access to the power markets of India and Bangladesh, they would not need to spill water from their hydropower plants, which is zero-cost energy going waste, because of lack of demand. So, if outage planning is done on a regional basis, and agreement of barter of power done between entities of Nepal and India, India could plan the scheduled maintenance of its coal-based power plants during the summer season and bring these plants up for supply to Nepal during the winter months. During the summer months, India could take power from Nepal.

There are also opportunities of utilizing diversities of demand during the day in the non-monsoon seasons. When there is less inflow of water in winter, this water could be optimized for generating only during the peak time during the day, i.e. say 6 to 9 pm. In contrast, during the off-peak time, power could be imported from India. There are endless possibilities for using this diversity of demand and supply resources in different seasons to different extents once the analytics are done. All this would help in reducing emissions, and hence a greener environment.

4.4 Expanding the Geographical Areas for Balancing of Intermittency of Renewables

Another reality that has disrupted our lives, is that of concern for our environment, and rightly so. Extreme weather events have increased due to higher carbon emissions. Environmental concerns have led to a global agreement to go for more and more renewable sources of energy. A major portion of the renewable energy sources in Asia is located in India, largely wind and solar power. According to the latest assessment of renewable energy potential in India by MNRE (Annual Report 2017–2018), the solar potential of wind power (at 100 metres hub height) is 302 GW. That of solar is 749 GW. The present installed capacity in India is about 38 GW wind and 37 GW of solar. So, there is huge untapped potential. The other South Asian countries also have renewable energy potential. In India, because of the vast market for setting up renewable energy plants, due to India's commitment to meet high renewable energy targets, prices of renewable energy are one of the lowest in the world. The other South Asian countries can either set up renewable energy plants in their countries or buy this renewable power from renewable energy plants in India instead of setting up new fossil fuel-based plants to fulfil their commitment to the world.

In either case, the intermittency of renewable power plants like wind and solar power has to be tackled since generation takes place in these plants depending on the vagaries of nature. At present, tackling this intermittency in India lies with the host state, where the renewable plants are located, and this is done mainly from their hydro plants unless constrained by irrigation requirements and coal-based plants. Coal-based plant is, by nature, baseload plants, not meant to fluctuate their generation frequently over the day, which would adversely affect their health. There would be a loss of efficiency of the plant and an increase of auxiliary consumption per unit of generation, besides under-utilization of a plant to its capacity. It would also cause increased emissions of carbon and oxides of sulphur and nitrogen per unit of generation, emissions of sulphur and nitrogen being subject to norms of the Environment Ministry in India. In addition, the plant would be subjected to heat stresses, which could cause fracture of the parts of the boiler or turbine subjected to heat variations and therefore cause damage to the plant. A picture of such damage to the main steam valve is shown below (Fig. 4.1).

Remedies exist by making existing coal-based plants more flexible in their operation, at a low cost, to monitor the temperature in the various thick metal parts of the plant, which are subjected to temperature variation and consequently heat stresses. However, since these plants would be operating at low power factors, they would be emitting higher emissions per unit of generation, as mentioned earlier. By contrast, hydropower plants are flexible, and can ramp generation up and down very quickly. It can go from zero generation to full generation in 2 minutes, with no adverse effects.

Expanding the balancing areas would be a more efficient solution. Wind and solar power are largely located in 8 states of India, but balancing sources are spread worldwide. Balancing would first need to be introduced on a national basis to use the collective balancing capability

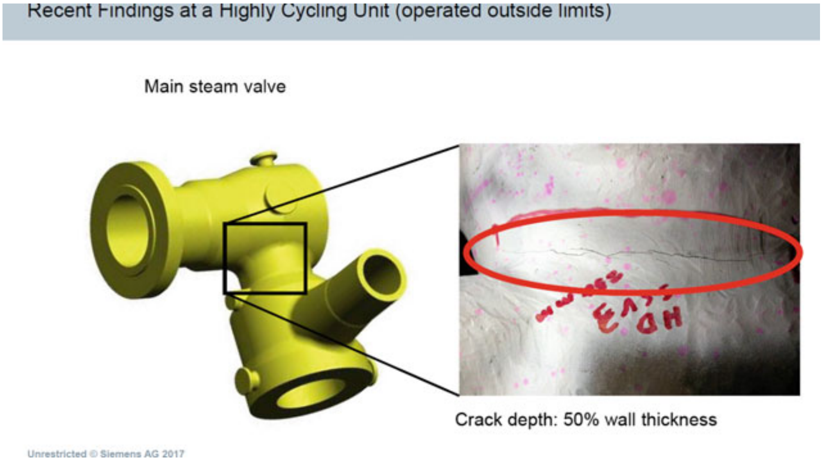

Fig. 4.1 Damage to the main steam valve

for mitigating the intermittency of these renewable sources of energy. Expanding the balancing areas further, beyond national boundaries, the storage and pondage hydropower plants of Bhutan and Nepal could provide an ideal foil to the intermittency of wind and solar (when clouds suddenly cover the sun, making solar generation drop suddenly—please see the figure below, Fig. 4.2, generation curve of Charanka solar park in Gujarat over a day in September 2012) generation.

For the normal cycle of daily solar generation, when the generation becomes zero after the cycle, say at 6 pm, some other generation needs to replace this energy. This can be planned either through hydropower generation, which is ideal, if available, or ramping up of gas-based generation, which is quicker to ramp up than coal-based generation. The fluctuations of wind generation (Please see the fluctuations of wind generation in Gujarat for six days from June to August 2015 in Fig. 4.3). This is the aggregate wind generation in the State, which has already reduced the intermittency because of the geographical separation. Individual wind farms have much higher fluctuations. Energy storage may also be used to mitigate the intermittencies, which could be pumped storage power plant, grid-scale battery or any other form of storage, but most of these technologies are relatively expensive.

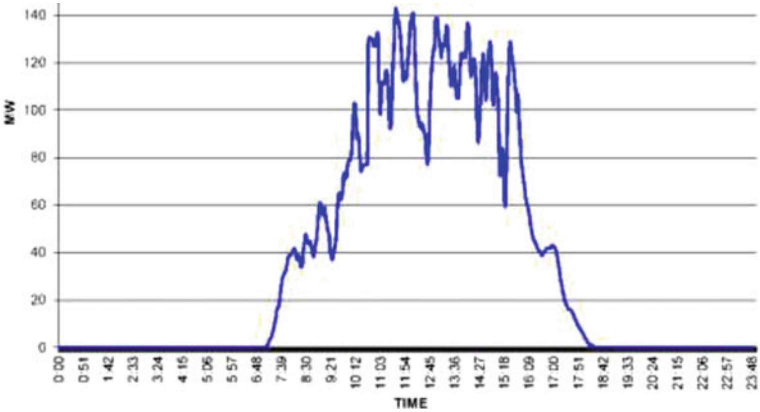

Fig. 4.2 Generation curve of Charanka solar park in Gujarat

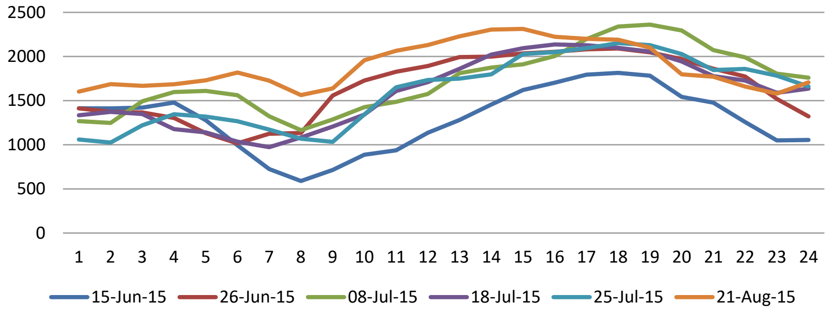

Fig. 4.3 Wind Generation Scenario during monsoon in Gujarat

Since, in the normal cycle of the day, solar generation ramps down slowly and the peak demand also comes up gradually, coal-based generation can also be planned so that the ramp rate is 1–2% per minute for each coal-based plant, which is allowed without any adverse effects.

Figure 4.4 shows the anticipated load curve of India, for the peak load day in 2021–2022, as per the CEA's National Electricity Plan, and how this is likely to be met from the existing generation sources in India (Reserves are also shown). The curve shows that coal-based generation is backed down from about 08.00 hrs to 17.00 hrs when solar power generation is taking place. Now, if this backed-down generation could be exported to Nepal during the day, and the water in the reservoirs in Nepal stored so that hydropower generation of Nepal could be exported back to India during the peak hours, that would be optimum utilization of the generation resources in both countries. It would also require lesser reserves on a South Asian basis. The emissions per unit of generation would reduce substantially by regional cooperation and at a reduced cost.

4.5 Conclusion

The benefits of expanding the balancing areas through regional cooperation, therefore, are:

a. Better utilization of power resources of the South Asia Region.
b. Enable higher integration of renewables.
c. Better utilization of coal-based stations.

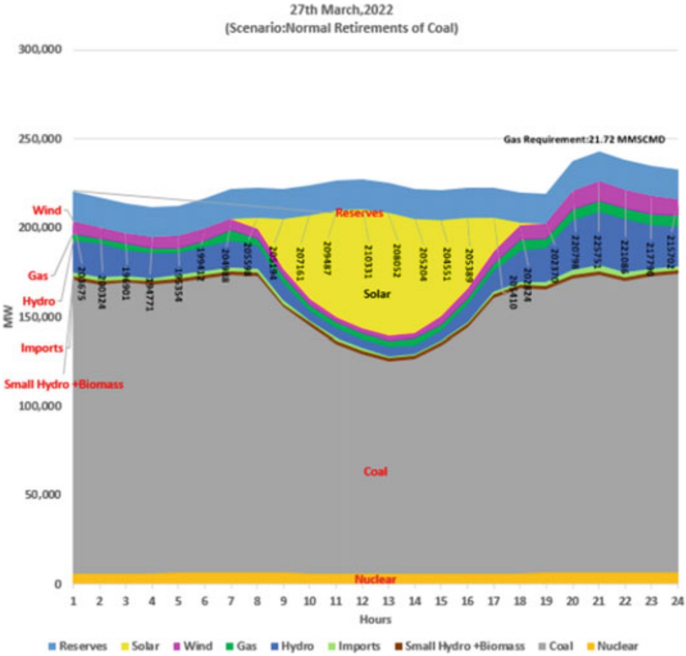

Fig. 4.4 Anticipated load curve for India

d. Optimum use of hydro generating stations.
e. Less requirement of energy storage.
f. Lesser emissions.

This, in sum, would lead to a greener world and a greener future for the people of this world.

CHAPTER 5

Regional Energy Trade in BIMSTEC Region: Facilitating Clean Energy Transition and Fostering Sustainability

Rajiv Ratna Panda

5.1 Introduction

BIMSTEC is a group of seven member governments that make up the Bay of Bengal Initiative for Multisectoral Technical and Economic Cooperation (BIMSTEC) (Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka, and Thailand). The Region Links South and Southeast Asian (SSEA) Nations Together and Facilitates Bilateral Economic, Political, and Sectoral Ties Between Nations.

Climate Change (CC) and natural resource degradation impact on peoples' lives and livelihoods across the BIMSTEC region, with most

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vulnerable and economically disadvantaged members of society experiencing its harshest effects. With a population of 1.9 billion people and significant coastal towns that rely on natural resources for survival, this area is especially vulnerable to the effects of climate change. The BIMSTEC region is now more vulnerable to the escalating effects of climate due to accelerated melting of Himalayan glaciers, which has caused floods and landslides in the region's hills and plains or raised sea levels. Since the 1990s, fossil CO_2 emissions (FCo_2E) have risen in BIMSTEC nations (Fig. 5.1). The region's FCo_2E has increased by 330% and 47%[1] during 1990 and 2010, respectively, as of 2018 Fig. 5.2. The power sector contributes significantly to the total FCo_2E in the region. The region's total FCo_2E is heavily influenced by the power industry. According to the 2019 study on fossil CO_2 and GHG emissions of the world countries,[1] data analysis for the year 2018 reveals that the power sectors in the BIMSTEC region are responsible for 44% of FCo_2E. The region has seen a rise in fossil CO_2 emissions from the power industry of 446% and 51% from 1990 and 2010 levels, respectively Fig. 5.1. In the year 2018, According to FCo_2E data of 2018, the power sector contributed 46% to India, 43% to Bangladesh, 35% to Sri Lanka, and 33% to Thailand.[1] This is primarily due to the dominance of fossil fuels in power generation, i.e., Coal in India, natural gas in Bangladesh, and

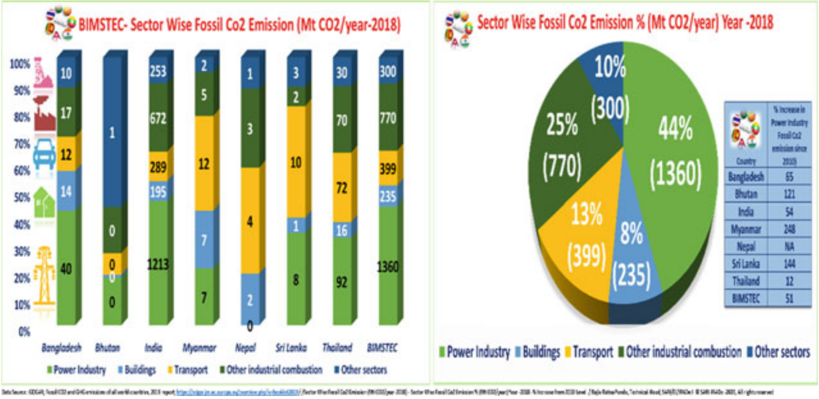
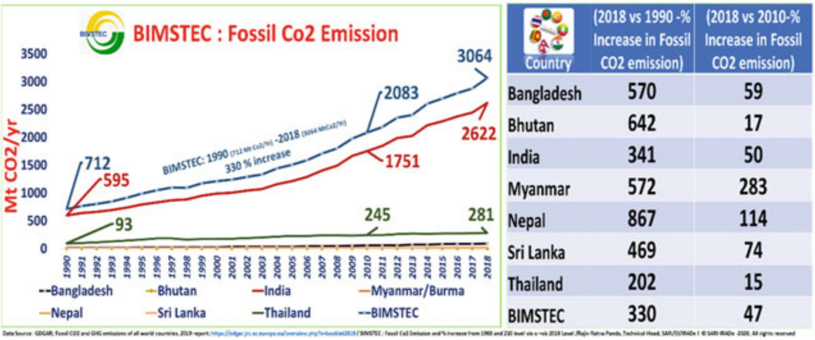


Fig. 5.1 Sector-wise CO_2 emission (Mt CO_2/year 2018) and % increase from 2010 level[1]



Country	(2018 vs 1990 -% Increase in Fossil CO2 emission)	(2018 vs 2010-% Increase in Fossil CO2 emission)
Bangladesh	570	59
Bhutan	642	17
India	341	50
Myanmar	572	283
Nepal	867	114
Sri Lanka	469	74
Thailand	202	15
BIMSTEC	330	47

Fig. 5.2 BIMSTEC-Fossil CO_2 emission and % increase from 1990 to 2010 level vis-a-vis 2018 level[1]

Thailand. Around 48% of the power energy mix is coal, and 20% is renewable energy (RE), excluding major hydro, hydro makes up 13%, oil & diesel accounts for 8.2%, and gas makes up 14% in the year 2019[1,2] of BIMSTEC region. The majority of the large BIMSTEC nations are sensitive to disruptions in the world's energy supply since they import a significant portion of their energy demands from elsewhere.

5.2 Commitment by BIMSTEC Countries to Address Climate Change

Health, livelihoods, food security, access to water, human security, economic progress, and the creation of a sustainable BIMSTEC area are all under risk due to climate change in BIMSTEC countries. Recognizing the difficulty, BIMSTEC nations have been working to raise the proportion of renewable energy and lower emissions, and in 2015 they submitted Intended Nationally Determined Contributions (INDCs) to UNFCC. Bhutan, the country that invented "Gross National Happiness", has pledged to maintain its carbon neutrality. The emission of greenhouse gases will not exceed carbon sequestration by Bhutan's forests, estimated at 6.3 million tonnes of CO_2 as per the INDC submitted.[3] As per the INDC submitted,[3] Bhutan offsets 4.4 million tonnes of CO_2e through hydroelectricity exports. Besides, Bhutan can offset up to 22.4 million tonnes of CO_2e per year by 2025 in the region by exporting electricity from the clean hydropower projects. Bangladesh is one of the fastest-growing economy in the region[4] and has committed to an unconditional contribution to reduce GHG emissions by 5% from Business as Usual (BAU) levels by 2030[5] in the power, transport, and industry sectors, based on existing resources and conditional 15% reduction[5] in GHG emissions from BAU levels by 2030, subject to appropriate international support in the form of finance, investment, technology development, transfer, and capacity-building.[5] Thailand committed to reducing its greenhouse gas emissions by 20% from the projected business-as-usual (BAU) level by 2030.[6] Thailand's contribution level could increase up to 25%, subject to adequate and enhanced access to technology development and transfer, financial resources, and capacity-building support.[6]

India, the largest and the biggest economy in the region, has committed to reducing its GDP intensity by 33 to 35% by 2030[7] from the 2005 level. It also commits to achieve about 40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 with the help of the transfer of technology and low-cost international finance, including the Green Climate Fund (GCF). Nepal[7] plans to add 12,000 MW Hydropower, 2100 MW of solar power, 220 MW of bioenergy, 50 MW of electricity from small and micro hydropower plants in 2030.[7] Myanmar[8] plans to increase hydroelectric generation within the limits of Hydroelectric technical potential, 9.4 GW by 2030[8] 0.3.

5.3 Low Per Capita CO_2 Emission and Electricity Consumption

Although the absolute emissions are rising, the BIMSTEC countries are among the least responsible for contributing to global warming on a per capita basis even though they are the ones who must deal with its negative effects. Except Thailand, all other BIMSTEC countries' Fossil CO_2 per capita is less than 2 t CO_2/cap/year,[1] while the global average is 4.97 t Co_2/cap/year Fig. 5.3. Additionally, this demonstrated how remarkably low BIMSTEC Countries' Per Capita Electricity Consumption (PCEC) is high when compared to other nations/regions. The PCEC[9] ranges from 190 kWh per person for Nepal to 2821 kWh per person for Thailand, 2976 for Bhutan and the region on average, it is only around 1086 kWh per person, which is much lower than the world average of 3132 kWh per person Fig. 5.3. This illustrates the comparatively low standard of living in comparison to other nations/regions of the world caused by

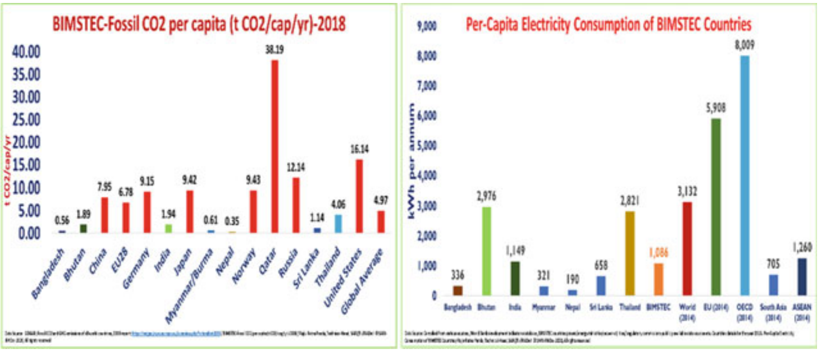
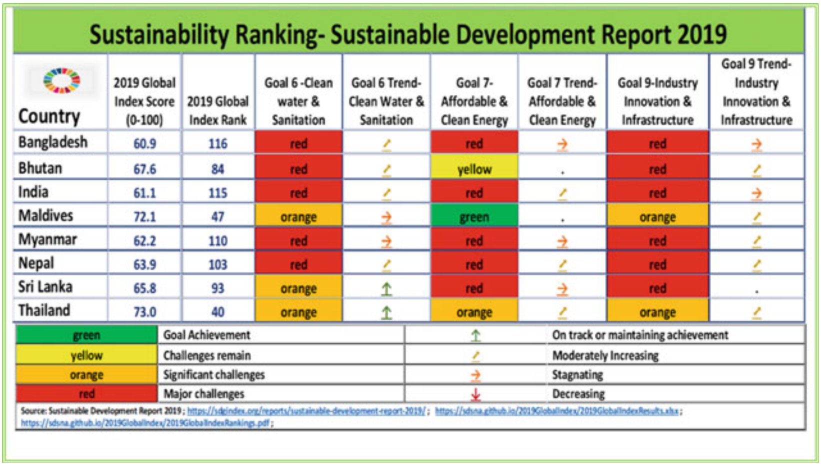


Fig. 5.3 BIMSTEC-Fossil CO_2 per capita comparison 2018 and per capita electricity consumption[1,2,9]

limited energy resources, despite the BIMSTEC region's installed electricity capacity more than doubling since 2010, from 176 GW in 2010 to 447 GW by 2019. Developmental goals must therefore be matched with concerns about climate change, and methods must be developed equitably with just burden-sharing and a common goal and shared vision.

5.3.1 *BIMSTEC's Sustainability Challenges*

The 2030 Agenda for Sustainable Development[10] was adopted by all United Nations Member States in 2015, with 17 Sustainable Development Goals (SDGs). It recognizes that "ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth–all while tackling climate change and working to preserve our oceans and forests".[10] Out of 17 SDGs, some of the more relevant goals with strong linkage to the energy sector are Goals 6, 7, and 9. Goal 7 focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all; Goal 6 stresses ensuring the availability and sustainable management of water and sanitation for all; and Goal 9 aims to build resilient infrastructure and promote inclusive and sustainable industrialization foster innovation. Despite the strong emphasis on renewables by the BIMSTEC country government and other aspects to achieve SDGs, achieving sustainability continues to remain a challenge in the BIMSTEC countries. As per the Sustainable Development Report 2019[11] (which reports where each country stands with regard to achieving the SDGs), except Maldives (47) and Thailand (40), all other BIMSTEC countries rank below the top 50 countries. Bangladesh ranks (116) the lowest among BIMSTEC countries, India ranks (115) second lowest. On the affordable and clean energy achievement (SDG-7) front Fig. 5.4, only Maldives has achieved the target,[11] while most of the other BIMSTEC countries are facing major challenges (Bangladesh, India, Myanmar, Nepal, and Sri Lanka) in this regard.[11] It is well known that there is a strong linkage between water and energy. Energy has an important role in achieving SDG-6, i.e., on sustainable water management, access to clean water, and sanitation. Ensuring clean water and sanitation requires robust, state-of-the-art efficient energy systems, while the energy sector needs water as input across its value chain. On one hand, energy use is vital for a wide range of activities related to sustainable water management, including water processing, distribution, wastewater treatment, and desalination, on the other hand, (as per the IEA report on Water–Energy Nexus)[12] the energy sector is responsible for 10% of global water withdrawals, mainly for power plant operation as well as for production of fossil fuels and biofuels. On ensuring the availability and sustainable management of water and sanitation for all (SDG-6), no BIMSTEC country has achieved the goal.



Sustainability Ranking- Sustainable Development Report 2019

Country	2019 Global Index Score (0-100)	2019 Global Index Rank	Goal 6 -Clean water & Sanitation	Goal 6 Trend-Clean Water & Sanitation	Goal 7-Affordable & Clean Energy	Goal 7 Trend-Affordable & Clean Energy	Goal 9-Industry Innovation & Infrastructure	Goal 9 Trend-Industry Innovation & Infrastructure
Bangladesh	60.9	116	red	↗	red	→	red	→
Bhutan	67.6	84	red	↗	yellow	.	red	↗
India	61.1	115	red	↗	red	↗	red	→
Maldives	72.1	47	orange	→	green	.	orange	↗
Myanmar	62.2	110	red	→	red	→	red	↗
Nepal	63.9	103	red	↗	red	↗	red	↗
Sri Lanka	65.8	93	orange	↑	red	→	red	.
Thailand	73.0	40	orange	↑	orange	↗	orange	↗

green	Goal Achievement	↑	On track or maintaining achievement
yellow	Challenges remain	↗	Moderately Increasing
orange	Significant challenges	→	Stagnating
red	Major challenges	↓	Decreasing

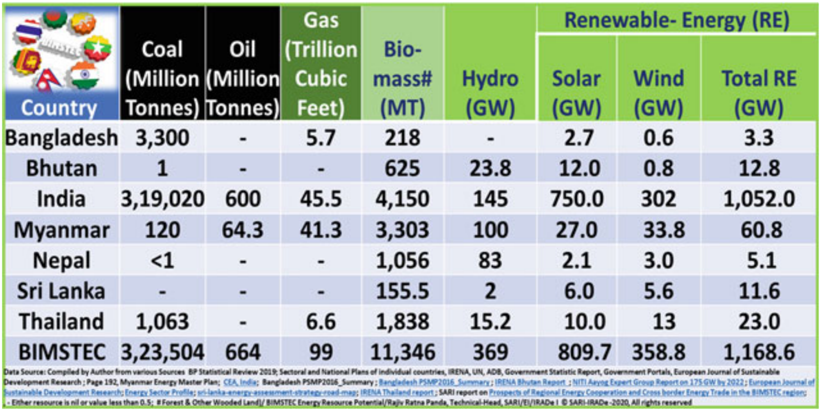
Source: Sustainable Development Report 2019; https://sdgindex.org/reports/sustainable-development-report-2019/; https://sdsna.github.io/2019GlobalIndex/2019GlobalIndexResults.xlsx; https://sdsna.github.io/2019GlobalIndex/2019GlobalIndexRankings.pdf;

Fig. 5.4 Sustainability ranking of BIMSTEC countries-sustainable development report 2019[11]

Most BIMSTEC countries are facing major challenges (Bangladesh, India, Myanmar, Nepal, and Sri Lanka), while the rest (the Maldives, Sri Lanka, and Thailand) are facing significant challenges.[11] Modern energy systems and clean energy supply are required for water processing, sustainable water management, delivery of clean water, and quality sanitation sustainably in the BIMSTEC region, whereas energy system needs robust water supply; and these linkages have enormous significance and profound implication for economic growth, life, and well-being of the people of BIMSTEC countries on a sustained basis.

5.3.2 Sustainable Energy Resource Potential

Among the fossil fuel, BIMSTEC region is well endowed with abundant natural energy resources, comprising 323 billion tonnes of coal, 664 million tonnes of oil, 144 trillion Cubic Feet (TCF) of natural gas, 11,346 million tonnes of biomass. The region is equally endowed with large amount of non-fossil fuel recourse, 369 GW of large hydropower and renewable energy (solar and wind) of 1168 GW potential Fig. 5.5, though a large part of it remains untapped. Only a small percentage of these resources have been used as a result of the lack of a strong and comprehensive regional view or approach, as well as the lack of



Country	Coal (Million Tonnes)	Oil (Million Tonnes)	Gas (Trillion Cubic Feet)	Bio-mass# (MT)	Hydro (GW)	Renewable- Energy (RE)		
						Solar (GW)	Wind (GW)	Total RE (GW)
Bangladesh	3,300	-	5.7	218	-	2.7	0.6	3.3
Bhutan	1	-	-	625	23.8	12.0	0.8	12.8
India	3,19,020	600	45.5	4,150	145	750.0	302	1,052.0
Myanmar	120	64.3	41.3	3,303	100	27.0	33.8	60.8
Nepal	<1	-	-	1,056	83	2.1	3.0	5.1
Sri Lanka	-	-	-	155.5	2	6.0	5.6	11.6
Thailand	1,063	-	6.6	1,838	15.2	10.0	13	23.0
BIMSTEC	3,23,504	664	99	11,346	369	809.7	358.8	1,168.6

Data Source: Compiled by Author from various Sources BP Statistical Review 2019; Sectoral and National Plans of individual countries, IRENA, UN, ADB, Government Statistic Report, Government Portals, European Journal of Sustainable Development Research ; Page 192, Myanmar Energy Master Plan; CEA, India; Bangladesh PSMP2016_Summary ; Bangladesh PSMP2016_Summary ; IRENA Bhutan Report ; NITI Aayog Expert Group Report on 175 GW by 2022 ; European Journal of Sustainable Development Research; Energy Sector Profile; sri-lanka-energy-assessment-strategy-road-map; IRENA Thailand report ; SARI report on Prospects of Regional Energy Cooperation and Cross border Energy Trade in the BIMSTEC region;
- Either resource is nil or value less than 0.5; # Forest & Other Wooded Land)/ BIMSTEC Energy Resource Potential/Rajiv Ratna Panda, Technical-Head, SARI/EI/IRADe I © SARI-IRADe-2020, All rights reserved

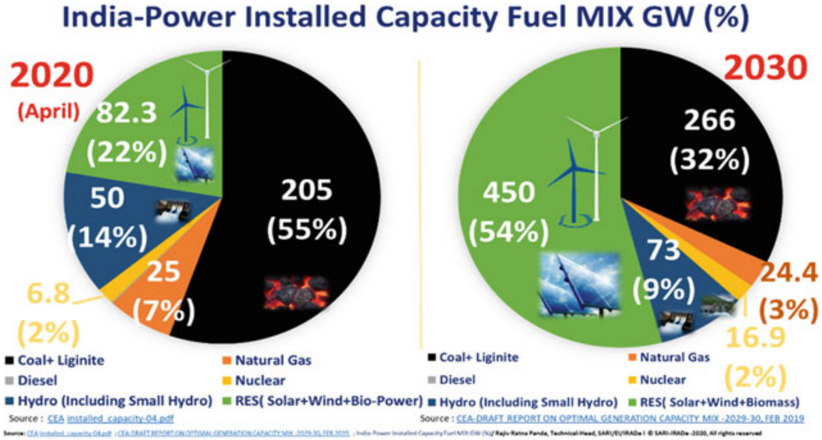
Fig. 5.5 Energy resource potential-sustainable resources in the BIMSTEC region[13] widespread regional energy cooperation and due to the reliance on the bilateral method of cooperation as the dominant mode of energy cooperation. Against the total hydro potential of 369 GW, the BIMSTEC's total installed hydropower capacity is only 57 GW (15.44%) has been exploited so far. Similarly, a large amount of renewable energy (wind, solar, and hydro) remains to be tapped out of 1168 GW of potential though some progress has been made. There is a huge amount of resource diversity among the BIMSTEC countries. The abundant source of coal resources is mainly concerted in India (319 billion tonnes), followed by Bangladesh (3.3 billion tonnes) and Thailand (1 billion tonnes). India (145 GW), Myanmar (100 GW), Bhutan (83 GW), and Nepal (23.8 GW) have significant hydropower potential. Renewable energy potential is dominated by India (1052 GW), followed by Myanmar (60.8 GW) and Thailand (23 GW). These resource diversities along with complementarity in season energy demand-supply situation creates the condition to incentivize the need to aggressively pursue regional exploitation of energy resources mutually among BIMSTEC countries in a climate constrained world.

5.3.3 Regional Energy Trade (RET) for Clean Energy Transition (CET) and Sustainability

Addressing climate change and fostering rapid clean energy transition require regional energy cooperation and a collective approach. The presence of a large coal-based generation capacity, and the reliance on fossil fuel, are imposing an increasing burden on the environment in the region both at the national and regional levels. Fortunately, Regional Cross-Border Energy (Electricity) Trade (RCBEeT) provides BIMSTEC countries with an excellent opportunity with an economic rationale to take forward the Clean Energy Transition (CET) and Sustainability agenda. RCBEeT, through economies of scale, pooling of power grids with diverse demand and supply and tapping into cross-border renewable energy resources, can accelerate the transition to sustainable energy, meet growing demand, and reduce the cost of supply. RCBEeT can lead to the effective utilization of natural resources, increase the reliability of power supply, enable mutual support during contingencies, contribute to economic growth, substantially promote energy market integration and act as the single most effective confidence-building measure in the region.

RE potential cannot be developed fully unless there is a regional approach as the domestic requirement in some resource-rich countries may be limited compared to the potential available. For example, Bhutan and Nepal have 23.8 GW and 83 GW[14] hydropotential, respectively, whereas the domestic demand is limited. For example, Bhutan's projected electricity demand will be around 1.15 GW[15] only in 2040. Similarly, Nepal's projected peak demand is expected to be around 7.4 GW[16] by 2034. Myanmar, which possesses the second-highest hydropower potential (100 GW), projected electricity demand would be around 14,542 MW[17] only in 2030. Therefore, a regional approach through CBET would help the sustainable development of such RE resources through economies of scale and diversification of market, thereby higher share of hydroelectric capacity, which leads to significantly reducing the carbon footprint of the BIMSTEC power sector, otherwise, most of the resources will remain untapped.

BIMSTEC's power generation capacity is projected to increase from 293 GW in 2014 to almost 904 GW in[19] 2030, a threefold increase as per the BIMSTEC energy outlook in 2030.[18] RE-based capacity addition is expected to grow at an annualized rate of 16.6%, increasing from 38 GW in 2015 to 383 GW in 2030. In 2030, the proportion of renewable energy in the mix of power will be the highest (42%) as compared



Source : CEA installed_capacity-04.pdf

Source : CEA-DRAFT REPORT ON OPTIMAL GENERATION CAPACITY MIX -2029-30, FEB 2019

Source: CEA installed capacity-04.pdf ; CEA-DRAFT REPORT ON OPTIMAL GENERATION CAPACITY MIX -2029-30, FEB 2019 ; India Power Installed Capacity Fuel MIX GW (%)/ Rajiv Ratna Panda, Technical Head, SARI/EI/IRADe | © SARI-IRADe-2020, All rights reserved

Fig. 5.6 India-power installed capacity fuel MIX GW (%) 2020 versus 2030[18] to 12% in 2015. This percentage is also anticipated to grow further and very quickly as Thailand and India updated their plans for RE. India's renewable energy goals have been sharply raised to 450 GW[19] of RE by 2030 from the earlier target of 175 GW by 2022. India now has 82 GW of installed renewable energy (Wind, Solar, and Biopower) capacity (April 2020). By 2030, the proportion of renewable energy (RE)—Wind, Solar, and Biopower—to the total installed capacity is expected to be around 54%, up from the current 22% Fig. 5.6[18]of the BIMSTEC region. From 2020 to 2030, coal's share will drop from 55 to 32% Fig. 5.6. The Government of Thailand, the second-largest economy in the region, has agreed to increase the non-hydro RE target from 20 to 30% by 2036[20] (about 15% of Thailand's total energy consumption was provided by renewable energy as of April 2018).[20]

A robust BIMSTEC Grid can have significant environmental and sustainability impacts. With the high penetration of renewable energy required in the near future, particularly from intermittent sources such as solar and wind, there is a need to manage concerns related to balancing the power grid and its security and stability. Hydropower of Nepal, Bhutan, and Myanmar, if developed properly, can address these challenges/issues related to the integration of renewable generation as hydro is one of the important and proven balancing sources. RCBEeT can result in greater thermal capacity utilization on a regional basis, especially during the winter months when hydroelectric plant output is lower. It would also enhance plant thermal efficiency, which would lower the amount of emissions produced per unit of electricity produced by such facilities. An interconnected power system in the BIMSTEC region will be more flexible by taking advantage of diversity in resource and demand patterns and a greater set of flexible generation and demand-side technologies, and thus easier to integrate variable renewable resources such as wind and solar photovoltaic (PV). Large interconnected power systems covering wide geographies of BIMSTEC region can integrate higher shares of variable renewables more effectively; as a larger balancing area, there is natural smoothing of the RE resource (e.g., the wind blows, and the sun shines with different levels of intensity across the BIMSTEC countries).

A BIMSTEC Regional Ancillary Service Market (BRASM) can also be proposed and developed in the coming future to exploit the full potential of renewable energy and sustainable RE grid integration in the BIMSTEC region. BIMSTEC regional grid integration can increase access to flexible resources, including from the interconnectors themselves. Denmark offers a good example of how the regional grid is a major source of flexibility, an enabler for RE Development & Integration. In 2016, 80% of Denmark's wind generation[2,21] was economically balanced through CBET by utilizing Norway's hydro resources. Through RCBEeT and enhanced interconnection, BIMSTEC system operators will have access to a greater quantity and variety of flexibility resources than they would have otherwise. This can potentially lead to economic, optimal, and more environmentally friendly management of the regional electricity grid. Through RCBEeT, BIMSTEC countries manage contingency more effectively, reliably, and in the most economical manner. Recent successful handling 9 P.M., 9 minute event showcases the benefits of having an interconnected region and CBET in managing contingencies effectively.

Governments of the BIMSTEC region are making proactive efforts to increase the cross-border electricity trade (CBET) in the region. CBET has increased in the BIMSTEC region from ~350 MW in 2012 to almost ~363 MW by 2020.[2,23] The major share of CBET has only been enabled between the four countries, i.e., Bangladesh, Bhutan, India, and Nepal (BBIN). Many new cross-border interconnections are being planned and proposed. On the eastern side, the import of electricity from Bhutan and Nepal to India and the export of electricity from India to Bangladesh and Myanmar will be the key drivers for developing the transmission infrastructure from a long-term perspective. By 2030–2035, 30 GW[2] of cross-border transmission interconnection capacity is anticipated. Despite the fact that the majority of CBET is bilateral, regional trilateral/multilateral CBET can improve resource optimization and demand diversification. Gains from Multilateral Electricity Trade among BBIN Countries[24] study finds that "Multilateral electricity trade over bilateral trade increases the level of trade, reduces generation capacity in India and Bangladesh, reduces the use of fossil fuel and hence CO_2 emissions".

Ministry of Power, Government of India, has allowed trilateral power trade and CBET through Indian power exchange through its guidelines on Import/Export (Cross Border) of electricity 2018.[25] The Draft Electricity (Amendment) Bill, 2020 of India[26] defines "Cross border trade of electricity means transactions involving import or export of electricity between India and any other country and includes transactions related to the passage of electricity through our country in transit between two other countries". So clearly region is gearing up for regional electricity trade, i.e., trilateral and multilateral power trade in the BIMSTEC region.

In order to increase cross-border trade through innovative market products, the five-year vision document for the Indian power sector[27] recommends putting balancing market products in the trading of balancing services from quick response plants like Hydro in cross-border electricity trade front. To improve market-based CBET, it also suggests the introduction of financial instruments (futures and derivatives). If the above is implemented, international CBET in regional grid balancing will grow in coming years.[2,27]

While electricity trade will be dominant from cross-border trade in the energy sector, trade of liquid fuel (oil, petroleum products) and natural gas across the border also possessed a tremendous opportunity in the BIMSTEC region. For liquid fuel, the Regional Cross-Border Energy (Oil) Trade (RCBEoT) through pipeline mode of transport is more environmentally friendly and sustainable due to lower energy consumption as compared to the other mode of transport.

Recognizing the benefit of RCBEoT, the first transnational 69-kilometre pipeline (Motahari in north Bihar, India to Amlekhgunj, Narayani Zone of southern Nepal) in the BBIN region was commissioned in July 2019[28] Fig. 5.7. It has an annual wheeling capacity of 2 million metric tonnes of motor fuel and enables Nepal to import fuel from India at a lower cost. The pipeline will save Nepal about \$8.7 million[28] a year in transport costs for fuel, reducing the carbon footprint.

Fig. 5.7 Motahari (Bihar, India)–Amlekhgunj, Narayani zone, Nepal pipeline[28]

The India–Bangladesh Friendship Pipeline (IBFPL), a Greenfield transnational border pipeline[29] for transportation of petroleum products from Siliguri Marketing Terminal of Numaligarh Refinery limited to Petroleum Product Storage Depot at Parbatipur of Bangladesh Petroleum Corporation (BPC) in Bangladesh, is under construction and scheduled to be completed by mid-2022. The length of the IBFPL pipeline is approximately 129.50 KM with a design capacity of 1 MMTPA. The INR 346 crore IBFPL project is being implemented with Grant-in-aid support of Rs. 285 crores from India for the Bangladesh portion of the pipeline.[30] The rest of the funds around Rs. 61 crores invested by the Numaligarh Refinery Limited (NRL)–a Bharat Petroleum Corporation Limited (BPCL) subsidiary located at Golaghat in the north-eastern state of Assam.[30] This project demonstrates a spirit of energy cooperation in the region.

BIMSTEC region, in particular Bangladesh, India, and Myanmar (BIM) region, possess immense potential for Regional Cross-Border Energy (Gas) Trade (RCBEgT). BIM countries are also developing robust domestic gas pipeline networks which will facilitate RCBgT by giving last-mile pipeline connectivity for gas trade. India's national Gas Grid is planned to be expanded to 27,000 km from 16,200 km.[31] Currently, around 7000 km of pipeline is under construction in India. Natural gas, a relatively cleaner form of fossil fuel, can significantly reduce emissions in the BIMSTEC region. Currently, RCBEgT through cross-border pipelines gas is supplied from Yadana, Yetagun, and Zawtika gas fields in Myanmar to Thailand.[32] There are plans for a 350-kilometre Myanmar to Agartala (Sitwe-Aizawl-Silchar) gas pipeline to import gas (estimated at 6.0–6.5 MMSCMD) from Myanmar to India.[33] There are also plans for RCBEgT, i.e., India–Bangladesh–Myanmar gas pipeline.[34] Bangladesh, India, and Myanmar (BIM) region can act as potential Region Gas Hubs and be an energy bridge between South Asia and Southeast Asia (Fig. 5.8).

At a macro level, full-scale BIMSTEC Regional Energy Trade (BRET) and power grid interconnection will have a profound impact in facilitating clean energy transition and sustainability in the BIMSTEC region through on (a) accelerating the de-carbonization of power generation (b) facilitate the sustainable transition to cleaner and efficient public transport (c) affordable renewable energy development (d) fostering rapid adoption of electric vehicle (e) expansion of natural gas, LNG and development BIMSTEC Regional Gas Grid (f) moving towards modernization of the

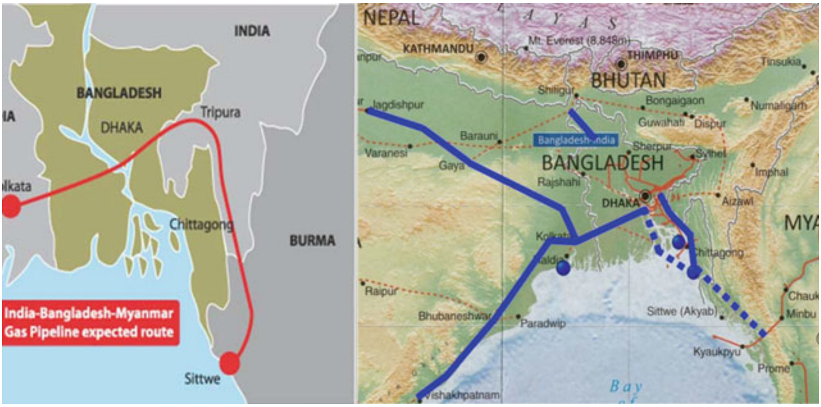


Fig. 5.8 Myanmar—Bangladesh—India pipeline connection

power grid, smart grid, and (g) mobilizing and optimizing investment in cross-border energy infrastructure projects, i.e., cross-border hydropower and transmission interconnection projects in the BIMSTEC region. Given the central role played by energy across the 17 SDGs, the sustainable energy benefits from cross-border power grid integration can help achieve many other SDGs in the BIMSTEC region, including those on poverty, hunger, health, water and sanitation, infrastructure, environment, and climate change.

5.4 CONCLUDING REMARKS

Duly recognizing the imminent threats posed by climate change on the lives and livelihoods of peoples across the BIMSTEC region, BIMSTEC Member States included climate change as the 14th Priority area of cooperation on 10 December 2009.[37] In the Third BIMSTEC Summit held in Nay Pyi Taw, Myanmar, in March 2014, Leaders agreed to explore collaborative initiatives to address the impacts of climate change in the BIMSTEC region.[38] Taking the previous Initiatives forward, the Leaders of BIMSTEC at their Retreat in Goa, India, in October 2016 resolved to strengthen cooperation to protect and preserve the environment.[39] The Leaders stressed the necessity of pursuing sustainable development and implementing the Paris Agreement on climate change at the regional and national levels.[39] BIMSTEC countries signed Memorandum of Understanding for the establishment of the BIMSTEC Grid Interconnection,[40] which highlights (a) encouraging the new or renewable sources of energy projects (b) provide reliable, secure, and economical electricity supply (c) enhance energy security (d) encourage cross border energy trade (e) coordinate & optimize the energy infrastructure investment, and (f) BIMSTEC Grid Interconnections Master Plan and regional trade arrangements and sharing the benefits equitably, resulting from the reductions in investments on generation, transmission systems, and fuel cost.

While the economic, financial, strategic benefits, and, to some extent, potential CO_2 reduction of regional energy cooperation and grid integration in BIMSTEC countries have often been highlighted, the comprehensive climate, environment, and in particular sustainability benefits in terms of meeting climate and sustainable development goals and in clean energy transition through the regional energy trade has not received the due attention. With growing concerns to address unsustainable development and environmental degeneration, aggravated climate change adverse impacts in BIMSTEC countries, and regional cross-border energy trade can be an important tool in meeting climate environment and sustainability goals. BIMSTEC countries should focus on improving cross-border physical transmission infrastructure development and developing required complementary regulatory, policy, pricing, and market mechanisms, which are yet to evolve fully in the BIMSTEC regional context. It would be highly desirable for each participating nation to develop complementary, pertinent policies and rules, with sustainable power grid connectivity playing a key and integral role. By reducing the risks involved, a unified regional policy, legal, and regulatory framework will establish the necessary systemic conditions for a viable CBET investment market. It is critical to have a clear understanding and concrete vision of the regional power/energy market because the majority of the BIMSTEC countries (apart from India) are at a very early stage of power market and sector reform. A competitive, transparent regional electricity/energy market is necessary for long-term sustainability, and each BIMSTEC nation's domestic energy/power market development is preferred. A thriving regional electricity/energy market will boost cross-border energy trade/commerce, streamline investments, and raise the competitiveness of the BIMSTEC power/energy sector, making it profitable for investors looking for reasonable, reliable, and risk-mitigating short- and long-term returns on their investment. All of this calls for an integrated and regional approach to energy, and to fully realize the potential of the BIMSTEC energy sector, an integrated energy strategy along with clear roadmap and concrete action plan should be developed by BIMSTEC countries under the aegis of the BIMSTEC through consultative and participative processes involving all stakeholder concerned.

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CHAPTER 6

India's Energy Security: The Case of Oil

Barnali Nag

6.1 INTRODUCTION

While a volatile global market poses a systematic risk to most economies, the silver lining for a country like India is that being an emerging economy that is evolving in terms of its policies and reforms and gradually finding its foothold in the global economy, it can cope and adjust more to the volatility of worldwide economics and incorporate it into its planning. For India, ensuring energy security for the economy implies providing affordable, environmentally sustainable, and accessible energy supply to fuel the exponentially growing demands for energy for production and consumption purposes.

Very broadly speaking, India's energy usage has two pillars with diverse challenges. These are—(i) power generation which is primarily dependent on coal-fired thermal power plants, and (ii) crude oil and petroleum

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products, which supply energy for almost all transportation needs of the country, apart from catering to some industrial and household requirements. Each of these two pillars has associated complexities like in power generation, India is committed to shifting from a cheaper energy source of coal to cleaner energy choices to transition into a carbon-free growth path in the future. On the other hand, the major problem associated with oil is India's extensive dependence on imported crude oil to meet all its petroleum needs. The escalating oil import bill, along with uncertainties of highly volatile world oil prices and geopolitical conflict between oil-exporting countries, adds to the challenges of depending solely on imports for this crucial fuel.

In this chapter, we focus on energy security issue in the context of a volatile global environment. While India's long-term policy planning needs to consider environmental implications of coal usage, import dependence on oil and cost implications of replacing existing generation capacities with renewables, supply uncertainty about international volatility is more relevant in the context of oil. Most of the chapter is focused on understanding changes in the world oil market and its relevance to India.

6.2 Energy Challenges in India

India's energy challenges on the demand side include rapidly increasing energy demand from rising production, income, and improving lifestyles of the average Indian. The demand side is additionally plagued with low end-use efficiency of energy consumption. Also, the predominant dependence on coal has come under the global scanner for its environmental implications. On the supply side, long-term policy planning is needed for structural shifts in the economy. For example, the current government's vision to move from services to the manufacturing sector was captured in the Make in India initiative. This would mean planning for at least the next 20 years and knowing where the fuels would come from to run the engine of growth, and also knowing how much demand management, technology adoption, and conscious shifts in the mix of energy sources would be possible taking into consideration other factors like dependence on imports and environmental implications. Also, any drastic long-term policy shift would imply having a short-term robust plan of uninterrupted energy supply to firms and households in the interim if and when major technology or energy shifts happen in the economy.

Parikh et al. (2009) projected India's energy requirements for the next 25 years and have concluded that on the supply side, "even after employing all domestic energy resources to their full potential," the economy will primarily be dependent on coal and oil and that import dependence will also continue to rise. However, global pressures to commit to carbon emission reductions would have implications on India's pure fossil fuel-intensive growth policy. Like China and Australia, India shifted its energy policy toward coal, its most abundantly available energy source after the oil crises of the '70s. However, increased coal usage directly conflicts with India's long-term commitment to bringing down per capita carbon emissions. Also, India's coal reserve is high ash content leading to incomplete burning and inefficient energy production. Hence India is already getting dependent on cleaner and high-grade coal from countries like Australia. The IEA's projection of India's energy requirement predicts that despite being the world's second-largest coal producer, increasing demand for coal will turn India into the world's largest coal importer. India's thermal coal imports rose to around 200 million tons in 2019.

The transition from carbon-intensive cheaper energy sources to modern cleaner energy is the recent policy trend in most countries to achieve environmental safety, energy security, and reducing climate change. The COP21 Paris Agreement of United Nations Framework Convention on climate change (UNFCCC) in 2015 was a step toward a worldwide response to combat climate change, with 196 participating countries committing to their best efforts to reduce emissions aiming to maintain the global increase in temperature well under 1.5–2 °C above the pre-industrial level. Individual countries volunteered for intended nationally determined contributions (INDC) to emission reduction. The Government of India has committed itself to the INDC of reducing carbon emission intensity of its GDP by 33–35% by 2030 from 2005 through measures like enhancing the share of renewable energy sources to 40% in total installed capacity by 2030.

The Indian energy market continues to be severely supply-constrained, with almost one-quarter of the population of India not having access to electricity, and per capita, electricity consumption is as low as 1075 KWh per year. Thus, it seems for India, coal cannot be the sole long-term solution to India's energy needs and dependence on oil, along with its availability, accessibility, and affordability issues that need to be addressed in any policy planning. Also, oil as an energy source is the least substitutable in the transportation sector. With rapid urbanization and increasing income, the Indian car market is expanding rapidly, and transportation demand, in general, is growing in the economy. It can be expected that economic growth in India would exponentially increase demand for vehicles from the urban middle class as also from a growing manufacturing sector aided by the rapid expansion of road network and urbanization all across the country. Presently around 90% of India's passenger transport and 65% of its freight transport is carried through roads. WSJ, 2016 reports that in 2015–2016, there was a 7.2% growth in sales of new passenger vehicles, while around 24 million new vehicles were manufactured in India. The government also has major expansion plans for roads and committed to building 30 kilometers of new roads per day from 2016, targeting around 66,117 km of roads (IBEF, 2016). Energy security for India would imply ensuring access to a guaranteed and affordable supply of oil so that the massive transportation lifeline planned for the country does not slow down.

Since India imports most of its oil requirements, oil is probably the most important energy source for India, which has security implications in any global turbulence. IEA (2015) predicts that India's dependence on oil imports would rise above 90% by 2040. India's concerns of oil security surrounding availability and affordability of oil date back to the oil crises of the 1970s and 1980s, which led to the nationalization of the coal sector to improve the country's energy self-sufficiency.

6.3 The Global Oil Scenario

Today's discussion on energy security is no longer so much about world supply struggling to catch up with demand. The growth rate of global primary energy consumption has been steadily declining over around a decade. In 2019, before the pandemic hit the world economy, immediate energy consumption rose by only 1.3%, and this growth was driven mostly by renewables and natural gas. According to BP Statistics, growth was slower than their ten year average for all fuels (BP Statistics, 2020). Oil, like other natural resources, has high supply inelasticity, especially in the short run. Hence, major demand disruptions lead to massive instability of resource prices in the international markets. This price instability affects the net importers and the resource exporting countries that are dependent on export revenue for their economies like Iraq, Iran, Russia, and Venezuela.

The massive industrialization drive in China during the first decade of the twenty-first century led to soaring commodity prices in the world market of energy, metals, and minerals and rapid capacity expansion in these sectors to meet the seemingly unending demand from the Asian giant. China's crude oil consumption had gone up to 7.5 million barrels a day in 2007, from 5.5 million barrels a day in 2003, and it emerged as the world's biggest importer of crude. However, demand from China started slowing down from 2011 onward due to slowing economic growth in China and China's capacity expansion toward self-sufficiency in many of these sectors. During the early 2000s, China was the biggest driver of energy demand and other developing countries. This led to a sudden increase in demand for all resources, including oil. As the existing oil supply could not match up with the market, there was a spike in all resource prices, including oil leading to massive investments in the exploration and production of oil. However, this commodity supercycle came to an end after the financial crisis and after slowing down and reorientating the Chinese economy. Supplies could not adjust to this decline. There was a sharp decline in the prices of most natural resources. Prices fell worldwide for all fossil fuels in 2015, and the crude price index experienced a 47% decline indicating the growing excess supply over-consumption of crude. A major share of the growth in world energy consumption has been contributed by the emerging economies where also growth has been slow at 1.6%, much below the ten year average of 3.8%. In the entire global scenario of sluggish energy demand, only India recorded a consumption increase of 5.2% compared to China's 1.5%.

6.4 Changes in the World Oil Market

The world oil market has seen major transformations since the days of the oil crises of the 70s and 80s when OPEC could exercise control over pricing, supply, and distribution all over the world, and the oil embargo served as a credible threat against political differences. However, that is no longer the case due to globalization aided with the following developments in the world oil market:

1. Supply revolution in the world oil market happened with the development of hydraulic fracturing, which facilitated the extraction of

oil deposits in the shale, which were considered prohibitively cost-intensive till around a decade back. The technology increased the oil production of the US by more than 50% within a decade.

2. The oil embargos of the 70s and 80s led to various measures to conserve, substitute, and end-use efficiency improvement on the demand side and major exploration initiatives and capital investments not only within own country but in newer territories like Africa and Central Asia on the supply side. Countries started looking for strategic options for diversifying energy supplies in ways that would reduce their vulnerabilities to disruptions in global oil supplies from the Middle East. Thus global oil demand reduced significantly.
3. An international market in oil emerged in the 1990s, driven by spot trading and later into a much more sophisticated futures market for hedging against risks of supply volatility. With maturing of the global oil markets, OPEC and oil-producing multinationals no longer can influence prices or destinations.
4. One characteristic of oil, compared to its alternatives, say coal or natural gas, is that it is far easier and cheaper to transport. Hence, the risks of physical supply disruptions are lower than the other sources, making it more attractive to its users and more convenient in trading and shipment. The rapid expansion of sources of oil production, other than OPEC and trade options of crude and refined product across countries has made it immensely difficult to physically cut off oil supply to any targeted country, except maybe in case of a natural disaster. Any attempt to do so, say through an oil embargo, would only alter trade patterns among sources and destinations.

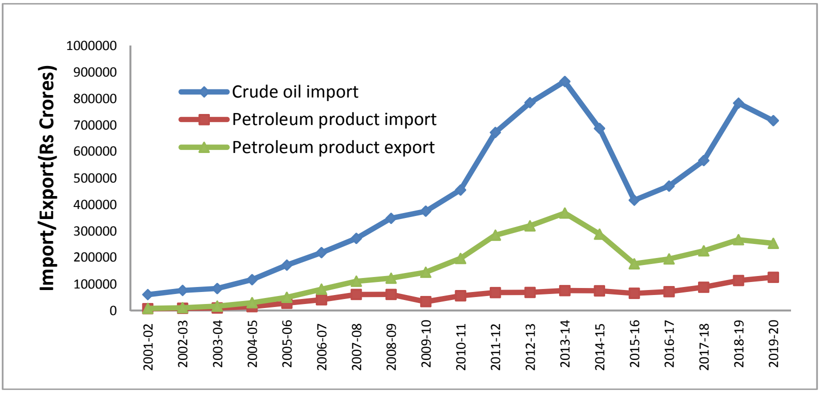
All the above factors imply that the “oil weapon” has lost its edge due to the growth of a seamless world market of crude and petroleum products. The only way this could be disrupted would be through production cuts, forcing prices up. However, the producers had learnt the implications of such an action as predicted by Saudi Oil Minister Ahmed Zaki Yameni when he famously said, “The Stone Age did not end for lack of stone, and the Oil Age will end long before the world runs out of oil.” Oil importing nations, in general, drastically reduced their oil consumption through substitution and efficiency improvements and the US, in particular, developed technologies like hydraulic fracturing, which reduced their import demand for oil drastically.

Oil is no longer a weapon to be used by middle eastern producers trying to fulfill political objectives by coercing the consumer nations in the West. On the contrary, it has become more about waging a price war with other producers through excess production. Saudi Arabia's continued production increases are targeted on the one hand to drive the high-cost-intensive shale oil out of the market and, on the other, to deter Iran from re-entering the oil market after international sanctions against Iran were lifted during the beginning of 2016. Such price war has security implications not on oil-importing countries but on economies that are solely dependent on oil exports like Algeria, Venezuela, Kuwait, Iraq, and many other countries.

Also, another interesting development of the world market which needs to be kept in mind is that in the current global scenario, almost no country is a pure importer or exporter of oil, which emphasizes the fact that energy independence is no longer a tenable goal for countries, but energy security perhaps is. The crude quality and refining capabilities of countries vary widely, and the final product specifications and their demand for various petroleum products. India, like many erstwhile oil-importing countries viz. China, Japan, Malaysia, the Republic of Korea, and Thailand expanded their refining capacities with domestic demand and eventually turned into exporters of various refined products. In 2019, India exported around 1.32 million barrels/day, with diesel being the major export at 635,669 barrels/day (PPAC, 2021). The wide variety of petroleum products and specifications demanded in the world oil market has given strategic advantages to individual countries and refiners as exporters of refined products. Asian trade-in products comprise nearly 8.3 million barrels/day of imports and 6 million barrels/day of exports. Globalized world, the independence of the energy market, like most other goods markets, is neither achievable nor desirable. Being closed and inward-looking will probably not protect any economy from volatility outside. On the contrary, risk could be diversified by developing a wide network of energy buyers and sellers.

6.5 INDIA'S ENERGY SECURITY IN THE CONTEXT OF A VOLATILE WORLD MARKET

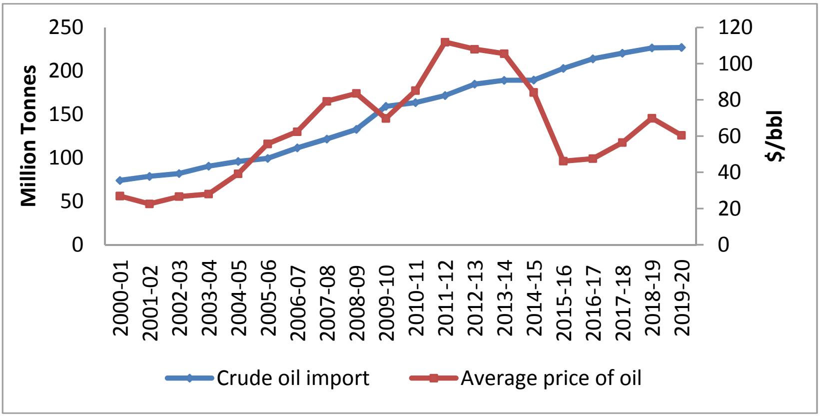
India is the third-largest importer of crude oil, followed by the US and China. India's imports had been steadily increasing from 78.7 million tons of crude oil in 2001 to almost 227 million tons in 2019. Import of petroleum products has increased from 7 million tons to 43.8 million tons during the same period. India's petroleum products exports also increased steadily from 10 million tons in 2001 to 65.7 million tons in 2019. Figure 6.1 illustrates the changing trade pattern in value of refined petroleum product export and import in India. Net export of petroleum products peaked during the early part of the last decade and came down with a global economic slowdown in the latter part.



Value of crude and petroleum product export/import in India

Although India has around 83% import dependence on crude oil, it has the fifth-largest refinery capacity that increased from 3.7mb/d in 2010 to more than 5mb/d in 2019. For India, the comparative advantage in the oil trade lies in specializing in refined products than crude production.

Figure 6.2 shows India's crude oil import and changes in import price of crude from 2000 to 2019. It can be seen that India's oil import has increased steadily over the last two decades and does not seem to be responsive to price fluctuations of oil. So when prices have been high, India had no other option but to take a hit on its import bill. However, during low prices, the quantum of import has not been much responsive to prices. However, India saved nearly $70 billion on importing crude and other petroleum products in 2015, when prices fell. Countries usually build up strategic reserves when resource prices are low. US, Japan, and several European and African countries have built up strategic oils reserves aimed at being used during sudden price and supply volatility in the market. India's oil import data does not indicate that India has taken this approach. Strategic reserves, however, aim to manage short-term volatility. A more long-term strategy to secure supply is needed in a country like India, which is primarily dependent on imports to meet its crude oil demand.



Crude oil import by India and Oil prices from 2000 to 2019

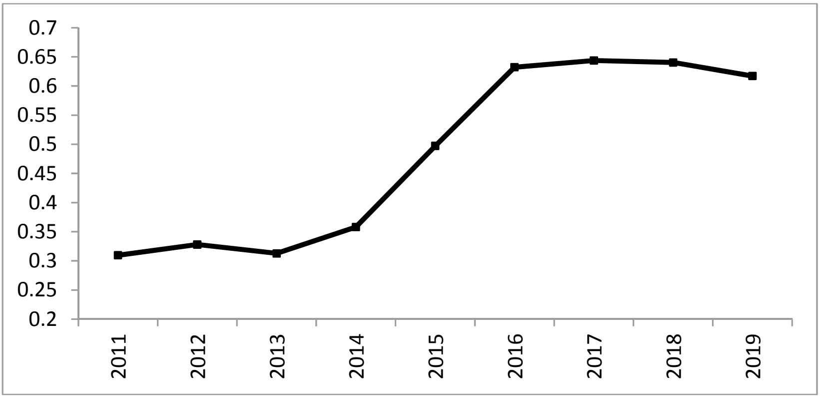
6.6 India's Oil Import Risk Measure Using Diversification Index

The oil import trend and oil prices that oil import is highly inelastic to price changes are apparent from the oil import trend and oil prices. Hence to ensure a secure supply of oil, India needs to diversify its crude oil import. India's crude oil imports mainly depend on the Middle East and South America, making up an average approximation of 93% of total crude oil imports from 2011 to 2019. Import from Iraq was up by 86.9% in 2019 from 2015. In 2019, the largest import of oil was from Iraq, followed by Saudi Arabia. To reduce its import risk and dependence primarily on OPEC nations, India started to import crude oil from the US, Canada, and Mexico in 2017. Even though the largest amount of imports come from Iraq, Iran, Saudi Arabia, South American, African, and some CIS countries have increased.

Diversification of import sources has been considered a common indicator to measure risk caused by geopolitical disruptions in energy imports. The concentration of markets is measured by the Hirschman–Herfindahl–Agiobenebo and has been used in literature by Neff (1997) and Agiobenebo (2000). Using the approach of Wu et al. (2009), India's diversification is measured through a scatter of oil imports as follows:

$$Idiv = 1 - HHA = 1 - \sqrt{\sum_{1}^{n} S_i^2}$$

S_i is the oil import share of source i, the measure shows that the higher the diversity of import sources for a country, the lower the risk from supply disruption from a source. A higher I_{div} would mean a lower risk for the importing country.



Diversification index for crude oil import in India

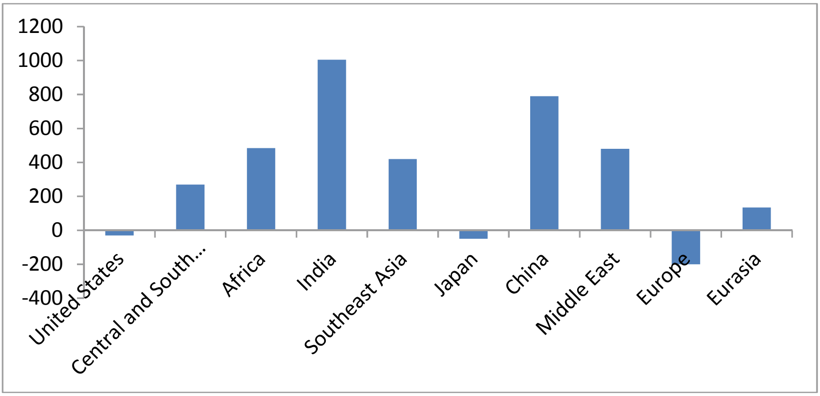
Based on the calculation of the diversification indices for a period from 2011 to 2019, India's changing risk measure in import is shown in Fig. 6.3. It can be seen that from 2013 onward, India has been able to lower its risk from supply disruptions by diversifying across different countries for buying its crude.

6.7 India in the World Market of Oil

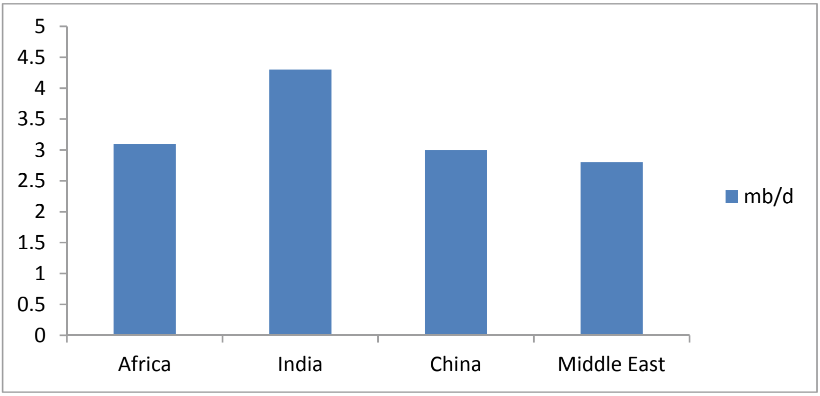
Before the Coronavirus pandemic that hit the global economy, the IEA Oil Market Report had reported a rise in global oil demand to 101.1mb/d in the last quarter of 2019. This rise was after a fall in demand till 2018 due to slowdowns in the OECD, America, and China. Apart from the excess production in the US and the Middle East and price spikes of oil in the past which had suppressed demand for oil through substitution, another factor that has been responsible for reducing dependence on oil in the developed world has been technology responsible for vehicles with high energy efficiency standards, hybrid cars, and shifts to renewables. For more than a decade, oil has been one of the most oversupplied commodities due to record output in the US and the decision of OPEC not to cut down production below its target of 30 million barrels a day to maintain market share.

In contrast to the slump in demand in major parts of the world, oil demand continued to soar in India. While demand for refined fuels in China reduced to 353,000 barrels per day in the first quarter of 2016 from a year earlier, India's demand for liquid fuels grew by 400,000 barrels per day in the first quarter of 2016, which was the fastest in the world, accounting for about 30% of the total global increase (Cunningham, 2016). Consumption of petroleum products marked an increase of 11.6% in 2015 from the previous year, and diesel consumption expanded by 7.5% to 74.6 million tons and gasoline use increased 14.5% to 21.8 million tons. India consumed 214 million tons of oil products in 2019–2020. India is currently the third-largest consumer of oil and the fourth-largest refiner, and a net exporter of refined products in the world market, making it a very attractive market for refinery investment (IEA, 2020). This would also make India even more important as a major consumer of crude oil.

So, India maintains its high growth rate of demand for commodities in a bearish world commodity market. India needs to leverage the possibility of being the largest consumer of oil and be the solution to the commodity supercycle created by China, which ended in 2011 and created a glut in the world market. As illustrated in Figs. 6.4 and 6.5, based on International Energy Agency's estimates, the largest energy demand growth is expected to come from India by 2040 and demand growth in oil is highest from India, followed by Africa.



Change in primary energy demand (mtoe) 2018–2040 (*Data source* International Energy Agency Report, 2019)



Oil demand in selected countries and regions, 2018–2040 (*Data source* International Energy Agency Report, 2019)

6.8 Securing Oil Security for India

Most of the oil import of Asia comes from the Middle East. While OPEC continues to conspire to keep oil prices low to squeeze out the high-cost producers and rivals in the market, the Asian importers make independent decisions and strategies to safeguard themselves against potential supply disruptions or volatile prices. It is apparent from the world oil market that there is already excess capacity created with the producers in anticipation of demand explosion from the US and China, which have both started slowing down along with demand slumps in Europe. On the other hand, India is emerging as a major oil importer along with China. It seems reasonable for India to leverage its position as the largest emerging market for the oil-producing countries and take appropriate initiatives to remove its persistent vulnerability from oil import bills and price volatility in the world market.

India needs to strategize not only to meet its oil demand of the near future but also to secure its supply options for the long term into the future. Some of the policy options that could reduce security risks are discussed below. Some of India's options have already explored with limited success, and some are yet to be explored. The policy initiatives broadly come under two major dimensions of market issues and geopolitical issues.

1. Market issues:

    a. Deregulation of Prices—Till very recently, in India, the center would provide subsidies on crude to make it affordable to the consumers. Still, state-level taxes would raise the prices in any case. So the double distortion of subsidies and taxes have had cumulative implications on the petroleum product market in India in the form of public sector refiners struggling to recover losses and low investments in refining capacity, exploration or production on the supply side, and distorted consumption and substitution decisions across petroleum products among consumers on the demand side.

       India has taken advantage of low world prices to deregulate oil prices. India has removed subsidies on diesel and petrol. However, although diesel provides higher end-use efficiency, diesel prices continue to be lower than petrol in India since diesel is considered to have productive usage in the economy against petrol which has more consumptive usage. Such a policy leads to distortion in demand and business decisions, for example, more diesel cars flooding the market.

Deregulation of petrol and diesel prices in India would help the public sector refiners recover losses and invest in capacity expansion. The private sector companies like Reliance, which cannot match up with the regulated domestic prices, would have to export its products and now supply to the domestic market. This, however, may reduce diesel exports from India in the short run. In terms of achieving energy security in the long run, a domestic price above world prices can help build a more resilient economy in the long run that falters less during spikes in international oil price.

b. FDI in oil exploration—The Government of India approved the Hydrocarbon Exploration Licensing Policy (HELP) to provide a uniform licensing system to cover all hydrocarbons such as oil, gas, coal bed methane, shell oil and gas, etc., under a single licensing framework. This is expected to boost investments and enhance domestic oil & gas production in the sector (GoI, 2016). Although the timing of the move coincided with the global drop in crude prices, which made oil and gas exploration somewhat less attractive, the policy will be beneficial for long-run production initiatives in the sector. Also, such a policy would increase the possibility of domestic production being able to meet more and more of local demand, as has happened in China.

c. Oil futures market: While a common argument against a futures market in oil is that it increases the market volatility in the world market. However, the volatility primarily arises from non-commercial participants in the market who make a profit out of speculation. This, however, cannot discount the role of the futures market for which they exist in the first place, i.e., they help commercial participants to hedge against supply uncertainty in the market.

Isaak (2015) discussed the role of an oil futures market in Asia as an instrument of security extensively. The current futures market in crude that exists like NYMEX, WTI, or ICE Brent are poor market indicators for companies trying to hedge in Asia. However, the Middle East to Asia is the largest oil flow in the world. Trading companies could take an active initiative to bring together all major oil importers of the Asian region to initiate the setting up, structuring and reforming a futures market, and using it extensively to hedge against price fluctuations. Unless the volume of trading increased enormously and is not dominated only by physical trade—compared to Western counterparts dominated by paper trade—the futures market would not be setting market prices and could also be subject to manipulation.

2. Geopolitical Issues:

   a. Oil stockpiling: Oil stockpiling is a simple security measure adopted by almost all oil-importing countries to avoid any sudden supply disruption. While IEA members are required to hold a minimum of 90 days of the previous year's oil import as reserves, some of its members, like Japan and the Republic of Korea, hold strategic reserves higher than the minimum IEA requirement. China is known to have been stockpiling a major strategic reserve. According to the National Bureau of Statistics, China, China built the first phase of its strategic petroleum reserve program with four sites in 2009, totaling 91 million barrels (Bloomberg, 2016). According to the EIA, China intends to build at least 500 million barrels worth of reserve space by 2020, and many analysts believe the country's pace of hoarding has risen as oil prices have fallen (WSJ, 2016). In contrast, India, although majorly import-dependent, did not have a robust policy for maintaining strategic reserves until very recently. Currently, around ten days of import requirement is stockpiled at three locations in Southern India, viz. Vizag (1.3 MT), Mangalore (1.5MT), and Padur (2.6MT). However, being the third-largest consumer of oil, India's strategic reserve of 5.3MT to last at most around 10 days is insufficient, to say the least, compared with 88MT in the US and 44MT in China.

      India has considered some innovative approaches to stockpiling, like offering income tax exemptions for the sale of stored crude oil by foreign firms to the local market as an incentive for these companies to lease space, which would help finance the strategic reserve building program. Major global oil companies like Kuwait Petroleum Corporation, Saudi Aramco, and Shell have shown interest in such an initiative (Doshi & Six, 2017).

Although oil stockpiling may reduce the risk of supply distortions in the future, it needs to be kept in mind that there is a huge opportunity cost of building and maintaining infrastructure to stockpile oil, to buy the oil, and fill up the reserve, not to be used in the immediate future. India has not been able to fill up 100% of its reserve capacity, and Padur is reported to be empty and Mangalore half empty. As discussed earlier, in the current global oil market that has evolved, control of oil distribution and pricing is no longer in the hands of the producers.

The huge network of producers and consumers of crude oil and petroleum products and the diversity of specifications and requirements the world over, further strengthened by the futures market, have reduced the chances of any single country being faced with a physical cut off of supply. Hence, it would probably make better economic sense for China and India to leverage their positions jointly as major oil-consuming giants in Asia and collaborate on building a central strategic oil reserve. However, overcoming geopolitical fragility could be a challenge in achieving this shortly.

b. "Dollar for barrel": It has been a strategic policy of China to secure access to oil supply from capital-starved oil-exporting countries in exchange for providing soft loans to them. For example, in Angola, Chinese companies provided finances for post-war reconstruction in exchange for equity shares in oil blocks. Countries like Venezuela, Brazil, Ecuador, Russia, Argentina, and Kazakhstan have also entered similar agreements with China. In exchange for a supply commitment to China, Petrobas received a $10 billion loan from China Development Bank to ease some of its debt burden (Forest, 2016). Indian companies, unlike China, have not been able to use this strategy successfully so far. With falling world oil prices, all the countries that have used oil as collateral have to let go of most of their oil production to repay the debt. Hence it is doubtful if this strategy would be of much interest either to the borrowers or lenders in the current market scenario. India has been more proactive in investing in the midstream petroleum industry in exporting countries. For example, India signed a deal with Iran and Afghanistan to provide $500 million to develop a port on the Gulf of Oman.

6.9 Concluding Remarks

Overall, for India, longer-term strategies to ensure energy security need to involve exploration and increased production and innovation and adoption of new technologies like fracking, improvement in efficiency, and gradual shift toward renewables as alternate sources of energy. However, energy disruptions in the short and medium term can have disastrous consequences on the economy. Hence, some of India's options to build up energy security are to build trade relations with more countries to import oil from and invest in new territories to explore sources of oil. In this context, building up ties with Russia and African countries could be an important direction to secure oil supply for the future. Also, India could initiate a lead among Asian economies as one of the largest oil consumers in a fraught market with oligopolistic supply insecurities and political conflicts apart from the looming threat of climate action on fossil fuels in general. The changing global market scenario of the diversity of production of crude and refined products has also reduced India's vulnerability.

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PART II

Climate Change-Some Mitigation Measures

CHAPTER 7

Importance of Pumped Hydro Energy Storage (PHES) System Toward Renewable Energy (RE) Integration and as an Enabler Toward Zero-Emission Concept

Vinod Kumar Agarwal and Mohnish Makwana

7.1 Objective and Background of the Study

India has a massive Renewable Capacity addition program and the pace of renewable addition has prompted justifiable concerns about grid balancing and stability. An influential study commissioned by India's Ministry of Power finds that the 175 (NERL, https://www.nrel.gov/analysis/india-renewable-integration-study.html) GW renewable capacity target could be met with 'all generating stations exploiting their inherent ramping abilities' and hydropower being repositioned to satisfy peak

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demand, after the sun sets. The extension of targets, however, will almost certainly require planning for additional fast-ramping infrastructure. Looking into the revised plans for RE (Renewable Energy) addition, which now stands in the range of 450 (Mint, https://www.livemint.com/industry/energy/india-on-track-to-achieve-450-gw-renewable-energy-target-by-2030-power-minister-11628917933241) GW, government and industry have begun to look around different solutions toward balancing the grid in the face of large integration of RE, such as flexing of generation in thermal stations, peaking hydro stations and pumped hydro energy storage, grid-scale battery storage and demand side management, including renewing their focus on reviving Indian hydropower to ensure the continued stability of the grid at each of the moment.

This has taken the form of a proposed and contentious revision to the national hydropower policy and ambitions of adding up to 10 GW of pumped storage. Overall, Indian hydropower policy is in a state of flux, with several ongoing debates about how seemingly imminent policy interventions should be structured and the role hydropower should play in meeting power demand and balancing the grid in a renewable-heavy grid. This paper describes the challenges due to large penetration of RE capacity in the grid and the role of Pumped Hydro Energy Storage (PHES) toward RE integration and as an enabler of zero-emission concept, including some basic details about PHES's Techno-economic and Financial Viability.

7.2 OVERVIEW OF INDIA'S POWER SYSTEM AND RENEWABLE ENERGY SCENARIO

Currently India has over 370 (CEA, https://cea.nic.in/) GW of total power generation installed capacity (as on March 2020). India is a coal-dominated power system with the highest installed capacity of 198,734 MW (Fig. 7.1).

During the year 2019–2020, peak demand registered a growth of 3.99%, with total peak demand at around 182.53 GW as compared to 175.53 GW during the year 2018–2019. India's generation mix consists of 62.3% of thermal; 12.3% of hydro; 1.9% of nuclear and 23.5% of renewable energy (RE). This clearly shows the domination of thermal in India's generation mix. In the case of RE, wind constitutes the maximum share, followed by solar. The break-up of total RE capacity in India is shown

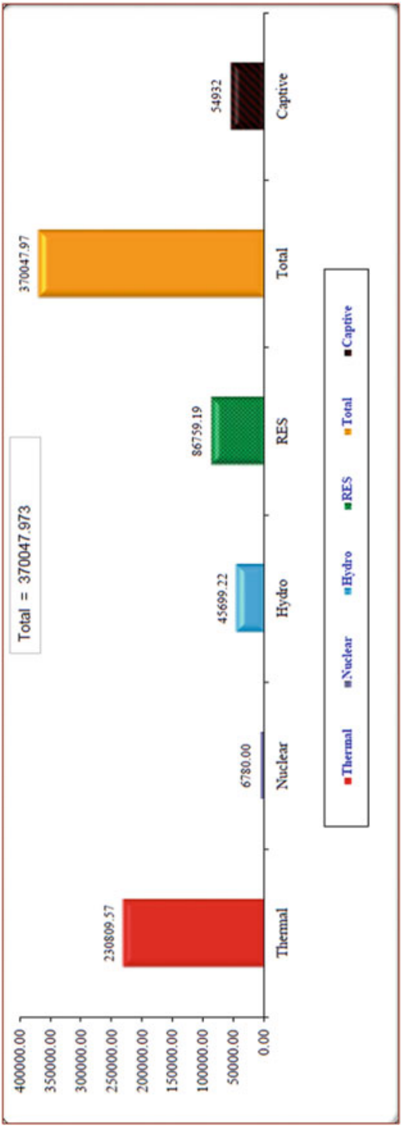

Fig. 7.1 India-power installed capacity fuel mix (MW)

Table 7.1 India—Renewable Energy Capacity—86.76 GW

Small Hydro Power (MW)	*Wind Power (MW)*	*BM Power/Cogeneration (MW)*	*Waste to Energy (MW)*	*Solar Power (MW)*	*Total (MW)*
4683.16	37,669.25	9861.31	139.80	34,405.67	86,759.19

in Table 7.1 (CEA, https://cea.nic.in/executive-summary-report/?lang=en).

If we look into the immediate time frame, India has set ambitious targets of attaining 175 GW (100 GW of solar, 60 GW of wind and 15 GW of other renewable source of energy) of renewable energy by March 2022. If this happens, the percentage of non-fossil fuel (Hydro, Nuclear and Renewable Energy Source—Renewable Energy Sources [RES]) in the installed capacity is expected to increase to 49.3% by March 2022, and 57.4% by March 2027. In terms of Electrical Energy generation mix, the share of RES generation would be around 19.24% and 23.3% of the total generation expected in the year 2021–2022 and 2026–2027, respectively, as per the committee report on ‘Optimal Energy Mix in Power Generation on Medium and Long Term Basis’, published by the Ministry of Power, Government of India.

7.3 Challenges Due to Large Penetration of the RE Capacity in the Grid and Solutions Thereof

India’s integrated power grid is one of the largest synchronous power grids in the world. With the high penetration of renewable energy required in the near future, particularly from intermittent sources such as solar and wind, there is a need to manage concerns related to balancing India’s power grid and its security and stability. Considering the high variability and unpredictability of generation from the renewables, efficient and economical grid operation is increasingly becoming one of the critical challenges for India’s power system. The variability of renewable energy is easily accommodated when power demand and renewable supply are matched—both rising and falling together. However, they often fail to match, that is, the power demand and renewable supply move in opposite directions, giving rise to concerns about grid security and stability. This challenge calls for the need to address various issues related to the integration of renewable generation and include avenues such as provision of spinning reserves, enhancing the level of flexibility in the generation, need to provide storage devices such as pumped hydro energy storage, or other forms of storage like electrical batteries, etc., and incentivizing the management of the demand so as to support grid balancing. In order to find out a long term and economical solution toward renewable transition and balancing of the grid, in light of the large penetration of renewables, it is essential to examine in detail the suitability and the efficacy of each of the option stated above. Further in respect of all of them, and most notably in respect of the storage solutions, mainly pumped hydro energy storage and electrical batteries, there is a need to come out with a market mechanism which may be able to encourage the development and provision of above services in the form of Ancillary Services.

7.4 Role of PHES Toward RE Integration and as an Enabler of Zero-Emission Concept

Pumped hydro energy storage (PHES) accounts over 94% of installed global energy storage capacity and retains several advantages such as lifetime cost, levels of sustainability and scale of operation. The existing 161,000 megawatts (MW) of pumped storage capacity across the globe support power grid stability, reducing overall system costs and sector emissions. PHES operations and technology are adapting to the changing power system requirements incurred by variable renewable energy (VRE) sources as a new energy transition solution. Since the sun does not always shine and the wind does not always blow when the demand is high, the produced renewable energy needs to be stored until the demand is high and which can be met at the appropriate time when the demand has actually increased. Pumped hydropower energy storage stores energy in the form of potential energy that is pumped from a lower reservoir to a higher one putting the water source available to the turbine to fit the energy demand. In this type of system, low-cost electric power (electricity in off-peak time) is used to run the pumps to raise the water from the lower reservoir to the upper one. During the periods of high power demand, the stored water is released through hydro turbines to produce power. Reversible turbine-generator groups act as pumps or turbines, when necessary.

During earlier days, the pumped hydropower plants were mainly used to store energy at night to be shifted to the peak demand times over the course of the day. However, with the penetration of RE to the grid, this dispatch process has changed significantly. Further based on the requirement there is a thrust toward different technologies like close loop off-river type PHES Systems, which work very efficiently to address the imbalances caused by RE capacity.

7.5 Existing PHES Capability in India and Future Prospects

India has a huge potential for electricity generation from hydro source, including that of PHES and broad details in this respect are as given under (Table 7.2) (http://164.100.47.193/lsscommittee/Energy/16_Energy_43.pdf).

The break-up of the region-wise potential of the PHES plants is as given under Table 7.3.

Looking at the good potential of the PHES available in the country, sometime back it was announced by the planning authorities in India that in order to support the balancing of the grid and take care of the intermittency due to addition of massive levels of renewable energy, there are plans to add 10 GW of PHES capacity to the grid. It was emphasized that considering a target of 175 gigawatts of renewable capacity by 2022, India will need to be ready with all technologies at its disposal to manage the grid. It was also added that the proposed 10 GW of pumped storage would complement, the chemical storage.

The break-up of the PHES plants in operation, as well as the PHES plants which are not able to operate in the pumped hydro made due to one reason or the other is given under Tables 7.4 and 7.5, respectively:

Efforts are on to address the issues in respect of the PHES plants, which currently are not being operated in pumping mode.

Table 7.2 Total hydro potential in India (including PHES)

	Conventional		*Pumped storage*		*Total*
	Nos.	*I.C. (MW)*	*NOS.*	*I.C. (MW)*	*I.C. (MW)*
Identified Hydro Capacity	593	145,320	63	96,524	241,844
In operation	197#	40,613.62	9	4785.6	45,399.22
Under construction	34*	10,973.50	3	1205	12,178.50
Allotted for development					
(i) Cleared by CEA and yet to be taken up for construction	40	25,460	1	1000	26,460
(ii) Under Examination/scrutiny in CEA	6	1224	0		1224
(iii) DPRs appraised and returned for revision	29	9S52	0		9852
(iv) Under S&l	35	5439	3	2920	8359
(v) S&l is held up/to be taken up	45	14,332	1	660	14,992
Sub-total (i – v)	**155**	**56,307**	**5**	**4580**	**60,857**
Total (1 + ll + lll)	**386**	**107,894.1**	**17**	**10,570.60**	**118,464.72**

Table 7.3 Region-wise break-up of the PHES potential in India (CEA, https://cea.nic.in/wp-content/uploads/2020/03/mom-psp.pdf)

Region	*Probable installed capacity (MW)*	*Capacity developed (MW)*	*Capacity under construction (MW)*
Northern	13,065 (7 Nos.)	0	1000 (1 Nos.)
Western	39,684 (29 Nos.)	1840 (4 Nos.)	80 (1 Nos.)
Southern	17,750 (10 Nos.)	2005.6 (3 Nos.)	0
Eastern	9125 (7 Nos.)	940 (2 Nos.)	0
North Eastern	16,900 (10 Nos.)	0	0
Total	96,524 (63 Nos.)	4785.6 (9 Nos.)*	1080 (2 Nos.)

Table 7.4 Break-up of the PHES capacity in operation (CEA, https://cea.nic.in/wp-content/uploads/2020/03/mom-psp.pdf)

S. No.	*Name of project*	*State*	*Installed capacity (MW)*
1	Kadamparai	Tamil Nadu	4 × 100 = 400
2	Bhira	Maharashtra	1 × 150 = 150
3	Srisailam LBPH	Telangana	6 × 150 = 900
4	Purulia	West Bengal	4 × 225 = 900
5	Ghatghar	Maharashtra	2 × 125 = 250
		Total	2600

Table 7.5 Break-up of the PHES capacity not in operation (CEA, https://cea.nic.in/wp-content/uploads/2020/03/mom-psp.pdf)

S. No.	*Name of Project*	*State*	*I.C. (MW)*	*Reasons for not working in pumping mode*
1	Kadana St. I&II	Gujarat	2 × 60 + 2 × 60 = 240	Due to vibration problem
2	Nagarjuna Sagar	Telangaua	7 × 100.80 = 705.60 (Revised)	Tail pool dam not yet operational
3	Sardar Sarovar	Gujarat	6 × 200 = 1200	Tail pool dam under construction
4	Panchet Hill	DVC	1 × 40 = 40	Tail pool dam not constructed
		Total	2185.6	

7.6 Financial Implications in Managing Renewable Generation

Renewable capacity being infirm in nature, the states at times are reluctant to install higher capacity of RE due to adverse financial impacts, they experience due to various reasons. These include the requirement of keeping standby capacity when the wind and solar power goes down, the necessity of having flexible generation which can ramp up and down in consonance with ramping down and up by the variable generation, the impact on the States Deviation Settlement Mechanism (DSM) charges for inter-state flow of power, the impact on coal-based generation, in terms of reduction of efficiency and operation at lower Plant Load Factor, as well as higher transmission charges on account of lower capacity utilization factor of wind and solar power.

Since such impacts were being observed as reluctance by the renewable rich states to go for higher and higher RE capacity, the Government of India in the year 2017 had set up a committee in order to estimate the financial implications on the renewable rich states due to the installation of the additional RE capacity and to work out that what alternative solutions can be considered for those. The committee went into the details of such financial implications and the estimates as worked out by the committee in respect of the two RE-rich states, viz. Tamilnadu and Gujarat are as given under Tables 7.6 and 7.7, respectively.

It is seen that the major portion of the financial implication is on account of Rs. 0.50 per unit because of replacement of the cheaper fuel charge of Rs. 2 per unit by taking power from the must-run renewable generation at an average of Rs. 4 per unit (considering 25% replacement). Presently, all procurement of generation from solar and wind power plants is through competitive bidding, which has lowered the tariff of solar power and wind power to about Rs. 2.50 per unit. On the other hand, it is being observed that setting up of new coal-based plant would entail a tariff of about Rs. 3.50 per unit for the first year, consisting of a fixed charge of Rs. 1.50 per unit (considering operation at 85% PLF) and a fuel charge of about Rs. 2 per unit, with escalation due to increase in coal prices with time, leading to an even higher levelized tariff. The levelized tariff of wind and solar generators, on the other hand remains the same in the case of non-scalable tariff. Therefore, if we were to

Table 7.6 Financial impact in the case of Tamilnadu (CEA, https://cea.nic.in/wp-content/uploads/2020/03/report.pdf)

Tamil Nadu Summary		
1	Total balancing charge for CGS Coal and gas based station (fixed + fuel charge) (Rs/kWh) – Spread over renewable generation	0.20
2	Total balancing charge for Tamil Nadu Coal based station (fixed + fuel charge)(Rs/kWh) – Spread over renewable generation	0.03
3	Impact of DSM per unit – Spread over renewable generation	0.35
4	Impact on tarrif (Rs./Unit) forTamilnadu discom for backing down Coal generation assuming solar and wind at Rs. 4/kWh and coal fuel charge at Rs. 2.0/kWh – Spread over renewable generation (Considering 25% on account of renewables)	0.50
5	Stand by charge (Rs/kWh) – Spread over renewable generation	0.23
6	Extra transmission charge (Rs/kWh)- Spread over renewable generation	0.26
	Total Impact –Spread over renewable generation (Rs/kWh)	1.57

consider procurement of power from new capacity in future, this Rs. 0.50 per unit mentioned above would reduce to zero or may even be negative. If it is assumed that this is zero, the financial impact of renewable capacity would reduce to about Rs. 1 per unit, i.e. Rs. 1.07 per unit for Tamil Nadu and Rs. 0.95 per unit for Gujarat, or we can say an average of about Rs. 1.00 per unit. Based on the above the committee broadly concluded that the financial implications to the renewable-rich states for installing additional RE would be in the range of Rs. 1/-KWH and possibly while planning toward large RE capacity addition in the systems of RE-rich states, it can be kept into consideration that how they can be compensated toward this financial impact.

Table 7.7 Financial impact in the case of Gujarat (CEA, https://cea.nic.in/wp-content/uploads/2020/03/report.pdf)

Details of calculation for Gujarat

Item No.	*Balancing cost*	*Rs./Unit*
1	Total balancing charge for CGs Coal and gas based station (fixed + fuel charge)(Rs/kWh) – Spread over renewable generation	0.24
2	Total balancing charge for Gujarat Coal and Gas based station (fixed + fuel charge)(Rs/kWh) – Spread over renewable generation	–
3	Imapct of DSM per unit (Rs/kWh) – Spread over renewable generation	0.12
4	Impact on tarrif (Rs./Unit) for Gujarat discom for backing down Coal generation assuming solar and wind at Rs. 4/kWh and coal fuel charge at Rs. 2.0/kWh – Spread over renewable generation (Considering 25% on account of renewables)	0.5
5	Stand by charge (Rs/kWh) – Spread over renewable generation	0.33
6	Extra transmission charge (Rs/kWh) – Spread over renewable generation	0.26
	Total Impact – Spread over renewable generation (Rs/kWh)	1.45

7.7 TECHNO-ECONOMIC AND FINANCIAL VIABILITY IN THE CASE OF PHES

Given the need for balancing, PHES cannot be compared with a conventional hydro plant and its capacity to the grid should not be viewed just on basis of the volumetric tariff. The flexibility benefits that could be rendered by PHES need to be broken down into different components, and a provision should be built to pay/incentivize each of it. This approach would ascertain the value of flexibility to the grid, that is, the values for fast response, each start/stop, grid resilience and inertia, as well as for black start, etc. Assuming that a PHES with 75% overall efficiency pumps for 8 hours a day, it can generate for around a 6-hour period. In such a situation, the negative energy component is neutralized as long as the price for the 6 hours [peak hrs.] is more than 1.33 (8/6) times the pumping [off-peak] price. Hence, the entire operational financial viability of PHES depends on the differential between peak and off-peak periods.

Going forward, if we envisage a large difference between peak and off-peak period rates, then in addition to addressing the issue of negative energy factor, there may be some component from the differential in peak and off-peak rates toward the capacity charges as well.

7.8 Concluding Remarks

Toward zero-emission concept, hydro, wind, solar and pumped hydro energy storage (PHES) as hybrid power solutions, constitute a realistic and feasible option to achieve high renewable levels, considering that their components are properly sized. In some locations, the solar and wind resources have an anti-correlation, complementing each other and giving a combined less variable output than independently. However, such complementarity cannot be ensured at all times and the pumped hydro energy storage (PHES) systems as the most reliable avenue, provides the most commercially important means of large-scale grid energy storage, improving the daily capacity factor of the generation system and render valuable support toward zero-emission concept.

The important design toward zero-emission concept includes the building of the hybrid power systems which follows the minimization of power production cost, ability to draw energy from the grid during surplus conditions, reducing the total life cycle cost and increasing the reliability and flexibility of the power generation system. Operators of pumped hydropower plants need to react to an increasing number of short-term electricity markets and prices that are strongly influenced by RES. Variable-speed and ternary PHS systems allow for faster and wider operating ranges, providing additional flexibility, enabling higher penetrations of VRE at lower system costs at high reliable levels. At the same time closed loop off-grid PHES systems are more efficient and economical and due to the relatively lower degree of civil work involved, invite lesser opposition by the environmentalist as well.

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PART III

Energy Access and Women Empowerment

CHAPTER 8

Women's Land Ownership and Household Decisions: Implications for Child Health in Rural India

Koustuv Saha, Vijay Laxmi Pandey, and S. Mahendra Dev

8.1 INTRODUCTION

Agriculture is the major source of livelihood for the rural population. In India, the feminization of agriculture is taking place, and around 80% of farm work is undertaken by women (Oxfam, 2013). They are mostly engaged in farm work that is labour intensive and non-mechanized such

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as sowing, weeding, transplanting, etc. It is being reported that around 83% of agricultural land in India is inherited by male family members although, women constitute over 42% of the agricultural labour force (Mehta, 2018). In rural landowning households, only 16% of women own land (Agarwal et al., 2020). Ownership of land gives women stable and secure financial security compared to liquid assets, such as jewellery, flocks, herds, etc. During a financial crisis, households are more likely to sell liquid assets first (Agarwal, 1997; Han et al., 2019). The absence of land ownership affects women's economic empowerment in agriculture, and they lack entitlement to access productive agricultural resources.

Empowerment of women through land and ownership rights can reduce hunger across the world by 12–17% (FAO, 2011). Studies have shown that land ownership gives financial security to women and improves their bargaining power within the household (Agarwal, 1997; Anderson & Eswaran, 2009; Haddad et al., 1997). Subsequently, improvement in bargaining power helps in reduce discrimination by giving women more control over household decisions that affect their wellbeing (Ashraf et al., 2010; Doss, 2013; Malhotra & Schuler, 2005). In addition to it, there is evidence that an increase in women's access to economic resources results in higher investment in human capital such as education, health, and nutrition (Anderson & Eswaran, 2009; Mishra & Sam, 2016; Pandey, 2010). The persistence of stark inequity in landholdings between men and women in India is disturbing, considering that landholding by women can lead to better economic and social security for both women and their dependents (UNDP, 2013). Recognizing the importance of women's land ownership, the Sustainable Development Goal (SDG-5. A) has emphasized gender equality by giving equal rights to women for ownership, control, and tenure security of agricultural land.

An association between ownership of land and women's empowerment has been shown in the Indian context. A study by Florence et al. (2014) using household data from West Bengal revealed that women's land ownership has a positive association with their participation in decisions regarding the use of agricultural land and the purchase of productive assets by the households. It was reported by Roy (2008) that the right to inheritance of land by women increases their autonomy within their marital families in India. However, our understanding of the effects of women's land ownership on their overall empowerment and their health status is very limited for India.

Further, women's empowerment is one of the important indicators that determine children's nutritional status, especially for children under five years of age. A positive association has been observed between women's empowerment and children's nutritional status (Folaranmi, 2013). Maternal empowerment and education have a positively impact-5 child stunting (Siddhanta & Chattopadhyay, 2017). In India, around two-thirds of the population is estimated to be malnourished (Rao et al., 2018). The prevalence of underweight in women aged 14–49 years was about 23% in 2015–2016 (NFHS-4, 2016). Malnutrition was the major cause of death of children under-5 (around 68.2% of the total death) in 2017 (LANCET, 2019), and the problem of malnourishment is more serious in rural areas than urban areas. Besides, the recently released NFHS-5 (2019–2020) factsheets for 22 states/UTs show a worsening of malnutrition indicators in most of the states.

With this background, the present study aims at understanding the ownership rights on women's empowerment consisted of women's decision-making and freedom of movement and on maternal and child heh outcomes in rural India. For this purpose, the study tests the veracity of the hypothesis that *improved woman land rights can increase woman autonomy and empowerment*. The hypothesized importance of land ownership for woman empowerment is based on two points. First being the owner of land can provide a more secure fall-back position for the woman in case of termination of the husband's support. Thus, the woman has a better bargaining position with respect to her husband (Agrawal, 1997). Secondly, in rural India, a person's social status is tied up to their land ownership status in a way unlike any other asset is. Since nearly all rural households in India are engaged in agriculture, women's ownership of the main productive asset can have far-reaching implications for the household wealth status (Roy, 2008). The other hypothesis states that *women's land ownership will lead to an improvement of their health and their child's health*. Studies have shown that compared to men, women's income or their ownership of assets is consistently associated with greater positive effects for household calorie level, food expenditures, and children's nutritional status (Allendorf, 2007; Shroff et al., 2009).

Using regression technique, the positive relationship between women's land ownership and women's autonomy was validated in our paper. The results show that joint ownership of land for women is insufficient to improve empowerment, and it is only in the case of sole ownership that women's autonomy and decision-making powers improve. A direct positive relationship between women's land ownership and women's health outcome (as measured by the body mass index) was found. However, no direct association between women's land ownership and children's nutritional status measured by stunting and underweight was observed in our study.

8.2 DATA AND METHODOLOGY

8.2.1 Data Source

The nationally representative National Family and Health Survey (NFHS-4) conducted in 2015–2016 was used for the empirical analysis. The survey comprised nearly 7 lakh women and one lakh men from 29 states and 7 on territories in India. The information used pertains to health and family welfare, husband's background and women's work, household characteristics, and women's empowerment. All women of age 15–49 years who were usually members of the household or who spent the night in the household were eligible for the survey. In around 15% of the total selected households, men age 15–54 who were usual members or who spent the night in the household were eligible for the men's questionnaire.

The scope of our analysis is restricted to rural areas in the 27 largest states of India and the union territories. Only currently married women respondents with living children aged 6 to 59 months, who were regular residents of their households, are included in the present analysis. After removing observations with missing or inconsistent values, the sample consists of 19,337 women respondents with 25,266 children aged 6–59 months. We would also like to mention that NFHS-4 data appear to be erroneous concerning land ownership by women, as pointed out by Agarwal et al. (2020), "*Under the Survey, villages were the Primary Sampling Units (PSUs), but the schedule for land ownership was canvassed only to a sub-sample of 15% of households, with interviews being conducted in every alternate selected household in 30% of the selected villages. In this sub-sample (as is the NFHS practice), only women aged 15-49 and men aged 15-54 are interviewed; hence for land ownership also, details only for these age categories were covered, thus leaving out older family members. Also, NFHS-4 includes all land owned and does not separate out agricultural land. --- the sample expansion of NFHS-4 relative to NFHS-3 by some*

5.5 times more households, necessitated the recruitment of a large number of new data collectors with limited experience, thus increasing the likelihood of substantial non-sampling errors". In the following subsections, the major variables included in the analyses are described.

8.2.2 Women Land Ownership Variable

The Women's land ownership variables are defined in a similar way as by Allendorf (2007), Mishra and Sam (2016), and Rehman et al. (2019). The women land ownership variables (*Sole Land Ownership* and *Joint Land Ownership*) are constructed based on the respondent's answer to the question "*Do you own any land either alone or jointly with someone else?*", which could be "*Alone only*", "*Jointly only*", "*Both alone and jointly*", or "*Does not own*". The variable for sole women land ownership *(SLO)* takes value unity when the respondent's response is "*Alone only*" or "*Both alone and jointly*". It is equal to zero if the respondent either does not own any land or only owns land jointly with somebody else. The variable for joint women land ownership *(JLO)* takes the value one when the respondent's answer is "*Jointly only*". Allendorf (2007) points out that landowning women being a subset of landed households are likely to be wealthier than the reference group of non-landowning women, which includes both landed and non-landed households. To control for this asymmetry in wealth status of the two household groups, we have included a variable, *lives in the landed household*, to indicate if any member of the household other than the respondent owns the land.

8.2.3 Women Empowerment Index

The women empowerment index is constructed based on the respondent's answers to four questions on various aspects of the intra-household distribution of decision-making powers (WDM) and three questions on the respondent's freedom of movement (FOM). The four decision-making (WDM) questions are:

i. "*Who decides how your husband's earnings will be used: mainly you, mainly your husband, or you and your husband jointly?*"
ii. "*Who usually makes decisions about health care for yourself: mainly you, mainly your husband, you and your husband jointly, or someone else?*"

iii. "*Who usually makes decisions about making major household purchases: mainly you, mainly your husband, you and your husband jointly, or someone else?*"
iv. "*Who usually makes decisions about visits to your family or relatives: mainly you, mainly your husband, you and your husband jointly, or someone else?*"

If a respondent's answer to any of the above four questions is "*Respondent*" or "*Respondent and husband jointly*", it is marked as positive. All other responses are marked as negative. Concerning the question regarding the respondent's husband's earnings, 131 women reported that their husbands had no earnings and 20 observations with missing values. Rather than dropping these observations, these responses are taken to be negative.

The three questions on the respondent's freedom of movement (FOM) are:

i. "*Are you usually allowed to go to the market alone, only with someone else, or not at all?*"
ii. "*Are you usually allowed to go to the health facility alone, only with someone else, or not at all?*"
iii. "*Are you usually allowed to go to the places outside this village/community alone, only with someone else, or not at all?*"

If a respondent's response to any of the three questions is "*Alone*", it is marked positive., If instead, her response is "*With someone else only*" or "*Not at all*", it is marked negative.

The *women empowerment index* (WEI) for a respondent is calculated as the proportion of positive responses among all seven responses. Thus, the possible values of the *WEI* run from zero to unity, with higher values denoting greater women empowerment.

8.2.4 Maternal Health and Child Health Variable

Maternal health is measured using the body mass index (BMI). BMI is calculated as the ratio between the mother's weight (in kg) and her height square (in m^2). The incidence of child malnutrition is captured in two alternative ways, one, by checking if the child is stunted, and two, by checking if the child is underweight. A child is stunted if their *z* score for height-for-age is at least two standard deviations below the median. Similarly, a child is identified as underweight if their *z* score for weight-for-age is at least two standard deviations below the median. The *z* scores for height-for-age and weight-for-age are computed using the WHO Stata Anthro macro package.

8.2.5 Empirical Framework

There are both direct and indirect benefits of women's land rights for child health. Figure 8.1 represents the different direct and indirect routes through which women empowerment as measured by the *WEI* is hypothesized to affect child malnutrition. There is the direct route from land ownership to child health, the indirect route through women empowerment, and the longer indirect route running through empowerment and women health. Essentially, there are three relationships to be estimated as part of testing the overall hypothesis that women's land ownership can improve their child's health. First, the relationship between women's ownership of land and women's empowerment is estimated. Second, the relationship between women's health, empowerment, and land ownership is seen. Third, the association between child health and women's characteristics which includes the ownership of land, empowerment, and maternal health is estimated.

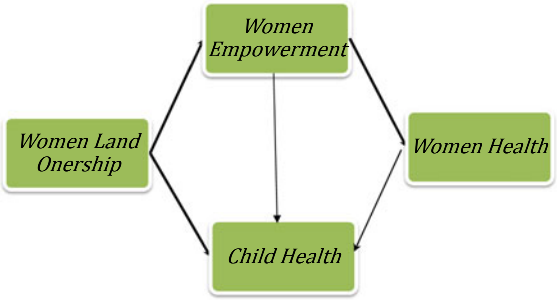

Fig. 8.1 Possible routes for women's land ownership to influence child health outcomes

The list of variables included in the analysis is given in Table 8.1. All regression analyses and tests were conducted in STATA 13 using the survey data analysis commands. This involved first declaring the design of the NFHS sample survey and using the *svy:* prefix for the commands. This meant that STATA automatically accounted for sample weights, clustering, and attendant problems of using cross-section data like the possibility of heteroskedasticity.

8.2.6 Child Health Equation

There are direct benefits of women's land ownership which can lead to better child health and a lower incidence of child malnutrition. Earlier studies have demonstrated that an equal amount of income accruing to a woman as compared to a man produces greater positive effects for child survival and nutritional status (Allendorf, 2007; Quisumbing et al., 1995; Thomas, 1990). Other studies have made the efficiency argument that women's land rights lead to increased agricultural productivity and thereby increases the overall number of productive resources available in a household (Agarwal, 1994; Allendorf, 2007; Kodoth, 2001). In terms of the present framework, the presence of a direct and independent effect of women's land rights on child health will be evinced in a positive and statistically significant variable in the child health (stunting and underweight) equations even after controlling for women empowerment as measured by the WEI (Allendorf, 2007; Rehman et al., 2019).

Following Rehman et al. (2019) and Allendorf (2007), we include controls for the child's characteristics like age, sex, and whether the child is firstborn; for maternal characteristics like age, education, and employment; and for household characteristics like wealth, religion, and caste. The household's level of wealth has been shown to be highly significant and negatively related to child malnutrition (Allendorf, 2007; Rehman et al., 2019). We have used the wealth index published by the NFHS. The index includes household assets like television and radio and housing characteristics like the type of roof, source of drinking water, and type of toilet. Based on this information the, NFHS wealth index ranks households into five categories: poorest, poorer, middle, richer, and richest. As the state in which a woman is also born matters due to differences in the social norms for an inheritance, especially for land ownership, we have included a dummy variable for this purpose. Agarwal (1995) has reported

Table 8.1 Variables included in the regression equations

Variable name	*Variable description*
Child health	Stunting < 2 SD Height-for-age z score/Weight-for-age z score
Child's age	Child's age in months
Child's sex	Male = 1, Female = 0
Firstborn	This indicates that the child is the firstborn
Number of children	Number of children under five years of age living in the household
Place of delivery	Child delivered at a public/private institution = 1
BMI	Respondent's body mass index
WEI	Women Empowerment Index
Position in household:	
• Household head	Respondent heads the household
• Wife of household head	Respondent is the wife of the household head
• Others [Reference category]	Respondents related to household heads in any other manner
Education:	
• None [Reference category]	Respondent lacks education
• Primary	Respondent has completed primary school
• Secondary or higher	Respondent has completed secondary school or higher
Husband's education:	
• None [Reference category]	Husband lacks education
• Primary	Husband has completed primary school
• Secondary or higher	Husband has completed secondary school or higher
Media exposure	Respondent has access to a TV/radio/newspaper at least once a week = 1
Age	Respondent's age in years
Cash employment	Respondent is compensated in cash at her job = 1
Women land ownership:	
• Does not own land [Reference category]	Respondent does not own any land
• Lives in a landed household	Someone other than the respondent owns land in the household

(continued)

Table 8.1 (continued)

Variable name	*Variable description*
• JLO	Joint Land Ownership; respondent, only owns land jointly with someone else
• SLO	Sole Land Ownership; respondent is the sole owner of the land
Wealth index	Household wealth index with five categories. The lowest/poorest category is the reference
Religion	Index for religion of the household with four categories. Hindu household as reference
Caste/Tribe	Index to indicate if the household is a SC or ST household. Non-SC/ST households as reference
State dummies	Indicating the state where the respondent resides
Age difference	Husband's age minus respondent's age in years
Media exposure	Respondent has access to a TV/radio/newspaper at least once a week = 1
Currently pregnant	Respondent is currently pregnant = 1

that south and west India are more conducive to women getting landed property than north India.

A variable is also included to indicate if the mother has access to the source of mass media, a television or a radio or a newspaper, at least once a week. Media exposure is an important source of information for women, which may allow some exposure to the outside world (Mishra & Sam, 2016). Women's education and employment are both important sources of women's empowerment which in turn is expected to positively impact child health. A dummy variable was included to indicate if the child was delivered at a health facility or home. Mother's health being a crucial immediate determinant of a child's nutritional outcomes, respondent's BMI was included in the equation (Jose et al. 2020).

8.2.7 Women Empowerment (WEI) Equation

The woman's land rights may improve child health outcomes through their influence on the intra-household distribution of decision-making powers and women empowerment. The theory of intra-household bargaining, as posited in works by Lundberg and Pollak (1993) and Agarwal (1994, 1997), argues that ownership of the productive asset, especially arable land, improves women's decision-making powers by acting as a force for the women landowner. As women come in charge of more of the key household decisions and their autonomy increases, it can lead to better child health outcomes through greater use of health care, better immunization and nutritional status, and reduced child mortality rates (Allendorf, 2007; Bloom et al., 2001; Kishor, 2000). If this route for the indirect effects of women's land rights on child health is operational in the case of the present study, we should find the coefficients of the women's land ownership variables to be positive and statistically significant in the WEI equation.

Similar to the equations for child health, the WEI equation includes controls for the respondent's characteristics, household characteristics, and possible sources of empowerment. The choice of covariates for this equation is based on earlier works like Allendorf (2007), Rehman et al. (2019), and Mishra and Sam (2016).

8.2.8 Women Health Equation

Women's land rights by increasing women's autonomy in decisions about their healthcare and decisions about how to utilize the household earnings can lead to households spending more on women's healthcare and nutrition (Brule, 2010; Mishra & Sam, 2016; Rehman et al., 2019). Using data from NFHS 1998–1999, Basu and Koolwal (2005) find evidence of women's autonomy in household decisions in India improving the quality of women's diet, women's nutrition, and lowering the incidence of women's malnutrition.

The resulting improvement in the mother's health has important implications for the child's health (Dharmalingam et al., 2010; Jose et al., 2020; Kim et al., 2017). The functioning of this route of influence from mother to child health will be indicated in positive and statistically significant coefficients of women health (BMI) in the child health equations, positive and statistically significant coefficient of women empowerment (WEI) in the equation for maternal health (BMI) and positive and statistically significant coefficients of the women land ownership variables (JLO & SLO) in the WEI equation.

The same set of control variables added to the women empowerment equation were also included in the women health equation. One addition is a dummy indicating if the respondent was currently pregnant. This is done to account for the fact that the BMI may not be accurate for a pregnant respondent.

Hence the three equations to be estimated are given by:

1. *WEI = g (SLO, JLO, Respondent's Characteristics, Husband's Characteristics, Household Characteristics)*
2. *BMI = h (WEI, SLO, JLO, Respondent's Characteristics, Husband's Characteristics, Household Characteristics)*
3. *Child malnutrition (stunting/underweight) = f (WEI, SLO, JLO, BMI, Child's Characteristics, Respondent's Characteristics, Husband's Characteristics, Household Characteristics).*

The women empowerment (WEI) and maternal health (BMI) equations were estimated using OLS regressions, whereas the child malnutrition equations (Stunting/Underweight) were estimated using logistical regression techniques since the dependent variables were dummy variables.

8.3 RESULTS AND DISCUSSIONS

In this section, first, we will be discussing the descriptive statistics of variables included in regression analysis, the intra-household decision-making (WDM), and empowerment. The regression results and discussions are given in the next subsections.

8.3.1 Descriptive Statistics

We begin by presenting the descriptive statistics of the variables included in the regression analyses in Table 8.2. The mean BMI of women of age 15–49 years was 21. The average age at which the first child is born was about 27 years. Around 40% of mothers were illiterate. Only 33% of all the women present in the sample reported owning any land, either alone or jointly with someone else. The share of women who owned land alone was even lower at 18%. Hence there is considerable room for improving the equity of the inter-gender land distribution in rural India. Over, all stunting was found to be highly prevalent in the sample as 41.56% of all the under-five children in the sample were found to be stunted whereas, the prevalence of underweight was 39% in under-five children.

8.3.2 Intra-Household Decision-Making and Women Empowerment

The WDM is found to have a mean value of 2.73 and a standard deviation equal to 0.02 for the complete sample of women. Thus, the average woman in the sample has some say in at least two of the four household decisions. With respect to freedom of movement, the mean value is 1.29 (standard deviation of 0.01), representing that women have freedom of movement in at least one of the three scenarios. Table 8.3 shows the distribution of the women empowerment index (WEI) variable across the sample. Approximately 21% of women in the sample were highly empowered with the positive response to all seven questions. However, almost 12% did not have any say in decision-making and had no freedom of movement. Around 26% of the women have given a positive response to four out of seven *WEI* questions.

Table 8.4 presents the percentage of women with positive responses to each of the underlying questions of the FEI. Among the four WDM decisions, a woman is most likely to have some say regarding her healthcare, and she is least likely to have any say about how to spend her husband's income. Adjusted Wald tests showed that among the WDM questions, the proportion of women with decision-making powers for household purchases and visits to relatives were not statistically significantly different from each other (*P*-value is 0.11). Other than this, the differences in the proportions of women with decision-making powers for all other combinations of the WDM questions were statistically significant at 1%. Concerning FOM, complete freedom of movement is less than 45% among all three scenarios. Women are least likely to be allowed complete freedom of movement is in going to places outside the village. Adjusted Wald tests showed that the proportion of women with the freedom to go to market, to the health facility, and outside village were all significantly different from each other (*P* values equal to 0).

Table 8.5 presents the mean of the WEI variable for the women who live in households with a different type of land ownership status. From the mean WEIs of each of the woman subpopulations, it appears that women

Table 8.2 Descriptive statistics of the variables included in the regression analyses

	Mean	*Standard deviation*
WEI	0.57	3.75
BMI	20.86	0.32
Age (years)	27	5
Age at first birth (years)	21	3
Age difference (years)	5	4
HAZ	−1.67	1.62
WAZ	−1.66	1.16
Child's age (months)	32	15
Number of children	1.9	0.9
	The proportion of the sample (%)	
Women's Education:		
None	40.04	
Primary	45.51	
Secondary or higher	14.45	
Media exposure	58.88	
Husband's education:		
None	27.48	
Primary	53.25	
Secondary or higher	19.27	
Women land ownership:		
Landless household	39.85	
Lives in a landed household	26.79	
JLO	14.84	
SLO	18.52	
Stunting	43.65	
Underweight	38.81	
Place of delivery (public/private institution)	75.78	
Wealth index:		
Poorest	21.90	
Poorer	20.83	
Middle	18.97	
Richer	19.93	
Richest	18.37	
Cash Employment	16.43	

(continued)

Table 8.2 (continued)

	Mean	*Standard deviation*
Religion:		
Hindu	81.72	
Muslim	13.65	
Christian	1.98	
Other	2.65	
Caste/Tribe:		
SC	22.41	
ST	12.76	
Other	64.83	

in landless households are slightly more empowered than the women

Table 8.3 WEI distribution

WEI	*Number of respondents*	*Percentage of respondents*
0	2015	11.58
1/7	992	5.7
2/7	1151	6.62
3/7	1997	11.48
4/7	4455	25.61
5/7	1598	9.19
6/7	1540	8.85
1	3645	20.96

Table 8.4 Share of women with decision-making power and Freedom of Movement

Percentage of Women Who Decide Singly or Jointly About	
Her Healthcare	70.73
Large Household Purchases	68.20
Visits to Family or Relatives	68.79
What to Do with Husband's Income	64.97
Percentage of Respondents Who are Free to Go Alone	
To the Market	44.84
To the Health Facility	42.85
Outside the Village/Community	41.22

Table 8.5 Mean WEI of women with respect to land ownership

	Landless households	*Landed households*	*Landed households with JLO*	*Landed households with SLO*
WEI	0.579	0.572	0.537	0.593

in landed households (though the difference was not statistically significant). Though, women in landless households have significantly higher WEI than women having JLO. Further, in the landed households, sole land ownership (SLO) by women could be associated with higher women autonomy than joint land ownership (JLO). The difference in average WEI for SLO and JLO was statistically significant at less than 1%. Hence, the sole land ownership status of women has implications for women's empowerment.

8.4 REGRESSION RESULTS

8.4.1 Determinants of Women Empowerment (WEI)

Table 8.6 reports the results for the association between WEI and women's land ownership. As expected, woman sole land ownership has a statistically significant and positive effect on woman empowerment or autonomy as measured by the WEI. Sole ownership of land gives more autonomy to women as compared to those who do not own any land. This is in line with the findings of Allendorf (2007) and Mishra and Sam (2016). Though Allendorf (2007) did not distinguish between joint and sole land ownership status, and their women empowerment variable was based only on a subset of the variables used to construct the *WEI*.

Interestingly, joint land ownership has a statistically significant and negative effect on women empowerment. This result would seem to imply that a woman who shares ownership of land with another family member is less empowered than a woman who lives in a landless household. Rehman et al. (2019) also found that joint ownership of land (JOL) has a negative, though statistically insignificant, effect in rural Pakistan. The possible explanation given is that in rural areas, joint ownership can

Table 8.6 Factors affecting women's empowerment

WEI	
Position in household:	
Other [*Reference*]	
Household head	0.180***
	(0.0123)
Wife of household head	0.0627***
	(0.00692)
Education:	
None [*Reference*]	
Primary	0.0402***
	(0.00791)
Secondary or higher	0.0898***
	(0.0117)
Husband's education:	
None [*Reference*]	
Primary	–0.0216***
	(0.00773)
Secondary or higher	–0.0264**
	(0.0109)
Media exposure	0.0279***
	(0.00835)
Age	0.00588***
	(0.000617)
Age difference	0.000497
	(0.000715)
Cash employment	0.0852***
	(0.00883)
Women land ownership:	
Landless household [*Reference*]	
Lives in a landed household	–0.00637
	(0.00789)
JLO	–0.0292***
	(0.0112)
SLO	0.0342***
	(0.00915)
Wealth index:	
Poorest [*Reference*]	
Poorer	–0.00438
	(0.00965)
Middle	–0.00864
	(0.0113)

(continued)

Table 8.6 (continued)

WEI	
Richer	−0.00168
	(0.0125)
Richest	0.00790
	(0.0147)
Religion:	
Hindu [*Reference*]	
Muslim	−0.0217**
	(0.0106)
Christian	0.0108
	(0.0261)
Other	−0.0117
	(0.0214)
Caste/Tribe:	
Other [*Reference*]	
SC	0.0171**
	(0.00790)
ST	0.0234**
	(0.0105)
State dummies:	
Andhra Pradesh [*Reference*]	
Arunachal Pradesh	0.106***
	(0.0410)
Assam	0.0578
	(0.0361)
Bihar	−0.0272
	(0.0355)
Chhattisgarh	0.0188
	(0.0380)
Gujarat	0.000800
	(0.0394)
Haryana	−0.0392
	(0.0391)
Himachal Pradesh	0.196***
	(0.0376)
Jammu and Kashmir	0.102***
	(0.0364)
Jharkhand	0.0920**
	(0.0371)
Karnataka	−0.0697
	(0.0432)

(continued)

Table 8.6 (continued)

WEI	
Kerala	−0.0571
	(0.0371)
Madhya Pradesh	−0.0353
	(0.0353)
Maharashtra	0.0876**
	(0.0374)
Manipur	0.105***
	(0.0397)
Meghalaya	0.116**
	(0.0461)
Mizoram	0.304***
	(0.0453)
Nagaland	0.0949**
	(0.0441)
Odisha	−0.0642*
	(0.0357)
Punjab	0.0603
	(0.0444)
Rajasthan	−0.0107
	(0.0360)
Sikkim	0.360***
	(0.0442)
Tamil Nadu	0.0962***
	(0.0373)
Tripura	0.0685
	(0.0453)
Uttar Pradesh	−0.0235
	(0.0345)
Uttarakhand	0.169***
	(0.0377)
West Bengal	0.156***
	(0.0369)
Telangana	−0.0150
	(0.0456)
Constant	0.305***
	(0.0386)
Observations	19,337
R-squared	0.105

Note Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

leave women with very few rights since it is mainly dominated by the male counterpart. The variable JOL defines only the ownership of the land, not who controls the land in joint ownership. Even a negative association, though not significant, was observed for the women who do not have ownership of land in landed households compared to women in landless households. Therefore, there is a need to have gender equality in farmland ownership in rural areas. However, it is especially difficult to find support for more equitable land distribution among men and women due to the apparent zero-sum nature of the redistribution policy, taking land from men to give to women (Allendorf, 2007). Further, in the light of increasing land fragmentation, it is very difficult to find stakeholders willing to support land redistribution in favour of women (Rehman et al., 2019).

Among the other sources of empowerment, women's education, cash employment, and media exposure all have statistically significant and positive effects. However, the husband's education levels have a negative and significant association with the *WEI*. This is likely because the relative educational attainment of the woman and her husband decides the distribution of decision-making powers in the household. Hence holding other things constant, as the husband's level of education increases, the share of household decisions under his ambit may also increase. Cash employment and media exposure have a positive and significant association with *WEI* as cash employment provides women not only with an independent source of income but also allows for greater interaction outside the household, and media exposure allows access to news and information for women who may have little opportunity of encountering the larger society.

The results show that women's autonomy increases with their age though the age difference with the husband does not have a significant effect. Both women head and women married to the head of the household have greater intra-household decision-making powers than other women. Hence position in the family hierarchy is an important determinant of women's decision-making. Household wealth is generally seen to be an insignificant factor in determining women's empowerment.

The coefficient for Muslim households is statistically significant and negative, implying that Muslim women have less autonomy in household decisions than women from other religious backgrounds. The coefficients for SC households and the ST households are statistically significant and positive. As compared to Andhra Pradesh (AP) which is a reference state, Himachal Pradesh (HP), J&K, Jharkhand, Maharashtra, Tamil

Nadu (TN), Uttara Khand (UK), West Bengal (WB), and most of the northeastern states have better *WEI* but Odisha as lower *WEI*.

8.4.2 Factors Affecting Women's Health (BMI)

The estimated coefficients from the *BMI* equation are listed in Table 8.7. A unit increase in the *WEI* increases the respondent's *BMI* by 0.23. In terms of magnitude, the effect of a unit increase in respondent's *WEI* on her *BMI* is similar to that of her having primary education as opposed to no education. Hence women's empowerment or autonomy is an important determinant of their health. However, women's land ownership has no significant impact on *BMI*.

Besides the respondent's level of education, her husband's level of education also has a statistically significant and positive impact on her BMI. Hence, more educated spouses though have a negative relationship with WEI but are better capable of creating conditions conducive to women's health and nutrition. This is possible due to the likelihood of a more educated person understanding the importance of women's health in attaining children's health and nutrition better. Access to mass media is also found to be highly significant and positively correlated with BMI. Household wealth level is statistically significant and positively associated with women's BMI. Since the wealth index also includes variables for the quality of drinking water and sanitation available in the household, it is expected to be strongly correlated with women's health.

The coefficient for Muslim households is statistically significant and positive. In conjunction with the significant and negative coefficient for Muslim households in the *WEI* regression, this implies that Muslim women are more likely to have better health but lower autonomy than other religions. The coefficients for both SC and ST households are statistically significant and negative. This is as expected, considering that SC and ST communities are among the poorest and most discriminated against in the country. Contrary to the case of Muslim respondents, SC and ST respondents have greater autonomy but lower health than respondents who are not SC or ST. Compared to AP (which is a reference state), Arunachal Pradesh, J&K, Manipur, Mizoram, Meghalaya, Nagaland, Punjab, and Sikkim have better, *BMI* but Chhattisgarh, Gujarat, Jharkhand, Madhya Pradesh (MP), Maharashtra, Odisha, and Rajasthan have lower *BMI for the women aged 15–49 years*.

Table 8.7 Women empowerment (WEI) and women body mass index

BMI	
Position in household:	
Other [*Reference*]	
Household head	0.0201
	(0.130)
Wife of household head	0.110
	(0.0777)
Education:	
None [*Reference*]	
Primary	0.284***
	(0.0858)
Secondary or higher	0.293**
	(0.148)
Media exposure	0.311***
	(0.0761)
Husband's education:	
None [*Reference*]	
Primary	0.228***
	(0.0855)
Secondary or higher	0.419***
	(0.132)
Age	0.112***
	(0.00811)
Age at first birth	−0.0242*
	(0.0126)
Currently pregnant	1.025***
	(0.105)
Cash employment	−0.0809
	(0.0940)
Women land ownership:	
Landless household [*Reference*]	
Lives in a landed household	−0.0717
	(0.0876)
JLO	0.100
	(0.101)
SLO	−0.0420
	(0.0999)
WEI	0.230**
	(0.113)
Wealth index:	
Poorest [*Reference*]	

(continued)

Table 8.7 (continued)

BMI	
Poorer	0.381***
	(0.0925)
Middle	0.747***
	(0.111)
Richer	1.454***
	(0.131)
Richest	2.596***
	(0.158)
Religion:	
Hindu [*Reference*]	
Muslim	0.429***
	(0.129)
Christian	0.351
	(0.297)
Other	0.409**
	(0.206)
Caste/Tribe:	
Other [*Reference*]	
SC	−0.208**
	(0.0895)
ST	−0.223**
	(0.0976)
State dummies:	
Andhra Pradesh [*Reference*]	
Arunachal Pradesh	0.728*
	(0.389)
Assam	−0.208
	(0.326)
Bihar	−0.0400
	(0.313)
Chhattisgarh	−0.676**
	(0.329)
Gujarat	−0.758**
	(0.351)
Haryana	−0.540
	(0.370)
Himachal Pradesh	−0.0431
	(0.380)
Jammu and Kashmir	0.822**
	(0.344)

(continued)

Table 8.7 (continued)

BMI	
Jharkhand	−0.698**
	(0.323)
Karnataka	0.409
	(0.361)
Kerala	0.593
	(0.458)
Madhya Pradesh	−0.650**
	(0.308)
Maharashtra	−0.935***
	(0.342)
Manipur	1.028***
	(0.379)
Meghalaya	−0.00306
	(0.431)
Mizoram	0.374
	(0.454)
Nagaland	0.350
	(0.460)
Odisha	−0.0414
	(0.327)
Punjab	0.961**
	(0.442)
Rajasthan	−0.532*
	(0.317)
Sikkim	1.434***
	(0.517)
Tamil Nadu	1.408***
	(0.376)
Tripura	0.0749
	(0.412)
Uttar Pradesh	0.131
	(0.307)
Uttarakhand	−0.0712
	(0.357)
West Bengal	0.413
	(0.353)
Telangana	−0.379
	(0.452)
Constant	16.57***
	(0.401)
Observations	19,337

(continued)

Table 8.7 (continued)

BMI	
R-squared	0.150

Standard errors in parentheses, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

8.4.3 Determinants of Child Health

The estimated coefficients from the child health regressions are listed in Table 8.8. The odds ratios for mother's BMI are statistically significant and less than unity for all two indicators of child's malnutrition. A unit rise in maternal BMI lowers the odds of her child being stunted by 4% and of being underweight by 9.3%. Our result agrees with earlier studies which have shown mothers' BMI to be one of the most important determinants of child malnutrition (Jose et al., 2020).

In conjunction with the results from the *WEI* and *BMI* regressions, the evidence of a positive association between maternal *BMI* and child health indicates that there is an indirect link running from women's land rights to child health outcomes through women's health. Hence women's land rights by providing leverage in intra-household bargaining enhance respondent's access to nutrition and health care for herself. The resulting improvement in women's health leads to healthier children that are less prone to suffer from malnutrition.

Neither SLO nor JLO has any statistically significant impact on child health. The *WEI* variable is also statistically insignificant. Hence the direct route from women's land ownership to child health and the indirect route of women's land ownership on child health through WEI are not operating in our sample. Among the sources of women empowerment, women's education is a highly important determinant of the likelihood of child malnutrition. The odds ratios for a husband's higher education are statistically significant and less than one only for stunting. The land ownership variables are statistically insignificant. Understandably, household wealth level is an important determinant of child malnutrition. Older children are more likely to suffer from stunting and low body weight. Similarly, male children are more likely to be stunted than female children.

With respect to other castes, stunting in children from SC and ST households was more prevalent, and underweight was more prevalent in children from ST households. At the state level, it shows that compared to reference state i.e., AP, the possibility of children under-5 being stunted

Table 8.8 Factors affecting child malnutrition (odds ratios)

	Stunting	*Underweight*
Child's age	1.010***	1.008***
	(0.00120)	(0.00120)
Child's sex	1.083**	1.045
	(0.0367)	(0.0376)
Firstborn	0.891***	0.891***
	(0.0385)	(0.0393)
Number of children	1.092***	1.018
	(0.0239)	(0.0210)
Place of delivery	0.980	0.959
	(0.0425)	(0.0418)
Position in household:		
Other [*Reference*]		
Household head	0.951	0.842**
	(0.0758)	(0.0709)
Wife of household head	1.047	1.047
	(0.0444)	(0.0457)
Education:		
None [*Reference*]		
Primary	0.835***	0.812***
	(0.0376)	(0.0367)
Secondary or higher	0.674***	0.616***
	(0.0515)	(0.0488)
Media exposure	0.999	0.977
	(0.0467)	(0.0458)
Husband's education:		
None [*Reference*]		
Primary	0.937	0.944
	(0.0436)	(0.0447)
Secondary or higher	0.849**	0.917
	(0.0583)	(0.0653)
Age	0.989**	1.001
	(0.00441)	(0.00431)
BMI	0.960***	0.907***
	(0.00559)	(0.00594)
Cash employment	1.065	1.053
	(0.0583)	(0.0585)
Women land ownership:		
Landless household [*Reference*]		

(continued)

Table 8.8 (continued)

	Stunting	*Underweight*
Lives in a landed household	0.940	0.933
	(0.0447)	(0.0452)
JLO	0.999	1.038
	(0.0539)	(0.0578)
SLO	1.000	1.040
	(0.0540)	(0.0545)
WEI	1.057	1.094
	(0.0642)	(0.0652)
Wealth index:		
Poorest [*Reference*]		
Poorer	0.848***	0.850***
	(0.0496)	(0.0478)
Middle	0.734***	0.767***
	(0.0472)	(0.0477)
Richer	0.620***	0.644***
	(0.0464)	(0.0475)
Richest	0.488***	0.521***
	(0.0447)	(0.0461)
Religion:		
Hindu [*Reference*]		
Muslim	1.180***	1.014
	(0.0725)	(0.0656)
Christian	1.002	1.245
	(0.152)	(0.198)
Other	1.188	1.201
	(0.183)	(0.171)
Caste/Tribe:		
Other [*Reference*]		
SC	1.289***	1.067
	(0.0629)	(0.0522)
ST	1.128*	1.112*
	(0.0710)	(0.0706)
State dummies:		
Andhra Pradesh [*Reference*]		
Arunachal Pradesh	0.451***	0.257***
	(0.106)	(0.0634)
Assam	0.679**	0.502***
	(0.117)	(0.0914)

(continued)

Table 8.8 (continued)

	Stunting	*Underweight*
Bihar	1.094	0.972
	(0.178)	(0.165)
Chhattisgarh	0.859	0.864
	(0.151)	(0.163)
Gujarat	1.375*	1.365*
	(0.229)	(0.245)
Haryana	1.072	0.942
	(0.206)	(0.189)
Himachal Pradesh	0.831	0.765
	(0.160)	(0.162)
Jammu and Kashmir	0.622***	0.397***
	(0.108)	(0.0740)
Jharkhand	1.056	1.131
	(0.183)	(0.200)
Karnataka	1.043	1.298
	(0.199)	(0.260)
Kerala	0.754	0.499***
	(0.178)	(0.125)
Madhya Pradesh	1.032	1.102
	(0.168)	(0.187)
Maharashtra	1.199	1.059
	(0.222)	(0.194)
Manipur	0.774	0.302***
	(0.167)	(0.0723)
Meghalaya	1.074	0.492***
	(0.247)	(0.115)
Mizoram	1.056	0.233***
	(0.257)	(0.0750)
Nagaland	0.667	0.277***
	(0.175)	(0.0837)
Odisha	0.702**	0.723*
	(0.121)	(0.130)
Punjab	0.580**	0.492***
	(0.139)	(0.123)
Rajasthan	0.896	0.817
	(0.148)	(0.143)
Sikkim	1.210	0.241***
	(0.313)	(0.103)
Tamil Nadu	0.782	0.790
	(0.137)	(0.148)

(continued)

Table 8.8 (continued)

	Stunting	*Underweight*
Tripura	0.517**	0.434***
	(0.135)	(0.107)
Uttar Pradesh	1.332*	1.076
	(0.210)	(0.179)
Uttarakhand	0.975	0.790
	(0.212)	(0.163)
West Bengal	0.525***	0.603***
	(0.0982)	(0.116)
Telangana	0.926	0.786
	(0.215)	(0.179)
Constant	2.189***	5.754***
	(0.515)	(1.441)
Observations	25,266	25,266

Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

is lower in Arunachal Pradesh, Assam, J&K, and WB whereas, it is higher in the case of Gujarat, Odisha, and Punjab. It is more likely for the children under-5 not to be underweight if they are from J&K, Kerala, WB, and from the North Eastern States than the under-5 children from AP (reference state). However, under-5 children from Gujarat, Odisha, and Punjab states are more likely to be underweight compared to AP.

8.4.4 Limitations of the Study

There remain several opportunities to build upon this work. Women empowerment index can be improved by using different weight distributions among the constituent questions. It is also possible to have unobserved or omitted variables which simultaneously affect the status of women's land ownership, empowerment, and health. Reverse causality could also arise if a more empowered woman is more likely to own land (Mishra & Sam, 2016). Thus, there is a possibility of improving the analysis by using econometric techniques that are more robust to address the endogeneity bias.

8.5 CONCLUSIONS

The present paper set out to establish a link between women's land ownership and child health outcomes in rural India. It was posited that owning land will improve a woman's bargaining position within the household and increase her intra-household decision-making powers that subsequently will improve her own and her children's nutritional status. Our analysis revealed that shared land ownership status for women was not associated with improvement in women's empowerment (WEI) or decision-making powers. However, women who reported being the sole owners of a piece of land were more likely to have greater decision-making power and are more empowered. Women's education, media exposure, and employment opportunities were also found to significantly improve the empowerment of women. Thus, a more equitable inter-gender distribution of land rights will help improve the intra-household power relations of women and increase women's empowerment. The analysis shows that women's BMI is positively associated with women's empowerment but has no significant association with land ownership directly. Thus, women's empowerment or autonomy is an important determinant of their health.

There was no significant association between women's land ownership, either jointly or solo, with children's health. However, a positive and significant association between maternal BMI and child health indicates that there is an indirect link between women's land rights to child health running through women's empowerment. Hence women's land rights by providing leverage in intra-household bargaining enhance women's access to resources, nutrition, and health for children under-5. Child's characteristics, mother's characteristics, wealth status of the household, women's educations, and employment opportunities are also important factors influencing women empowerment, maternal health, and under-5 children's health. Thus, there is a need to strive for gender equality in attaining lone land ownership, education, and employment for women for reducing malnutrition among children and women.

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CHAPTER 9

Gender Aspects of Transition to Clean Cooking Energy: Evidence from Two States of India

Ashutosh Sharma, Chandrashekhar Singh, and Saumya Vaish

9.1 INTRODUCTION

The concern regarding clean energy access at the global platform is reflected in UN Sustainable Development Goals (SDGs), which has kept goal 7 (SDG-7) to achieve universal access to affordable, reliable, and modern energy services by 2030. Moreover, the use of modern fuels at the household level will have distinct implications for other SDG Goals

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as well, particularly for SDG-3 (to ensure healthy lives and promote well-being for all at all ages), SDG-5 (to achieve gender equality and empower all women and girls), and SDG-13 (to take urgent action to combat climate change and its impacts).

Men and women have different energy needs due to their different roles in society and the household (Skutsch, 2005). In India, 819 million people rely on biomass traditional for cooking (IEA, 2016). The use of biomass fuels for cooking has a range of adverse consequences, especially for women and can place additional pressure on local forest resources, particularly in places where fuelwood is scarce (Adkins et al., 2012). The consequence of inaccessibility or unavailability of clean cooking fuel hits women the hardest. Traditionally women are responsible for cooking and childcare in the home (Westendorp, 2011). Women suffer health hazards at all the biomass chain stages because they predominantly manage the work as gatherers, processors, carriers or transporters, and end-users or cooks (Parikh, 2011). In fetching fuel, fodder and water for homes, women forego opportunities to engage in income-generating activities and often sacrifice their education and health. For instance, Kishor and Gupta (2009) point out that there is equality in children's school attendance in urban India, but in rural areas, the female disadvantage in education increases with age. Cooking with biomass results in indoor-air pollution (IAP) that causes a variety of respiratory illnesses such as chronic obstructive pulmonary disease (COPD), asthma, bronchitis, and pneumonia (Bruce et al., 2000). Women spend more time inhaling the polluted air that is trapped indoors. Balakrishnan et al. (2002) study of 436 households in southern India shows that woman cooks are exposed to statistically significantly higher exposure to the respirable particulate matter than non-cook men.

How can clean energy access help women? At a household level, access to clean energy services can improve women's social, economic, and political status through (i) reducing the time and effort on a household activity, (ii) improved health, (iii) increased productivity and expanding income-generating opportunities, and (iv) educational conditions and easing their participation in public affairs (UNDP, 2006; World Bank, 1996, 2000).

The links between energy and SDGs make it imperative to understand the challenges of access to modern energy services. This study reports the transition to liquefied petroleum gas (LPG) for cooking, its gender implications and policy relevance in India. To observe the impact of energy

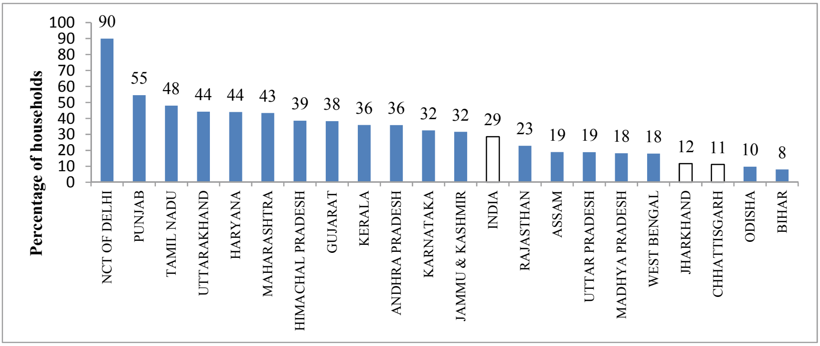


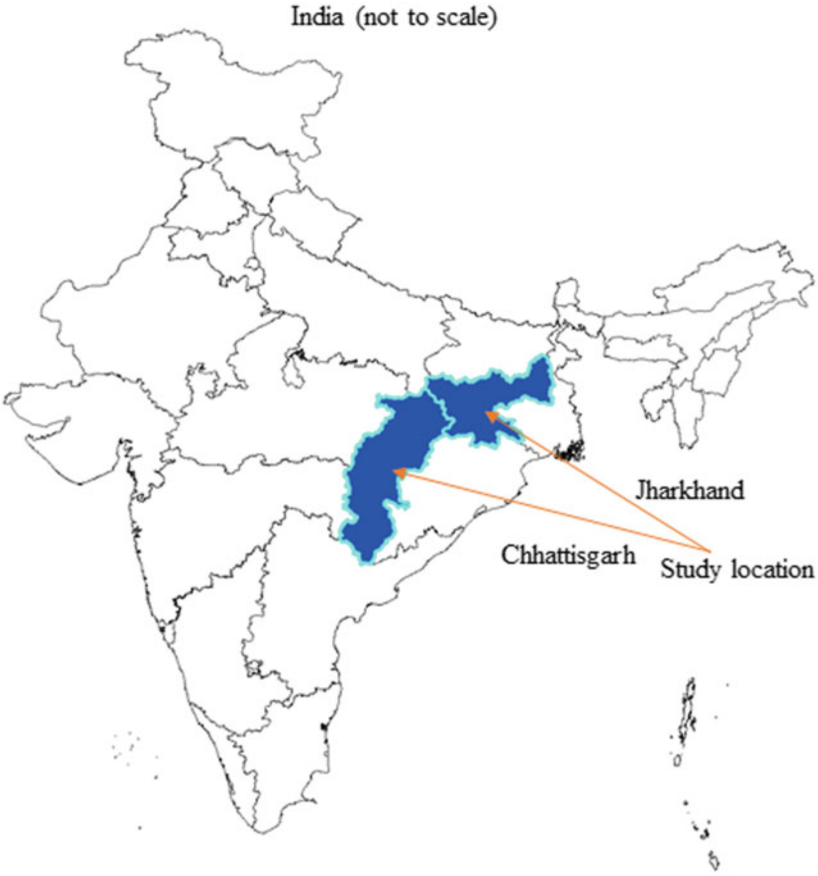
Fig. 9.1 LPG/PNG as a primary source of cooking fuel in India and its significant states (in %) (*Data Source* Census, 2011)

transitions, we chose the state with the least LPG access to understand each type of fuel's impact. The study selected two Indian states Chhattisgarh (Chh henceforth) and Jharkhand (Jh henceforth), extremely poor in terms of LPG access for cooking in 2011 (Fig. 9.1).

9.2 Data Sources and Methods

9.2.1 Description of Location

The study was conducted in two districts: Ranchi, in "Jh" and Raipur in "Chh" state. The aerial distance between Ranchi and Raipur is nearly 450 Km. Raipur district has 36% urban and 64% rural population whereas Ranchi district has 43% urban and 57% rural population. These districts represent a balanced mix of rural and urban people in the selected state. Therefore, it is useful to understand the significant clean cooking fuel issues in rural and urban areas. In Ranchi, 29.5% of households and in Raipur, 19.3% of households use LPG as the primary source of cooking (Census, 2011). Raipur has 11% tribal population, whereas Ranchi has nearly 36% tribal population (Census, 2011). Map 9.1 depicts the study locations.



Map 9.1 Study location in India: Chhattisgarh and Jharkhand

9.2.2 *Method*

The study involved a socio-demographic survey and the energy consumption pattern of the households in the selected districts. A pilot study was conducted in Ranchi and Raipur in November 2016 through a structured household questionnaire. The pilot study questionnaire was modified, and the task was completed from 1 April 2017 to 30 June 2017 through door-to-door personal interviews. Household monthly energy consumption, energy expenditure, and monthly income data for salaried persons, self-employed, and daily wage workers were collected using a 30-day recall period. For agriculturist households, since income arrives during crop harvesting season and not throughout the year, we used a 365-day recall period and divided the annual payment received to arrive at the monthly income.

9.2.3 *Sampling Method*

The study used a stratified random sampling technique. LPG coverage rate in the respective district is used to decide the sample size. The sample size in Ranchi was 300 households, and in Raipur, 510 households. The selected districts were divided into rural and urban stratum. The rural and urban stratum was further divided into sub-stratum, comprising villages in rural area and wards in urban area. The sub-stratum was formed to keep an equal population, nearly 15,000, in each of them. The district sample size was allocated in the rural–urban strata based on the population proportion (Census, 2011). In Ranchi, 180 rural and 120 urban households were surveyed, and in Raipur, 300 rural and 210 urban households were surveyed. The number of households in each village/ward was kept at approximately 250 households. In larger villages and wards, we divided them into smaller hamlets of nearly 250 households and randomly chose one hamlet for the survey.

The selection sequence was from strata to sub-strata, from sub-strata to village/ward, and then different households. In each village and ward, 30 households were surveyed. The study randomly selected six rural and four urban sub-strata in Ranchi and ten rural and seven urban sub-strata in Raipur, with replacement. Further, from each selected rural and urban sub-strata, one village or ward was randomly selected. Survey households were chosen by randomising, selecting a given household at random in the village or ward, and then selecting every sixth household from the randomly chosen initial household. No selected household was locked or unwilling to participate in the survey. Therefore, we got a 100% survey response rate. We interviewed 759 female respondents and 51 male respondents during the survey.

9.2.4 *Results and Discussion*

Separately for rural and urban, monthly income of the households, 4 cut-off points were done to create income group based on equal percentile. Therefore, five income groups (₹) were formed for rural and urban samples, as presented in Table 9.1.

9.3 HOUSEHOLD ENERGY CONSUMPTION PATTERN

Different fuels tend to have distinct time cycles for purchase and consumption (O'Sullivan & Barnes, 2006). Some fuels households tend to purchase more frequently, like fuelwood, dung cake, and small quantities consumed within days. In India, domestic LPG refill is available mainly in a 14.2-kg cylinder that may be consumed over more than 30 days, especially in poor households or households with fewer members. Therefore, the survey collected data on households' cooking fuel for the last 30 days, separately for purchased and consumed quantity. Dung cake, fuelwood, coal, kerosene, and LPG were energy sources for cooking in the surveyed households.[1] Table 9.2 shows the energy source and location-wise cooking energy consumption per household. It is worth mentioning that only three households use kerosene for cooking using pressure stoves. In contrast, the remaining households use kerosene to lit fire (firing) for dung cake, fuelwood, or coal.[2] Therefore, kerosene remains an associated fuel linked with solid fuels for firing purposes and is less likely as an independent fuel.

To add different fuels, their weights are multiplied by the respective calorific content and efficiency of use to devise useful energy content in each fuel. Energy contents and fuel use efficiency (usable energy for cooking) for different fuels such as LPG, kerosene, and wood are calculated by assuming specific average efficiency in cooking for the fuel (Farsi et al., 2007). We have used the useful cooking energy value in MJ for different fuels given by O'Sullivan and Barnes (2006).

Figure 9.2 reports the fuel source-wise, useful energy consumption in MJ across Ranchi and Raipur's income group. We found that useful

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[1] None of the surveyed household reported cooking with crop residue like straw, leaves, and grass or with electricity. PNG is also not available in the two-survey location.

[2] Households, which do not have, access to kerosene use either paper, plastic or even borrow fire from the neighbourhood to igniting fire for biomass and coal.

Table 9.1 Rural and urban household's income classification in Jh and Chh

Income group	*Household income*					
	Rural households			*Urban households*		
	Range (₹)	*Mean*	*Standard deviation*	*Range (₹)*	*Mean*	*Standard deviation*
Group 1	≤ 5999	4537 (92)	1026	≤6279	5050 (66)	1140
Group 2	6000–7799	6724 (97)	625	6280–8449	7417 (65)	476
Group 3	7800–10,199	8910 (98)	754	8450–10,703	9211 (67)	597
Group 4	10,200–14,206	11,944 (97)	1084	10,704–14,539	12,258 (66)	1044
Group 5	≤14,207	22,396 (96)	10,101	≤14,540	23,427 (66)	10,125

Note Figures in parenthesis are the number of households

Table 9.2 Source-wise per household cooking fuel consumption in surveyed locations

Location	*Indicators*	*Average consumption per month*				
		Energy types				
		Dung cake (kg)	*Fuelwood (Kg)*	*Coal (Kg)*	*Kerosene (Liter)*	*LPG (Kg)*
Ranchi Rural	Value	30 (23.07)	109 (69.80)	41 (22.11)	1.4 (1.03)	10.4 (3.89)
	Households	67	163	33	162	69
Ranchi urban	Value	15 (11.20)	96 (57.09)	35 (23.82)	1.3 (0.57)	10.4 (3.97)
	Households	34	101	30	96	75
Raipur Rural	Value	17 (12.09)	65 (37.48)	40 (22.91)	0.8 (0.50)	7.0 (3.14)
	Households	231	230	26	188	136
Raipur urban	Value	14 (9.23)	63 (31.27)	31 (19)	1.3 (1.98)	10.2 (3.35)
	Households	60	100	9	60	125

Note Figures in the parenthesis denote the standard deviation energy consumption is higher in Ranchi over Raipur across the location and in all the income groups. Pachauri (2004) reported that households with higher income level consume more commercial energy than households with lower income level. Mottaleb et al. (2017) find that households use clean energy progressively with an increase in income. In Raipur, we found that the income level is directly proportional to LPG consumption, i.e. increasing income level shows an increasing LPG consumption trend, especially in the urban area. However, in Ranchi, this phenomenon is relatively less visible even in urban areas. Based on the useful energy from different fuels, we find that fuelwood remains the primary source of cooking fuel in Ranchi for all the income groups, except urban group 5 income households. In Raipur, the finding comes different. In urban Raipur, LPG is the primary cooking fuel for all income groups. The critical point emerging from Fig. 9.2 is that households use a portfolio of cooking fuels or a "fuel-stacking" approach even at higher income levels.

The higher consumption of useful cooking energy in Ranchi can be attributed to the three possibilities (1) large family size, (2) cooking practices-households cook more meals per day, and (3) inefficient use of cooking energy. Given the scope of our surveyed data set, we tried to investigate all three possibilities.

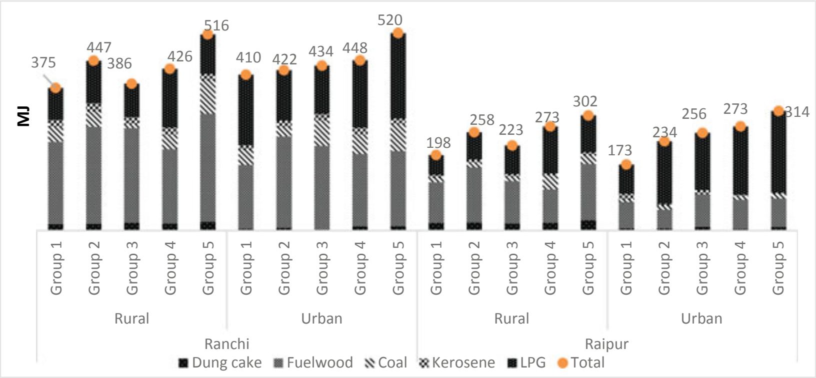

Fig. 9.2 Income class and source-wise average monthly useful energy consumed per household in Ranchi and Raipur

Table 9.3 Average family size in Ranchi and Raipur by income group

Income group	*Household size*			
	Ranchi		*Raipur*	
	Rural	*Urban*	*Rural*	*Urban*
Group 1	5	4.35	3.72	3.22
Group 2	5.33	4.85	4.83	4.58
Group 3	5.83	4.38	4.62	4.7
Group 4	5.69	5.21	5.35	5.23
Group 5	6.85	5.92	6.42	6.37

Table 9.3 shows that there is not a very large difference among income groups and across locations. Moreover, Parikh et al. (2016) report that useful cooking energy for households is not directly proportional to the household size reflected in falling per capita cooking energy consumption with increasing family size. Using our dataset, we found that out of 810 surveyed households, 647 households cook two meals a day and 163 households cook three meals a day. However, out of these 163 households, only 19 are located in Ranchi. It seems that household size and cooking habits have less relevance for highly useful cooking energy consumption in Ranchi. Therefore, we turn to the third possibility of inefficient and unsustainable cooking energy use.

In Ranchi, collected (unpaid) useful cooking energy consumption is enormous, both in rural and urban areas. Therefore, the inefficient burning of biomass in Ranchi households, due to the abundance of free availability, leads to the overuse of biomass.

9.4 SOURCES OF COOKING ENERGY AND EXPENDITURE

The most commonly used cooking fuels are dung cake, firewood, coal, and LPG. The households buy kerosene from government public distribution shops (PDS) at the subsidised price. Some households do buy kerosene from the private market directly to meet the monthly shortfall. Dung cake and fuelwood used in households were both self-collected and purchased. Self-collected or prepared biomass with unpaid labour may be serving as an essential motivation for households to use it. Tables 9.4 and 9.5 show the cooking fuel source-wise household distribution.

Table 9.4 Distribution of households cooking energy (dung cake, fuelwood, and coal) sources

Location	*Households fuel wise source*								
	Dung cake			*Fuelwood*			*Coal*		
	Purchase	*Self-collected*	*Purchase and self-collected*	*Purchase*	*Self-collected*	*Purchase and self-collected*	*Purchase*	*Self-collected*	*Purchase and self-collected*
Ranchi Rural	1	66	0	21	132	10	31	2	0
Ranchi Urban	0	31	3	10	56	35	26	0	4
Raipur Rural	47	183	1	75	155	0	13	13	0
Ranchi Urban	48	12	0	87	12	1	9	0	0

Table 9.5 Distribution of households cooking energy (Kerosene and LPG) sources

Location	*Households fuel wise source*				
	Kerosene			*LPG*	
	Government shop	*Private market*	*Government shop and private market*	*Government distributor*	*Private market*
Ranchi Rural	108	16	38	69	0
Ranchi Urban	85	9	2	75	0
Raipur Rural	186	0	2	135	1
Ranchi Urban	48	7	5	125	0

Household expenditure on cooking energy fuel has been calculated for the purchased energy sources only. There exists a local market for fuelwood and dung cake in both urban and rural areas. We found that the average price of fuelwood[3] and dung cake varies insignificantly within a district in urban and rural markets. The dung cake price was the same in Ranchi and Raipur, ₹0.3.0 per kg, across rural–urban locations. However, firewood was cheaper in Ranchi, at ₹6 per kg, compared to nearly ₹8.5 in Raipur.

Moreover, at the prevailing prices of biomass, coal and subsidised LPG, the calculations show that subsidised LPG remains the cheapest cooking energy source when we account for useful cooking calorific values. For instance, at a dung cake price of ₹ three a kg and a calorific value of 1.7 MJ per kg, the useful energy price for dung cake is ₹1.76 per MJ. Similarly, for fuelwood, the useful energy price in Ranchi is ₹2.60 per MJ, and in Raipur, it is ₹3.54 per MJ, given the useful energy content of 2.4 MJ per kg of fuelwood. However, for subsidised LPG, priced at nearly ₹35 per kg and useful energy content of 27.3 MJ per kg, the useful energy price is only ₹1.28 per MJ. So, households purchasing biomass and

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[3] To calculate the location wise (rural–urban) average price of fuels in a district we have calculated the weighted average price, where weights are the quantity consumed by households in the last 30 days.

coal for cooking are paying higher prices for useful cooking energy than households receiving subsidised LPG refills from governments.

Figure 9.4 shows income class-wise rural and urban household expenditure on different cooking fuels. It is cooking energy expenditure increases with income levels, more visible in Raipur and slightly subdued in Ranchi. This is mainly because, in Ranchi, the self-collected cooking fuel constitutes a large proportion of total useful cooking energy consumption even at a higher level of income (Fig. 9.3).

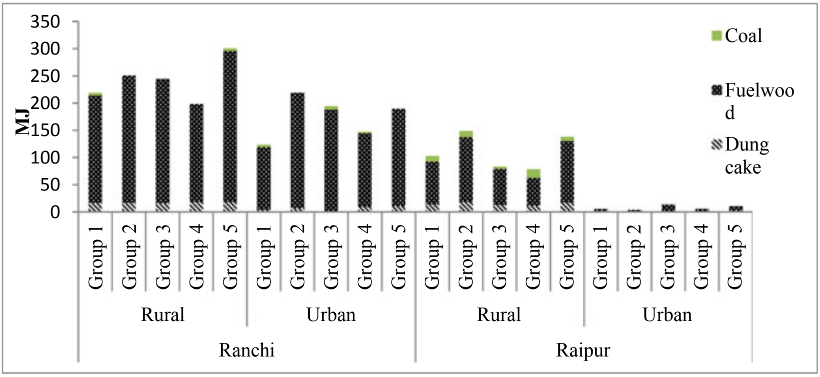

Fig. 9.3 Self-collected useful monthly cooking energy in Ranchi and Raipur

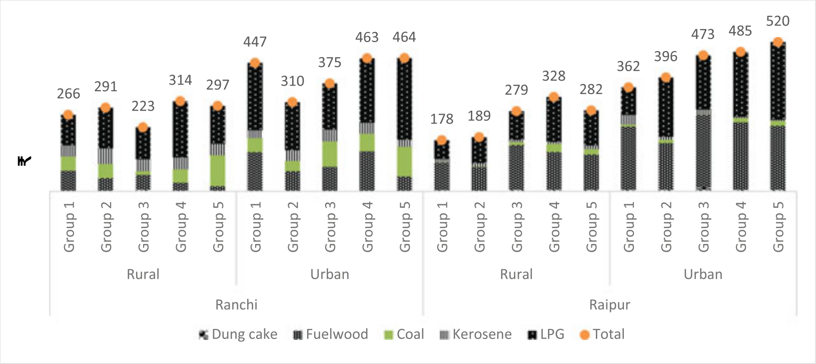

Fig. 9.4 Expenditure on monthly cooking energy in Ranchi and Raipur in Indian Rupees (₹)

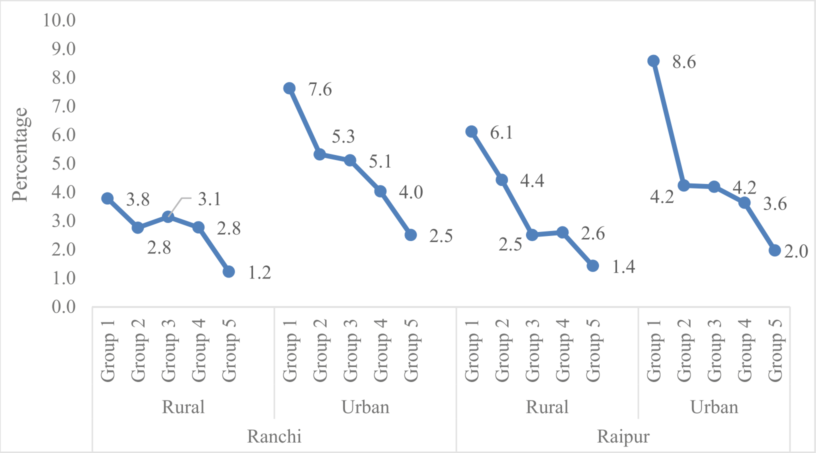

Fig. 9.5 Cooking energy expenditure as a percentage of household income

The share of monthly cooking energy expenditure as a share of household income has been depicted in Fig. 9.5. Cooking energy requirement does not increase proportionately with income, and therefore the share of cooking energy expenditure declines with rising income levels. Moreover, the poorer households purchase expensive fuels in terms of useful energy content, like biomass, and coal in the absence of LPG access. The above analysis (Figs. 9.4 and 9.5) does not account for self-collected biomass collected using unpaid labours of mainly women and girls. However, suppose we assign a monetary value to the self-collected biomass and coal at the prevailing local market price. In that case, we find that cooking energy expenditure becomes very high for poorer households or households who self-collect a large share of their cooking energy need.

9.5 GENDER ROLES IN COOKING

Access to cooking energy is a particularly gendered issue because women are primarily responsible for cooking in virtually all cultures. In the more significant part of the societies the world over, women continue to bear most of the home's responsibilities and spend at least twice as much time as men on unpaid domestic work (UN, 2010). The study collected data on the number of meals cooked, source of cooking energy, time spent on cooking, time spent on cleaning, etc., for the previous day of the survey. Our study found that in 806 households, women have primary responsibility for cooking, and only four households reported that men have primary responsibility for cooking. We further investigated the number of meals prepared by women and men in the past 30 days. Only in 521 households men have cooked at least one or more meals in the past 30 days. The average number of meals cooked by men in these 521 households has been reported in Table 9.8. Compared to Raipur, men had cooked more meals in Ranchi in all the income groups across the locations (Table 9.6). However, compared to men, women have a disproportionate burden for cooking (Table 9.7). The income data reveals that women members earn 30% of the total surveyed household income. Therefore, though women contribute generously to household income generation, men contribute significantly less to cooking and related activities.

Table 9.6 Average number of meals cooked by men in the past 30 days (all surveyed households)

Location	*Income groups*				
	Group 1	*Group 2*	*Group 3*	*Group 4*	*Group 5*
Ranchi Rural	5.58	6.94	5.73	7.36	7.88
Ranchi urban	5.08	3.33	4.2	4.29	9.3
Raipur Rural	2.78	4.59	3.18	3.37	3.06
Raipur urban	3	2.97	3.79	2.79	3.06

Table 9.7 Average number of meals cooked by women in the past 30 days

Location	*Income groups*				
	Group 1	*Group 2*	*Group 3*	*Group 4*	*Group 5*
Ranchi Rural	60.11	59.88	57.13	61.34	57.56
Ranchi urban	59.86	59	58.38	60	56.28
Raipur Rural	63.85	62.07	66.44	66.42	70
Raipur urban	61.83	65.62	66.22	65.74	67.71

Table 9.8 Session-wise cooking and cleaning time for households cooking two meals

Location	*Cooking and utensils cleaning time (in minutes)*							
	Morning				*Evening*			
	Biomass		*LPG*		*Biomass*		*LPG*	
	Cook	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*
Ranchi Rural	87.2	28.6	54.6	23.8	79.2	27	53.5	22.5
Ranchi urban	77	25.4	60	21.2	70.5	24.7	47.8	19
Raipur Rural	72	30.9	38.8	19.3	70	29.5	41.5	22.4
Raipur urban	68.9	30.9	49.1	22.5	68.9	30.4	47.8	23.9

Respondents in 647 households reported cooking two meals per day, and in 163 households replied cooking three meals per day. We analyse the two types of households separately. We find that men cooked only in one household in the morning session and two households in the evening session, which cooks two meals a day. A similar trend was observed in households cooking three meals a day; men cooked morning and after meal in two households. Interestingly, none of the household's men cleaned the cooking utensils, which is dirty and tedious, mostly when cooked with biomass, coal, or kerosene.

To understand the time-saving benefits of LPG over biomass (dung cake and fuelwood), we calculated the average cooking time and utensils cleaning time (Tables 9.8 and 9.9). The time calculation was done session-wise because a particular cooking fuel was not consistent for all the sessions[4] in several households. Compared to biomass, the results suggest that average cooking and utensils cleaning time for cooking with LPG remains lower for all the sessions and across the locations (Tables 9.8 and 9.9).[5]

Several studies in India in different regions emphasised the time allocation and distance travelled by women and children for fuel collection

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[4] We have not compared kerosene because only three households used kerosene for cooking one or more than one meal.

[5] The cooking and cleaning time is lower also compared to coal in all the locations. However, we have not depicted this in Tables 9.8 and 9.9 due to brevity and also due to absence of cooking with coal observations across regions and locations.

Table 9.9 Session-wise cooking and cleaning time for households cooking three meals

Location	*Cooking and utensils cleaning time (in minutes)*											
	Morning				*Afternoon*				*Evening*			
	Biomass		*LPG*		*Biomass*		*LPG*		*Biomass*		*LPG*	
	Cook	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*	*Cook*	*Clean*
Ranchi Rural	78	25.5	34	23	73.8	26.5	50	21.7	67.3	24.1	40	22.5
Ranchi urban	60	35	35	20	90	30	60	15	75	22.5	50	20
Raipur Rural	79.7	31.7	51.4	25.6	71.2	31.3	40	21.6	75.5	31.6	47.3	26
Raipur urban	84.3	32.6	43.4	22	82.7	33.4	44	20.9	80.4	30.9	45.3	21.9

Table 9.10 Collection and preparation responsibility of biomass

Location	*Number of households*							
	Dung cake				*Fuelwood*			
	Collection		*Preparation*		*Collection*		*Preparation*	
	Female	*Male*	*Female*	*Male*	*Female*	*Male*	*Female*	*Male*
Ranchi Rural	62	4	64	2	130	12	137	5
Ranchi urban	32	2	33	1	84	7	88	3
Raipur Rural	175	9	180	4	126	29	140	15
Raipur urban	11	1	12	0	7	6	11	2

(Agrawal, 1986; Laxmi et al., 2003; Parikh, 2011; Parikh & Laxmi, 2000). Table 9.10 shows the gender-wise group and preparation responsibility. Preparing or processing biofuels includes mainly activities such as making dung cake and also drying biofuels and chopping them into smaller pieces required for a different purpose, for using households. Women have an immense burden of collection and preparation of dung cake and fuelwood.

We find that even in households where men collect the dung, the burden of preparing the dung cake, which is highly unhygienic and time-consuming, is more likely to come to women. Also, even if men collect the fuelwood, they will be less likely to prepare, cut into small pieces, and cook. It is also worth highlighting that 263 households do not receive LPG delivery at their doorsteps, and someone has to collect it from the distribution centre. We found that only in 18 households women go to collect LPG from the distribution centre, and in the remaining 245 households, it is men who collect. This goes well with the earlier finding that as the quality of cooking fuel improves, men's role in fuel management increases (Parikh, 2011). However, women's declining role does not necessarily mean that they get entirely relieved; as the cooking task remains with women, they have to ensure fuel availability in the household. Table 9.11 reports the average distance travelled by household members to collect the dung cake and fuelwood. It also documents how frequently these biomasses are collected.

Table 9.11 Average distance from biomass source and frequency of collection

Average distance and frequency of collection			
Distance from source (in meters)		*Frequency of collection (per month)*	
Dung cake	*Fuelwood*	*Dung cake*	*Fuelwood*
39.4	2452.1	18.4	10.4
50.3	2387.4	17.7	8.1
412.6	2052.4	20.4	6.1
728.3	2346.2	17.7	7.4

9.6 RELEVANCE FOR LPG POLICY: PRELIMINARY FINDINGS REGARDING PMUY

On the policy front, the Government of India (GoI) had a long history of universal price subsidy on LPG cylinder refilling for domestic cooking purposes (Gangopadhyay et al., 2005). However, until mid-2016 Government of India (GoI) LPG subsidy programme focused on subsidising the domestic LPG consumers, severely undermining the poor household LPG accessibility aspect. For poor households, the one-time capital costs associated with the initial buying of stove and deposit for cylinder may hinder the broader adoption of this fuel for cooking (Farsi et al., 2007). On 1 May 2016, GoI launched the “Pradhan Mantri Ujjwala Yojana” (PMUY) scheme to provide targeted subsidy to poor households for initial LPG capital costs. In our sample, 126 households were found to be PMUY beneficiaries.

Figure 9.6 plots the cumulative number of surveyed households with formal LPG connections[6] since 2011. All the households with LPG connections before 2011 have been shown for the year 2011. It also plots the cumulative number of PMUY beneficiaries since 2016, the year scheme started. It was observed that there is a steep rise in access to LPG after the year 2015. Overall access to LPG increased from 143 in 2015 to 221 in 2016, of which 44 were PMUY connections and to 404 in 2017, of which 82 were PMUY connections.

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[6] In our sample, 404 households were having formal LPG connections on they receive subsidy and only one household was sourcing from the market not eligible for LPG subsidy benefit.

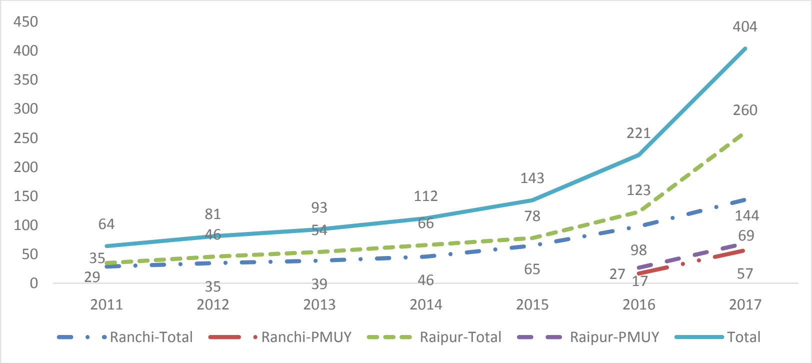

Fig. 9.6 Cumulative number of households with formal LPG connections

Interestingly, after the implementation of PMUY, the paid LPG (paying for initial capital cost) connections also increased in rural Raipur (Table 9.12). Totally 38 surveyed households received LPG connections under PMUY in 2017, and 30 households purchased on their own. In urban Raipur, we observed a similar trend. However, this trend is less evident in Ranchi. One reason could be improved service delivery, and the second can be a demonstration effect since people became more aware of the benefits. Khandker et al. (2012) pointed out that many non-poor households consume less than the required minimum modern energy services, reflecting apparent policy or service availability problems in rural areas.

Table 9.12 LPG connections by the year

District	*Location*	*Connection type*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
Ranchi	Rural	Paid	9	1	1	5	8	9	2
		PMUY	–	–	–	–	–	14	20
	Urban	Paid	20	5	3	2	11	7	4
		PMUY	–	–	–	–	–	3	20
Raipur	Rural	Paid	13	4	5	6	5	10	30
		PMUY	–	–	–	–	–	24	38
	Urban	Paid	22	7	3	6	7	8	65
		PMUY	–	–	–	–	–	3	4

Another interesting pattern is to see the useful energy consumption composition of PMUY beneficiary households and households who have bought an LPG connection by paying the capital cost. We term them non-PMUY households. We find that LPG share in useful cooking energy sources is nearly the same in a rural areas (Fig. 9.7). In the urban area, non-PMUY households' LPG share is higher in total useful energy mix than PMUY households in Ranchi and Raipur. However, given our sample size, findings related to PMUY are indicative and require further investigation.

The GoI provides a subsidy on the refill of LPG cylinders. Consumers are charged the refilling's full price and get subsidy amount refunded in their bank account under direct benefit transfer for LPG (DBTL) scheme. The LPG subsidy amount was nearly ₹300 per 14.2 Kg cylinder during the survey period. To understand the importance of LPG refilling subsidy, the respondents, having an LPG connection (404 households), were asked about the impact of subsidy removal on their cooking energy choice. The response has been reported in Fig. 9.8.

The responses received show that nearly 14% of the LPG households (count 57 out of 404) will stop using LPG (Fig. 9.8) and start using biomass or coal or a mix of it. In these households, the average consumption of LPG per month is 5.12 Kg, which will become zero once the LPG subsidy is stopped. However, 86% (347 out of 404) households revealed

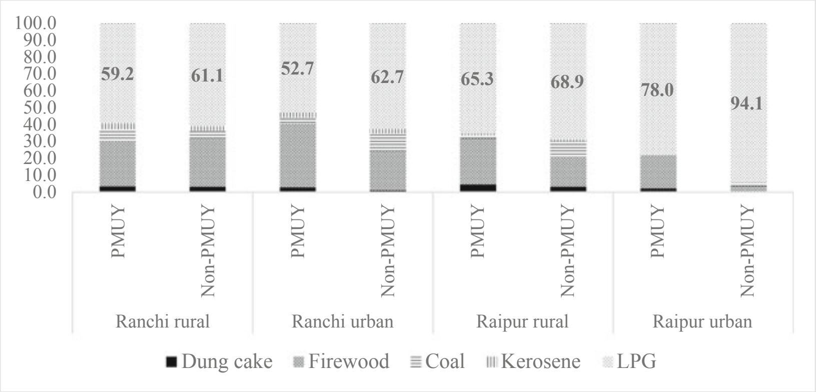

Fig. 9.7 Useful cooking energy share by energy sources in PMUY and non-PMUY households (in %)

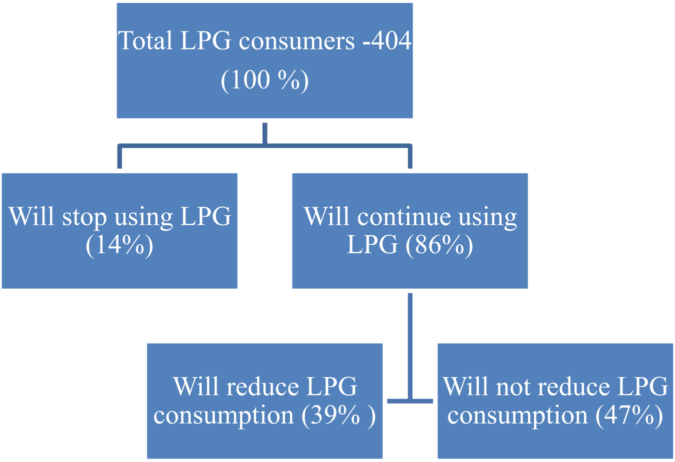

Fig. 9.8 Households response to a hypothetical question if the price of LPG is increased or LPG subsidy is removed

that they would continue using LPG. Further inquired whether they will consume the same amount of LPG now, 39% responded negatively (159 out of 404), and 47% (188 out of 404) responded positively. The response suggests that 39% of households with LPG connection will reduce LPG consumption. The average monthly LPG consumption in these households is 9.32 Kg, and the reported average monthly reduction will be 2.66 Kg per month. These households will compensate for biomass, coal, and a few said biomass and electricity mix. Those households who revealed that they would continue using the same amount of LPG have 10.27 Kg monthly average consumption of LPG, and it is the dominant cooking fuel in nearly all of these households. This is an important finding because it indicates that households consuming less LPG are more likely to switch to biomass, slipping down the energy ladder when LPG refill subsidy is stopped. In contrast, households with a higher consumption level of LPG are more likely to continue using it. A rising price of LPG may discourage poor households, mostly covered under PMUY, to reduce consumption.

9.7 Policy Discussion and Concluding Remarks

The study shows the significant dependency of households on biomass for cooking. Rural areas consume more biomass and less modern fuels like LPG. The study also finds that though in Raipur, the use of LPG improves with income level, especially in the urban areas, this trend is not observed in Ranchi, where the self-collected biofuel supply is adequate. Compared to Raipur, household useful cooking energy consumption in Ranchi is higher for all the income groups, both in rural and urban areas. The higher availability and use of self-collected biomass fuel in Ranchi leads to inefficient and excessive biomass use. With the growing population, the excessive and unsustainable exploitation of local resources like forests will deteriorate the interconnected ecosystem. With the increasing population and shrinking of forests, it is essential to initiate awareness programmes in areas where people use biomass and prioritise other clean energy access.

The study also finds that cooking with LPG saves time for cooking and utensils cleaning. Women have the skewed burden of biomass collection, processing, and cooking with it. The current dependency on biomass for cooking leads to drudgery, hardship, and lack of time for self-fulfilment activities. The study reveals that women play an active role in household income generation, but men's contribution to cooking and related activities is minimal. A largely patriarchal society compels women to do backbreaking, time-consuming, and in many cases, unhealthy but essential "survival work" (World Bank, 2004). The study strengthens the need and the significance of clean cooking energy transition in the energy policy.

The government's subsidised kerosene is partly used for lighting and partly to lit fire for biomass and coal. There is a growing pitch for removing the kerosene subsidy and declaring kerosene-free districts to reduce air pollution with improvements in electrification and solar lighting systems. However, in the absence of kerosene, people resort to plastic, paper and other means for this purpose, which is harmful to the environment and human health. Therefore, caution is needed before stopping the kerosene subsidy until biomass is a prevalent cooking energy source.

LPG refill subsidy plays an essential role in making clean cooking affordable to poor households. Our findings suggest that in the wake of subsidy removal from LPG refills, 14% of low LPG consumption, households may switch back to biomass. On the other hand, 86% of households responded that they would continue to use LPG though 39% said they would reduce its use. Therefore, to reduce the subsidy burden, the government can judiciously target the LPG subsidy depending upon the households' economic and LPG consumption status.

The study finds that compared to purchased biomass and coal, LPG is a cheaper fuel source for consumers in terms of useful energy. Therefore, access to LPG must be increased in the areas where there is a shortage of biomass. Even in the abundant biomass geographies, promoting LPG and encouraging people to increase its uptake will reduce the excessive exploitation of local forests. It will also benefit the environment through reduced air pollution. Though the evaluation of PMUY is beyond the scope of this paper, as it is still ongoing and full benefits cannot be captured, observations suggest that the PMUY scheme is rapidly improving LPG access to poor households after May 2016. The share of LPG consumption in the household energy mix is nearly the same for PMUY beneficiaries and those who purchased the LPG kit earlier (Non-PMUY). More detailed work is required to improve further the PMUY scheme's understanding of household cooking fuel consumption mix and its associated challenges.

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PART IV

Efficiency of firms

CHAPTER 10

Structural Efficiency of the Indian Petroleum Industry: Restructuring Options for Indian National Oil Companies

Deepak Sharma and Haripriya Gundimeda

10.1 Introduction

India has been grappling with vertical integration and privatisation of its national oil companies (NOC) for the past two decades. The Indian government has been restructuring its petroleum sector by consolidating multiple NOCs, disinvesting its shareholding in NOCs, and price deregulation (Mehta, 2017). However, the pace of disinvestment in NOCs has slowed as the government approaches the threshold of losing its majority shareholding. Additionally, previous attempts at privatising Hindustan

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Petroleum Corporation Limited (HPCL) and Bharat Petroleum Corporation limited (BPCL) have failed, and the government's ad-hoc intervention in the pricing of major petroleum products continues. Specialised multiple NOCs dominate every value chain in the Indian petroleum industry and, private sector occupies a fringe role (Sharma & Gundimeda, 2017). In 2018, Oil and Natural Gas Corporation (ONGC) acquired government's stake in HPCL and became India's first fully integrated NOC. India also wants to privatise its major refining and marketing NOC-BPCL by 2021. In this context, we evaluate the Indian government's recent restructuring options of integrating and privatising the NOCs and recommend strategies to achieve better structural efficiency in the Indian petroleum industry.

Vertically integrated petroleum companies participate in every industry's value chain, such as exploration and production of crude oil and natural gas, crude oil refining and petrochemicals, transportation and storage, and petroleum products marketing. The world's largest private petroleum companies such as ExxonMobil, Shell, BP, Total, and Chevron and the largest NOCs such as Saudi Aramco, PetroChina, Sinopec, Rosneft, Petrobras, Pemex, Petronas, and Kuwait Petroleum Corporation are vertically integrated top-ranked ng the top-ranked[1] firms in global rankings of companies. Vertically integrated oil companies have an advantage due to their capability to hedge against oil price volatility (Misund & McMillan, 2016). In recent years, the Gulf NOCs have increasingly ventured abroad in the down lock-in segment to lock-in demand for their crude oil (Ghoddusi & Wirl, 2021) while NOCs from China, India, Japan, and Korea have ventured abroad in the upstream segment to increase their energy security (Cheon, 2019). In 1998, China created two vertically integrated NOCs through assets swaps between its specialised upstream NOC—China Petroleum Corporation Limited and downstream NOC—China Petroleum and Chemical Corporation (Zhang, 2004). Limited number of specialised NOCs operate in the global petroleum industry. Specialised upstream NOCs operate in countries like Japan, South Korea, Oman, and Poland, and specialised

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[1] For the year 2018, thirty-eight out of the top fifty companies ranked in the Petroleum intelligence weekly annual rankings (Energy Intelligence, 2019), six out of the top ten companies in Fortune global 500 rankings (Fortune, 2019) and thirteen out of the top twenty companies in the Platts Top 250 Energy Rankings were vertically integrated (S&P Global Platts, 2019).

downstream NOCs operate in countries like Greece and Finland. India has a unique NOC organisational structure where specialised upstream and downstream NOCs operate simultaneously. Successive Indian governments have contemplated creating a vertically integrated NOC (Aiyar, 2014) and the creation of the ONGC-HPCL combination is a step in that direction.

Privatisation of BPCL is the other restructuring option being attempted in India. Developed countries like UK, Canada, Spain, and France have completely privatised their NOC before the 1990s. Bolivia and Argentina had completely privatised their NOC,s but it among the developing countries. Ample evidence exists to support that NOCs are operationally inefficient to private oil companies (Al-Mana et al., 2020; Gong, 2020; Hartley & Medlock, III, 2013) and privatisation (even partial) improves the performance of NOCs (Wolf & Pollitt, 2008). Complete privatisation which involves loss, of government control is rare in developing countries since NOCs are a source of high rents and revenue and a vehicle to distribute welfare through energy subsidies and energy access (Stevens, 2016). Many developing countries like China, India, and Russia have partially privatised while retaining majority holdings in their NOCs. The complete privatisation of BPCL will only reduce but not eliminate the Indian NOCs in the petroleum industry.

In this paper we assess whether the combination of ONGC and HPCL and BPCL privatisation is the best available option for restructuring the Indian petroleum industry from a structural efficiency perspective. We form 21 hypothetical combination of Indian NOCs and assess these combinations against international vertically integrated companies. We choose the year 2018 for this study since the merger of ONGC and HPCL, was undertaken in 2018 and the privatisation of BPCL was announced, in 2019 and therefore the year 2018 serves as a benchmark to compare our results. We apply the structural efficiency model proposed by Bogetoft and Wang (2005) to assess mergers in this paper. We construct separate technologies for specialised upstream, downstream, and integrated segment for the year 2018. We include 42 specialised upstream companies, 19 specialised downstream companies and 25 vertically integrated companies from 29 countries. The sample is well represented by oil majors, national oil companies, domestic and international companies. We bootstrap the efficiency estimates to get robust results.

The results from the study indicate that the combination of ONGC and Indian Oil Corporation Limited (IOCL) instead of ONGC and

HPCL would have the highest potential to increase the efficiency in the Indian petroleum industry. The upstream companies ONGC and Oil India have low technical efficiency and can increase their efficiency by following their peers' upstream segment. The downstream companies have higher technical efficiency and BPCL has a lower technical efficiency than IOCL and HPCL.

The study is organised as follows. Section 10.2 describes the historical review of the attempts taken by the government in restructuring the NOCs. Section 10.3 describes the methodology used for analysing structural efficiency of mergers. Section 10.4 describes the data and variables used in the study. Section 10.5 provides the results of the study and Sect. 10.6 provides the conclusion.

10.2 Restructuring of the Indian National oil companies—A Historical Review

The Indian government has historically restructured the NOCs through corporatisation, disinvestment, consolidation, and vertical integration. The Indian NOCs were corporatised in the early nineties and have been partially disinvested at regular intervals. The government is the majority shareholder in every NOC although the government shareholdings has reduced over the past 30 years. Life Insurance Corporation of India (LIC) has minority holdings in every NOC and the crossholdings between specialised upstream and downstream NOCs has also increased over time (Fig. 10.1). After independence multiple NOCs were formed in the Indian petroleum industry through indigenous effort, nationalisation, and joint ventures (Kaul, 1991). Ten specialised NOCs existing in different segments depicted the fragmented structure of the Indian petroleum industry (Table 10.1). In 1999 the government constituted the Sengupta Committee to examine the prospects of an alliance between the stand-alone refining, and marketing NOCs with integrated refining and marketing NOCs (Ministry of Petroleum and Natural Gas, 1999). The government accepted their recommendation broadly and merged Cochin Refineries Limited (CRL) with BPCL and Bongaigaon Refineries and Petrochemicals Limited (BRPL), Madras Refineries Limited (MRL), and Indo Burma Petroleum (IBP) with IOCL. Thus, the number of major NOCs declined to six by 2007. The privatisation of HPCL and BPCL was attempted and abandoned in 2003 due to intervention by the Supreme Court of India (Venkatesan, 2003).

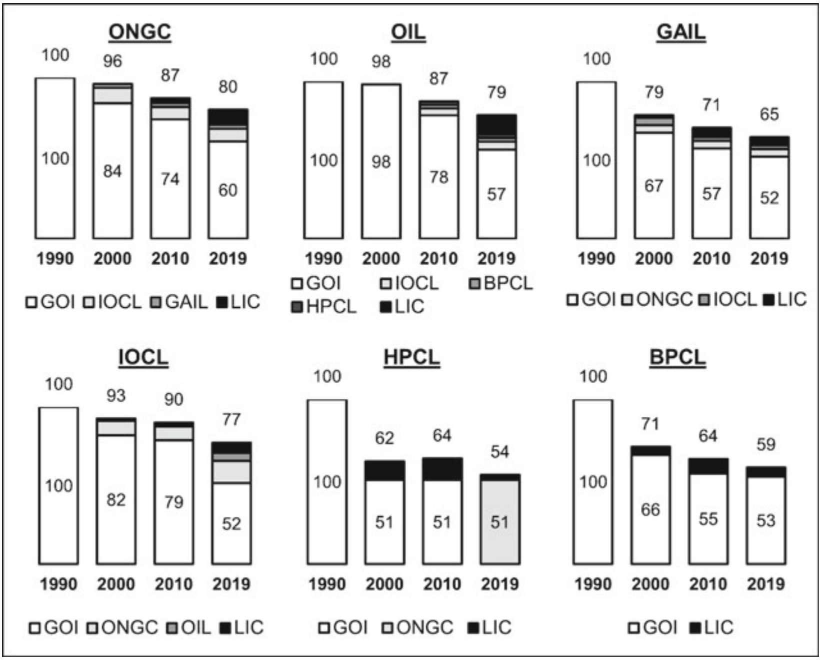

Fig. 10.1 Shareholding of Government of India (GOI), National oil companies, and Life Insurance Corporation (LIC) in major NOCs (*Source* Authors Depiction based on shareholding pattern data from Public Enterprises Survey (various issues) and Bombay Stock Exchange Website. *Note* Gas Authority of India Limited (GAIL), Oil India Limited (OIL))

The government formed the Sundararajan committee in 2005 to assess the viability of creating a vertically integrated NOC and explore synergies among the different NOCs (Ministry of Petroleum and Natural Gas, 2005). The Committee recommended against the merger of NOCS and instead suggested the specialised NOCS to focus on their core competency. The specialised NOCs however had already commenced the process of vertical integration separately. ONGC entered the downstream segment by acquiring the majority stake in Mangalore Refinery and Petrochemicals Limited (MRPL) in 2002. On the other hand, HPCL set up its exploration and production subsidiary Prize Petroleum Company Limited (PPCL) in 1999, BPCL set up its upstream subsidiary

Table 10.1 Types of Indian national oil companies in different phases

Type of company	*Pre-1972*	*1972–2009*	*2009–2017*	*2018–*
Vertically integrated				ONGC[h]
Exploration and production	ONGC (1956)	ONGC OIL (1981)[c]	ONGC OIL	
Standalone refining	CRL (1963)[a] MRL (1965)[b]	CRL MRL BRPL (1974)[d]		
Refining and marketing	IOCL (1964)	IOCL BPCL (1976)[e] HPCL (1974)[f]	IOCL BPCL HPCL	IOCL BPCL
Standalone marketing		IBP (1972)[g]		
Gas utility		GAIL (1984)	GAIL	GAIL

[a] Cochin Refineries Limited (now called Kochi Refineries Limited) was a refinery joint venture that became a subsidiary of BPCL in 2004 and merged with BPCL in 2009

[b] Madras Refineries Limited (now called Chennai Petroleum Corporation Limited) was a refinery joint venture that became a group company of IOCL in 2004

[c] Oil was a joint venture exploration and production company which became a NOC in 1981

[d] Bongaigaon Refinery Limited became a subsidiary of IOCL in 2001 and merged with IOCL in 2009

[e] BPCL was formed through nationalisation of Burmah Shell in 1976

[f] HPCL was formed through nationalisation of Esso and Caltex in 1974

[g] IBP was formed through nationalisation of Indo Burma Petroleum in 1970 and became a subsidiary of IOCL in 2002

[h] HPCL became a subsidiary of ONGC in 2018

Bharat Petro Resources Limited (BPRL) in 2006 and IOCL set up various international subsidiaries and joint ventures in USA, Sweden, and Cyprus in 2010. However, the subsidiaries of downstream NOCs hardly produce appreciable quantities of crude oil (panel [a] of Fig. 10.2). In contrast, the upstream NOCs—ONGC and Oil India—classified under the Others category have negligible share in the petroleum product marketing segment (panel [b] of Fig. 10.2). The Indian NOCs have still not achieved the desired level of vertical integration to be classified as vertically integrated oil and gas companies. Thus, in 2018 the government sold its majority stake in HPCL to ONGC and made a vertically integrated NOC that had substantial presence in the upstream and downstream segment of the Indian petroleum industry.

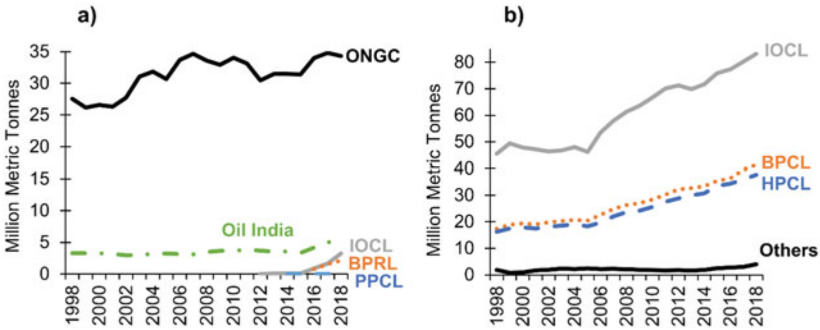

Fig. 10.2 (a) Production of crude oil by NOCs and their subsidiaries and joint ventures and (b) domestic Petroleum product sales by companies in India (*Source* Authors depiction based on company data from the Ministry of Petroleum and Natural Gas [2020])

10.3 Methodology

This paper follows the Bogetoft and Wang (2005) model for computing structural efficiency of merger of firms using the data envelopment analysis framework. Let there be $K = \{1, \ldots, K\}$ firms operating under integrated technology, $U = \{1, \ldots, U\}$ firms operating under upstream technology and $D = \{1, \ldots, D\}$ firms operating under downstream technology. We form a subset of H firms by merging firms under technology U and $D$and evaluate the technical efficiency of H firms under technology K. The merged firm is denoted by P^H which combines the inputs $\sum_{k \in H} x^k$ of U and D firms to produce the output $\sum_{k \in H} y^k$. The efficiency computation of the merged firm provides the improvement potential in the merger and can be assumed as the potential gain from the merger.

$$\sum_{k \in H} x^k = \text{ combined inputs}$$

$$\sum_{k \in H} y^k = \text{ combined outputs}$$

In the first step, we combine the firms and compute the efficiency of the merged unit concerning the given technology. This efficiency is the overall potential of the merged firm to increase its efficiency. The input-oriented efficiency of a merged firm H with combined inputs x^k and outputs y^k is given by E^H.

$$E^H = min\left\{E \in \mathbb{R}_+ \mid \left(E \sum_{k\in H} x^k, \sum_{k\in H} y^k\right) \in T\right\}$$

In this study, we compute the efficiency by combining the upstream firm U and the downstream firm D and compute the efficiency of the merged firm, $U + D$ with respect to the integrated frontier I. In the next step, we compute the individual learning potential for the individual firms that are part of the merger i.e., the learning potential of the upstream firm with respect to U firms operating under the upstream technology and the downstream firm with respect to D firms operating under the downstream technology. The individual learning potential is denoted by E^k. The learning potential is considered to compute the modified inputs of the merged firms and the efficiency is then computed against the integrated technology to find the pure merger potential E^{*H}. The input-oriented efficiency of merged firm H after considering the learning potential is given by E^{*H}.

$$E^{*H} = min\left\{E \in \mathbb{R}_+ \mid \left(E \sum_{k\in H} E^k x^k, \sum_{k\in H} y^k\right) \in T\right\}$$

The learning effect of the merger LE^H is the ratio of the overall potential of the merger E^H and the pure merger potential.

$$LE^H = \frac{E^H}{E^{*H}}$$

In panel (a) of Fig. 10.3, we can observe that the upstream firm U and downstream firm D has the potential to improve their output to U_o^* and D_o^* respectively and to decrease their inputs to U_i^* and D_i^* respectively. Thus, when the upstream and downstream firms are merged to create $U + D$, the overall merger potential is given by the ratio $(U + D)/I_o^*$ for output-oriented efficiency and by the ratio $I_i^*/(U + D)$ for input-oriented efficiency. However, when the improved potential through the learning effect is considered, the pure merger potential is given by the ratio $(U_o^* + D_{o)}^*)/I_o^*$ for output orientation and $I_i^*/(U_i^* + D_{i)}^*)$ for input orientation.

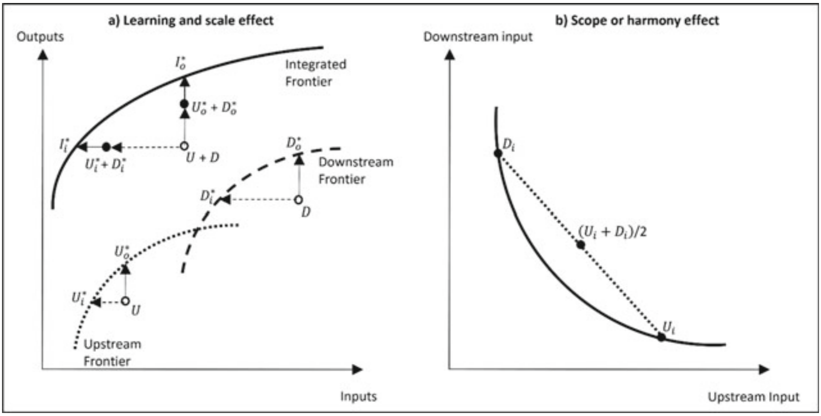

Fig. 10.3 Learning, scale, and harmony decomposition of merger (*Source* Author depiction adapted from Bogetoft and Wang [2005])

Potential savings in a merger can additionally be obtained by the scope or harmony effect. As shown in panel (b) of Fig. 10.3, we see that an upstream firm will have a greater number of upstream employees and downstream firms will have many downstream employees. After the firms are merged, the optimal combination of upstream and downstream employees can be computed to operate an integrated company. For computing the harmony effect, we construct an average merged firm with the average input and output and compute the potential to reduce the average input to produce average output and is given by HA^H. The value of HA^H less than 1 indicates potential savings due to improved harmony and more than 1 indicates a cost of harmonising the inputs and outputs.

$$HA^H = min\left\{ HA \in \mathbb{R}_+ \mid \left(HA \frac{1}{H} \sum_{k \in H} E^k x^k, \frac{1}{H} \sum_{k \in H} y^k \right) \in T \right\}$$

In the next step we compute the size or scale impact of merger by operating the merged firm at full scale instead of the average scale. The size gain is given by SI^H. The value of SI^H less than 1 indicates economies of scale operating at a higher scale and a value of more than 1 indicates diseconomies of scale.

$$SI^H = min\left\{ SI \in \mathbb{R}_+ \mid \left(SI \cdot HA^H \sum_{k \in H} E^k x^k, \sum_{k \in H} y^k \right) \in T \right\}$$

Thus, the basic decomposition of the merger effect E^H is given by the product of learning effect LE^H, scope or harmony effect HA^H, and size or scale impact SI^H.

$$E^H = LE^H \cdot HA^H \cdot SI^H$$

Low learning measure LE^H indicates that the firms could learn from peer firms and the regulators could propose yardstick competition to improve the efficiency of firms. Low harmony measure HA^H could indicate suboptimal input or output mix and can be rectified by creating a market for key inputs and outputs. Low size measure SI^H indicates that it would be necessary to undertake a merger to increase the size of the firms.

We undertake the merger analysis using output and input orientation to check the merger potential in increasing output or decreasing inputs. We also conduct the analysis using constant returns to scale (CRS) and variable returns to scale (VRS) to compute the impact of scale on efficiency. DEA The efficiency estimates are corrected for bias by bootstrapping according to the algorithm proposed by Simar and Wilson (1998).

10.4 DATA AND VARIABLES

The reference companies for constructing the upstream, downstream, and integrated technology were selected from the top-ranking firms in the Platts top 250 Energy company ranking. Then inputs and outputs were assembled from the annual reports. The inputs and outputs of firms considered in this study have been used in the existing empirical literature (Gong, 2020; Hartley & Medlock, III, 2013; Ohene-Asare et al., 2017). Oil and gas reserves serve as a proxy for capital input and upstream employees serve as a proxy for labour input in the upstream segment. Production of oil and gas is used as the upstream output. Refining capacity and retail station serve as a proxy for capital input and downstream employees serve as a proxy for labour in the downstream segment. Sale of petroleum products is used as the downstream output. 25 integrated companies, 42 upstream companies, and 19 downstream companies from 29 countries are considered in the study. The sample is well represented by ownership and area of operation. We have chosen 2018 as the base year in this study since the restructuring of ONGC and HPCL was undertaken during this period and the privatisation of BPCL was also planned in 2019. The summary statistics of the upstream, downstream, and integrated companies is presented in Table 10.2. It can be observed that integrated companies operate at many higher-scale upstream companies in the upstream segment. The median value of oil an integrated firm's d gas production and oil and gas reserves of an e times of an upstream firm. The scale difference between the integrated and downstream companies in the downstream segment is much lower compared to upstream segment. The median value of petroleum product sales of an integrated firm is 1106 thousand barrels compared to thousand barrels daily by a downstream firm.

In this section, considers Indian NOCs—ONGC, Oil India, BPCL, HPCL, and IOCL for merger analysis. We analysed 21 hypothetical combinations of these firms in this study (Table 10.3). Out of these 21 combinations, the government has already combined ONGC and HPCL.

10.5 Results

10.5.1 Individual Learning Potential

The results of the individual learning potential and the efficiency of companies' efficiency under upstream technology are Table 10.4. Under CRS assumption, ONGC (0.25) and Oil India (0.29) have the lowest efficiency estimates (bias corrected). Under the VRS assumption, the output efficiency of ONGC rises to 0.66 however the input efficiency is still low at 0.34. Thus, ONGC is scale inefficient as well as technically inefficient. Oil India has low technical efficiency under CRS and VRS assumption. Under the VRS assumption, ONGC has the potential output by 34% given the current input or decrease their input by 66% given the current output by following its peers in the upstream technology. Similarly, Oil India has the potential to increase output or decrease inputs by 71%. These results indicate a broad trend of stagnant oil production by ONGC and Oil India for the past 10 years (Fig. 10.2).

Table 10.2 Summary statistics for upstream, downstream, and integrated companies

	Oil and gas production ('000 b/d)	*Petroleum product sales ('000 b/d)*	*Oil and gas reserves (Mmbbl)*	*Refining capacity ('000 b/d)*	*Retail station (No.)*	*Employee (No.)*
Integrated companies (*n* = 25)						
Mean	2168	1982	13,559	1524	8869	116,083
Median	1688	1106	6850	1031	4849	71,000
Std. Deviation	2024	2004	23,177	1476	10,946	142,816
Minimum	108	215	209	240	292	5157
Maximum	9437	6783	116,300	5894	44,397	476,223
Upstream companies (*n* = 42)						
Mean	388		2135			4188
Median	309		1259			1606
Std. Deviation	302		2420			6428
Minimum	77		181			151
Maximum	1284		11,671			31,065
Downstream companies (*n* = 19)						
Mean		1073		1063	6139	12,591
Median		846		600	3501	8797
Std. Deviation		840		909	7060	14,386
Minimum		304		261	271	1483
Maximum		3025		3145	27,702	60,350

Table 10.3 Hypothetical combinations of Indian NOCs

1. ONGC (ON) + Oil India (OI) + BPCL (B) + HPCL (H) + IOCL (I)
2. ONOIBH
3. ONOIHI
4. ONOIBI
5. ONBHI
6. OIBHI
7. ONOIB
8. ONOIH
9. ONOII
10. ONBH
11. ONBI
12. ONHI
13. OIBH
14. OIBI
15. OIHI
16. ONB
17. ONH
18. ONI
19. OIB
20. OIH
21. OII

Table 10.4 Output and input efficiency (bias corrected) of upstream companies for the year 2018

Company	*Constant returns to scale*	*Variable returns to scale*		*Company*	*Constant returns to scale*	*Variable returns to scale*	
		Output	*Input*			*Output*	*Input*
Anadarko	0.90	0.85	0.82	Lundin	0.33	0.33	0.50
Antero	0.77	0.81	0.78	Marathon Oil	0.80	0.81	0.80
Apache	0.80	0.80	0.79	Murphy Oil	0.55	0.56	0.57
ARC	0.73	0.75	0.79	Noble Energy	0.51	0.57	0.51
Cabot	0.73	0.78	0.77	Novatek	0.27	0.79	0.50
Chesapeake	0.91	0.91	0.89	Occidental	0.49	0.67	0.45
Cimarex	0.95	0.91	0.92	Oil India	0.29	0.29	0.29
CNR	0.33	0.74	0.55	ONGC	0.25	0.66	0.34
CNX	0.54	0.66	0.55	PDO	0.38	0.61	0.47
Concho	0.78	0.79	0.77	PGNIG	0.26	0.26	0.26
ConocoPhillips	0.58	0.84	0.73	Pioneer	0.62	0.63	0.64
Continental	0.59	0.67	0.59	Premier Oil	0.87	0.76	0.81
Devon	0.72	0.81	0.73	QEP	0.66	0.66	0.71
Diamondback	0.40	0.41	0.44	Range	0.48	0.55	0.53
EnCana	0.74	0.76	0.75	Russneft	0.30	0.29	0.31
EOG	0.72	0.91	0.86	SouthWestern	0.67	0.88	0.84
EP Energy	0.70	0.76	0.85	Tullow Oil	0.59	0.59	0.61
EQT Corp	0.84	0.83	0.72	Ultra	0.83	0.75	0.74
Gulfport	0.87	0.85	0.87	Whiting	0.65	0.65	0.72
Hess U	0.61	0.62	0.61	Woodside	0.57	0.57	0.58
Inpex	0.32	0.45	0.35	WPX	0.76	0.80	0.84

The results of the individual learning potential and the efficiency of the companies under companies' efficiency under downstream technology are technical efficiency under CRS (0.95) and VRS assumption (0.96) and is therefore technically and scale IOCL has higher technical efficiency under VRS assumption (0.97) but lower efficiency (0.77) under CRS assumption. Thus, IOCL is scale inefficient and needs to enhance its scale to improve efficiency. BPCL has the lowest technical efficiency among Indian NOCs, (0.92) for output and 0.90 for input orientation under the VRS assumption. Thus, BPCL has the potential to increase its output by 8% given its input or decrease its input by 10% given its output. These results indicate that among the three NOCs, BPCL provides the maximum scope for the acquiring company to improve efficiency (Table 10.5).

The results of the technical efficiency estimate under the integrated technology is given in Table 10.6. ExxonMobil and YPF have the highest technical efficiency (0.96) under the CRS assumption. NOCs like PetroChina, Pemex, and Kazmunaigas have higher efficiency under VRS assumption than CRS assumption indicating that these companies are scale inefficient. Under the VRS assumption, most of the integrated companies have high technical efficiency. These firms serve as peer firms for the merged firms that we construct in this study.

Table 10.5 Output and input efficiency (bias corrected) of downstream companies for the year 2018

Company	*Constant returns to scale*	*Variable returns to scale*		*Company*	*Constant returns to scale*	*Variable returns to scale*	
		Output	*Input*			*Output*	*Input*
BPCL	0.88	0.92	0.90	Marathon	0.74	0.94	0.94
Cosmo Oil	0.84	0.89	0.90	Neste Oil	0.85	0.94	0.95
CPC	0.92	0.95	0.95	Phillips 66	0.94	0.98	0.98
Delek US	0.91	0.94	0.94	Preem	0.90	0.94	0.94
Essar Oil	0.97	0.96	0.96	Reliance	0.92	0.94	0.94
Hellenic	0.92	0.97	0.98	SK	0.77	0.78	0.78
HPCL	0.95	0.96	0.96	S-Oil	0.86	0.88	0.88
Idemitsu	0.68	0.70	0.72	Tupras	0.95	0.96	0.97
IOCL	0.77	0.97	0.97	Valero	0.91	0.94	0.94
JX Nippon	0.76	0.77	0.77				

Table 10.6 Output and input efficiency (bias corrected) of integrated companies for the year 2018

Company	*Constant returns to scale*	*Variable returns to scale*		*Company*	*Constant returns to scale*	*Variable returns to scale*	
		Output	*Input*			*Output*	*Input*
BP	0.93	0.97	0.98	Petrobras	0.86	0.98	0.98
Chevron	0.95	0.98	0.98	PetroChina	0.66	0.98	0.98
CNOOC	0.93	0.97	0.98	Petronas	0.93	0.98	0.98
ENI	0.93	0.97	0.98	PTT	0.94	0.97	0.98
ExxonMobil	0.96	0.98	0.98	Repsol	0.86	0.88	0.88
Gazprom	0.93	0.97	0.98	Rosneft	0.95	0.98	0.98
Husky Energy	0.93	0.98	0.98	Shell	0.93	0.97	0.98
Kazmunaigas	0.65	0.74	0.85	Sinopec	0.83	0.97	0.98
Lukoil	0.95	0.97	0.98	Suncor	0.95	0.98	0.98
MOL Group	0.93	0.97	0.98	Surgutneftegas	0.93	0.97	0.98
OMV	0.84	0.90	0.95	Total	0.94	0.98	0.99
Pemex	0.76	0.98	0.98	YPF	0.96	0.97	0.98
Pertamina	0.94	0.98	0.98				

10.5.2 Merger Decomposition

The results of the decomposition of the merger analysis under the bias-corrected output-oriented DEA VRS model is presented in Table 10.7. Out of the 21 combinations considered in the study, the combination of ONGC, Oil India, and IOCL had the maximum potential (E) to increase output by 56% after merger. However, after accounting for learning potential, the combination of ONGC and IOCL has the maximum potential to increase output by 50% after merger. The decomposition of the merger impacts of ONGC and IOCL suggests that 8% potential gains could be achieved through learning effect, 47% through harmony effect and 6% through scale effect. Since the scale effect is positive and the scope for harmony is also positive therefore this merger could improve efficiency significantly. The combination of ONGC and HPCL which has already been executed had the potential to increase output by 32% but after the learning effect is accounted, the potential to increase output falls to 19%. The decomposition of ONGC and HPCL merger reveals that 16% potential gains could be achieved through learning effect, 22%

through harmony effect however the scale impact would be negative with a loss of 5%. Therefore, the gains in efficiency of ONGC and HPCL could have been better achieved by individual learning effect and scope effect rather than through merger.

The results of the decomposition of the merger analysis under the bias-corrected input-oriented VRS model is presented in Table 10.8. The combination of ONGC, Oil India, and IOCL had the maximum potential to decrease inputs by 52% after merger. However, after accounting learning potential, the combination of ONGC and IOCL had the maximum potential to decrease inputs by 18%. The decomposition of the merger impacts of ONGC and IOCL suggest that potential gains of 39% could be achieved through learning effect, 20% through the harmony effect however the scale impact would be negative with a loss of 2%. Thus, the combination of ONGC and IOCL could optimise their input combination to improve efficiency after merger. The combination of ONGC

Table 10.7 Potential gains from mergers in bias-corrected output-oriented DEA-VRS model

Company	*E*	*E star*	*Learning effect*	*Harmony effect*	*Size effect*
OIB	0.90	0.94	0.96	0.93	1.01
OIBH	0.92	0.93	0.99	0.88	1.06
OIBHI	0.88	0.89	0.98	0.88	1.02
OIBI	0.95	0.96	0.98	0.96	1.00
OIH	0.91	0.92	0.99	0.88	1.04
OIHI	0.94	0.94	0.99	0.96	0.98
OII	0.90	0.95	0.95	0.97	0.98
ONB	0.52	0.63	0.84	0.71	0.88
ONBH	0.51	0.56	0.91	0.64	0.87
ONBHI	0.61	0.61	0.99	0.62	0.99
ONBI	0.53	0.53	1.00	0.55	0.97
ONH	0.68	0.81	0.84	0.78	1.05
ONHI	0.54	0.53	1.00	0.57	0.94
ONI	0.46	0.50	0.92	0.53	0.94
ONOIB	0.54	0.76	0.71	0.86	0.89
ONOIBH	0.49	0.64	0.76	0.77	0.83
ONOIBHI	0.58	0.58	1.00	0.61	0.95
ONOIBI	0.50	0.57	0.89	0.58	0.97
ONOIH	0.70	0.91	0.76	0.88	1.04
ONOIHI	0.51	0.56	0.90	0.61	0.93
ONOII	0.44	0.61	0.73	0.62	0.98

Table 10.8 Potential gains in bias-corrected input-oriented DEA-VRS model

Company	*E*	*E star*	*Learning effect*	*Harmony effect*	*Size effect*
OIB	0.90	0.96	0.94	0.95	1.01
OIBH	0.92	0.96	0.96	0.95	1.01
OIBHI	0.85	0.96	0.88	0.95	1.01
OIBI	0.94	0.98	0.96	0.97	1.01
OIH	0.91	0.96	0.95	0.95	1.01
OIHI	0.93	0.96	0.97	0.96	1.00
OII	0.90	0.95	0.94	0.96	0.99
ONB	0.63	0.94	0.67	0.95	0.99
ONBH	0.55	0.88	0.63	0.89	0.99
ONBHI	0.60	0.87	0.69	0.83	1.05
ONBI	0.53	0.85	0.63	0.82	1.03
ONH	0.77	0.96	0.80	0.97	0.99
ONHI	0.55	0.84	0.65	0.82	1.04
ONI	0.50	0.82	0.61	0.80	1.02
ONOIB	0.64	0.99	0.65	0.97	1.02
ONOIBH	0.53	0.90	0.58	0.94	0.96
ONOIBHI	0.58	0.91	0.64	0.83	1.09
ONOIBI	0.52	0.88	0.59	0.83	1.06
ONOIH	0.77	0.97	0.79	0.95	1.02
ONOIHI	0.53	0.88	0.61	0.82	1.06
ONOII	0.48	0.84	0.57	0.83	1.02

and HPCL had the potential to decrease input by 23%. But after the learning effect is accounted, the gains by merger reduce to 4% which is trivial. Thus, the gains from a pure merger would only be 4%. When the merger effect is decomposed, most of the potential gains is through the learning effect at 20% while the harmony effect is 3% and scale effect is 1%.

The overall results indicate that upstream NOCs, ONGC, and Oil India have the lowest technical efficiency and these companies have huge learning potential. Additionally, ONGC is scale inefficient and could benefit from operating at the optimum scale of operation by following its peers. The downstream NOCs like IOCL, BPCL, and HPCL have higher technical efficiency however IOCL has lower CRS efficiency compared to its VRS efficiency score which indicates that IOCL is not operating at the optimum scale of operation. Among the three downstream NOCs, BPCL has the lowest input technical efficiency score under VRS. Thus, BPCL privatisation could be beneficial as the acquiring company has significant potential to optimise inputs to improve efficiency.

The estimates of merger analysis suggest that the combination of ONGC and IOCL had the highest potential to improve output or input efficiency after accounting their individual potential. The decomposition of merger analysis of ONGC-IOCL combination suggests that the harmony effect dominates the total effect of potential gains through mergers. Thus, ONGC and IOCL could follow the best performing integrated oil companies and optimise their output or input combination to increase efficiency. Since the size effect is positive for the output-oriented ONGC-IOCL combination, therefore merger could also help the firm to operate at the optimum scale. The combination of ONGC and HPCL has the scope to increase output efficiency by 19% or input efficiency by 4% after accounting the individual learning potential. If the government aimed to improve input efficiency of NOCs through mergers, then the combination of ONGC and HPCL was among the least attractive option. Suitable alternatives like ONGC with IOCL or ONGC with BPCL would have been a better combination than ONGC and HPCL.

10.6 Conclusion

In this study, we have assessed the structural efficiency of the Indian NOCs by comparing their performance with international upstream and downstream companies and assessed the potential of different NOCs to increase their efficiency through mergers by comparing them with international integrated companies. We find that the upstream NOCs-ONGC and OIL have low technical efficiency while the downstream NOCs have higher technical efficiency. However, the biggest upstream NOC-ONGC and downstream NOC-IOCL are both scale inefficient and could improve their efficiency by operating at the optimum scale of operation. The government's aim in creating an integrated NOC was to achieve scale, bear higher risks and take higher investment decisions (Ministry of Finance, 2018). According to this study, the maximum potential to achieve scale efficiency exists in the combination of ONGC and IOCL. The Chinese NOCs have prevailed against Indian NOCs in bidding for international assets based on their size (Aiyar, 2014). The combination of ONGC and IOCL would have been financially stronger to challenge international companies in bidding for international assets. BPCL privatisation will be advantageous for the acquiring company since BPCL has the maximum potential to improve efficiency.

This study is an ex-post analysis of the merger that has already taken place and. Thus we aimed to assess whether ONGC-HPCL combination was the best available option to improve the efficiency of Indian NOCs. We do not recommend that vertical integration is the best restructuring option to improve efficiency. Recent evidence also suggests that de-integration of vertically integrated oil companies is occurring due to increased scope for value generation in specialised segments (Dale et al., 2014). As we observe from this study that there is significant individual learning potential for the NOCs to improve efficiency by following peers in their own set. However, it is also possible that government control inhibits the NOCs to learn from its international peers. Therefore, privatisation of NOCs has the potential to unlock value and improve efficiency of these NOCs. The study has the limitation of only computing technical efficiency of the NOCs since allocative efficiency requires information and input prices which are currently available for all the companies in our study.

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PART V

Sustainable Urban Development

CHAPTER 11

Benchmarking Urban Sustainability: An Indicator-Based Assessment of Selected Indian and Global Megacities

B. Sudhakara Reddy and P. Balachandra

11.1 Introduction

Cities are at the forefront of global socio-economic change, and rapid urbanisation is the phenomenon of the twentieth century. Presently, half of the world's population lives in urban areas, and the other half increasingly depends on cities for economic, social, cultural and political sustenance (Anon, 2018a, 2018b). Urbanisation occurs at an accelerating pace in developing countries, accompanied by the creation of large urban

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aggregations and megacities. Urbanisation is regarded as one of the most important social processes and has an enormous impact on the environment at local, regional and global levels. It is now widely acknowledged that unbridled urbanisation has significant implications for economic, environmental and social sustainability (Anon, 2018a, 2018b; Al-Zu'bi & Radovic, 2019; World Bank, 2015). Urbanisation results in major irreversible changes in production and consumption patterns of resources and impacts the carrying capacity of the earth's ecosystem. Hence, it is important to study the rapid urban changes that are taking place, especially in developing countries since these are the least equipped with the means to invest in basic urban infrastructure—roads, water, sanitation, and housing—and are struggling to provide vital economic opportunities for its residents.

In the context of rapid urbanisation, it is essential to apply a filtering mechanism based on sustainability principles in evaluating policy and planning decisions concerning urban systems. However, the criteria for sustainability differ between developed and developing countries. These differences prohibit us from applying the models of sustainability of advanced societies to those which lag. In such a scenario, we have to develop a different measure of sustainability using relevant indicators to assess urban sustainability. These indicators play an important role in turning data into relevant information for policymakers and help in decision-making. They also help in simplifying complex information. Indicators are now well established and are widely used in different fields and at various levels, viz., global, regional, national, and local (Anon, 2015a, 2015b; Furgal & Gosselin, 2002; Hoornweg et al., 2006). The main criteria for the selection of indicators are: (i) easy understanding by stakeholders; (ii) measurability using the available data at city and national levels; and (iii) relation to policy goals and capable of being changed. To be useful, indicators should be user-driven and depend on factors and the purpose for which they are used.

Since sustainable urban development became the catchword in most international discussions, several approaches to its assessment have sprung up, with an indicator-based approach becoming the prominent one. To assess urban sustainability, indicators are crucial for target setting, performance reviews and facilitating communication among policymakers, experts and the general public. Therefore, a wide range of indicators is in use across the diversity of different cities and regions, which vary according to particular needs and goals (Brandon & Lombardi, 2005; Kötter & Friesecke, 2011; Kuik & Verbruggen, 1991). However, practical challenges have led to mixed results in applying sustainability indicators in different environments and sometimes with little sustainability performance (Alshuwaikhat & Nkwenti, 2002; Seabrooke et al., 2004; Selman, 1999; Thomas, 2013). It has been argued that the main reason for failure to attain the desired performance is the inadequate selection of indicators that guide and monitor the process of sustainability (Briassoulis, 2001; Seabrooke et al., 2004; Sirgy, 2011). It has also been argued that the lack of consensus on indicators among different practices has been confusing while selecting and relating them with the objectives defined or policies implemented (Grimm et al., 2008; Hardoy et al., 2001; McGranahan et al., 2005; Nathan & Reddy, 2011). Although there is a rapidly growing literature on “good” urban practices, very little is known about how they are practised and their role in policy-making processes (Bulkeley, 2006). Attempts have been made to study the extent to which cities are becoming sustainable or unsustainable through the use of indicators and the challenges that are encountered in the process (Briassoulis, 2001; Mavrič & Bobek, 2015; Roy, 2009; Shen et al., 2011; Tanguay et al., 2010).

Given the above context, the main aim of the present study is to investigate, by using the indicator approach, whether the present pattern of urban development in India in the creation of megacities is sustainable. This will be done by evaluating and comparing the sustainability status of Mumbai and Bangalore cities, using indicators against some benchmark hypothetical sustainable city and selected global megacities. Thus, the objectives of the study are: (i) identifying and prioritising sustainable urban indicator variables spanning all the relevant sectors of a typical megacity, (ii) developing a sustainable indicator database for the hypothetical benchmark megacity and other cities included in the analysis, (iii) comparing and evaluating Mumbai and Bangalore with selected megacities of the world on sustainability benchmark, and (iv) suggesting appropriate policy measures and implementation strategies bridge the identified gaps to attain the goal of the sustainable urban system.

11.2 METHODOLOGY

11.2.1 Conceptual Framework

For the present study, the sustainability indicators concerning urban systems have been divided into three broad groups of dimensions, viz., economic, social, and environmental.

- *Economic Sustainability*—Capture the current as well as the dynamic economic strength of an urban system.
- *Social Sustainability*—Map the extent of equitable distribution of the benefits of economic development to the people.
- *Environmental Sustainability*—Assess the conformation of economic development to environmental standards.

The prioritisation of categories of indicators has been made with the support of literature and logical assessment (Marzukhi et al., 2011; Matthew & Giles, 2010; Mavrič & Bobek, 2015; Natalie, 2011; Shen et al., 2011; Silverio & Jesús, 2010; Stewart, 2010; Theo & Frank, 2007; UNHABITAT, 2009; Zainuddin, 2005). This process facilitated short-listing of 18 categories of sustainability indicators under the three dimensions. Figure 11.1 shows the overall hierarchical framework adopted to represent urban sustainability in various dimensions and categories.

Next, Figs. 11.2, 11.3 and 11.4 elaborate the above framework further into prioritised indicators under each category belonging to respective dimensions of urban sustainability.

11.2.2 Analytical Framework

In real-life situations, indicator values have different measurement units (income in local currencies, electricity in kWh, etc.). To develop composite indices by integrating these indicators, it is essential to transform all the indicators into some standard form. For each indicator included in the analysis, a relative indicator value is estimated using the actual and the sustainability threshold values. Thus, for each indicator, threshold values—minimum and maximum—are determined, and these are the best and the worst values for a given indicator obtained for cities across the world. In other words, we need to have one set of cities with

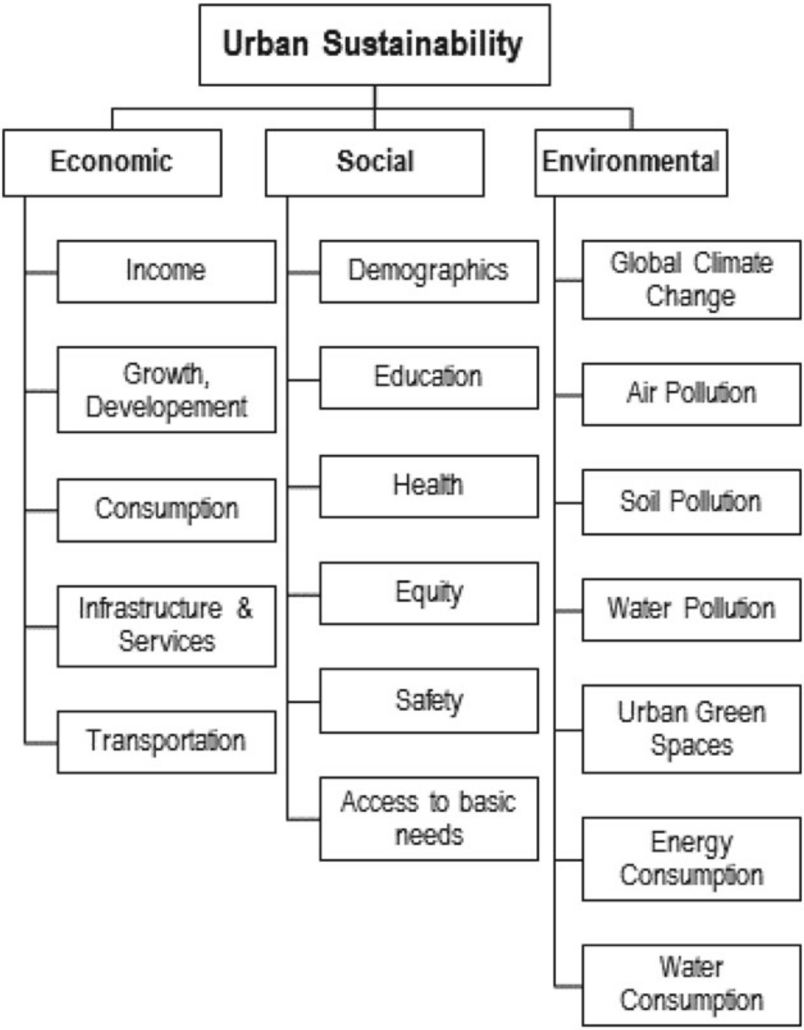

Fig. 11.1 Urban sustainability framework

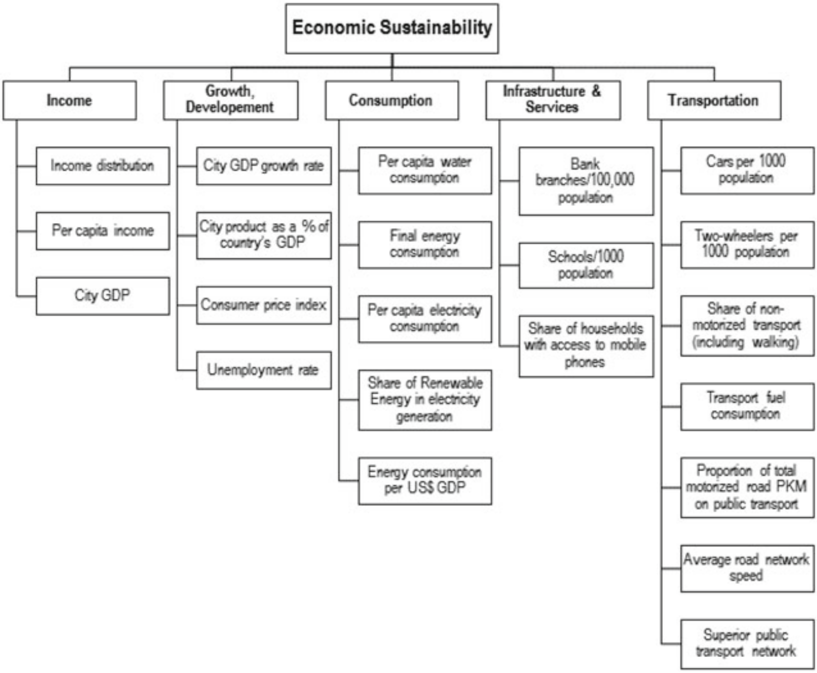

Fig. 11.2 Categories and indicators of economic sustainability

the best and another set with the worst values for every indicator. Collectively, it will result in two hypothetical cities, one with the best values for all the indicators and another with the worst values. The hypothetical city with the best values will be the most sustainable and will function as a sustainability benchmark for other cities. The standard indicator is developed using a scaling technique where the minimum value is set to 0 and the me equation used for this is

$$\text{Normalised indicator value} = \frac{\text{Actual value} - \text{Minimum threshold value}}{\text{Maximum threshold value} - \text{Minimum threshold value}} \tag{11.1}$$

The next step is to derive the composite index values for different *categories* of sustainability from indicators belonging to that particular

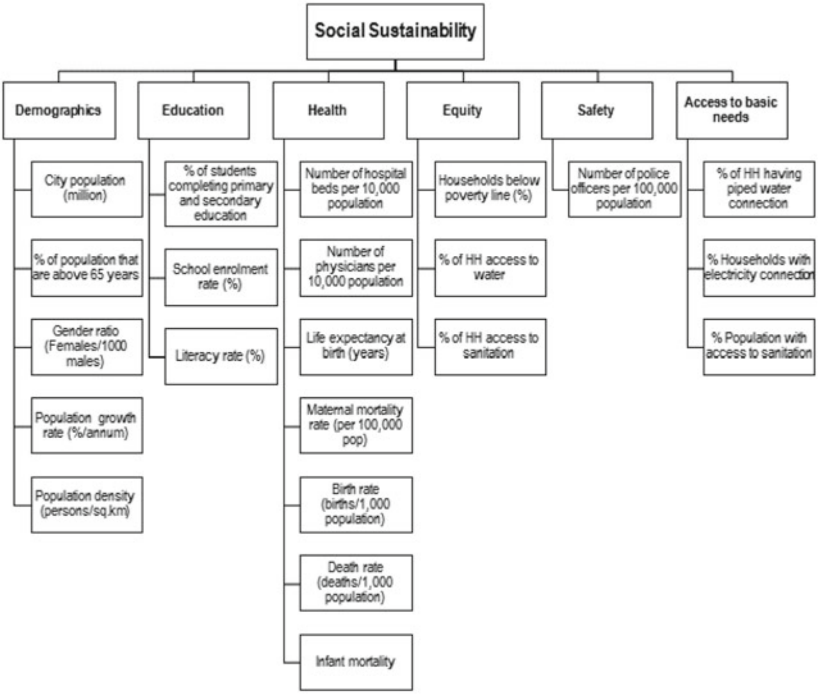

Fig. 11.3 Categories and indicators of social sustainability

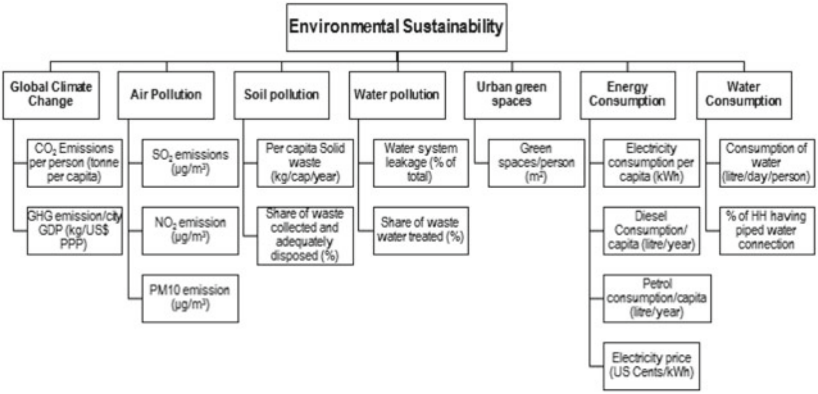

Fig. 11.4 Categories and indicators of environmental sustainability

category. Further, these category-wise index values are used for developing composite index values for various *dimensions* of sustainability. These indices are computed as the root mean square (Gnansounou, 2008) of the normalised indicator variables belonging to that category and obtained using Eq. (11.2). Similarly, composite dimension indices are computed as the root mean square of the composite category-wise index values belonging to that dimension.

$$dj = \left(\frac{\sum_{i=1}^{I} V_{ij}^{2}}{I} \right)^{0.5} \tag{11.2}$$

where,

d_j = Dimension or Category of type "j".
V_{ij} =Variables or categories "i" belonging to category or dimension "j", $i = 1, 2, \ldots., I$
I = Number of variables in a dimension.

Further, a composite urban sustainability index (USI) has been developed from these dimensions that are assumed to contribute to the overall urban sustainability (Eq. 11.2).

$$USI = \left(\frac{\sum_{j=1}^{J} d_j^{2}}{J} \right)^{0.5} \tag{11.3}$$

where,

USI = Urban sustainability index.
d_j = Dimension "j", $j = 1, 2, \ldots., J$
J = Number of dimensions.

11.2.3 Benchmarking Urban Sustainability—A Gap Analysis Approach

As stated earlier, the indicators of sustainability for each of the dimensions that are being determined for the study cities (Mumbai and Bangalore) will be compared with the benchmark indicators of a hypothetical sustainable megacity as well as three threshold cities (London, Singapore and

Shanghai). First, the standardised indicator dimensions for both the study and comparable cities, as well as the benchmark city, will be mapped on a radar diagram. The distance between the two points (any city and benchmark city) for a given dimension gives the prevailing gap. For example, the dimension gaps for the study cities suggest how far they are from achieving the levels of a benchmark sustainable city and also provide insights the dimensions seriously lacking. The quantified gaps in dimensions, as well as indicators, can provide greater insights into the reasons for the existence of sustainability gaps, targets that need to be fixed to bridge them, and strategies that need to be adopted for achieving these targets.

For the present study, the indicator data for study cities, comparable cities as well as threshold cities are gathered mainly from secondary sources of information such as journal papers, reference books, government reports, project reports, websites of concerned government departments and ministries, websites related to multilateral agencies and a variety of databases from the internet (Anon, 2010a, 2010b, 2014, 2016, Bangalore Census, 2011; BBMP, 2011; Chanakya et al., 2008; Chaudhuri, 2011; D'Souza, 2011; Glaeser, 2010; GOK, 2009; Mahendra et al., 2010; NUMBEO, 2012; PWC, 2009; Reddy, 2020; Rode & Kandt, 2011; Samuel et al., 2012; Sekher et al., 2008; SIEMENS, 2011; Singh, 2010; TERI, 2011; UNHABITAT, 2009, 2010; 2012; WHO, 2011; World Atlas, 2012, World Bank, 2009). Though the prioritised list had a large number of indicators, we could gather data only for 48 indicators under economic dimension, 45 under social dimension, and 36 under environmental dimension for a total of 129 indicators in the cases of Bangalore and Mumbai cities. However, even after significant efforts, we could not gather data for all these 129 indicators for threshold cities, and it became even greater challenge to get data for a given indicator for the three comparable cities. Finally, we could gather data for all the five cities as well as for two threshold limits for a total of 60 sustainability indicators, i.e., we could obtain data for 22 indicators each belonging to economic and social dimensions, and 16 indicators belonging to the environmental dimension (Tables 11.2, 11.3, and 11.4). Thus, the final sustainability benchmark comparisons are made using these 60 quantified indicators.

11.3 A Comparative Analysis of Mumbai and Bangalore

11.3.1 Demographic Profile

The demographic bases of Mumbai and Bangalore are structurally different and distinct in terms of overall size and features (Table 11.1). Mumbai is historically an urban region, an industrial powerhouse and a port city. On the other hand, Bangalore's growth is of recent origin, just 30 plus years, after information technology gained ground in the city and fuelled in part by a strong in-flow of migrants, particularly educated youth. Mumbai constitutes only 0.16% of the area of Maharashtra but is home to 16.4% of its population. This results in a very high population density (28,330/km^2) which is 90 times higher than that of the state as a whole. Comparatively, Bangalore has a larger land area (741 km^2), and much of it is used for housing, industry and parks. During the last decade, Mumbai's population grew by 10.4% whereas that of Bangalore is by 65.2%. The land-use data indicate that the residential area of Mumbai constitutes 38% followed by an equal percentage by green cover under forest land and agriculture. In Bangalore, the residential areas comprise around 43%. The green cover per person in Bangalore (18.9 m^2) is higher than that in Mumbai (13.2 m^2). The population density of Mumbai is higher than that of Bangalore, thus necessitating a different kind of long-term planning for improved service delivery.

11.3.2 Comparing Sustainability Indicators: Mumbai and Bangalore

To compare Mumbai and Bangalore, the two megacities in India, one an established one and the other an emerging one, we assess them on the basis of various indicators of sustainability—economic, social and environmental. The data obtained for all the dimensions are presented in Tables 11.2, 11.3, and 11.4 (columns 3 and 4).

Economic sustainability: It constitutes a subset of five indicator categories–income, growth, consumption, infrastructure and transportation containing 22 quantified indicators–formulated to evaluate the economic performance of the city (Table 11.2). Though the total size of Mumbai's economy is 2.5 times that of Bangalore, the per capita GDP is just higher by 1.06 times. The economic growth prospects for Bangalore appears

Table 11.1 Demographic data for the cities of Bangalore and Mumbai (2011)

Description	*Mumbai*	*Bangalore*
Population (million)	18.48	8.43
Decadal population growth (%)	10.4	65.2
Average literacy	88.48	89.58
Area Sq. km	653	741
Population density/km^2	28,330	11,371
Proportion to state population (%)	16.41	13.78
Land use (%)		
Residential	36.1	43.0
Business/industry	10.2	6.8
Transport/Roads	10.3	20.7
Green cover (forest, coast wetland and agriculture, etc.)	37.3	21.5
Others	6.1	8.0

Source For Mumbai: http://www.regionalplan-mmrda.org; For Bangalore: BBMP (2011)

to be slightly better than that of Mumbai. Water is a basic resource for sustaining human life, and the per capita water use for Mumbai (208 litres) is nearly double that of Bangalore (129 litres). Per capita electricity consumption levels are the same for both the cities; however, Bangalore's electricity supply is mainly from renewable energy sources. Access to education infrastructure appears to be better in Bangalore, whereas Mumbai fares better with respect to communication infrastructure except for internet access. Mobility patterns and related energy use play a significant role in deciding the quality of the urban environment. A high dependency on personal transport negatively affects air quality, noise, and liveability. On the other hand, the density of public transport network plays a very important role in the sustainable mobility of a city. For Bangalore, the accessibility of public transportation infrastructure is a low 46%, and hence the automobile ownership is very high (1.7/family). In the case of Mumbai, the corresponding figures are 88% and 0.36%, respectively, suggesting higher dependency on public transport (Table 11.2).

Social Sustainability: Achieving social sustainability requires satisfaction of basic needs such as food, housing, education, and health, and community needs such as safety and recreation facilities. Even positive demographic profiles indicate enhanced social sustainability. These

Table 11.2 Indicators of urban sustainability for five megacities—economic dimension

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Income	Per capita income (US$ PPP/year)	10,247	10,885	42,700	41,500	13,061	65,500	5004
	Income distribution (GINI Coefficient)	0.32	0.35	0.32	0.45	0.321	0.75	0.22
	City GDP (US$ billion PPP)	83	209	349	215	233	1479	24
Growth/Development	City GDP growth rate (%)	6.5	6.3	3.0	5.7	9.4	13.3	1.1
	City product as a % of country's GDP	2.29	5.76	33	100	4.5	100	1.00
	Consumer price index	31.96	37.33	110.69	104.86	70.44	191.15	28.61
	Unemployment rate (%)	14	17	8.1	2.1	4.8	50	2.1
Consumption	Per capita water consumption (litres)	129	208	161	308.5	411.1	527	53.1
	Final energy consumption (G.J./Capita)	10.95	15.14	74.49	158.37	140.54	215.96	10.95

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
	Per capita electricity consumption (kWh)	1576	1600	5150	7949	6003	17,619	352
	Share of Renewable Energy in electricity generation (%)	61	21	1.2	0.0	0.5	61	0.0
	Energy consumption per US$ GDP (MJ/US$)	1.57	6.5	1.4	5.31	14.66	14.8	1.2
Infrastructure and services	Bank branches/100,000 population	17	7.9	25.56	10.54	23.6	95.87	3.14
	Schools/1000 population	0.521	0.125	0.25	0.16	0.129	0.955	0.05

(continued)

Table 11.2 (continued)

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
	Share of households with access to mobile phones (%)	82.8	83	100	100	100	100	37.6
Transportation	Cars per 1000 population	47	26.5	317.2	117	169	587.1	26.1
	Two-wheelers per 1000 population	258	49.1	15.47	134	700	700	15.47
	Share of non-motorised transport (including walking)	38	33	33	48	34	65	8.1
	Transport fuel consumption (G.J./capita/year)	2.78	0.92	53.00	25.34	27.48	60.8	0.92

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
	The proportion of total motorised road PKM on public transport (%)	72.2	65.5	52.6	57.1	66	72.2	2.9
	Average road network speed (km/h)	27	23	17	27	15	49.3	15
	Superior public transport network, covering trams, light rail, subway and BRT (km/km^2)	0.0	0.0	0.79	0.21	0.07	0.79	0.0

components support four guiding principles, viz., equity, gender equality, social inclusion, security, and adaptability. Bangalore appears to have better gender performance compared to Mumbai, with higher gender and child sex ratios and higher female literacy. Educational opportunities are a major focus of social sustainability. Education provides employment, and workplaces provide a place for social interaction which is essential to improve the social wellbeing of citizens. Even though the school enrolment ratio is high (over 95%) both in Mumbai and Bangalore, those completing secondary education is only about 83% indicating a dropout of 12%. Provision of social infrastructure like schools, medical facilities, community centres and entertainment zones impacts the social sustainability of the city. In both the cities, for every 10,000 population, the number of beds in hospitals is around 20 and the number of physicians around 5 with a high infant mortality rate (>30). In relation to piped water connection, LPG connections and sanitation Bangalore scores over Mumbai (Table 11.3).

Environmental sustainability: Urbanisation provides higher income-generating opportunities resulting in higher resource use, which in turn causes a decline in urban environmental quality. Densely populated cities with high demand for motorised mobility contribute to high air pollution impacting the health of inhabitants. In relation to both global and local air pollution, the indicator values for Mumbai are double that of Bangalore. Fine particulate matter (PM10) concentrations are 90 $\mu g/m^3$ in Bangalore and 132 $\mu g/m^3$ in Mumbai, which is significantly higher than the prescribed limit of 40 $\mu g/m^3$. Bangalore has a lower CO_2 per capita emission (0.5 tonnes) than that of Mumbai (1.0 tonne). Waste is one of the key parameters of environmental sustainability since it plays a significant role in resource optimisation and environmental protection. Mumbai managed to contain the household waste to less than 209 kg/cap/year while it is 266.5 kg/cap/year for Bangalore. In the latter, there is a well-functioning waste management system that recycles 80% of the waste, and the balance goes to landfills. In Mumbai, the household recycling rate is under 32.4%, and only a very small portion of the waste goes to landfill (Table 11.4).

Table 11.3 Indicators of urban sustainability for five megacities—social dimension

Categories of Sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Demographics	City population (million)	8.1	19.2	8.17	5.18	17.84	32.45	4.796
	% of the population that is above 65 years	5.4	6.4	11.5	8.45	10.2	20.4	5.4
	Gender ratio (Females/1000 males)	922	810	1010	1041	982	1176	734
	Population growth rate (%/annum)	3.25	1.13	1.0	2.1	1.1	11.4	0.29
	Population density (persons/sq.km)	10,034	27,137	5206	7025.2	3030.2	43,079	1700
Education	% of students completing primary and secondary education	83	83	100	100	97	100	56
	School enrolment rate (%)	97	95.25	100	100	100	100	45
	Literacy rate (%)	88.48	82.5	99	94	97	100	22
Health	Number of hospital beds per 10,000 population	22	19.2	33	26	51.9	137	3
	Number of physicians per 10,000 population	5	5.4	24	18	26.6	42	3

(continued)

Table 11.3 (continued)

Categories of Sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Equity	Life expectancy at birth (years)	70	71	79	82	82.1	83.75	48.69
	Maternal mortality rate (per 100,000 pop)	125	63	9.3	3.0	9.61	540	3
	Birth rate (births/1000 population)	27	13.8	16	9.5	4.9	50.06	6.85
	Death rate (deaths/1000 population)	7.2	6.9	8.05	3.41	3.4	17.23	1.55
	Infant mortality	31	34.6	4.60	3.0	5.97	61.27	2.65
	Households below poverty line (%)	18	20	8.0	0.0	10	70	0
	% of H.H. access to water	99.2	98.4	100	100	100	100	40
	% of H.H. access to sanitation	95.9	52	100	100	58	100	25

Categories of Sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Safety	Number of police officers per 100,000 population	283	140	377	752	195	752	55
Access to basic needs (energy, water, sanitation)	% of H.H. having piped water connection	79	69	100	100	100	100	26
	Households with the electricity connection (%)	98.6	98	100	100	100	100	86.3
	Population with access to sanitation (%)	94.82	49	100	100	72.5	100	12

Table 11.4 Indicators of urban sustainability for five megacities—environmental dimension

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Global climate change	CO_2 Emissions per person (tonne per capita)	0.5	1	5.84	7.4	9.7	9.7	0.5
	GHG emission/city GDP (kg/US$ PPP)	0.049	0.092	0.137	0.178	0.743	0.743	0.049
Air pollution	SO_2 emissions ($\mu g/m^3$)	15.1	34	25	9	35	90	9
	NO_2 emission ($\mu g/m^3$)	41	86	37	22	53	130	22
	PM10 emission ($\mu g/m^3$)	90	132	29	29	81	150	11
Soil pollution	Per capita Solid waste (kg/cap/year)	266.5	209	566	306.6	369.5	995.6	146.8
	Share of waste collected and adequately disposed (%)	80	32.4	100	100	82.3	100	32.4
Water pollution	Water system leakage (% of total)	39	13.6	22	5	10	50.2	3.1
	Share of wastewater treated (%)	42.4	67.6	97	100	78.4	100	10

Categories of sustainability	*Indicators of urban sustainability*	*Indicator values*					*Threshold values*	
		Bangalore	*Mumbai*	*Comparable cities*			*Maximum*	*Minimum*
				London	*Singapore*	*Shanghai*		
Urban green spaces	Green spaces/person (m^2)	41	6.6	20.5	66.2	18.1	166.3	1.8
Energy consumption	Electricity consumption per capita (kWh)	1576	1600	5200	7949	6446.2	17,619	352
	Diesel Consumption/capita (litre/year)	57.9	12.3	185.7	384.3	266.6	734.5	10.9
	Petrol consumption/capita (litre/year)	39.4	15.9	297.6	237	216.7	1129.8	6.1
	Electricity price (U.S. Cents/kWh)	9.6	7.2	9.8	27	10	31.4	4.95
Water consumption	Consumption of water (litre/day/person)	129	208	161	308.5	411.1	527	53.1
	% of H.H. having piped water connection	79	69	100	100	100	100	26

11.3.3 *Categories and Dimensions of Composite Sustainability Indices: Mumbai and Bangalore*

To develop a composite sustainability index for Mumbai and Bangalore cities, we have to consolidate individual indicators under each category. First, the normalisation of indicator values (Eq. 11.1) has been done using the upper and lower threshold values (Tables 11.2, 11.3, and 11.4; columns 8 and 9). Second, the composite index values are derived for different *categories* of sustainability from indicators belonging to that category. Third, these category-wise index values are used for developing composite index values for three *dimensions* of sustainability (Eq. 11.2). Fourth, for benchmarking urban sustainability, a composite USI is developed using the dimension-wise index values (Eq. 11.3). USI is a single number (within the range of 0 and 1) and is used for comparing the level of sustainability reached by a city.

The category-wise composite sustainability indices are presented in Table 11.5 (columns 3 and 4). We observe from the table that Bangalore performs better than Mumbai in most categories of sustainability indices. Under the economic dimension, Bangalore is more sustainable compared to Mumbai with respect to all the categories, the differences being more significant with respect to category consumption. In the social dimension, Bangalore's conformity to sustainability is higher than that of Mumbai in all categories except health. Under the environmental dimension, the status remains the same except for categories like water pollution and energy consumption.

The good performance of Bangalore in category-wise sustainability indices translates into good performance even in the case of dimension-wise sustainability (Table 11.5; columns 3 and 4). Bangalore is thus more sustainable compared to Mumbai with respect to all the three dimensions; economic, social and environmental. With respect to economic sustainability, Bangalore has an indicator value of 0.519 compared to Mumbai's 0.446. Similarly, in the case of social sustainability, Bangalore has a value of 0.715 compared to Mumbai's 0.628. Finally, in environmental sustainability, Bangalore scores 0.720 and Mumbai 0.671. The estimated USI for Bangalore is 0.658 compared to 0.590 of Mumbai (Table 11.5).

It is important to remember that these are relative index values, and the maximum USI of 1.0 is obtained by using the best values for each of the indicators under different categories and dimensions. Thus, a city with USI of 1.0 is a hypothetical one with the highest achievement on

Table 11.5 Composite indicators of urban sustainability for five megacities

Dimensions of sustainability	*Categories of sustainability*	*Composite indicator values (Categories)*				
		Bangalore	*Mumbai*	*London*	*Singapore*	*Shanghai*
Economic	Income	0.472	0.445	0.601	0.487	0.481
	Growth/Development	0.656	0.623	0.534	0.778	0.690
	Consumption	0.454	0.277	0.212	0.467	0.641
	Infrastructure, services and urban equipment	0.522	0.424	0.608	0.583	0.593
	Transportation	0.467	0.390	0.625	0.466	0.574
Social	Demographics	0.689	0.660	0.703	0.718	0.748
	Education	0.816	0.777	0.996	0.975	0.964
	Health	0.528	0.604	0.752	0.822	0.857
	Equity	0.898	0.727	0.963	1.000	0.802
	Safety	0.330	0.120	0.460	1.000	0.200
	Access to basic needs (energy, water, sanitation)	0.857	0.644	1.000	1.000	0.908
Environmental	Global climate change	1.000	0.942	0.685	0.602	0.000
	Air pollution	0.757	0.469	0.845	0.959	0.637
	Soil pollution	0.785	0.655	0.793	0.911	0.738
	Water pollution	0.305	0.712	0.804	0.980	0.808
	Urban green spaces	0.240	0.030	0.110	0.390	0.100
	Energy consumption	0.823	0.844	0.647	0.684	0.619
	Water consumption	0.780	0.629	0.893	0.779	0.728
Economic sustainability index		0.446	0.519	0.600	0.539	0.569
Social sustainability index		0.628	0.715	0.789	0.836	0.926
Environmental sustainability index		0.671	0.720	0.601	0.726	0.784
Urban sustainability index (USI)		0.590	0.658	0.669	0.711	0.773

the sustainability radar. Similarly, the hypothetical city with 0 USI has the least achievement. Thus, all the cities in the world on a sustainability scale will fall in between these two limits. Similarly, the USIs of Bangalore and Mumbai need to be viewed from this context.

11.4 Urban Sustainability—Comparison with Benchmark Cities

11.4.1 Profile of Selected Cities

Here, we compare Mumbai and Bangalore with realistic benchmarks—one city each from U.K. (London) and China (Shanghai), and a city-country (Singapore). Mumbai, Singapore and Shanghai have approximately similar GDPs, whereas Mumbai, Bangalore and Shanghai are comparable on per capita income. London and Singapore are rich among all the cities under consideration. Such similarities are seen even with respect to other indicators too. For example, GDP growth rates are approximately the same for Bangalore, Mumbai and Singapore; and the population is growing at the same rate in Mumbai, London and Shanghai. Bangalore and London at the lower end and Mumbai and Singapore at the medium level have similar levels of energy consumption in relation to GDP. Shanghai consumes the highest amount of energy in relation to GDP, whereas the per capita electricity consumption is the highest in Singapore. The analysis suggests that there are similarities as well as differences among these cities with respect to economic, demographic and resource use indicators. We feel that benchmarking Mumbai and Bangalore with this set of cities would be appropriate.

11.4.2 Composite Index Values for Different Categories and Dimensions of Sustainability

The estimated composite sustainability index values for the three dimensions of sustainability are presented in Table 11.5. If we use category-wise index the values as the performance measure of sustainability, different cities have performed differently with respect to various categories. For example, under the dimension of economic sustainability, London has the best index value of 0.601 for income, Singapore for growth/development (0.778) and Shanghai for consumption (0.641). Bangalore does well with respect to growth/development with a value of 0.656, which is higher than that of Mumbai and London. The index value of 0.454 obtained for consumption by Bangalore is higher than that scored by Mumbai and London and is very close to that of Singapore's.

Under social sustainability, Shanghai has the best index values for demographics and health, whereas Singapore obtains high value for equity, safety and access to basic needs. London tops in education and access to basic needs, which it shares with Singapore. Bangalore obtains relatively high value for education, equity and access to basic needs; however, among the five cities is in third position with respect to equity and in the fourth position with respect to the other two categories.

Bangalore scores 1.0 for global climate change under the environmental dimension, whereas Mumbai tops with 0.844 in energy consumption. Singapore is the best under the environmental sustainability dimension by obtaining high values for air, soil, and water pollution, and urban green spaces. This indicates that Singapore is the most environment-friendly city among the five. In relation to other cities, Bangalore does well with respect to global climate change (top), energy consumption (second after Mumbai), urban green spaces (second after Singapore) and water consumption (second after London). However, it is in the last position in water pollution. Overall, Bangalore's performance with respect to environmental sustainability appears to be better compared to social and economic sustainability dimensions.

Table 11.5 contains the estimated index values for three dimensions of sustainability for the five cities, along with a composite USI for overall comparison. We observe from the table that Shanghai has the best value of 0.60 for economic sustainability and Singapore for both social (0.926) and environmental (0.784) sustainability. In comparison, Bangalore, with values of 0.519, 0.715 and 0.720, respectively, for economic, social and environmental sustainability dimension,s is better only in relation to Mumbai. Both Bangalore and Mumbai fare better than Shanghai in environmental sustainability. This suggests that Mumbai and Bangalore need to do a lot more to climb the ladder of sustainability. Mumbai's USI value of 0.590, is the lowest among the five cities, and Bangalore is ranked fourth, with Singapore topping the list with 0.773.

11.4.3 Benchmarking Urban Sustainability—Comparing Five Cities

Figure 11.5 shows the comparison of Bangalore and Mumbai for economic sustainability against the three cities. It may be observed from the figure that all the five cities are quite a distance away from the benchmark value of 1. Out of the five categories under economic sustainability, only those values with respect to growth/development indicators have crossed 0.6 and are approaching 0.8. This good performance is mainly because of the favourable indicators related to the low consumer price index and low unemployment rate. In the case of the remaining indicator categories, the values fall below 0.6, with Bangalore and Mumbai scoring around 0.4. The reason for such low values is due to lower per capita water and electricity consumption, a lower share of renewable energy, lower access to education and financial infrastructure, lower access to motorised transport and relatively higher congestion levels. The reasons are approximately the same for all the five cities with differing degrees of influence.

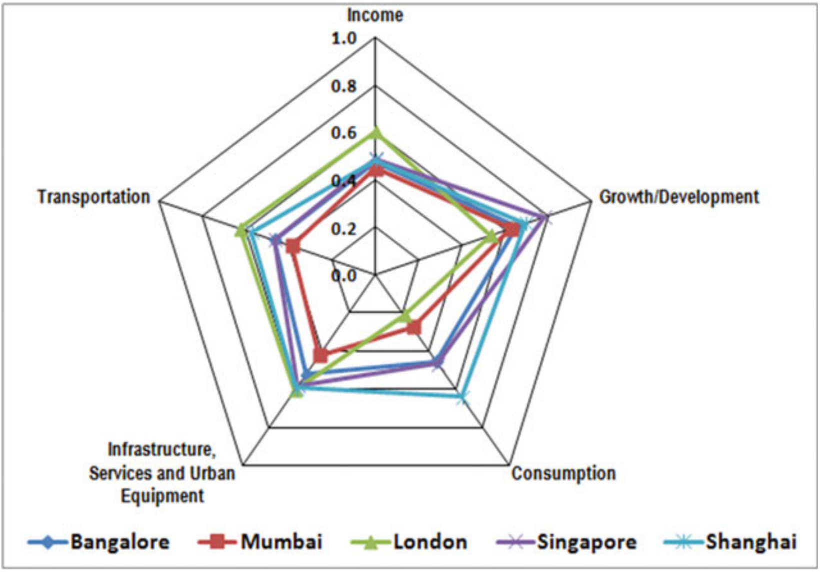

Fig. 11.5 Benchmarking economic sustainability

The next dimension considered is social sustainability (Fig. 11.6). Unlike in the previous case, the indicators are either close to or above 0.8 for all the cities, with the exception of Mumbai. With respect to safety, except for Singapore (1.0), all other cities have fared poorly, with Bangalore and Mumbai scoring less than 0.2. In relation to indicators like education, equity and access to basic needs all the cities to perform rather well. The reasons for this good performance are relatively high values scored for indicators related to longevity, population growth, literacy, maternal mortality rates, access to potable water, access to basic needs, etc. Overall the five cities have shown better social performance compared to economic performance.

Figure 11.7 compares the categories of environmental sustainability dimension among all the five cities as well as with the benchmark. Compared to economic and social sustainability indices, both the Indian

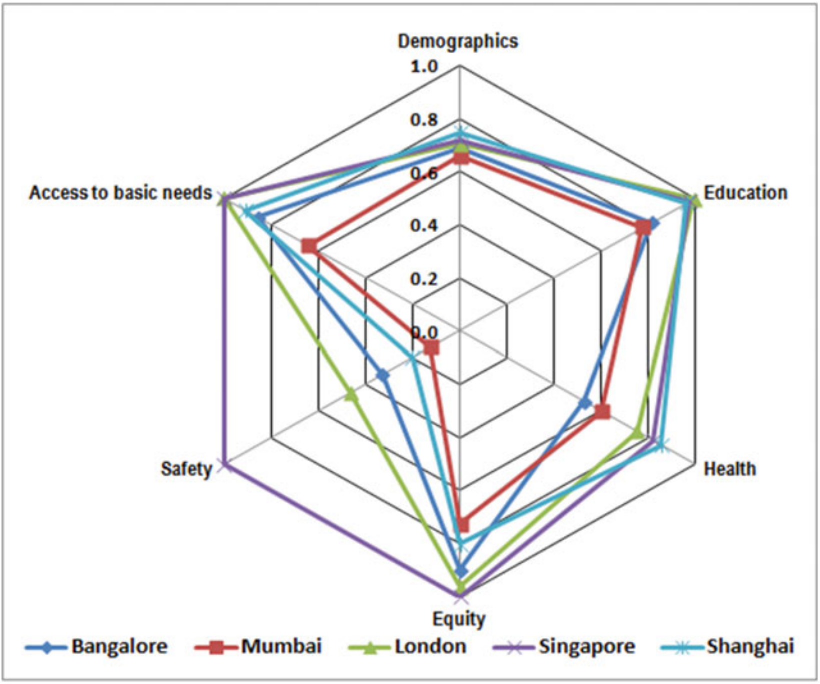

Fig. 11.6 Benchmarking social sustainability

cities have performed better with respect to environmental sustainability. Especially, the index values for climate change, energy consumption and soil pollution are relatively high. Shanghai res poorly in respect of most of the indicator categories under environmental sustainability resulting in poor overall performance. All the cities have scored lowly on urban green spaces. Bangalore does well with respect to five of the seven categories under environmental sustainability. The city scores poorly in relation to water pollution and urban green spaces.

A comparison of the composite index values of economic, social, and environmental sustainability dimensions (Fig. 11.8) shows that all the five cities fare poorly with respect to economic sustainability, with the index value of any city not exceeding 0.6. With respect to environmental sustainability, the cities have achieved composite index values closer to 0.8. The best performance is with respect to social sustainability, where the composite index values are around 0.8 (a few cities over 0.8 and a

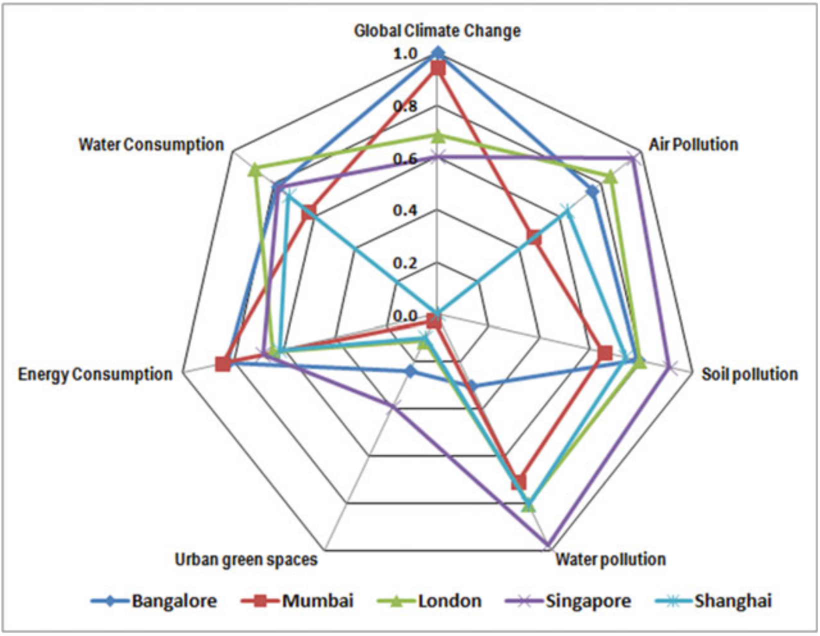

Fig. 11.7 Benchmarking environmental sustainability

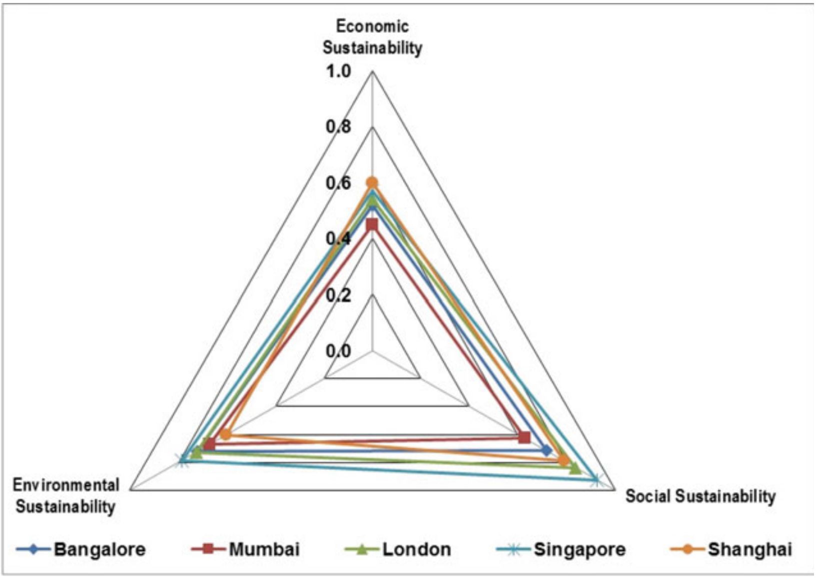

Fig. 11.8 Benchmarking urban sustainability

few slightly below it) with the sole exception of Mumbai. Further, both Bangalore and Mumbai, unlike the other three cities, perform better with respect to environmental sustainability compared to social sustainability. A lower economic development results in lower resource requirement, and this might be the reason for this deviation.

11.5 Discussion

With index values of 0.45 and 0.52 for economic sustainability, both Mumbai and Bangalore respectively occupy a lower position on the urban sustainability scale. The main reasons for this are lower sustainability scores obtained for indicators related to income, infrastructure and transportation. With respect to social sustainability, both Mumbai and Bangalore have bettered their performance with index values of 0.63 and 0.72, respectively. This relatively better performance is due to high scores obtained for indicators like education, equity and access to basic needs. The results suggest that both the cities can further improve their social sustainability index values by focusing on issues related to the safety of citizens and the development of the healthcare infrastructure. Compared to economic and social sustainability index values, both the cities perform slightly better with respect to environmental sustainability. It is better because of higher sustainability scores for indicators related to climate change, energy consumption and soil pollution. The very low score for urban green spaces is one of the contributors to lower environmental sustainability index values for both cities. Individually, Bangalore scores low for water pollution and Mumbai for air pollution. Both the cities need to make targeted interventions concerning indicator categories with low scores.

Of the five cities compared, Singapore emerges as the most sustainable city with an USI of 0.773. Bangalore is fourth on the list with a score of 0.658. To social and environmental dimensions, all the cities have obtained low values for economic sustainability. Urbanisation leads to better access to basic needs, infrastructure, less resource-intensive economic growth, better opportunity for employment, etc. Relatively low performance on indicators linked to economic sustainability has been the main reason for Bangalore and Mumbai to rank fourth and fifth, respectively, among the five cities. The relatively better performance with respect to environmental sustainability by both Bangalore and Mumbai is partially due to their lower achievements in economic development. Lower economic achievements mean lesser demand for fossil fuel-based energy resources and thereby lower environmental degradation.

For setting a clear direction for the city, a specific target is a must. Hence, one of the first steps towards establishing benchmarking targets is to have a strong policy commitment and a clear vision to achieve improvement strategies. Therefore, the target performance or benchmark level can be decided based on a combination of (i) the city's current performance and its desired position in the future; and (ii) the needs of the city for setting future public policy objectives concerning urban renewal. Of course, depending on the resource availability and timeframe, one may accept a lower performance level than the target. Therefore the setting of a future target should be on the basis of practical incremental improvements. The indicators need to be reviewed periodically to align them with the evolving urban system and be used to inform new policies and programmes where required. A public forum should be established to develop a clear vision and plan for implementing sustainable development initiatives. The forum should consist of representatives from local communities, professionals, technical and social groups, including youth, women and disadvantaged groups of the population. In this forum, active participation of policymakers is critical to enable linkage of indicators to policies and corrective measures. The forum should focus on issues that can control or influence and agree on indicators that need monitoring. The forum can improvise the list of indicators, policy prescriptions and corrective measures through workshops and awareness campaigns.

11.6 Conclusions

The study on evaluating Mumbai and Bangalore and three other megacities on the sustainability platform demonstrate the usefulness of benchmarking and provides better insights on sustainability performance. Although it is not in-depth research of the performance of Indian cities, it is a relatively quick demonstration of using a tool with existing data for identifying areas for improvement.

Measuring the sustainability of urban regions poses many challenges. It includes the processes of identification and collection of data that is valid, reliable and comprehensive. Another challenge is of interpreting indicators and concluding them for effective use in decision-making processes. The use of indicators for assessing urban sustainability performance is an important tool and is being adopted widely in recent times. There is an urgent need to harmonise indicator development initiatives at all local, national, and global levels. Many studies have explored the potential of various urban regions to achieve sustainability, and a indicator-based can be used for tracking such progress and setting targets.

Institutional innovations and indicators are needed to provide fertile ground for socio-economic improvements and creativity. It involves establishing a sense of urgency, developing a vision and strategy, communicating the vision of change and proposing new measures for evaluating progress. They must proceed with empowering people for broad-based action, winning short-term goals, consolidating gains, producing more changes and anchoring new changes in the lifestyle of the inhabitants. Urban regions need a paradigm shift towards a new economic, political and socio-environmental equilibrium.

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CHAPTER 12

Are PPP Arrangements Different in Green Infrastructure Sectors? an Exploratory Analysis of Indian PPP Projects

Raghu Dharmapuri Tirumala and Piyush Tiwari

12.1 INTRODUCTION

Many countries have recognized the need to fight global climate change in their race to economic development. As of 2019, 196 countries and the European Union have signed the Paris Agreement committing to combat increases in greenhouse gases, limit an increase in earth's temperature and the consequent effects, and in the process, promote green

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infrastructure. The Organization for Economic Co-operation and Development (OECD) had suggested a framework for countries that have committed to mitigating the negative impact of the human footprint on the natural environment (OECD, 2011). This includes separating the economic growth from the extensive and unsustainable use of natural resources, reducing carbon emissions, and mitigating pollution and biodiversity loss (OECD, 2011). This calls for a significant infrastructure investment commitment, estimated to be USD 95 trillion between 2016 and 2030, even if no further action is taken on climate change (Schmidt-Traub, 2015). It is estimated that Asia alone needs USD 26.2 trillion between 2016 and 2030, including climate mitigation and adaptation costs (Mehta et al., 2017). India committed to reducing its emissions by 33% to 35% by 2030, from 2005 levels. This calls for accelerated investments in green infrastructure projects with more capital expected to come from the private sector. India unveiled a coordination mechanism in December 2019 for a National Infrastructure Pipeline of approximately USD 1.5 trillion (INR 105 trillion) for the next five years. The private sector contribution is expected to be of the order of 30%.

Many countries have preferred public–private partnership (PPP) arrangements for their potential for time & cost savings, and of late, increasingly for their potential to provide interim financing for the projects (Singh & Khan, 2015). Under these arrangements, the public sector project proponents seek to transfer some or all of project activities, including design, engineering, construction, rehabilitation, financing, operations, and maintenance, to the private sector through a contractual framework allowing the latter to recoup their efforts through a variety of instruments (including user fees, ancillary project revenues, and viability gap support). Though the historical performance of PPPs had a mix of both successes and failures, these arrangements are still perceived as mechanisms that can foster rigour in project preparation, design, and implementation, ultimately resulting in net benefits over the life of the project (Marques, 2018; Verweij, 2015). The risk factor that affects PPPs' performance and determinants that ensure project sustainability has been a significant research area in the last two decades (Ameyaw & Chan, 2016; Swamy et al., 2018). However, there is relatively limited research on the differences between the PPP arrangements in green sectors and other infrastructure sectors.

Using projects in India as an example, this paper extends earlier research by focusing on the following questions: To what extent do the projects in green sectors differ from those in other infrastructure sectors? What are the policy implications for accelerating green sector projects under PPP arrangements?

In the next section, the context of green infrastructure and the role of PPPs are discussed, followed by the analysis of data from Indian PPP projects. Subsequent sections discuss the summary of the findings of the research, policy implications, and conclusions.

12.2 Context

The discourse on the development of green infrastructure to combat climate change, enable sustainable economic growth, and address socio-economic challenges has gained substantial ground in the recent past (Cole et al., 2017; Mehta et al., 2017; OECD, 2011). According to the International Capital Markets Association (ICMA), green infrastructure projects are typically from the "renewable energy, energy efficiency, pollution prevention and control, environmentally sustainable management of living natural resources and land use—waste management, terrestrial and aquatic biodiversity conservation, clean transportation (electric, hybrid, public, rail, non-motorized, multimodal, infrastructure for clean energy vehicles, reduction of emissions), sustainable water and wastewater management, climate change adaptation, eco-efficient and/or circular economy adapted products, production technologies and processes and green buildings" sectors (ICMA—International Capital Market Association, 2018). Securities and Exchange Board of India had also issued a circular setting out the green sectors, similar to that of ICMA (SEBI, 2017).

A global consensus in investing in the green sectors is emerging (Lennon, 2015), which comprises a range of technological, institutional, governance, and implementation initiatives. There is a growing recognition that the financing needs to achieve these goals are huge. The global investments required for developing green infrastructure, seen in conjunction with completing the sustainable development goals, are estimated to be USD 5 to 7 trillion per annum, with an annual deficit of USD 1.5 trillion (Schmidt-Traub, 2015). The contributions from the public sector and the multilateral/bilateral development assistance continue to be the primary source of financing for green infrastructure (Mehta et al., 2017). The share of private sector contributions, anticipated to bridge the financing gap, is increasing manifold ranging from an estimated 30%

(in the case of India) (Kelkar, 2015) to a staggering 90% in the case of China (Green Finance Task Force, 2015). Increasingly, the blending of public and private sources of finance for green infrastructure is becoming commonplace. Multilateral agencies such as United Nations Environment Programme (UNEP), Asian Development Bank, and World Bank have published reports proposing frameworks for increasing investments in green infrastructure and the role of the private sector (WEF, 2015).

PPP arrangements have been the preferred mode of infrastructure project implementation for many countries primarily for their cost-effectiveness, efficiency, and off-budget financing, despite facing many challenges (Wu et al., 2016). As per the Government of India, "Public Private Partnership means an arrangement between government or statutory entity or government-owned entity on one side and a private sector entity on the other, for the provision of public assets and/or related services for public benefit, through investments being made by and/or management undertaken by the private sector entity for a specified period, where there is a substantial risk-sharing with the private sector and the private sector receives performance-linked payments that conform (or are benchmarked) to specified and pre-determined performance standards, measurable by the public entity or its representative" (Department of Economic Affairs, 2016). This definition encompasses a very wide range of arrangements, including build–operate–transfer concession contracts, leases, licences, management contracts, performance-based contracts, and engineering, procurement construction contracts with a few years of O&M included. The success of PPP arrangements has been dependent on numerous factors, including appropriate risk allocation, understanding between the participating stakeholders, strong legal and institutional structures, and sustainable business models (Swamy et al., 2018).

The challenges of implementing projects under PPP arrangements continue to be a concern for the project proponents, even though these arrangements are considered as preferred methods of implementation of green infrastructure projects, particularly under Sustainable Development Goal 17 (Koppenjan, 2015). While there are many sector-specific studies, there is limited literature on adopting PPP arrangements in green infrastructure (Cheung et al., 2012; Hodge, 2010). This paper presents exploratory research on the key differences between the green infrastructure sectors and other infrastructure projects, using a database of PPP projects in India.

12.3 Main Discussion

Department of Economic Affairs, Infrastructure Division of Ministry of Finance, Government of India maintains a list of infrastructure PPP projects in the country (accessed on 20th November 2019 from https://www.pppinindia.gov.in/list-of-all-ppp-projects). This database provides a list of 1823 projects being implemented across various regions and sectors. It comprises details, including the project's name, sector, sub-sector, location, status, type of PPP, project size, names of stakeholder, project dates, costs, and bidding parameters. The database has been updated to include the missing project information through an extensive exercise comprising internet search, triangulating information from databases of Projects Today, InfraPPP World, Centre for Monitoring Indian Economy, and contacting project stakeholders in the government, private sector, consultants, and financial institutions.

The projects in the database have been categorized as green sector projects (in line with the taxonomy provided by the ICMA and SEBI circular) and other infrastructure projects. This exploratory research consists of comparing the green and non-green project groups to examine whether any differences exist. The comparison is carried over the different features such as sector, region, type of PPP arrangement, stage in the project life cycle, type of the nodal authority, and the project financials, as set out in Table 12.1.

Table 12.2 presents the details of the projects, classified by the sectors. Green sector projects comprise 28% (507) of the 1823 infrastructure PPP projects listed in the database. While 70% of the green projects are from the energy sector (financially freestanding projects), the rest of the projects (social and commercial infrastructure, water, and sanitation) would need financial support from the project proponents. Nearly 77% of the other infrastructure sector projects are transport-related. Energy and communication sector projects, which are considered financially freestanding, comprise 13% of the other infrastructure sector projects.

Table 12.3 sets out the regional distribution of PPP projects. Green sector projects, particularly the energy sector, are concentrated in a few hilly states in northern and eastern India, which are considered economically weaker. The distribution of other infrastructure sector projects is skewed towards more economically stronger states.

The distribution of projects by the stage is project life cycle is set out in Table 12.4. 57% of the green sector projects are in the pre-construction

Table 12.1 Features of comparison

Feature	*Value*	*Description*
Sectors	Energy, Social and Commercial Infrastructure, Water and Sanitation, Communications, Transport	Each of the sectors has an established revenue model, with a few being financially self-sustaining (able to meet costs with end-user charges or other revenue sources), while others depend on support from the project proponent. Energy, communication sectors are based on user charges and are considered financially self-sustaining. The transport sector comprises roads, ports, metro rail, and airports. All these sub-sectors have multiple models relying on a combination of user charges and support from project proponents. The water and sanitation sector typically needs financial help from the project proponents
Region	Different states and union territories	Indicates the development and financial robustness of the project proponents
Type of PPP arrangement	Build–Operate–Transfer, Build–Own–Operate, Lease, Licence, Performance Management, Management Contract, Service Contract	The types of PPP arrangements are ordered in the descending order of risk transfer. The risk transferred to the private sector (including the obligation to fund the projects) is highest in the Build–Operate–Transfer arrangement and progressively reduces with minimal risks being transferred in the Service Contract

Feature	*Value*	*Description*
Stage in the Project Life Cycle	Pre-construction, under construction, operations and management, completed and not active	Indicates the progress of the project
Type of Project Proponent	Urban local body or development authority, state parastatal, State government, Central Government agency, and Central government	Institutional capabilities are significantly higher at the central level than at the state level. Municipal level capacities are the weakest
Project Costs	Different ranges of project costs	Larger projects tend to be more complex
Bid Parameter	Revenue Share, Tariff/User fee, Highest Premium, Tipping Fee, Concession Duration, Cost of Construction, Lowest assessed bid price, Grant, Management Fee, Licence Fee	The bidding parameter indicates the expectation of the project proponent and the private partner of the risks involved and the returns expected. This also points to the robustness of the PPP arrangement
Time Period	Different ranges of time periods	Project dates set out in the database include the agreement signing, construction, financial closure, and the beginning of the commercial operations. The time elapsed from the earliest of these dates to the date of the database (15 November 2019) has been calculated. The timelines indicate the recency of the projects and the time elapsed in various stages of the project lifecycle

Table 12.2 Sectoral distribution of infrastructure PPP projects

Sectors	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
Energy	357	70.4	114	8.7	471	25.8
Social and commercial infrastructure	32	6.3	129	9.8	161	8.8
Water and sanitation	118	23.3	0	0.0	118	6.5
Transport	0	0.0	1013	77.0	1013	55.6
Communication	0	0.0	60	4.6	60	3.3
Total	507	100.0	1316	100.0	1823	100.0

Table 12.3 Regional distribution of infrastructure PPP projects

Region	*Green projects*		*Other infrastructure projects*		*Total*		*State rank by GDP**
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*	
North	173	34.1	334	25.4	507	27.8	
Himachal Pradesh	89	17.6	21	1.6	110	6.0	21
Rajasthan	27	5.3	146	11.1	173	9.5	7
Uttar Pradesh	26	5.1	51	3.9	77	4.2	3
South	51	10.1	317	24.1	368	20.2	
Andhra Pradesh	9	1.8	76	5.8	85	4.7	8
Tamil Nadu	14	2.8	67	5.1	81	4.4	2
East	159	31.4	110	8.4	269	14.8	
Arunachal Pradesh	125	24.7	3	0.2	128	7.0	31
West	124	24.5	555	42.2	679	37.2	
Gujarat	26	5.1	103	7.8	129	7.1	5
Madhya Pradesh	20	3.9	167	12.7	187	10.3	10
Maharashtra	69	13.6	151	11.5	220	12.1	1
Total	507	100.0	1316	100.0	1823	100.0	

*Ministry of Statistics and Programme Implementation, Government of India

Table 12.4 Projects at various stages of the lifecycle

Project stage	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
Pre-construction	194	38.3	52	4.0	246	13.5
Under construction	95	18.7	236	17.9	331	18.2
Operations and management	209	41.2	942	71.6	1151	63.1
completed	4	0.8	33	2.5	37	2.0
Not active	5	1.0	53	4.0	58	3.2
Total	507	100.0	1316	100.0	1823	100.0

or under construction stage, and 41% are in the operations and management (O&M) stage, indicating that many projects are yet to commence infrastructure service delivery. Nearly 75% of other infrastructure sector projects are either in the O&M location or had completed their project tenures.

Table 12.5 sets out the distribution of projects by the type of PPP arrangement. The distribution across green and other infrastructure sector projects is similar, with build–operate–transfer, build–own–operate variants accounting for nearly 84% of all projects.

Nearly 97% of the green sector projects are implemented at the state level, with the municipal bodies accounting for 18%, whereas 67% of other infrastructure sector projects are implemented by state government agencies, with local bodies accounting for 9%. The distribution of the PPP projects by the type of agency is presented in Table 12.6.

Green sector projects have larger expectations of returns, with approximately 26% of them being tendered out with bid parameters (highest premium, revenue share, lease rent or tariff/user fee) requiring the private partner to share the project returns with the project proponent, while only 15% from other infrastructure sectors have similar expectations, as presented in Table 12.7. The same can also be inferred with a lower number of projects being offered on a grant basis in the green sector than the other infrastructure sectors.

Typically, green sector projects are of smaller project sizes compared to the other infrastructure projects, as seen in Table 12.8, indicating a relatively lower level of complexity.

Table 12.5 Typology of PPP arrangements

PPP arrangements	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
Build–Operate–Transfer (all variants)	378	74.6	1078	81.9	1456	79.9
Build–Own–Operate (all variants)	98	19.3	164	12.5	262	14.4
Inputs-based distribution	1	0.2	5	0.4	6	0.3
Lease	5	1.0	9	0.7	14	0.8
Licence	2	0.4	9	0.7	11	0.6
Management Contract	8	1.6	41	3.1	49	2.7
Performance Management	11	2.2	10	0.8	21	1.2
Service Contract	4	0.8	0	0.0	4	0.2
Total	507	100.0	1316	100.0	1823	100.0

Table 12.6 Distribution by type of agency

Type of agency	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
Local body/Development agency	93	18.3	67	5.1	160	8.8
State parastatal	87	17.2	434	33.0	521	28.6
Central government agency	13	2.6	401	30.5	414	22.7
State government	311	61.3	245	18.6	556	30.5
Central government	3	0.6	169	12.8	172	9.4
Total	507	100.0	1316	100.0	1823	100.0

The pattern of the time elapsed in green sector projects and other infrastructure projects appear to be similar, as observed in Table 12.9.

The trend of projects analysed indicates differences in the manner green infrastructure projects have been approached in comparison with more mature other infrastructure sector projects. Presently, the green infrastructure projects appear to be in a euphoric state where substantial risks and high demands are being passed on to the private sector.

Table 12.7 Distribution by bid parameter

Bid parameter	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
Highest premium	79	15.6	106	8.1	185	10.1
Revenue share	11	2.2	69	5.2	80	4.4
Lease rent	5	1.0	14	1.1	19	1.0
Tariff/user fee	38	7.5	11	0.8	49	2.7
Tipping fee	6	1.2	0	0.0	6	0.3
Grant	15	3.0	133	10.1	148	8.1
Lowest assessed bid price	8	1.6	241	18.3	249	13.7
Management fee	1	0.2	0	0.0	1	0.1
Licence fee	0	0.0	60	4.6	60	3.3
Cost of construction	2	0.4	0	0.0	2	0.1
Concession duration	2	0.4	73	5.5	75	4.1
Others	62	12.2	14	1.1	76	4.2
Bid parameter not available	278	54.8	595	45.2	873	47.9
Total	507	100.0	1316	100.0	1823	100.0

Table 12.8 Distribution by project cost

Project cost (USD million)	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
0–15	241	47.5	385	29.3	626	34.3
15–70	152	30.0	407	30.9	559	30.7
70–140	54	10.7	223	16.9	277	15.2
140–700	38	7.5	220	16.7	258	14.2
700–1400	10	2.0	36	2.7	46	2.5
1400–7000	9	1.8	31	2.4	40	2.2
7000 and above	0	0.0	5	0.4	5	0.3
Cost not available	3	0.6	9	0.7	12	0.7
Total	507	100.0	1316	100.0	1823	100.0

Table 12.9 Distribution by time elapsed from project date

Time elapsed (Years)	*Green projects*		*Other infrastructure projects*		*Total*	
	Numbers	*%*	*Numbers*	*%*	*Numbers*	*%*
0–2	5	1.0	4	0.3	9	0.5
2–4	32	6.3	154	11.7	186	10.2
4–7	78	15.4	216	16.4	294	16.1
7–10	116	22.9	348	26.4	464	25.5
10–15	196	38.7	313	23.8	509	27.9
15–20	38	7.5	89	6.8	127	7.0
20 and above	7	1.4	45	3.4	52	2.9
Details not available	35	6.9	147	11.2	182	10.0
Total	507	100.0	1316	100.0	1823	100.0

This could be due to the lower appreciation of project dynamics of green infrastructure, anticipation of superior returns by the private sector developers and lower institutional capacities of the project proponents. To ensure that these projects achieve their objectives and leapfrog the challenges faced by PPP projects in general, policymakers should be aware of the pitfalls. These success factors influence the performance and manoeuvre the process effectively. The private sector would also need to be sensitized about the expectations of the public sector regarding the climate change mitigation measures and, more specifically, about the framework under which the projects are being offered.

12.4 Conclusions and Recommendations

This research investigates if there are any differences between the features of the green infrastructure PPP projects related to the other infrastructure sector PPP projects. An analysis of India's PPP database indicates that the green sector projects are predominantly implemented at the municipal, local authority, and state levels in economically not very strong states. The projects are smaller in size, and many are still in the development and construction phases. The project structures and the bid parameters adopted in these projects indicate that the project proponents expect the projects to meet the expenses from the revenues, and not much grant support is needed, in contrast to higher levels of support offered to other infrastructure sector projects.

With significant gaps looming large in green infrastructure financing (Mehta et al., 2017) and the need to accelerate the project implementation metrics of time and cost, PPP arrangements appear attractive (Koppenjan, 2015). However, PPP arrangements are prone to substantial challenges due to the conflicting interests of the public and private partners, different business expectations and unavailability of strong legal and institutional capacity (Swamy et al., 2018). A programme to enhance the project structuring capacities, introduce financial support structures and capacity-building initiatives for both the public and private sector stakeholders could increase the chances of greater adoption of PPPs in green infrastructure. The research can provide a useful pathway for evolving PPP mechanisms into true partnership models that improve service quality in an environmentally sustainable manner.

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PART VI

Quality of Growth, Human Development and Raising Resources

CHAPTER 13

What Drives the Quality of Growth? An Empirical Analysis

Shikha Jha and P. V. Srinivasan

13.1 Introduction

The global economic, social, and environmental landscape has transformed radically over the last two decades, fundamentally changing the scope of development in the twenty-first century. It is now well-recognized among development professionals that GDP is a poor measure of a country's progress and does not necessarily reflect its economic well-being under the circumstances prevailing today (Haddad et al., 2015; Stiglitz, 2020). Many developing countries have transformed from low- to middle-income status in a remarkably short time but continue to face

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persistent poverty, rising income inequalities, perpetual gender disparities, environmental degradation, and already visible impacts of climate change. The spread of the COVID-19 pandemic has demonstrated how it becomes more difficult to address rising inequalities when social protection systems are inadequate and public services are of poor quality. While more educated and well-off populations have been able to afford to work from the safety of their homes, the livelihoods of the poor and the less educated have generally been threatened, further worsening the inequalities (Deaton, 2021; Goldin & Muggah, 2020; UNDP, 2020).

Cities in the developing world are urbanizing rapidly with swathes of rural migrants moving to urban areas in expectation of a better life. However, they are forced to work in the informal sector at low wages and without written work contracts, formal pension programs, or health and retirement benefits. In much of the developing world, the benefits of economic growth accrue largely to formal or organized sector workers. Urbanization is also occurring at a huge cost to the environment. Apart from the upward pressure on property prices, the acute shortage in urban housing is pushing migrant workers to live in informal settlements that lack basic sanitation, piped water, and sewerage facilities. Rising liquid and solid waste generation is contributing to air and water pollution. The exploitation of natural resources at an ever-expanding rate is leading to greater environmental stress, loss of ecosystem services, and increased vulnerability to natural disasters which are creating additional risks to people and property. If natural resources are depleted beyond a threshold level, the ability of future generations to meet their needs may be compromised. Environmental degradation particularly harms the poor. Despite growing incomes, the overall quality of life is declining for many.

The pandemic has shown how greater deforestation due to logging, mining, and agricultural expansion into forests and intrusion into habitats of animal species increases the likelihood of transmission of diseases from wild animals to humans. The commodification of wild animals is another factor that drives infectious diseases to cross the species barrier from animals to humans (Volpato et al., 2020). Illegal transport and trade of such animals could spread pathogens among humans, putting global public health at risk (Ming et al., 2014).

These challenges have contributed to the emergence of a global consensus to go beyond GDP in measuring development, which is also driven by the Paris climate agreement and the Sustainable Development Goals and international understanding of other such common problems.

The new global development agenda lays emphasis on the need for a new measure of development progress, that focuses not just on a higher magnitude of GDP growth but on a better *quality* of growth which is growth that is widely shared and environmentally sustainable. High-quality growth reflects a fair distribution of the returns from growth across different sections of society and intergenerational equity in the distribution of natural resources.

The main objective of this paper is to analyze factors that can help improve the quality of growth. To measure the quality of growth, a new metric—the Inclusive Green Growth Index (IGGI) is used, considering its simplicity, ease of understanding and explanation, and ready availability of data (Jha et al., 2018). The IGGI is a three-pronged index that covers a multitude of issues under its three pillars of economic growth, social equity, and environmental sustainability. For example, the extent to which growth is strong and stable, how well it is distributed among the people and the degree to which natural resources are conserved define the index.

The rest of the paper is organized as follows. Section 13.2 describes the key features of the index. The subsequent section compares, contrasts, and discusses the overall development patterns displayed by the trends of the index and its main elements in different regions of the world. Section 13.4 analyzes how the effects of some potential drivers of the IGGI filter through the components of its pillars to affect the quality of growth. Also discussed here are the tradeoffs and synergies between the pillars. Section 13.5 concludes.

13.2 MEASURING THE QUALITY OF GROWTH

The IGGI is used to explore the quality of growth in countries worldwide, which is a robust and comprehensive measure composed of growth, socio-economic, and environmental indicators (Table 13.1).[1] For consistency and comparability, the scores of all the indicators, pillars, and the IGGI are scaled from 1 (worst) to 6 (best), with higher values indicating better country performance in the corresponding development outcome. The score of a pillar is obtained as the simple average of the scores of its indicators and similarly, the IGGI score is calculated as the simple average of

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[1] See Jha et al. (2018) for more details on how the IGGI is defined and constructed.

its three pillar scores. The index characterizes economic growth and environmental sustainability pillars by 7 indicators each and the social equity pillar by 14 indicators.

The seven indicators of the economic growth pillar cover the strength, stability, diversity of sources, and sustainability of growth. Per capita income growth provides the basis for creating and expanding economic opportunities. The inverse of the coefficient of variation of GDP per capita indicates stability in economic growth. Stability is an attribute of good-quality growth since unstable economic growth deepens poverty and inequality. The poor have less capacity to recover from shocks and are more vulnerable.

The quality of growth is also determined by the extent to which an economy is dependent on other economies. Higher diversification means a wider spread of the risk of weak export sector growth. Trade

Table 13.1 Measuring the quality of growth: Inclusive Green Growth Index—Indicators of its three pillars

Economic growth	*Social equity*	*Environmental sustainability*
1. GDP per capita growth rate	1. Employment population ratio	1. Natural resource rent
2. Inverse CV of GDP per capita growth	2. Life expectancy gender gap	2. Renewable freshwater resources
3. Trade openness	3. The primary enrollment gender gap	3. Water productivity
4. Hirschman–Herfindahl Market Concentration Index	4. Labor force participation gender gap	4. Air pollution
5. Age dependency ratio	5. Life expectancy at birth	5. CO_2 per GDP
6. Adjusted net savings	6. Infant mortality rate	6. Energy intensity of primary energy
7. Gross general government debt	7. Access to improved sanitation	7. Use of renewable energy
	8. Access to improved water	
	9. Access to electricity	
	10. Gini coefficient on inequality	
	11. Poverty gap	
	12. Mean years of schooling	
	13. Primary completion rate	
	14. Political participation gap	

Source Jha et al. (2018)

openness measures a country's vulnerability to external economic shocks with more open economies being more vulnerable to the shocks (Barrot et al., 2017). A diverse export basket suggests a wide spectrum of sources of growth and is positively correlated with stable growth, which is vital forhigh-quality growth (Hesse, 2009). The Hirschman–Herfindahl Market Concentration Index measures the dispersion of trade value across an exporter's trading partners.

The age dependency ratio—the ratio of dependents (younger than 15 years or older than 64) to the youth or working-age population—is an indicator of economic sustainability and quantifies the capacity of the productive population to support children and elderly dependents. Adjusted net savings is an estimate of the net stock of physical, financial, natural, and human capital available for future generations. Lower adjusted net savings or higher public debt mean less sustainable economic development (World Bank, 2007).

The 14 indicators relating to the social equity pillar include the distribution of the benefits of growth among all the people in terms of employment, income, gender, health, education, and basic needs. These social dimensions indicate the status of participation in economic and social activities of a broad range of people that includes the poor and marginalized, such as women and ethnic minorities. IGGI incorporates male–female differences by age, e.g., gender labor force participation gap and political participation gap. High-quality public services are essential for a decent standard of living. Hence this pillar includes indicators such as life expectancy at birth and infant mortality rates (outcomes of access to good quality health care services), mean schooling years, and the completion rate for primary education (outcomes of access to basic education by the poor), access to safe drinking water and sanitation, and access to electricity.

The seven indicators in the IGGI's environmental pillar relate to a wide variety of environmental sustainability issues. The natural resource rent is an indicator of the extent of resource depletion; higher rents indicating faster rates of depletion. This indicator measures the total revenue that can be generated from extracting oil, natural gas, coal, and mineral and forest resources. Annual freshwater stocks and water productivity are used as indicators for the sustainability of water resources, which are already showing signs of distress. Given the high risk of losing much of this precious resource, water is being called *blue gold*. The extent of air pollution is indicated by the proportion of the population exposed to particulate matter of 2.5 microns or smaller in diameter. Climate change mitigation efforts are captured by carbon dioxide emissions per unit of GDP, energy intensity, and the use of renewable energy.

13.3 Quality of Growth in Different Regions of the World

This section looks at the trends in the quality of growth across the world using annual country-level data for the period 1990 to 2015. The computed scores of the IGGI show that richer regions of the world can maintain a better quality of growth (Fig. 13.1). The numbers for 2015, the latest year in this data series, for example, show that the quality of growth performance is the weakest in Sub-Saharan Africa, followed by Developing Asian economies. The OECD countries achieve the highest scores with the Middle East and North Africa regions following closely behind.

Regional performance by the IGGI pillars shows quite a variation in different regions of the world (Fig. 13.2). The economic growth pillar performs in the narrow (3.5–4.0%) bracket across the board. This

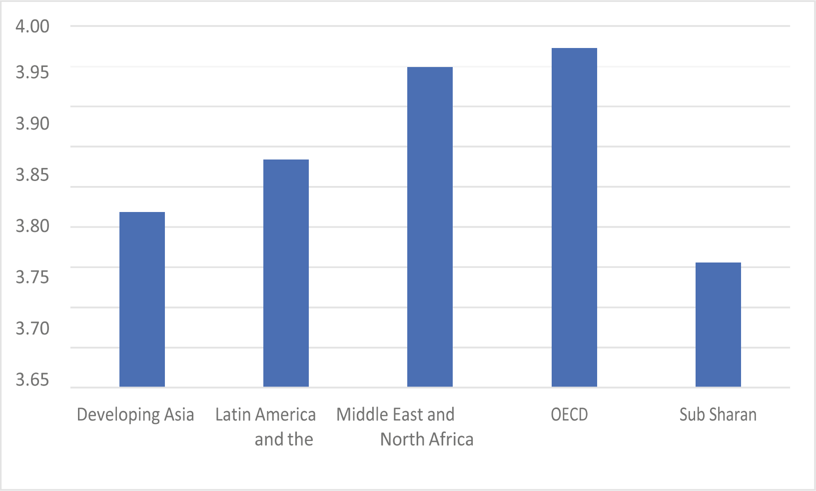

Fig. 13.1 Inclusive Green Growth Index, performance by region, 2015 (*Source* Authors)

possibly captures the catching-up process among poorer countries as more advanced economies reach stable growth levels. Among the three pillars, the performance of most regions is the best in social equity and the worst in environmental sustainability except in Sub-Saharan Africa whose record in social welfare is worse than in environmental sustainability.

As richer nations can afford the resources required for better social protection systems and welfare programs, they provide top-of-the-line public services, and their performance sets the best-practice benchmark in social equity. In developing countries on the other hand, fiscal transfers for welfare programs are usually made through "leaky buckets," meaning that only a fraction of the allocated funds reaches the intended recipients. The "leak" here refers to the total administrative costs of running the program, inefficiencies in implementation, and potential losses due to corruption. With weak governance structures and underdeveloped institutions, corrupt practices in such welfare programs remain widely prevalent. They may take the form, e.g., of absentee teachers in public schools who find private tuitions more lucrative, theft of food from subsidized food distribution programs, embezzlement of funds from mid-day

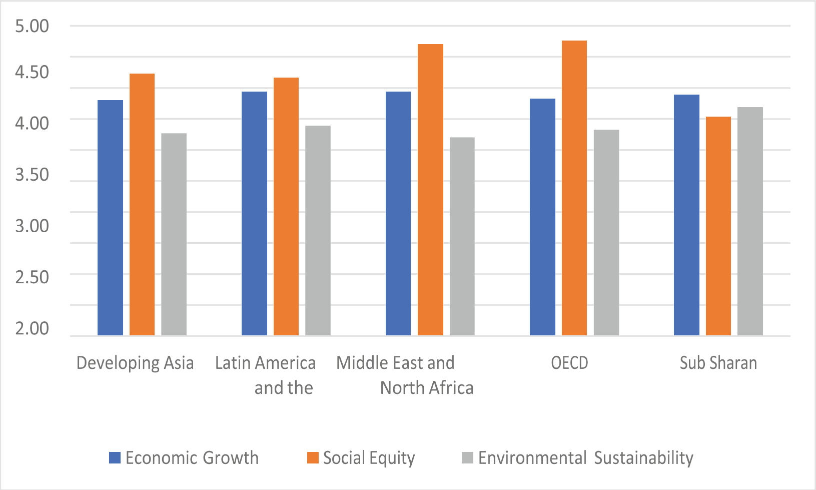

Fig. 13.2 Pillars of the Inclusive Green Growth Index, performance by region, 2015 (*Source* Authors)

meal schemes, and diversion of medical supplies from primary health care centers, and others.

Both developing and advanced countries show, as of 2015, the poorest records in environmental sustainability among the three pillars. Sub-Saharan Africa lands just slightly above the social pillar. Among the 7 indicators of the environmental sustainability pillar, developing countries' low scores can be ascribed to three main problems which are high air pollution, depletion of freshwater resources, and low water productivity. In contrast, the low score in richer nations is due to higher energy intensity and higher carbon emissions per unit of GDP.

To examine if and how the differences between rich and poor nations have evolved, a comparative picture of countries in OECD and Developing Asia is presented in Figs. 13.3 and 13.4. Since 2000, Developing Asia has shown a consistent improvement in the social equity pillar vis-à-vis other pillars (Fig. 13.3). Most countries have improved access to electricity, improved sanitation, and safe water but health services leave much to be desired. On average, there is still a large scope for providing better access to health care, cutting infant mortality rates, and raising life expectancy.

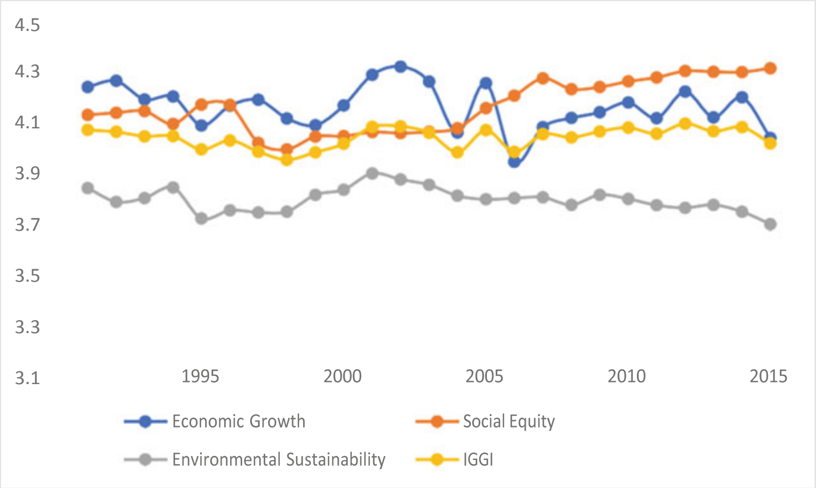

Fig. 13.3 Trends in Inclusive Green Growth Index and its pillars, 1990–2015—Developing Asia (*Source* Authors)

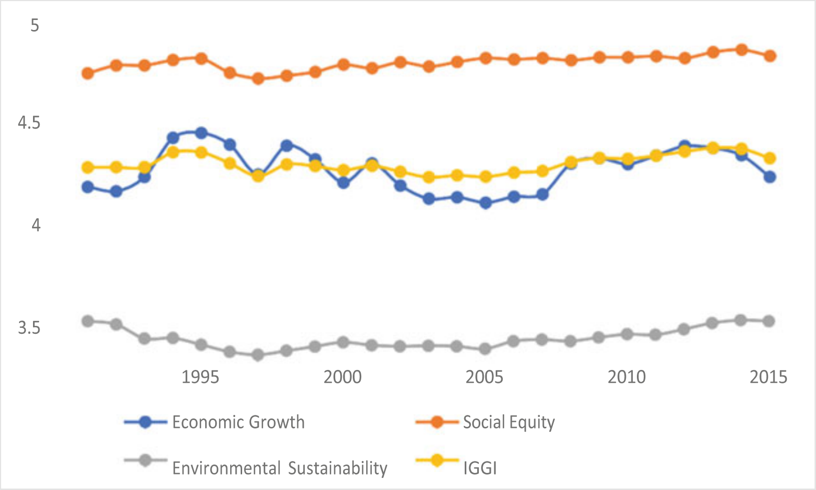

Fig. 13.4 Trends in Inclusive Green Growth Index and its pillars, 1990–2015—OECD (*Source* Authors)

Developing Asia shows a mixed performance in environmental sustainability, especially with a declining trend over time in this century that can be attributed largely to its worsening water sustainability, high air pollution, and substantial untapped potential for renewable energy (except for a few countries like Bhutan and Nepal where more than 80% of energy consumption is from renewables). However, Developing Asia outperforms rich nations by maintaining energy intensities and carbon emissions per unit of GDP at lower levels. On the other hand, the substantially superior achievement of OECD countries in the environmental pillar compared with the other two pillars is obvious from the exhibit in Fig. 13.4.

While economic activity in both Developing Asia and OECD countries moves widely from year-to-year (Figs. 13.3 and 13.4), the corresponding fluctuations in the IGGI scores for both regions are far more muted. Similar trends are observed—though not reported here—even at the individual country level. Apart from other features of the IGGI noted earlier, this observation of the stability of the IGGI vis-a-vis growth provides another rationale for countries to pursue the IGGI as the preferred target.

To improve the quality of growth by raising the score of the IGGI, governments need to know what drives its different pillars and what the impacts of those drivers are. They also need to know for each IGGI pillar the underlying constraints that are holding back improvements in its performance, if any.

13.4 Drivers of and Policy Choices for Higher Quality Growth-An Empirical Analysis

In this section, panel data regression analysis is used to systematically test how different explanatory variables drive the quality of growth through their effects on the three pillars of the IGGI. The main objective of this exercise is to examine if there are any tradeoffs or synergies in the use of different policy drivers. There may be potential tradeoffs involved when some policy choices help one pillar to the detriment of other(s) or synergies when they complement one another.[2]

Since the values taken by the IGGI and its pillars are restricted to range between 1 and 6, the limited dependent variable model was considered appropriate to use. The results discussed below are from the estimated panel Tobit regression model, which provides the best fit for the data (Table 13.2) among other regression models considered such as the Generalized Method of Moments and the Instrumental Variable Method.

13.4.1 Explanatory Variables

Based on the availability of data the following explanatory variables are considered for the regression analysis: the nature of growth (whether it is accelerating, maintained in a stable range, or decelerating); institutional quality; macroeconomic stability; financial development; financial openness; and social and infrastructure spending (Table 13.2). Annual country-level data is used for the period 1998 to 2015. The data for explanatory variables was drawn from the World Bank sources: World Development Indicators (credit to the private sector, remittances as a percentage of GDP; public spending on social and physical infrastructure)

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[2] *Tradeoffs*—positive effect on some of the IGGI indicators and negative on some others; or

Synergies—unidirectional effects (either positive or negative) of a driver on all the indicators.

Table 13.2 Results from the regression analysis

Explanatory variables	*Proxy for the explanatory variables*	*Independent variables: IGGI and its 3 pillars*			
		IGGI	*Economic growth pillar*	*Social equity pillar*	*Environmental sustainability pillar*
Growth acceleration (GA) phase	Growth acceleration dummy	0.0231*** (0.00838)	0.0818*** (0.0197)	−0.0147 (0.0112)	0.00135 (0.00967)
Growth maintenance (GM) phase	Growth maintenance dummy	0.0254*** (0.00699)	0.0625*** (0.0164)	0.0167* (0.00939)	−6.08e−05 (0.00807)
Institutional quality	Institutional risk score, 1 = low, 6 = high	−0.0859*** (0.00923)	−0.139*** (0.0195)	0.0164 (0.0136)	−0.0430*** (0.0114)
Macroeconomic Instability	Inflation volatility, log	−0.0150*** (0.00390)	−0.0456*** (0.00912)	−0.0146*** (0.00525)	0.0180*** (0.00452)
Financial development	Credit to private sector (% of GDP)	0.000744*** (0.000177)	−5.76e−05 (0.000394)	0.00234*** (0.000250)	−0.000668*** (0.000213)
Financial openness	Remittances (% of GDP)	0.00512*** (0.00118)	0.00408 (0.00267)	0.0194*** (0.00163)	−0.00851*** (0.00140)
Public spending on social and physical infrastructure	Government spending (% of GDP)	−0.00112 (0.00143)	−0.0148*** (0.00323)	0.00760*** (0.00199)	0.00161 (0.00171)

(continued)

Table 13.2 (continued)

Explanatory variables	*Proxy for the explanatory variables*	*Independent variables: IGGI and its 3 pillars*			
		IGGI	*Economic growth pillar*	*Social equity pillar*	*Environmental sustainability pillar*
Constant		4.073***	4.569***	3.753***	3.648***
		(0.0467)	(0.0973)	(0.0843)	(0.0693)
Observations		1843	1843	1843	1843
Number of countries		132	132	132	132

Note Robust standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Source Authors

and Worldwide Governance Indicators (institutional risk). Data sources for the indicators of the IGGI are available in Jha et al. (2018).

13.4.1.1 Phases of Growth

To define alternative phases of growth, the average increase in per capita income is divided into four growth categories: (1) miracle growth (≥5%); (2) stable growth (0–5%); (3) stagnant growth (≈0%) and (4) growth crisis (<0%). *Growth maintenance* (GM) phase is when in consecutive periods the country maintains its growth rate within either stable or miracle categories. *Growth acceleration* (GA) phase is when the economy jumps one or two steps up in the growth categories—growth crisis, stagnant, stable, and miracle growth. *Growth collapse* is defined in an identical manner to growth acceleration but in the reverse direction (Fig. 13.5).

Dummy variables are used to indicate the phases of growth in a country. If the current year's growth rate is in the same range as that of the previous one or two years, growth is assumed to be maintained, and the *GM* dummy takes a value of 1; it takes the value "0" otherwise.

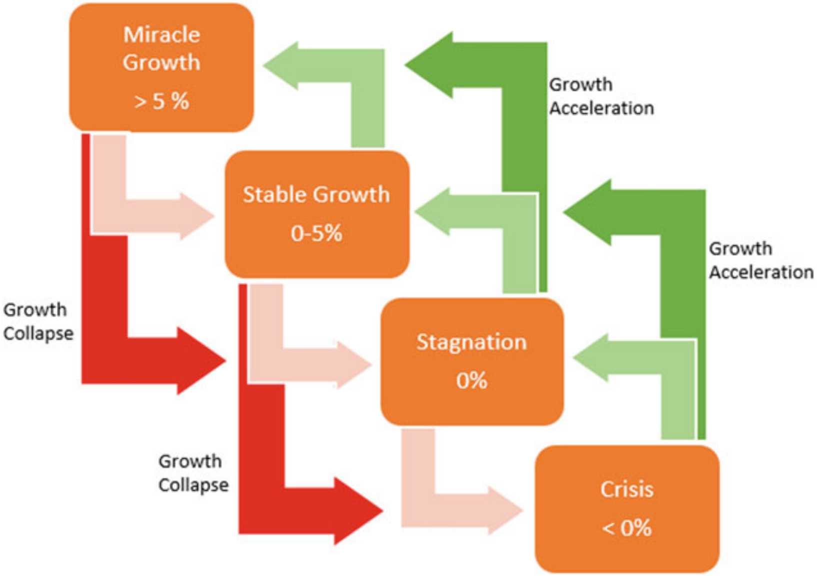

Fig. 13.5 Alternative phases of growth (*Source* Authors)

Similarly, if the current year's growth rate falls in a higher (lower) growth category than that of the previous one or two years, growth is said to be accelerating and the *GA* dummy takes the value 1; it takes the value "0" otherwise.

13.4.1.2 Institutional quality

Institutions are human-devised rules that shape people's interactions. Formal institutions include constitutions, statutes, and explicit government rules and regulations. Informal institutions are unwritten rules like traditions; codes of behavior; and social mechanisms such as cultural norms and societal values. Differences in economic institutions are the main determinants of differences in prosperity across countries (Acemoglu & Robinson, 2008). Countries with weaker institutions tend to get stuck longer in stagnation episodes (Jerzmanowski, 2006). An analysis of developing countries' data for the 1980s and 1990s shows that good policies and institutions that promote broad-based growth play a central role in promoting pro-poor growth (Kraay, 2006). Specifically, evidence shows that institutional reforms help developing Asian economies achieve better socio-economic outcomes such as lower poverty and gender inequality, reduced maternal and under-5 mortality rates, better access to sanitation, higher education attainment, and better infrastructure (Sen, 2015).

To proxy institutional quality, this paper uses the concept of institutional risk, defined as the gap between the maximum possible score (6) and the actual score (1–6) on WGI's good governance index (Jha et al., 2018). Thus, institutional risk is the inverse of the good governance indicator, with the score ranging from 6 (worst) to 0 (best).

13.4.1.3 Macroeconomic Instability

Inflation volatility is used as a proxy indicator for macroeconomic instability in the economy.

13.4.1.4 Financial Development and Financial Openness

A well-functioning financial market is instrumental in providing financial services to households and firms and helps developing economies grow. The regression analysis uses two explanatory variables to reflect this function: credit to the private sector (financial development) and remittances as a percentage of GDP (financial openness). Access to finance helps firms grow by facilitating the utilization of investment opportunities, expanding business operations, providing new products, performing crucial research and development activities, and acquiring the latest advancements in equipment and technology.

13.4.1.5 Public Spending on Social and Physical Infrastructure

This crucial component of any good policy is proxied by the variable government spending as a percent of GDP.

13.4.2 Findings from the Regression Analysis

13.4.2.1 Growth Phases

The dummy variables for GM or GA phases of growth have a statistically significant positive influence on the economic growth pillar and on the overall IGGI. The causes of whether growth accelerates or is maintained within a narrow range differ (Hausman et al., 2005). A successful acceleration strategy should be tailored to local conditions. Most economic reforms help maintain growth whereas accelerations, associated with increases in investment and trade and real exchange rate appreciation are unpredictable (Hausman et al., 2005). The most successful growth accelerations follow the relaxation of a few binding constraints in key dimensions, rather than jointly unlocking several growth channels (Jerzmanowski, 2006).

13.4.2.2 Institutional Quality

The institutional risk variable has a statistically significant negative relationship with IGGI and the economic and environmental pillars, indicating that institutional quality is indeed a driver of the quality of growth. The social pillar does not have a statistically significant relationship with institutional risk. This finding suggests that institutional reforms are necessary to overcome the problems of lagging development and persisting poverty. While reforming institutions is not easy as it involves the political process and the distribution of political power in society, experience shows that countries that undertook institutional reforms and made political transitions achieved success in economic development.

13.4.2.3 Macroeconomic Instability

The regression results show that higher inflation negatively influences the economic growth and social equity pillars but positively affects the environmental sustainability pillar indicating a tradeoff with other pillars. The reason for this result could be the high positive correlation between economic growth and environmental degradation due to the high energy intensities of GDP and greater exploitation of natural resources as economic growth picks up. Inflation reduces real disposable incomes and pushes more people into poverty and reduces the demand for oil and other natural resources in short supply.

13.4.2.4 Financial Development and Financial Openness

Both financial development and financial openness positively influence the social equity pillar, as expected, and the overall IGGI while negatively affecting the environmental pillar indicating tradeoffs involving policies based on these drivers.

13.4.2.5 Social and Physical Infrastructure Spending by the Government

The government spending variable interestingly affects the social pillar positively and the economic pillar negatively. This indicates that while government spending improves social equity, it seems detrimental to economic growth. Some of the reasons could be that government spending displaces private sector activity, distorts resource allocation, and discourages productive choices.

13.5 Concluding Remarks

An unrelenting pursuit of growth can lead to the neglect of social well-being and environmental sustainability. The COVID-19 pandemic is a striking example of the dire consequences that human beings can face due to the damage caused to the environment in addition to the likely impacts of climate change. Pathogens crossing over from the animal to the human world can cause extensive and widespread damage. The pandemic has underscored the importance of achieving a better quality of growth and provides an opportunity for building back better and focusing afresh on social equity and environmental sustainability. This is however a challenging process. Preventive measures such as action against climate change provide benefits that are public goods in nature and there are incentives to free ride. Due to the differences in perspectives of advanced and developing countries as to the responsibilities e.g., in relation to climate change mitigation, the progress in the implementation of agreed measures has been questionable.

Starting with the premise of the inadequacy of GDP growth as an indicator of well-being and the need for a measure to incorporate other aspects of development, this paper applied a new measure—the Inclusive Green Growth Index (IGGI)—for tracking the progress of economies in terms of their quality of growth by considering social and environmental aspects in addition to the economic.

Quality of growth in developing nations is found to lag by the richer nations such as the OECD countries. However, the data shows a toward trend improvement in the social pillar since 2000, but a trend to decrease in the environmental pillar. The growth pillar is mostly fluctuating without a trend.

A stable or accelerating growth situation positively affects the quality of growth, indicating that it is important to see that there is no growth collapse or deceleration. For developing countries to have a better quality of growth, it is important to maintain if not accelerate their growth rates, which were relatively high in the past decades.

Institutional variables show a robust relationship with IGGI, which underscores the importance of improving institutional quality for all three pillars of the index. This is strong evidence that institutional quality is indeed a driver of high-quality growth.

More importantly, the results show that the design of policies to influence the different pillars of the IGGI needs to account for potential tradeoffs, as seen in the case of the financial development and openness variables where the direction of influence is in the opposite directions for the environmental pillar compared to the economic and social pillars. It is important to further explore the reasons for such tradeoffs.

The empirical results from this paper have implications for policymaking for post-pandemic recovery. The governments must more actively provide for greater social protection against poverty and other shocks to the economy. To enlarge fiscal space and provide public services more efficiently it is necessary to have good public financial management systems with efficient revenue administration and sound public expenditure management systems. The governments must also manage their environmental issues through better legislation and implementation mechanisms. More generally they should focus on well- functioning governance structures to fulfill their commitments to the new global development agenda.

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CHAPTER 14

Human Development of India: Why Does It Always Look Challenged?

Bibhas Saha

14.1 Introduction

In the Autumn of 2020, when India reached a grim milestone of daily one hundred thousand Covid-19 deaths, the country seemed poised to overtake the US on the total infection count and possibly also on the total death toll.[1] But soon after, the death rate decelerated, infection slowed without a further tightening of the social distancing rules, shops reopened and travelled resumed. Things almost returned to normal over the winter. Despite a severe record contraction of GDP, somehow, the economy got back on its feet. A few months later, as vaccination began in the UK and

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[1] Yasir, Sameer, (2020) India's Covid-19 death toll passes 100,000, *New York Times*, 3 October, https://www.nytimes.com/2020/10/03/world/asia/india-coronavirus-deaths.html, accessed on 14 March 2021.

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US, India emerged as a key global player—manufacturing vaccines and syringes not just for itself but for the rest of the world.

Miracle or mystery, India somehow managed to come out of a deep crisis, despite not having a good public health care system, as it has done so many times in the past. Although by no means the pandemic was over, India's highly energetic pharmaceutical and biotechnology sectors stepped up at the right time. This is in sharp contrast to the pictures of poor hospital facilities, absurdly cruel restrictions on migrant workers and ever-chaotic government failures to reach out to the most vulnerable sections of society. But that is what India is—miserable failures in one count and unbelievable success in other counts—just as we see in education and other human development indicators of India. They always look challenged.

In particular, we always wonder if India's growth and development are sustainable. The United Nations endorsed Sustainable Goals 3 and 4, namely health and education, need critical attention. Historically, on both counts India has been a laggard country, but it is without dispute that without good human capital growth cannot be endured, and development cannot be sustained. The pandemic has shown that there is serious lacuna in public health, although India's vibrant private sector has responded to the challenges quite remarkably. In this essay we take an in-depth look on both education and health.

The Human Development Report 2020, published by the United Nations Development Programme (UNDP), shows that since 1990, the year of great economic liberalisation, India steadily improved its human development indicators. In the last thirty years, life expectancy at birth has risen by 12 years, average years of schooling increased by 3.5 years and average income, an important element of the Human Development Index (HDI) wielding 1/3rd weight, grew spectacularly by 274%. As a result of these, and crucially due to income gains, the HDI improved by 50%, from 0.429 in 1990 to 0.645 in 2021.[2] At present, India ranks 131 out of 189 countries, not a very respectable position, but notable enough for a nation that aims to be a major player in the global economy. It is

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[2] Strictly speaking, due to several changes in methodologies the HDIs are not always easily comparable. Nevertheless, the improvement is to be noted.

also to be noted that in South Asia, India's performance pales compared to Sri Lanka and Bhutan and is barely competitive with Bangladesh.[3]

Health is another component of human development carrying equal weight to income. A vital indicator of health is infant mortality—the number of deaths per 1000 live births. In 1960, this was staggeringly high for India—161.4. In 2000, thanks to improved hospital facilities, that figure came down to 66.6 and in 2018 to 29.9. While the decline of nearly 130 deaths in 58 years has been a remarkable achievement, it loses quite a bit of gloss when comparing India with its neighbours. In 2018, Sri Lanka had only 6 deaths, Bangladesh 25, Nepal 27, Bhutan 25 and Maldives only 7, per 1000 live birth rates. The only country to have a worse infant mortality rate is Pakistan (57 in 2018). Immunisation is another area where India's performance is patchy. In 2015–2016, among the 12–23 months old children, only 62% received full immunisation.[4] This is a matter of added concern because Indian women have historically low body mass index (BMI). The good health of mothers is crucial for infant health and early-stage immunity. The 2015 National Family Health Survey-4 (NFHS) revealed that low BMI was extensively prevalent among adult women. Twenty-four per cent of women in Haryana, 31% of women in Bihar and 51% of women in Andhra and Telangana.

According to Sethi et al. (2019), 'India witnesses 30 million pregnancies each year. Most Indian women enter pregnancy with poor nutrition. At least 20% of women are thin (body mass index, BMI < 18.5) and an equal proportion overweight (BMI ≥ 23), 53% anaemic, and 8% enter pregnancy as adolescents (~4.5 million). In the South Asian context, early marriage is strongly associated with an early childbearing, lower likelihood of availing antenatal care services and poor maternal and new born outcomes'.[5] Thus, we see that women's health and, in turn, the child

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[3] Human Development Report (2020) United Nations Development Programme, New York, http://hdr.undp.org/en/countries/profiles/IND.

[4] India's commitment to health is also questionable. India is spending far less than not just the East Asian countries, but also some of its South Asian neighbours. In 2014 Sri Lanka spent 2% of its GDP on health, while India spent only 1.4%. In the same year, China spent 3.095% of its GDP, Malaysia 2.3% and Thailand 3.2%. The world average was 5.959%.

[5] Sethi, V., Dhachandra, K., Murira, Z., Gausman, J., Bhapot, A., Wagt, de A., Unisa, S., Bhatia, S., Baswal, D., Subramanian, S.V., (2019) Nutrition status of nulliparous married Indian women 15–24 years: Decadal trends, predictors and program implications, PLOS, August 27, https://doi.org/10.1371/journal.pone.0221125.

health of the nation are strongly linked to social factors (such as when the women are married and how much nourishment is given to pregnant women) and also the outreach of the public health care programme—rural versus urban and early age nutrition. Given our widespread gender discrimination, and poor quality of public health care, while private health care is costly, the country's health fundamentals have always been very weak. They will continue to look so, no matter how dynamic, enterprising, and export-oriented the pharmaceutical sector remains.

The Human Development Report 2020 also stresses that women in India are disadvantaged in many other dimensions. The mean years of schooling for males are 8.7 years and for females only 5.4 years. As an indicator of differential labour market performances, the estimated gross national income (GNI) per capita for females is $2331, while the same for males is nearly five times—$10,702. The labour market participation rate for women is just 20.5%, while it is 76.1% for males. The gender development index (GDI) for India is 0.82, significantly lower than Bangladesh's GDI of 0.904.

14.2 Education

India's improved performance in HDI has been largely due to the income component; like China, India also has surprised the world with the rapid growth of GDP since 2000. But its performance in the health component is poor, and the same in the education component can be regarded as moderate. India's progress has been notable in universalising primary education by committing substantial resources to build more schools, hire new teachers, and provide a meal at school broadly under the campaign Education for All (*Sarba Siksha Abhiyan*). Most villages now have a school within one kilometre, and the gross enrolment rate at the primary level is now (over) 100% (for both boys and girls). The enrolment is also rapidly improving for the minorities and disadvantaged communities like SC (scheduled castes) and ST (scheduled tribes). The Right to Education Act has been passed to recognise the rights of citizens to education.

14.3 Learning

In recent times the focus of education experts has shifted to learning and school completion. Are the children learning what they are supposed to learn? Why don't the children complete their high school? These questions are very important for several reasons. First, today's children are the future labour force of India, and they will face competition from their East Asian cohorts who attend school for many more years and whose learning outcomes are also better. Second, the dropout problem at the secondary level—more for girls than boys—has remained a constant feature over the last few decades. Third, growing income inequality is causing huge social strife. Since higher education is a vector of rapid income rise, it is important not to widen the education gap further.

India's literacy has progressed slightly less than 1% per year, and it reached 73% in 2010–2011. The 2020–2021 census has not been done yet but reaching the 80% mark is very likely. As for dropouts, the picture is much more complicated, and systematic data are lacking. By some estimates, it appears that by 2013–2014 data on dropout, roughly 4 to 5% of children drop out at the primary stage, and nearly 18% drop out at the secondary stage. So, if 100 students start at grade 1, one can estimate that 75.57 students will complete secondary education, while other students will drop out at various stages, mostly around grade IX.[6] See Saha and Saha (2018) for more on this.

Two surveys provide us with good information on learning. First is the National Achievement Survey (NAS) conducted by the government-run National Council of Education Research and Training (NCERT) covering all states. It involves testing grade V students at school with pen and paper on language, maths and environmental studies. The fourth cycle of NAS conducted in 2014 covered a sample of 1,50,101 students in 8266 schools across 34 States and Union Territories. The second survey is called the Annual Status of Education Report (ASER), conducted by the non-governmental education organisation (NGO) *Pratham*. The main aim of ASER is to generate estimates of basic reading and arithmetic estimates for children aged 5–16. It also assesses the schooling status of children aged 3–16. The test is conducted at the household level as part of its annual education survey. In 2016, the survey was carried out in 17,473 villages

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[6] This is estimated by the authors based on Table 10 (on page 8) and Table 25 (on page 36) of Education Statistics at a Glance 2016 (Government of India, 2016).

of 589 districts, covering 350,232 households and 562,305 children in the age group 3–16.[7]

Two tests differ in both design and purpose. The NAS design aims to map students' achievement into a common national scale. It is especially useful to see states' relative performance in terms of the overall average and each percentile point of the score distribution. In contrast, the ASER test tells us whether the students can demonstrate some very basic things that every primary school child is expected to learn. The focus of ASER is on the underperforming students, revealing any deficiency in learning.

Some interesting facts have emerged from the NAS (2015) report. (i) Girls are now performing better than boys. (ii) There is no noticeable disparity between rural and urban India with respect to children's performance. (iii) SC/ST children continue to perform below others.

From the ASER, 2016 report, we get another picture. As their test asks students to perform certain tasks on literacy and numeracy that they were expected to learn several years earlier, we get to see how deficient the children are relative to a minimum standard expected from their age groups. The general findings of ASER, 2016 are as follows. (i) Between 2014 and 2016, there has been some improvement in the children's reading ability at the primary school level. (ii) But at higher levels of schooling, there has been no improvement either in literacy or numeracy.

We reproduce here two tables, Table 14.1 and 14.2, from (ASER, 2016, p. 52) to illustrate how shockingly poor the state of learning is in rural India. Only 9.8% of students of grade I meet or exceed the expectation of reading grade I text or grade II text.[8] The remaining 90.2% of grade I students fail the reading test, out of which a whopping 46.1% cannot identify letters/alphabets. For older children, the picture is not better either. Only 13.4% of grade II students can read grade II text. The percentage of children who cannot read beyond grade I text ranges from 17.3 to 19.2% among students in grades III to IV. Even among the eighth graders, 13.0% of students cannot read grade I text. However, the picture is somewhat improving over time, as Table 14.2 shows, both in government and private schools. The children are deficient in learning

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[7] The coverage of ASER has been steadily growing. In 2012 it reached 331,490 households in 568 districts, surveyed 595,139 children in the age group 3–16 and assessed 448,467 children age 5–16.

[8] The highest level of text students was given to read was grade II.

by a wide margin. Perhaps Indian children are two to three years behind their Western countries and Asian economies.

Table 14.1 Percentage distribution of learning-deficient children in rural India

Currently studying in grade	*Could not identify letters*	*At most identified letters*	*At most read words*	*At most read Grade I text*	*Could read Grade II text*	*Total*
I	46.1	31.7	12.4	5.0	4.8	100
II	23.5 31.5	31.5	19.8	11.8	13.4	100
III	13.6	24.1	19.9	17.3	25.1	100
IV	8.5	17.2	17.7	19.2	37.4	100
V	6.0	13.3	14.2	18.6	47.8	100
VI	4.0	9.6	11.6	18.0	56.9	100
VII	2.8	7.2	8.9	15.1	66.1	100
VIII	2.0	5.4	6.5	13.0	73.0	100

Source (ASER, 2016, p. 52)

Table 14.2 Trends in reading ability

Year	*Percentage of Grade III children who can read Grade II text*		
	Government school (%)	*Private school (%)*	*Weighted average (%)*
2010	16.8	29.7	19.6
2012	16.7	33.8	21.5
2014	17.2	37.8	23.6
2016	19.3	38.0	25.2

Source (ASER, 2016, p. 52)

14.4 CAUSES OF DEFICIENT LEARNING

There is no singular factor that can be identified as the most crucial cause of the problem. A range of factors, such as teacher absenteeism (mainly in government schools), poor quality of teaching, irregular school attendance, late start in schooling and lack of home support, are some of the reasons the researchers have identified. Here we will discuss some of them.

14.5 PRIVATE VERSUS PUBLIC SCHOOLS

It is now a reality that a significant proportion of schools, even in rural India, go to private schools. ASER (2016) reports that around 30% of the children go to private schools in rural India; this figure is about 50–65% in urban India. In a global report, EdInvest (2000, pp. 5–7) identified six types of private schools in developing countries, which can be very inexpensive schools run primarily for poor children by charitable organisations and NGOs, or moderately expensive ones aimed at middle-class children, or very expensive international and boarding schools catering to the rich. Tooley and Dixon (2003) provided an early account of private schools in India catering to the poor and those who could not be accommodated in government schools due to strict regulations.

An age-old question in the education literature is: Are private schools *truly* better schools, or do they *look* better because they attract better students? The answer relies on whether the school's contribution to the student's performance can be sufficiently separated from the student's contribution (due to intrinsic ability). As we know now, the best way to avoid school selection bias, which is caused by a student's ability or social status, is to randomise the student admission process. Still, admission is rarely decided through randomisation anywhere in the world. In the literature on school efficiency, the selection issue is dealt with in a variety of ways.

Despite methodological differences, most studies tend to agree that private schools are more 'efficient' than public schools; this evidence is robust for developed countries, but less so for developing countries, although the definition of 'school efficiency' matters in any context public–private comparison. For more on this, see Jimenez and Lockheed (1991), Kingdon (1996), and for more recent work, Desai et al. (2008), Pal (2010) and Muralidharan and Sundaraman (2015).

But there are some important exceptions to the above view. Newhouse and Beegle (2006) studied Indonesian school children's performance in grades 7–9 and found that public schools were more efficient than private schools. The superiority of the public schools is attributed to an unobserved higher quality of teaching inputs provided by the public schools. In a study of 10 Latin American countries, Somers et al. (2004) concluded that there was no significant private school effect on a child's performance once the household, student and peer group characteristics were accounted for. This is consistent with another study conducted for Chile by McEwan and Carnoy (2000), in which a 1980 voucher programme was examined to see how it affected the growth of (for-profit) private schools. After controlling for various factors, the study found that public schools were relatively more efficient than private schools.

For India, there are several studies of recent vintage. Chudgar and Quin (2012) analysed the India Human Development Survey 2005 (IHDS) data for a sample of 10,000 children (70:30 split for rural and urban) with detailed information on their individual and household characteristics along with scores in mathematics, reading and writing. The authors applied the propensity score matching technique to correct the school selection bias. Their general finding is that after the school selection bias is corrected, the private school effect disappears. That means, in the authors' view, there is no difference between the private and public schools either in rural India or urban India.

The conclusion of the above study is perhaps too strong, and some methodological criticism may be raised. Two studies tried to employ the best possible approach focusing on Andhra Pradesh. These studies are Muralidharan and Sundararaman (2015) and Singh (2015).

Muralidharan and Sundararaman (2015) conducted a two-tier experiment of school admission in 180 villages of Andhra Pradesh in 2008 involving over 10,000 households. Each village was carefully chosen to ensure that there were at least one public school and one private school in the village. Parents of public school children were invited to apply for a voucher that would enable their children to switch to a private school, and the voucher would also cover the cost of doing so.[9] Subsequently, 90 villages were randomly selected, in which another lottery was conducted to assign the voucher. These were treatment villages, where

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[9] The participating private schools did not have any discretion to deny admission to voucher recipients, if places were available.

moving to a private school is the treatment. The remaining 90 villages were the control group, where no such voucher was given. The experimental design mimics the random assignment of school admissions, which would avoid any school selection bias. The academic performance of the students was tracked for four years to generate a panel dataset.

Their study found that there was no private school effect in most subjects, such as Telugu, Math, English and science/social studies. The only effect was observed for Hindi, which is not generally taught in public schools in the state. So, this study largely confirms the finding of Chudgar and Quin (2012).

In another study for Andhra Pradesh, Singh (2015) uses data collected under the Young Lives project between 2002 and 2011.[10] Young Lives is a longitudinal study of child poverty in four countries: Ethiopia, India (only the state of Andhra Pradesh participates), Peru and Vietnam. The survey tracked two cohorts of children. One cohort consisted of 1008 children born between January 1994 and June 1995; the second cohort had 2011 children born between January 2001 and June 2002. The children's educational data and test performances were analysed to estimate the private school effect by comparing the private and public students after controlling their time-varying and time-invariant effects. The author uses the value-added model to refine the private school effects by netting out persistence or decay of learning. Singh (2015) observes a strong private school effect only for English, but mixed effects for Telugu and no effect for math. A more interesting finding is that English medium private schools do worse than public schools in Telugu subject. Once again, we do not see a strong private sector effect.

We have noted that private schools in India and South Asia present a great variety, and some of the private schools could be set up by philanthropists or NGOs. The literature is very scanty about these schools. Pal and Saha (2019) have studied two Nepalese (national) surveys of school leaving certificate (SLC) exam data from 2002 and 2004. Nepal passed a unique amendment to its Nepal Education Act 2028 in 1992, opening the scope for private investment in education. Under the act, a private

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[10] Young Lives is a longitudinal study of child poverty in four countries: Ethiopia, India (only the state of Andhra Pradesh participates), Peru and Vietnam. The survey tracked two cohorts of children. One cohort consisted of 1008 children born between January 1994 and June 1995; the second cohort had 2011 children born between January 2001 and June 2002.

school can freely set school fees and profit but must pay tax on it. The trust schools, which are essentially not-for-profit privately run schools (set up by philanthropists or NGOs), are regulated for fees and curriculum. These schools are slightly more expensive than government schools but cheaper than private schools. The authors used the instrumental variable approach and concluded that the not-for-profit schools are the best school among the three types of schools, as far as the SLC marks are concerned. Their research points to the possibility that socially motivated schools, e.g., missionary schools in India) can bring the best of both the public and private sectors and affordably provide good quality education.

14.6 Teacher Incentives and Other Issues

There is also considerable effort to understand how public schools can be reformed to deliver good-quality teaching. One important area to look at is the teachers' pay and incentives. As has been widely reported in the media and confirmed by academic studies, teacher absenteeism is a big problem (Chaudhury et al., 2006). In this context, three Randomised Controlled Trial (RCT) studies provide some insight.

From a sample of 500 public schools in Andhra Pradesh, keeping 100 schools as a control group, Muralidharan and Sundararaman (2011) treated 400 schools with four different incentive schemes. The treatments were: (i) giving a bonus to schools for better than the average performance of students, (ii) giving individual teachers bonuses for better than the average performance of their students, (iii) giving all treatment schools an extra contract teacher, and (iv) giving all treatment schools a cash grant for school materials. The student performances were tracked over two years.

The main findings of this paper are as follows. First, the treatment schools performed better than the control schools. Secondly, after-treatment scores were higher in treatment schools than the pre-treatment scores at every percentile of the score distribution. That is, the treatment effect is lasting beyond one period. Third, individual incentive schools (treatment 2) outperform the group incentive schools (treatment 1). Fourth, the treatments sadly did not affect teacher attendance/absenteeism. Finally, extra contract teacher and cash grant inputs were not as effective and were more expensive programmes than the incentive schemes.

The main takeaway message of this experiment is that individual teacher-targeted cash incentive is the most effective incentive. But we should not forget the warning (Levitt & Dubner, 2005, pp. 19–54), who uncovered the perverse effect of 'teacher cheating' of cash incentive in the United States.

Duflo et al. (2012) conducted an RCT where financial incentives and monitoring both were introduced. The experiment was conducted in a network of non-formal schools in Western India run by the NGO *Seva Mandir* over a period of 4 years starting from September 2003. The treatment and control groups had 57 schools each. Each treatment school was given a camera, and students were given instructions to take a picture of the teacher at the start and close of the day. The financial incentive scheme included a (non-linear) payment scheme for teacher attendance combining both fines for working more than 20 days a month and fines for working less than 20 days.

The results of the experiment showed that both monitoring and incentives were strongly effective in reducing absenteeism. In fact, the improvement in attendance got stronger with treatment over time. After 4 years, teacher attendance was 72% in treatment vs 61% in control.

Fourthly, the authors also estimated the teacher's labour supply elasticity with respect to bonus to be between 0.2 and 0.3. Finally, the students in the treatment school also showed greater benefit from the programme. One year later, their test scores were significantly higher than students in the control schools. Two and half years later, the treatment students were ten percentage points more likely to transfer to a formal primary school than their cohort in the control schools.

The above two studies focussed on teacher incentives and teacher absenteeism. However, there is also an issue of remedial learning, which is very important for weaker students. Banerjee et al. (2007) conducted one such RCT in Mumbai. The experiment involved giving remedial education to the weakest students of grade 3 or 4 in the treatment schools via supplementary teachers. The experiment showed that remedial education increased average test scores in the treatment schools, and the impact got much stronger in the second year of the treatment. The weakest students gained the most. However, the gains begin to fade out after the programme was discontinued. That the remedial programme is effective is very encouraging. But the question remains about the durability of its effect.

14.7 New Education Policy and Concluding Remarks

The Government of India has announced the New Education Policy after the draft policy has undergone a nationwide public consultation. The policy document on school education has identified thirteen themes ranging from learning outcomes and child health to teacher training (Government of India, 2020). It is heartening to see that the government has put child's learning on the top of the agenda. Although we do not know how much money will be allocated to improve the learning outcomes, hopefully, the dire learning situation we discussed above will get serious attention. The second objective that the government aims to pursue is universal secondary education, which seems to be a natural extension of the successful universal elementary education. We know that this would be extremely challenging because of both supply and demand side issues here. We have not discussed here the problems of child labour and the problems of dropouts. See Shah and Steinberg (2017) for a thorough discussion of the demand side problems and the empirical evidence on how young students respond to income opportunities by dropping out of school. This problem needs special attention. There are structural problems that cannot be simply addressed by budgetary allocation or improving schooling conditions. The New Education Policy has highlighted the need for vocational education to tackle the dropout problem. Vocational programmes can play a crucial role in keeping children at school and giving them much-needed job skills that they normally acquire through informal apprenticeship.

We hope that with sustained efforts in universalising education, primary health care and child nutrition India would on track for sustainable development. The market incentives, private enterprises and state interventions have to work in tandem to unleash the potential Indians have. Progress is sustainable only when we have enriched our human capital.

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CHAPTER 15

Auctions in Kautilya's Arthasastra

P. G. Babu and Vikas Kumar

15.1 Introduction

Nowadays, auctions are used to sell things as diverse as flowers, tea, mining rights, paintings, and spectrum for telecommunication (Klemperer, 1999). In India, auctions seem to have taken the fancy of auditors, courts, and other enforcement agencies. Starting with the allocation of the 2G spectrum, at one point, it appeared that the Supreme Court was almost conferring a constitutional status to auctions as the primary price discovery mechanism. Interestingly, the entire debate leaves the question of the government's objective in auctions unclear. Successive governments seem to lean on auctions of natural resources to raise the maximum possible revenue and bridge their budget deficits. The use

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of auctions by states in pre-modern India offers a different perspective about the desirable objectives.

While resource allocation and price equity, which are essential for sustainable development, were also the key concerns in the auctions designed by Kautilya, his understanding of competition differs radically from our conceptions of the same. We will argue that pre-modern statecraft viewed auctions as a means to protect the interests of consumers rather than promote efficiency.

Shubik (1999, pp. 213–218) traces the history of auctions back to ancient Babylonia, where prospective brides were auctioned, and follows it through Roman history to the twentieth century (also see Doyle & Baska, 2002). According to Shubik (1999, p. 217), “the earliest known reference [to auctions] in the Far East is to the sale of belongings of deceased monks in the seventh century A.D.” But these and other related auctions of property of deceased or bankrupt persons were not part of usual market exchanges. So, Shubik (1999, p. 214) suggests that “[a]uctions found little favor in the Orient, where bargaining has been traditional, little importance being attached to the time taken to make a sale. Consequently, the rise of the auction appears to have followed the economic development in the West.”

This paper draws attention to the existence of an elaborate system of auctions in a pre-modern non-western society. It tries to add to our understanding of pre-modern auctions by examining procedures and laws governing auctions discussed in the *Kautiliya Arthasastra* (completed by the third century CE), the oldest extant Indian treatise on law, economic activities, and statecraft.[1] The paper relates to two streams of literature. On the one hand, it adds to the literature on competition in the pre-modern world. Liebermann (1985) discusses competition in consumption from the Jewish perspective. Raskovich (1996) examines

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[1] Cinematic renditions of the popular story of King Harishchandra such as the tele-serial *Upanishad Ganga* (The Human Goal: Dharma—Story of Raja Harishchandra—Episode 9) include two instances of auctions. However, auctions do not figure in ancient sources of this story such as *Vyasa Mahabharata*, *Markandeya Purana* and *Devibhagavata* and medieval sources such as Raghavanka’s *Harishchandra Kavya*, a 12th Century Kannada text.

the rise of monopolies in the market for religion in the ancient Middle East. de Roover (1951) throws light on market regulations in pre-modern Europe. Kumar (2012) examines market regulations from the perspective of ancient Indian treatises. On the other hand, it adds to the economic literature on pre-modern Indian traditions of knowledge (Kumar, 2010, 2011, 2012; Sihag, 2009).

The discussion in the paper is organized as follows. Section 15.2 introduces the *Kautiliya Arthasastra* and locates it within the larger body of ancient Indian traditions of knowledge. Section 15.3 throws light on markets from the perspective of the *Kautiliya Arthasastra* and compares auctions of goods and land. This section highlights the differences between the two types of auctions in terms of the degree of competition allowed by the auction design and then poses an exegetical problem. The last section offers concluding remarks. Note that *sutras*—aphoristic sentences—from the *Kautiliya Arthasastra* will be referred to as, say, II.4.6 (Book II, Chapter 4, Sentence 6). The source for the original text of the *Kautiliya Arthasastra* is Kangle (2006 [1969]). Unless otherwise specified, the source for translations is Kangle (2003 [1972]). Other sources of translations include Shamasastry (1988 [1915]), Rangarajan (1992), and Olivelle (2013).

15.2 Background

Ancient Indian thinkers proposed three complementary goals for human life—*dharma* (spiritual), *artha* (material), and *kama* (sensual). The school of thought that eventually dominated maintained that in the event of a conflict between goals, *dharma* prevailed over *artha* which in turn prevailed over *kama* (Doniger & Kakar, 2003; Kangle, 2003 [1972]; Rocher, 1985). According to exceptions to this rule, *artha* was the foremost goal for kings (*Kautiliya Arthasastra*, I.7.6–7, VIII.1.47–49, IX.7.60–63, 81) and courtesans (*Kamasutra* I.2.15). Expert traditions of knowledge (*sastras*) emerged around each of these goals. Economic activities were discussed as part of law and statecraft in the *Arthasastra* and *Dharmasastra* traditions.[2] Between the two, the former is chronologically prior and provides a more elaborate discussion on economic activities and statecraft and informs the treatises in the latter tradition. We will rely

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[2] There is perhaps no pre-modern Indian text that discusses economic activities outside the perimeter of law and statecraft.

on the *Arthasastra* tradition to understand auctions in ancient India. We will use the *Kautiliya Arthasastra* (Kautilya's *Arthasastra*) as an exemplar of the *Arthasastra* tradition.[3] None of the pre-*Kautiliya Arthasastra* treatises has survived. Post-Kautiliya treatises like the *Kamandakiya Nitisara* have very little to say about legal and economic issues because they are focused on war and diplomacy. Even here, they deviate a lot from the *Kautiliya Arthasastra* under the influence of the *Dharmasastra* tradition. So, henceforth, the *Kautiliya Arthasastra* will be referred to as the *Arthasastra* in our discussion.

The *Arthasastra* is a treatise on statecraft, law, and economic activities meant for practitioners.[4] The treatise consists of 150 chapters unevenly distributed across 15 books. 15 chapters in Book I deal with issues directly managed by kings like the appointment of ministers, envoys, etc. Books II through IV contain 69 chapters dealing with internal administration, legal system, and the economy. The discussion on foreign policy and war and the impact of natural calamities on policymaking occupies 49 chapters (Books VI–XIII).[5]

Arthasastra is commonly, but inappropriately, translated as "Economics." The ancients used *vartta* to refer to both key economic activities like agriculture, cattle-rearing, and trade, and the related domain of knowledge (Kangle, 2006 [1965], pp. 166–167). *Vartta* is "the closest Sanskrit term we have for the word 'economics'" that refers to "the pursuit of livelihood (vritti)" (Kangle, 2003 [1972], p. 9; Trautmann, 2012, p. 3). The *Arthasastra* defines wealth (*artha*) "as the human production of livelihood, then, as the earth inhabited by human beings

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[3] Soon after it was first translated into English by Shamasastry (1988 [1915]), the *Arthasastra* won instant recognition as "perhaps the most precious work in the whole of Sanskrit literature" (Thomas, 1922, p. 467) because it possibly "throws more light on the cultural environment and actual life in ancient India than any other work of Indian literature" (Maurice Winternitz quoted in Trautmann, 1971, p. 3; also see McClish, 2019; Olivelle, 2013, p. 39). The *Arthasastra's* discovery transformed the ancient Indian from an otherworldly being to a calculative this-worldly being (Gowen, 1929, pp. 174, 178; Trautmann 1971, p. 2; Weber, 1946, pp. 123–124). Since then Kautilya has been equated with Machiavelli. But Kumar (2010, pp. 292–293) argues that popular imagination in India nurtures a complex image of Kautilya, unlike the West where Machiavelli is equated with cunning.

[4] The text differentiates between "scholars and practitioners" (I.5.8).

[5] For the literature on the *Kautiliya Arthasastra* see Olivelle (2013) and McClish (2019).

engaged in such production and finally, as the acquisition and protection of the inhabited, productive earth – by a king" (Trautmann, 2012).[6] The purpose of the Arthasastra is defined as the acquisition, presentation, and augmentation of *artha* and its use by the king (I.4.3–4, also I.5.1–2, I.15.52, XV.1.1–2). Olivelle (2013, p. 63) translates *Arthasastra* as *Treatise on Success*, but this generalizes the scope of the treatise too much. Likewise, translating it as *Science of Politics* is inappropriate because it also deals with law, economy, and public administration rather than just political manoeuvring. So, *Science of Political Economy* seems to be the most appropriate translation (cf. Doniger & Kakar, 2003, pp. XIII, 205; Trautmann, 2012, p. 8) even though the use of "political economy" in a pre-modern context might sound anachronistic.

The consensus about the authorship of the *Arthasastra* suggests three things. Firstly, while the unity of authorship was never convincingly demonstrated, recent scholarship has assembled sufficient intra-textual evidence against the claim that the treatise was written in one period, let alone by an individual (McClish, 2019; Olivelle, 2013; Scharfe, 1993; Trautmann, 1971). The scholarly consensus suggests that the text can be divided into two broad parts: the *Kautilya Recension*, the original prose text, and the *Sastric Redaction*, the verse and prose interpolations influenced by the *dharma* tradition (McClish, 2019; Olivelle, 2013, pp. 9–10). Our discussion is restricted to Book II (for auctions of goods) and Book III (for auctions of land) that seem to belong to the same early stratum of the treatise, namely, the *Kautilya Recension*.

Secondly, Olivelle (2013, p. 31) suggests that it was commonplace in ancient India to ascribe authorship to revered figures of the past to confer prestige and authority. We can add that retrospective ascription to a revered figure, say, a god or sage, also ensured survival and dissemination of one's work in an age of scarce means of transmitting knowledge. Olivelle argues that given the obscurity of the name Kauṭilya in ancient literature, one could have easily found a better candidate. So, it is prudent to accept the traditional ascription of the authorship of the treatise to Kautilya, at least in the case of the oldest stratum.

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[6] *Artha* is polyvalent: goal, meaning, money, purpose, pursuit, reason, wealth, legal case, profit, self-interest, power, a goal of life, and the name of a god (Doniger & Kakar, 2003, pp. XIII, 1, 219; Doniger & Smith, 1991, pp. 303–304; Kangle, 2006 [1969]; 2003 [1972]; Trautmann, 2012, pp. 2–3).

Thirdly, the extant text was composed over several centuries and completed by the third century CE. The extended timeline of composition has two implications. One, phrases like *Kautilyan economy* and *Kautilyan market* refer to hypothetical entities described in the treatise often devoid of any direct historical correlates because it is difficult to date *sastras* and relate them to a specific territory. Sastras deliberately eschewed references to the place and time of writing. Two, we will discuss markets as described in the treatise without committing to any position regarding the relationship between the treatise and its "contemporary" economy.

15.3 AUCTIONS

One of the most important features of a Kautilyan economy was the participation of the state/king in all branches of the economy, either alone or in partnership with others. So, Kautilyan states were simultaneously market agents, market regulators, and, at times, even market makers.[7] A few other essential features of Kautilyan markets include the stipulation of transparency in deals, commitment to just prices, and confiscation of profit made by deviation from just prices, scarcity of capital, and a very high degree of risk and uncertainty (Trautmann, 2012). Given its role as a producer of a wide range of goods, the state presumably had first-hand information regarding costs, and even otherwise, it could rely on undercover agents to collect relevant information.

The Kautilyan state seems to have been concerned with market manipulations for three reasons (see Kumar, 2012, p. 65). One, it was ultimately responsible to "maintain" among others "persons in distress when these are helpless" (II.1.26) and granting tax exemptions to those in distress (II.24.17, also II.1.36). Two, a population impoverished by unscrupulous agents could be easily instigated by rebel princes/vassals or even foreign powers (VII.4.7, VII.5.16–18). Three, manipulation of markets could be used to foment trouble and raise resources to challenge the state. In short, markets were too important to be left to the discretion of traders. We can add that inter-state traders could serve as spies to foreign kings (I.12.22),

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[7] See Kangle (2006 [1965]), Trautmann (2012), and Olivelle (2013) for consequences of the embeddedness of the state in markets.

and even otherwise, trade was a factor to be accounted for in foreign policy (VII.4.7). Using simple games, Kumar (2010, Example 2) discusses various situations in which heeding popular opinion is in the self-interest of the Arthasastra's king. Furthermore, princes were trained since childhood that as a king, they ought to uphold dharma, i.e., justice in the broad sense rather than merely following law codes. Trautmann (2012), for instance, argues that in ancient India, the idea of kingship did not entail unbridled exploitation of subjects (see also Kangle, 2006 [1965]).

The *Arthasastra* contains information on two kinds of auctions that roughly correspond to open ascending-bid auctions (also known as English auctions), each for "markets"[8] for land and goods. Kautilyan auctions did not apply to natural resources like minerals, which the king monopolized. There is no reference in the treatise to descending-bid auctions (also known as Dutch auctions).[9] Further, sealed-bid auctions are repugnant to *Arthasastra's* legal framework that valued transparency in market transactions (III.1.2–4) and allowed very few exceptions (III.1.6–12). This section first discusses auctions of goods and land separately and then compares them.

15.3.1 Auctions of Goods

Auctions of goods under the watch of the Superintendent of Customs (*Sulkadhyaksa*) are described in Book II (On the Activities of Superintendents, *Adhyaksapracarah*).

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[8] The scare quotes are necessary since these markets do not necessarily conform to our contemporary understanding. Consider, for instance, Rosenbaum's (2000) criteria for identifying markets.

[9] Olivelle (2013, p. 555) suggests that "it may be in the interest of a trader to set an artificially high price, from which it could only come down as a result of bidding." However, the text does not support this reading.

> Traders shall declare[10] the quantity and price of the goods that have arrived at the foot of the flag[11], 'Who is willing to purchase these goods, so much in quantity, at this price?' When it has been thrice proclaimed, he should give it to those who have sought it. In case of competition among purchasers, the increase in price together with the duty shall go to the treasury. (II.21.7-9) … Or, if through fear of a rival purchaser a (trader) increases the price beyond the (due) price[12] of a commodity, the king shall receive the increase in price, or make the amount of duty double ["when the *mulyavrddhi* (increase in price) amounted to less than the *sulka* (duty)" – Kangle, 2003 [1972]: 142-143]. The same (penalty) eightfold (shall be imposed) on the Superintendent concealing (the trader's offences). (II.21.13–14)

Olivelle (2013, pp. 555, also 39) identifies the transaction described in the above *sutras* (particularly, II.21.8) as an auction: "Clearly we are dealing with an auction here rather than a normal sale. Such auctions may have been carried out for imported goods, as well as goods sold wholesale to retail traders." But since the treatise abounds in references to the sale of goods, the circumstances under which auctions of goods were conducted would bear elaboration. The markets for goods were divided between retail and bulk trade sectors. Trautmann (2012, p. 126) observes the following regarding the relationship between the two.

> [I]t was often the practice to separate long-distance trade from local trade, each being conducted by different bodies of traders … Long-distance traders brought goods in bulk to the [city] gate, where they were bought by local traders to sell at retail inside the city. Long-distance traders were

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[10] In ancient Indian law, shouting/calling out played an important role in a variety of contexts in addition to auctions. For instance, shouting to attract potential rescuers played an important role in ancient Indian law regarding distress contracts (III.13.35, see also Asahaya's commentary on *Naradasmriti*, Jolly, 1889, p. 130; Lariviere, 2003, p. 342). Also, shouting to alert others relaxed liabilities of a driver/rider of a cart/animal that has gone out of control (IV.13.14, also *Manava Dharmasastra* VIII.291–292 (Olivelle, 2006) and *Yajnavalkya Dharmasastra* II.298–299 [Dutt, 2011]). *Manava Dharmasastra* (VIII.233) suggests that a herdsman is not guilty if an animal is stolen "despite his shouts", and IV.13.14, which suggests that one cutting a tree is not guilty of hurting others if he shouts, "get out of the way." Also see *Yajnavalkya Dharmasastra* (II.303), Brihaspati (XVI.20), and *Naradasmriti* (VI.13.16) (Dutt, 2011; Jolly, 1889).

[11] Apparently, "the emblem of the king" (Kangle, 2003 [1972], p. 141) established near the customs house "in the vicinity of the big gates" (II.21.1).

[12] See Footnote 19 regarding the translation of "(due) price."

> not allowed to sell at retail. The city gate is the location where wholesalers and retailers meet and transact business. It is also the place where the king imposes taxes in the form of customs duties.

So, auctions of goods were conducted at the junction of bulk/long and retail/short trade networks. This separation allowed the state to control prices by regulating supply. Another point of interest with regard to auctions of goods relates to Shubik's (1999, pp. 213–214) claim that auctions require "an adequate concentration of population to provide sufficient numbers of buyers and sellers, on the one hand, and a coinage so that the values of bids are immediately recognizable on the other." Both these conditions are satisfied in the case of Kautilyan auctions of goods. The *Arthasastra* presumed extensive circulation of coins so much that it allowed monetization of talionic punishments (IV.10 is devoted to this). Regarding the locus of auctions, the treatise mentions that such auctions happened near cities, which must have had a greater population density than the countryside.

15.3.2 Auctions of Immoveable Property

Auction of immovable property like land is described in the following *sutras* of Book III (*Dharmasthiyam*, On Justices):

> Kinsmen, neighbours and creditors, in this order, shall have the right to purchase landed property (on sale). After that, others who are outsiders (may bid for purchase). (Owners) shall proclaim a dwelling (as for sale) in front of the house, in the presence of members of forty neighbouring families, and a field, a park, an embankment, a tank or a reservoir (as for sale) at the boundaries, in the presence of village elders who are neighbours, according to the extent of the boundary, saying 'at this price who is willing to purchase?' What has been thrice proclaimed and not objected to ["by any one claiming the right of pre-emption, etc." – Kangle 2003 [1972], p. 219], the purchaser shall be entitled to purchase. Or, in case of competition, the increase in price together with the tax shall go to the treasury. The (successful) bidder at the sale shall pay the tax. In case of a bid by one who is not an owner, the fine shall be twenty-four *panas*. If the (bidder) does not come (to take possession), the owner whose property was auctioned may sell (again) after seven days. (III.9.1–8, also see Kangle, 2006 [1969], p. 109)

Olivelle (2013, p. 197) translates "according … purchase?'" in the above as "In conformity with its boundary lines, who will buy at this price?" This translation seems to be correct, particularly because proclamations in the case of auctions of goods (II.21.7–9, see Section 3.1 above) include both quantity and price (Olivelle, 2013, pp. 601–602). Olivelle's translation has implications for our understanding of the role of proclamation in auctions. In auctions of land, a proclamation is not merely an announcement of price but also of undisputed legal ownership that, of course, was open to disputation by the witnesses (also see Footnote 10).

Three other features of these auctions need to be noted here: the order in which potential bidders can join the process, the role of neighbours as witnesses and the determination and payment of the price. Regarding the first, Trautmann (2012, p. 123) notes that the priority "given to a kinsman, neighbor and creditor over the stranger … recognizes the strong connection of farmland with the family among farmers in ancient India, since the kinsman as the buyer is privileged over all other buyers." Other general restrictions on land transactions stated later in III.9 would have also applied to the set of bidders: (a) taxpayers can sell or mortgage only to taxpayers, (b) Brahmins (members of the priestly caste) can sell gift-land only to Brahmins, and (c) taxpayers cannot buy land in tax-free villages (III.10.9–12). Rank ordering of bidders and these additional restrictions on who can bid removes land transactions "from the free-market model" (Trautmann, 2012, p. 123).

Regarding the role of neighbours in land transactions, it is noteworthy that "disputes concerning immovable property (are to be decided) on the testimony of neighbours [*read* heads of households]" (III.8.1, also III.9.15, 24). The sale of land through auction in the presence of locals seems to be a mechanism for discovering and enforcing just prices in land markets.

> [T]he *Arthashastra* insists that the transaction be transparent, being conducted in the presence of knowledgeable witnesses,[13] that is neighbours – as many as forty of them – and that the price be announced, not

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[13] Trautmann introduces another condition, namely, witnesses should be *knowledgeable*. This is not mentioned in the treatise, even though it may be implied.

> once but three times, 'without objection'. What objection? Most assuredly, an objection from a witness would be about the commonly accepted value, and therefore the proper price, of land. (Trautmann, 2012, pp. 123–124)

Further, note that Shamasastry (1988 [1915], p. 193) translates "Kinsmen… families" as:

> Kinsmen, neighbours, *rich persons*, shall in succession go for the purchase of land and other holdings. Neighbour of *goods* [sic] *family*, forty in number and *different from the purchasers above mentioned*, shall congregate in front of the building for sale and announce it as such. (emphasis added)

Here Shama Sastry disagrees with Olivelle (2013) and Kangle (2003 [1972]) (as well as Trautmann, 2012, pp. 123–124). The two key differences are the stipulation that the witnesses should belong to "good" families, and the sets of witnesses and bidders ought to be mutually exclusive. While the Kautilyan legal system treats persons from "good" families differently from others (III.1.5, III.11.26, III.12.29), this is not mentioned in the sutras on the auction of land. It also seems that the set of witnesses and bidders may have been coterminous contrary to Shama Sastry's interpretation. There are two reasons for this. One, the size of villages ideally varied between 100 and 500 families (II.1.2). So, in small villages, the requirement of 40 witnesses (heads of households) covers almost half the village! Two, in pre-modern Indian villages, closely related people united by kinship ties (obviously, belonging to the same caste) settled together so that neighbours and kinsmen must have been largely coterminous.

The significance of the requirement of forty neighbours as witnesses,[14] the proclamation of price thrice,[15] and re-auction after seven[16] days is not explicitly stated anywhere in the treatise. The lawgiver seems to have meant “many witnesses” or “sufficiently many witnesses” rather than a specific number of witnesses.[17] The number “forty” would have been chosen for its sacerdotal or customary significance related to, say, the movement of the planet Venus, which was monitored to determine the

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[14] The number *forty* is also important in other contexts in the *Arthasastra*, e.g., “for one doing harm to members from *forty* neighbouring families, the fine shall be 48 *panas*” (III.20.15, emphasis added). Cities were divided into “unit[s] of ten households, 20 households, or *40* households” (II.36.2, emphasis added). State officials could cheat people in *forty* different ways (II.8.20–21). The number *forty* also finds mention in the context of measurement. A *nalika*, which was a measure of time, consisted of 40 *kalas* (II.20.34). The denominations of weights manufactured included 40 *suvarnas* (II.19.8). Also, the “work month for the elephant corps [of the army]” (Rangarajan, 1992, p. 729) or “months for calculating wages of attendants of horses and elephants” (Kangle, 2003 [1972], p. 141) was equal to 40 days and nights (II.21.53). Even otherwise the number *forty* must have been important insofar as *four*, *five,* and *eight* were units of counting in a variety of contexts (for a compilation of a few usages see Olivelle, 2013, Appendix 2; Rangarajan, 1992, Appendix 1). In medieval India, a particular genre of poetry was known as *chālisā*, i.e., a collection of forty verses on a specific (mostly devotional) theme (e.g., *Hanumān Chālisā, Durgā Chālisā*, etc.). The number *forty* was also important across the world in ancient and medieval times. In the Biblical story of Noah it rained for forty days and nights (Genesis 7:4). Joseph mourned his father’s death for forty days (Genesis 50:1), Moses spent forty days on Mount Sinai (Exod 24:18), and Jesus fasted for forty days and nights (Matt 4:2; Mark 1:13; Luke 4:2). More generally, the number forty is closely associated with life cycle ceremonies across cultures. The widespread importance of the number could possibly be linked to its mathematical properties or astronomical facts of interest to ancient civilizations.

[15] The requirement of price announcement thrice reminds of modern English auctions. The number *three* is also used elsewhere in the *Arthasastra* where decision under uncertainty is involved, e.g., “when there is agreement in the reports of three (spies), credence (should be given)” (I.12.15), “In case of non-admission [of the claim], however, witnesses shall decide, those who are trustworthy, honest or approved, three at least in number” (III.11.26), and the period of retraction of sale for agricultural produce is “three days” (III.15.5) whereas for “quadrupeds” is “three fortnights… [f]or, it is by that time that purity or otherwise *can be known*” (III.15.17–18, emphasis added).

[16] The number *seven* is also important in other contexts in the *Arthasastra*, e.g., sale of “means of livelihood” could be retracted within “seven days” (III.15.6).

[17] As in the *sutra* that says that state officials can cheat people in *forty* different ways (II.8.20–21). For a discussion on the use of numbers in ancient Sanskrit literature see Doniger and Kakar (2003, pp. xxi–xxv).

sowing season (II.24.7–8). While it is not stated in the treatise, invalidation of auctions in the absence of forty witnesses could be linked to a price discovery mechanism.

15.3.3 Comparison

Having introduced auctions of land and goods, we can now compare them with each other and also modern auctions. Three features are common to both kinds of Kautilyan auctions: aversion to deals made in secrecy, commitment to just prices, and an aversion to uncontrolled competition. The auctions of land, in fact, go further by ensuring that land transactions do not hurt the kin and the neighbourhood. These features are in turn related to Shubik's (1999, p. 217) observation that pre-modern auctions in the East prioritized justice over profit.

Both the auctions of land and goods resemble modern open ascending price auctions with a reservation price. While the treatise does not explicitly mention reservation prices in the context of auctions, it can be inferred from the commitment to just prices that were decided so as not to hurt any of the stakeholders, including sellers, and the stipulation that in the event of a glut in the market the state ought to step in to stabilize prices (II.16.2–3, 7, IV.2.33–34) and that traders unable to profit from selling valuable goods deserved a sympathetic treatment from the state in the form of tax exemptions (II.16.11–12) (also Kumar, 2012, pp. 63–67). But there is a crucial difference between Kautilyan and modern auctions. In Kautilyan auctions, bids could also not exceed the upper bound of just price because the excess profit, if any, made by a seller accrued to the state. The idea of just price is most clearly captured in the following passage from Book IV (Eradication of Thorns, *Kantaksodhanam*):

> [Superintendent of Commodities, *Panyadhyaksha*] should fix for them, moreover, a profit above the authorized purchase price of 5 percent in the case of local commodities, and 10 percent in the case of foreign commodities. For those who increase the price beyond that or, in buying or selling, realize a profit beyond that, the fine is 200 Paṇas for every five Paṇas of additional profit per 100 Paṇas. That also explains the proportional increase in the fine corresponding to the increase in the price. (IV.2.27–30, Olivelle, 2013, p. 228)

This passage essentially "links profit with the cost of bringing things to the market, by making it proportionate to the distance, virtually a charge for transportation" (Trautmann, 2012, p. 129).[18] Olivelle (2013, p. 555) argues that because of the state's claim on excess profit, "it may be in the interest of a trader to set an artificially high price, from which it could only come down as a result of bidding". Olivelle's suggestion is problematic because the treatise prescribes penalties at the rate of "two hundred panas for (an additional profit of) five panas in one hundred panas" (IV.2.28–30). In other words, manipulation of prices by individuals (or, for that matter, by groups) was risky. Note here that in case bidding raises prices beyond the limits set by the superintendent, the good would go to the buyer with the highest willingness to pay, which is efficient and necessary for an optimal allocation, even though the seller will not benefit as the state captures the excess profit.

Just prices[19] were iteratively fixed after taking into account production (supply), investment, transportation cost, duties, interest, rent, risk, and demand (II.16.1–7, IV.2.36) and the interests of various stakeholders—sellers, buyers, and state (*qua* recipient of taxes and trader of royal goods). But determining the just price was only half the job. The state had to announce and enforce these prices.[20] It tried to achieve this by limiting competition in markets, promoting beneficial imports, imposing import and export controls, and criminalizing trade at non-designated

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[18] While the restriction on the rate of profit may be interpreted as the state's hostility to traders, the state also protected the interests of traders. See Kumar (2012) and Trautmann (2012) for a discussion on the variety of ways in which the Kautilyan state intervened in favour of traders.

[19] There is no phrase in the *Arthasastra* that translates exactly as *just price* (Kumar, 2012). A wide range of closely associated expressions are used in the literature. Different authors use different phrases: "normal price" (Olivelle, 2013, p. 148), "(due) price" (Kangle, 2003 [1972], pp. 142–143), and "proper value" (Shamasastry, 1988 [1915], p. 122). At times even the same author uses several different expressions to capture the intent of the treatise. For instance, Trautmann (2012) uses several different expressions to describe the idea of fairness in transactions involving goods or land: fair (99, 129, 130, 140), true (99, 124, 125, 127), just (112, 124), proper (116, 124, 127), reasonable (129), stable (129), steady (130), customary (112, 124, 127), and commonly accepted (124).

[20] Other texts like Manu (VIII.403) suggest that prices ought to be publicly fixed "every five days or every fortnight" (Olivelle, 2006), while Brihaspati (XIII.7) suggests that transactions happened "before an assembly of merchants, the king's officers being aware of it (also)" (Jolly, 1889).

locations.[21] The *Arthasastra* assumes that severe fines would check deviation from just prices. By criminalizing trade at non-designated locations, Kautilya tries to ensure transparency in transactions through publicity, which also helps to ensure that the parties to a transaction do not evade taxes due to the state. Contracts that were not made in an appropriate public forum were deemed invalid and attracted a fine in the range of 48–96 *Panas*[22] (III.1.2–5), which is comparable to the annual salary of the lowest attendants in state services (V.3).

Yet another similarity between the auctions of land and goods relates to the structure of the proclamation, which covered three things: the identity of the good/piece of land offered, the quantity/extent being offered, and the price at which the good/land is offered. In both cases, the price was linked to the quantity on offer. This indirectly suggests that the unit price was perhaps related to the total amount purchased, at least in the case of goods.

Differences between the two kinds of auctions are also noteworthy. First, in auctions of land, there is one seller and many buyers. The buyers enjoy unequal priority in the order they can bid. However, unlike auctions of land where bidders were ranked on extra-economic grounds, auctions of goods are characterized by free entry insofar as it was open to many buyers and many sellers irrespective of their identity. Second, bidding through proxies was not allowed in case of auctions of land and was a punishable offence with a fine of 24 *Panas*, whereas there was no such restriction in the case of goods. Third, unlike markets for land, where the community publicly identified the price at which the transaction took place, price discovery in the markets for goods was left to the Superintendent of Trade/Customs. Fourth, unlike auctions of goods, auctions of immoveable property violate Shubik's location condition (large population centres with large numbers of buyers and sellers, i.e., thick markets) insofar as they are most likely rural affairs in Kautilya's scheme. But following Olivelle (2013, p. 601) and II.36.2, one could argue that III.9.1–8 might have governed immovable property transactions in cities

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[21] II.16.4, II.16.11–13, 19, II.21.7–13, II.21.22–23, 31, II.22.8–14, III.9.5.

[22] *Pana* refers to the basic unit of currency—a silver coin, whereas the smallest unit was 1/2 Kakani = 1/128 Pana (II.12.24, Kangle, 2006 [1965], p. 181; Olivelle, 2013, pp. 458–459). The lowest annual salary of employees of the Kautilyan state was 60 *panas* and the highest legal fine was 1,000 *panas*. Among goods generally sold in market those priced 2 *panas* were considered to be high value goods.

as well. Fifth, unlike auctions of goods where just profit is sanctioned, the treatise is silent regarding profit in land transactions and leaves the matter to the discretion of the local community. Sixth, auctions of land had an in-built retraction clause if the buyer failed to take possession of the property within a stipulated period. This, in turn, suggests that deferred payment must have been permissible in auctions of land. While retraction is not explicitly discussed in the case of auctions of goods, the general rules on "Cancellation of Sale or Purchase" (III.15) may have been applicable in this context as well.

We can now summarize the key points of the above comparative discussion with the help of the following claim.

Claim 1: Kautilyan auctions of goods are Pareto-efficient but do not maximize sellers' profit, whereas Kautilyan auctions of land are neither Pareto-efficient nor do they maximize the profit of sellers.

The claim about profit is true as prices were restricted to just profits, whereas the claim regarding Pareto inefficiency of land auctions follows from the fact that entry was restricted, and bidders were ranked based on extra-economic grounds. But the claim about Pareto-efficiency may fail to hold in the case of goods if there are at least two bidders whose valuation of the goods being auctioned strictly exceeds the upper limit of the corresponding just price and the bidder with the highest valuation fails to get good. We can conclude this comparative discussion by noting that while Olivelle (2013, pp. 601–602) is right that the two types of auctions are structurally similar in terms of the essential procedure, they differ regarding the degree of competition allowed by the design of the auction.

15.3.4 An Exegetical Detour

We have tried to use the treatise to understand the idea of the auction as conceived in ancient India. We can now turn to the treatise and contribute to its exegesis using the preceding comparative discussion. Three points are noteworthy regarding the organization of the discussion on auctions in the treatise.

Firstly, the auctions of land and goods are placed in two different books and under the supervision of two different types of government officers. This suggests that despite broad similarities, the two kinds of auctions are viewed differently in the treatise. We have already seen that even after taking into account Olivelle's correction to Kangle's translation, the auctions of goods and auctions of land differ insofar as the latter is characterized by severe entry barriers and unequal priority to eligible bidders, among other things.

Secondly, indeed, the treatise has two different notions of competition. The treatise uses different words for competition in the two contexts: *spardhā* (III.9.5, land) and *sangharṣa* (II.21.9, goods). *Spardhā* explicitly refers to competition, and it also gives a sense of direction (in which contestants are moving), whereas *sangharṣa* refers to general struggle (where competition is implied) without providing a sense of direction. While further assessment of the difference noted here awaits closer scrutiny of medieval commentaries on the *Arthasastra*, we can further investigate other occurrences of these words within the treatise. Before that, note that both these words are hard to find in other ancient treatises that have sections dealing with the regulation of economic activities (e.g., the *Dharmasastras* of Manu, Yajnavalkya, and Visnu). Surprisingly, the word spardhā occurs only in one more place in the entire text, namely, IV.7.17, where it is used in the sense of (professional) rivalry. The word *saṅgharṣa* and its derivatives occur in five other places in the text: II.6.22 ("price increases due to competition for purchase … constitute[s] income [of the state]," Olivelle, 2013, p. 110), VIII.2.5 (struggle within the ruling class in a state under co-rulers or illegitimate rulers), VIII.4.19 (disputes among subjects), IX.2.16 (shared rivalries of corporate troops), and XII.4.8 (price competition between spies disguised as vendors/tavern keepers selling poisoned food in enemy camp).

Saṅgharṣa is used both in cases of two actors as well as multiple actors and is used both to refer to clearly identified market competition as well as general rivalries including those directed at third parties. In contrast, both occurrences of *spardhā* relate to instances of competition in contexts involving fewer actors. This inference seems reasonable insofar as land auctions are likely to include fewer buyers than auctions of goods. But the hypothesis that two different words have been used because of the difference in the structure of markets might be incorrect if the two *sutras* belong to different layers of the treatise or are even drawn from other sources. In that case, one may explain away the use of different words simply by arguing that vocabularies keep changing over time. It bears noting that according to the existing scholarship, these *sutras* belong to chapters (II.21 and III.9) in the *Kautilya Recension*. But McClish (2009, pp. 181–182) suggests that II.21 and III.9 might belong to two different strata within the *Kautilya Recension*.

Thirdly, there is another exegetical problem, namely, the ordering of *sutras* in the adhyaya II.21. All translators of treat II.21.13–14 ("Or, if… the duty") as part of the text. But II.21.13–14 seems to be a commentarial gloss on II.21.9 ("In case of… treasury") that has found its way into the text. II.21.13–14 apes II.21.10–12 to elaborate the terse statement in II.21.9. If we remove II.21.13–14 and reshuffle the remaining sutras as suggested below, then the text reads better:

> II.21.1-2 (duties of the Customs and Tolls department), II.21.3-6 (stamp related violations at the time of the entry of goods into the territory), II.21.10-12 (violations related to duties to be paid), II.21.7-9 (auction of the goods legally allowed into the territory and penalties for deviation from the prescribed format for auction), and II.21.15 (summary of the discussion).

The remaining part of the chapter (II.21.16–31) discusses provisions related to duty-free goods followed by the treatment of exports.

15.4 Concluding Remarks

Economic theorists have so far paid little attention to pre-modern economies outside the West. In light of the widely held belief that the rise of auctions followed the economic development in the West, this paper introduces auctions discussed in the *Kautiliya Arthasastra*, the best-known ancient Sanskrit treatise on statecraft, economic activities, and law. This paper complements Kumar (2012), which discusses cartels from the perspective of the *Kautiliya Arthasastra*.

The paper compares two types of auctions described in the treatise that correspond to open ascending-bid auctions with reservation prices and an upper bound to potential bids. The discussion highlights the difference between the two types of Kautilyan auctions in terms of the degree of competition allowed by the auction design. It also argues that Kautilyan auctions differ from modern auctions insofar as they were designed around the ideal of just prices. Finally, it argues that Kautilyan auctions of goods are Pareto-efficient but do not maximize the seller's profit. In contrast, Kautilyan auctions of land are neither Pareto-efficient nor do they maximize the seller's profit. It also discusses the possibility that Kautilyan auctions of goods may not be Pareto-efficient.

So, while resource allocation and price equity that are essential for promoting sustainable development were among the key concerns of Kautilyan auctions, his understanding of competition is different from ours. This difference can possibly be accounted for by the radically different economic and technological contexts and the state of understanding of market dynamics. The Kautilyan world was marked by an acute scarcity of capital, a very high degree of risk and uncertainty, stagnant technology and very low rates of population growth because of which social stability was a key policy objective in resource allocation.

Finally, the analysis in the paper is put to exegetical use to speculate about the different compositional origins of the treatise chapters dealing with auctions. Kumar (2011) suggested the use of game-theoretic analysis to identify interpolations in the *Arthasastra* and the *Kamasutra* (Treatise on erotic love) and to identify ideas borrowed and improved upon by the *Kamasutra* from the *Arthasastra*. There is a need to nurture economic exegesis to understand pre-modern treatises better.

Future work should examine the nature of competition and price discovery mechanisms in different types of auctions in the *Kautiliya Arthasastra*. More generally, the role of the Superintendent of Trade/Customs in auctions of goods and in establishing prices in markets of goods requires further investigation. A comparison of the Superintendent with the Walrasian auctioneer could yield interesting insights into the functioning of Kautilyan markets. The Walrasian auctioneer clears the market as it observes no constraints on price. The Kautilyan auctioneer could possibly run into circularities. In fact, limiting competition should raise prices, making the attainment of just prices difficult. But the treatise links just price with just profit. So, just price is seen as a dynamic price linked to production and transportation costs. There is another point that needs to be made explicit, even if it is inherent in the idea of just profit. Even as it was concerned about the destabilizing impact of speculation and fluctuations on social stability, the state was also concerned about the viability of businesses that is assured by limiting profits and not prices.

Another point that needs research is whether the ancients followed the format of auctions described in the treatise. Since *sastric* or technical literature in Sanskrit is silent on implementation of laws, this issue requires exploration of medieval commentaries and ancient Indian fictional literature and historical sources, *a* la Sternbach's (1952, 1953) exploration of non-juridical Sanskrit sources from the perspective of contract laws and Derrett's exploration of inscriptions (Lingat, 1973, pp. 273–274).

At this point, we can only suggest that laws promulgated by a state or formulated by scholars need not necessarily rely on state machinery for enforcement. The resilience of the caste system provides an example of decentralized enforcement of extremely stringent penalties for violations prescribed in the *Dharmasastras*. See Akerlof (1976) for an analysis of the enforcement of the caste system without the intervention of the state. Rocher (1993) also discusses the decentralized community-level enforcement of law codes in pre-modern India without access to written texts and intervention of formal courts or the state.

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CHAPTER 16

Professor (Dr.) Jyoti K. Parikh

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Positions held and Academic qualifications

Professor Jyoti K. Parikh is Executive Director of Integrated Research and Action for Development (IRADe), New Delhi. She was a **Member of the Prime Minister's Council on Climate Change—India and is a recipient of Nobel Peace Prize awarded To IPCC authors in 2007**. She served as the senior professor and Acting Director of Indira Gandhi Institute of Development Research (IGIDR), Mumbai 1986–03. IIASA, Austria for 8 years (1980–86, 76–78) and Planning Commission, as senior energy consultant at New Delhi (1978–80).

She has served as energy consultant to the World Bank, the U.S. Department of Energy, EEC, Brussels and UN agencies such as UNIDO, FAO, UNU, and UNESCO, Environment Consultant to UNDP, World Bank and so on. She worked as an advisor to various ministries for Gov. of India.

She obtained her M.Sc. from University of California, Berkeley, in 1964 and Ph.D. in Theoretical Physics from University of Maryland, College Park in 1967. She has guided 12 Ph.D. theses in energy, environment and climate change and given lectures in more than 40 countries around the world.

Publications include nearly 200 project research papers and 25 books and monographs in the area of **energy economics, climate change and modelling, energy technology assessment, rural energy, power sector, environment economics, natural resource management, and climate change**.

She has guided Sixteen Ph.D./Masters theses in energy, environment and climate change area and given lectures in more than 40 countries around the world. The topics ranged from vulnerability and adaptation of agriculture, forestry, power sector, construction sector, and carbon emission baselines for power, transport, cement, and steel sector.

Detailed titles and references can be found in www.irade.org.

16.1 DETAILED C.V. OF DR. JYOTI PARIKH

Professor Jyoti K Parikh is the Executive Director of Integrated Research and Action for Development (IRADe), New Delhi. She was the Senior Professor at Indira Gandhi Institute of Development Research (IGIDR), Mumbai. She also worked at the International Institute for Applied

Systems Analysis (IIASA), Austria; and served as senior energy consultant at the Planning Commission, New Delhi (1978–80). She was visiting professor at the Institute of Advanced Studies (IAS) of UNU, Tokyo 1995–96. She was the Acting Director of IGIDR during 1997–98. She has experience of nearly thirty years on energy and environment problems of the developing countries.

She has served as energy consultant to the World Bank, the U.S. Department of Energy, European Economic Community, Brussels and UN agencies such as UNIDO, FAO, UNU, and UNESCO, Environment Consultant to UNDP, World Bank, and so on.

She has guided 12 Ph.D. theses in energy and environment.

She obtained her M.Sc. from University of California, Berkeley, in 1964 and Ph.D. in Theoretical Physics from University of Maryland, College Park in 1967.

16.1.1 Past and Present Interests, Projects and Activities

She has published nearly 200 research papers and 25 books and monographs in the area of environment, energy and physics.

She has carried out a number of national and international projects. Her analytical work spans over areas such as environment, energy demand modelling, power system simulations, alternative fuels (CNG, ethanol), biomass allocation in rural energy systems, energy policy, demand side management in electricity sector, impacts of climate change, natural resource accounting, sustainable development and restructuring consumption patterns, incremental costs and Global Environment Facility (GEF), supporting globally efficient projects by GEF, North–South issues in IPCC response strategies, Joint implementation of climate change projects: opportunities for North–South cooperation, trade and environment, and large-scale survey on rural energy, water and sanitation, environmental economics for sustainable development into decision-making process. It covers four major focal areas: Air Quality; Water Quality; Community Land Regeneration; and Biodiversity within the overall framework of sustainable development.

16.1.2 Academic Qualifications

Year and degree	*Place*
1967, Ph.D., Theoretical Physics	University of Maryland, College Park Md. USA
1963, M.Sc., Physics and Mathematics	University of California, Berkeley, CA, USA
1961, B.Sc. Physics and Mathematics	Gujarat University, Ahmedabad
1957, S.S.C.E. Board Matriculation Exam	Gujarat, India (First in the state—45,000 students)

16.1.3 Honours and Awards

- Nobel Peace Prize awarded to IPCC authors in 2007.
- Women achievers award—2000.
- Special energy award by IBPL Urja Research Foundation on the occasion of 50 years of independence of India (1998).
- Golden Jubilee for India's independence award for energy efficiency—1997.
- Second prize IFORS in "Operations Research for development" (1996).
- Bhasin Award for Energy and Environment—1995.
- Boutros Ghali Award for 1995 instituted by the Foundation for United Nations given at the United Nations University (UNU).
- Gold Medal from the Systems Society of India for energy and environment—1988.

16.1.4 International Appointments

- Board Member of the Journal "Current Alternative Energy (CAE)", December 2020.
- Member of the Global Agenda Council—World Economic Forum on Decarbonizing Energy (2014–16).
- Member of the Research Advisory Committee of the **Institute for Global Environmental Strategies (IGES)** Japan, April 1, 2002, till March 31, 2005.

- Convening Lead Author for the chapter on “Carbon Regulation for **Millennium Ecosystem Assessment**”—2002 till 2005.
- Technical Advisory Committee (TAG) for Energy Trust Funds Programmes of the **World Bank** (2003) that include Energy Sector Management Programme (ESMAP), Asia Technical Assistance in Energy (ASTAE), Africa Renewable Energy Initiative (AFREN), Africa, 2002–2004.
- Advisory Board of **Tyndall Center for Climate Change**, University of East Angela, Norwich, UK, 2001–2004.
- International Steering Committee of **ENERGIA**, Network on Gender and Environment, Nederland, 2002–2004.
- Scientific and Technical Advisory Panel (STAP) to Global Environment Facility (GEF)—1995–1998.
    - ✔ Inter-governmental Panel for Climate Change (IPCC).
    - ✔ Convening lead author for the Second Assessment (1993–95).
    - ✔ Reviewing editor for the Third Assessment (1999–2000).
    - ✔ Reviewing editor for the SRES (1998–99).
- Member of the Advisory Panel on Biodiversity for Executive Director, United Nations Environment Programme, 1994–1996.
- START (A Global Change System for Analysis, Research and Training) Scientific Steering Committee (SSC), USA—from May 1997.
- Member of the Steering Committee and part of the management of the on. EU-LDC Network Foundation, Netherlands Hq., 2000.

16.1.5 National Appointments

- Member, Committee on Distribution Reforms (DRUM) (2004), Ministry of Power, New Delhi.
- Member of Prime Minister’s Council on Climate Change—India.
- Member, Climate Change and Insurance Task Force (2004), Ministry of Environment and Forests, New Delhi.
- Member, Committee for CDM projects Ministry of Non-Conventional Energy Sources, New Delhi, 2001–2003.
- Member, Advisory Group on Energy and Environment, Ministry of External Affairs, Govt. of India, 2001.

- Member, Major and Medium Irrigation Working Group Programme for the Formulation of the Tenth Five Year Plan (2002–2007), Planning Commission, Delhi, 2000.
- Member of Advisory Panel on Global Environmental Issues set up by the Ministry of Environment and Forests, Government of India, 1996–1998.
- Advisory Committee on AIJ Issues, Ministry of Environment and Forests, 1997–2000.
- Member, Advisory Committee, Central Electricity Regulatory Commission (1998–2000).
- Member, Tariff Policy Committee, Uttar Pradesh Electricity Board (1989).
- Convener of Sixth National Power Systems Conference held in 1990.
- Consultant for Kerala State Electricity Board.
- Senior Consultant for the World Bank study on long term issues for Power Sector in India and has written a number of papers in power systems for IEEE transactions for power systems.
- Non-official part-time director on the Board of Indian Renewable Energy Development Agency Ltd. (IREDA) by the Government of India in the Ministry of Non-Conventional Energy Sources (MNES) in August 2001.
- Advisory Group on Energy and Environment, Ministry of External Affairs, Government of India, 2001.
- Member of Advisory Panel on Global Environmental Issues set up by the Ministry of Environment and Forests, Government of India, 1996–1998.
- Advisory Committee on AIJ Issues, Ministry of Environment and Forests, 1997–2000.
- Vice President, Executive Committee of Indian Chapter of Society for Ecological Economics, 2000–2001.
- Member of editorial boards of International Journal, Utilities Policy and Energy, The International Journal and reviewer for many other journals.

16.1.6 National Project Coordinator

- Chairperson of EERC (Environmental Economics Research Committee) of EMCaB Project of the World Bank, 1997–2003 distributing US$ 1.5 million for 56 projects across India in Universities, NGO and Research Institutes.
- Gender, Pollution and Health: Conducted one of the largest studies that for the first time captures pollution, health, energy, water, housing and socio-economic characteristics for 14,000 households in 4 states of India in 12 districts and 100 villages. It involved surveyors, medical doctors, pollution measurement and stakeholder's perceptions. Massive (statistical) analysis exercise is underway.
- Capacity Building for Environmental Governance (1995–2000): UNDP project had four major focal areas: Air Quality; Water Quality; Community Land Regeneration and Biodiversity within the overall framework of sustainable development. It involved government, academic and research organisation, stakeholders, industries, and pollution control boards. Involved 15 organisations across India, 20 workshops—regional, national and international. More than 1000 persons were involved.

16.1.7 Experience

Year	*Institution*	*Remarks*
Aug 2003 to till date	Integrated Research and Action For Development	Executive Director • Rural energy, environment and health • Sustainable Development and Consumption Patterns • Climate Change • Natural Resources Accounting and Valuation • Capacity building in Environmental Economics • Resource Mobilisation

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Year	*Institution*	*Remarks*
June 1986 to July 2003	Indira Gandhi Institute of Development Research, Bombay	Acting Director and Senior Professor; carried out work on: • Rural energy, environment and health • Sustainable Development and Consumption Patterns • Climate Change • Natural Resources Accounting and Valuation • Guiding Ph.D. Students • Capacity building in Environmental Economics
Sept. 1995 to Sept. 1996	United Nations University/Institute of Advances Studies	Visiting Professor, set up Env. Resources Project and guided international research students
June 1980 to 1986	IIASA, Laxenburg, Austria	Research Scholar, Resources and Environment for countries in Asia, Africa and Latin America. Energy-agriculture interactions and other topics, decentralized industries and capital goods for energy
Sept. 1978 to Sept. 1980	Planning Commission, New Delhi	Senior Consultant, Energy Demand Model for India
May 1976 to Sept. 1978	International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria	Research Scholar, Energy Systems; worked on energy planning strategies for developing countries in system analytic framework, macro-economic models and for renewable energy and global energy models

(continued)

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Year	*Institution*	*Remarks*
1974	Dept. of Science and Technology; Office of Environmental Planning; Govt. of India, New Delhi	Specialist; worked on problems of environmental planning and monitoring environmental information system; - carried out tasks of science and engineering research council which assessed collaborative research projects in the new frontier areas such as bio-medical engineering, environmental standards etc. by visiting institutions; - also identified joint technical programs with other countries; - represented Government of India at the International Conference of Women Scientists at Cracow, Poland, IWY (1975)

16.2 Books and Monographs

16.2.1 Environment

1. *Reconciling Environment and Economics* eds Jyoti Parikh and T. Raghuram, IGIDR Publication, 333.7/PAR (2003).
2. *Rural Energy and Health Impact*, Project report of Tamilnadu, UP, Rajasthan, H.P. (EERC report).
3. *Sustainable Management of Wetlands*, eds Jyoti Parikh and Hemant Datye, Sage Publishers, New Delhi. ISBN: 9780761996026 (June 2003).
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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
Implications of declining costs of solar, wind and storage technologies on regional power trade in South Asia, BBIN countries	EEG	Team Leader	IRADe-PR-72, 2020
State Background Report	MacArthur Foundation	Team Leader	IRADe-PR-70, 2020
State Selection Report	MacArthur Foundation	Team Leader	IRADe-PR-69, 2020
Experiences out of the COVID-19 and developing a framework towards a resilient Electricity Grid System for BBIN Region in South Asia	EEG	Team Leader	IRADe-PR-68, 2020
Sustainable and Disaster Resilient Urban Development India: A comparative study of 10 cities to draw lesson for South Asia	Ministry of Urban Development, MoUD	Team Leader	IRADe-PR-65, 2019
Gender and Fossil fuel subsidy reform: Findings from and recommendations for India, Bangladesh and Nigeria	IISD	Team Leader	IRADe-PR-62, 2019
Gender Analysis for the Project Appraisals of IGEN IV and IGEF	GIZ	Team Leader	IRADe-PR-61, 2019
Assessment of food security and livelihood due to climate change in Uttar Pradesh, Himachal Pradesh and Odisha	MoEFCC	Team Leader	IRADe-PR-60, 2019

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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
'Developing urban climate vulnerability index, VI and asses the vulnerability of six selected cities using the VI'	MoEFCC	Team Leader	IRADe-PR-59, 2019
Study to develop Roadmap for Implementation of India's NDC Goal 3	MoEFCC	Team Leader	IRADe-PR-58, 2019
Framing the debate on Climate Change	U.S. Embassy, New Delhi	Team Leader	IRADe-PR-57A, 2018
Viability of Electricity as a cooking solution on a large scale for Rapid Cooking Energy Access	NABARD	Team Leader	IRADe-PR-57, 2018
GTWG-Clean coal technology	Department of Science and Technology, DST	Team Leader	IRADe-PR-56, 2018
Modelling Studies on Greenhouse Gas Emissions and Emission Intensity of Indian Economy	Ministry of Environment, Forests and Climate Change, MoEFCC	Team Leader	IRADe-PR-53, 2016
Review of Status of Marine National Park, Jamnagar	Ministry of Environment, Forests & Climate Change, MOEFCC & GIZ	Team Leader	IRADe-PR-52B, 2015
Policy Brief on Emerging Mechanisms & Responses of Cities to Climate	Asian Cities Climate Change Resilience Network, ACCCRN	Team Leader	IRADe-PR-52A, 2015
Environmentally Sustainable and Integrated Energy Strategy for Gujarat	Gujarat Power Corporation Ltd., GPCL	Team Leader	IRADe-PR-51, 2015

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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
Preparation of Third National Communication, TNC and other new information to the UNFCC project, India's First Biennial Update Report-National Circumstances	InsPIRE Network for Environment, NATCOM	Team Leader	IRADe-PR-50, 2015
Socio Economic Vulnerability of Himachal Pradesh to Climate Change	Department of Science and Technology, DST	Team Leader	IRADe-PR-49, 2015
Sustainable and Disaster Resilient Urban Development	Ministry of Urban Development, MoUD	Team Leader	IRADe-PR-48, 2014
Prospects for Regional Cooperation on Cross-Border Electricity Trade in South Asia	US Agency for International Development, USAID	Team Leader	IRADe-PR-43, 2014
Economy wide Model for Low Carbon Strategy	Planning Commission	Team Leader	IRADe-PR-42, 2014
Research Study on Low Carbon Development Pathways for an Inclusive India	World Wildlife Fund, Germany and World Wildlife Fund, India	Team Leader	IRADe-PR-41, 2014
CDMP Review of Six cities	United Nations Development Programme	Team Leader	IRADe-PR-40, 2013
The Impacts of India's Diesel Price Reforms on the Trucking Industry	International Institute for Sustainable Development	Team Leader	IRADe-PR-39, 2013
Identifying specific policy options with the aim of reducing carbon intensity in India	Department for International Development and AEA	Team Leader	IRADe-PR-38, 2013

(continued)

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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
Climate Resilient Urban Development: Vulnerability Profiles of 20 Indian Cities	Rockefeller Foundation	Team Leader	IRADe-PR-37, 2013
Assessing Socio-Economic Vulnerability to Climate Change: A case study of Assam	Indian Council of Social Science Research	Team Leader	IRADe-PR-36, 2012
Maps India Study on Poverty and Low Carbon Development Strategies	South South North Trust	Team Leader	IRADe-PR-35, 2012
Monitoring & Evaluation of Off Grid Solar Photovoltaic Systems installed in Punjab and HP in 07–08, 08–09 and 09–10	Ministry of New and Renewable Energy	Team Leader	IRADe-PR-34, 2012
Measuring Ecosystem Services for Green India Mission-Case study of Paderu project I Andhra Pradesh	Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ	Team Leader	IRADe-PR-32, 2012
Techno-economic and Socio-agronomic Analysis of Bio-diesel System	Ministry of New and Renewable Energy	Team Leader	IRADe-PR-29, 2011
Management of Ecosystem of Marine National Park, Gujarat in Harmony with Industrial Development	Ministry of Environment and Forests	Project Leader	IRADe-PR-28, 2010
Indian Renewable Energy Status Report, Background Report for DIREC 2010	German Technical Cooperation, GTZ and National Renewable Energy Laboratory	Team Leader	IRADe-PR-27, 2010

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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
Indian Perspectives on Global Energies Scenarios till 2050	Technology Information, Forecasting & Assessment Council and International Institute for Applied Systems Analysis	Team Leader	IRADe-PR-26, 2010
Activity Analysis Model for Climate Policies for India	Ministry of Environment and Forests	Team Leader	IRADe-PR-23, 2009
Green Accounting for the State of Andhra Pradesh	Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ	Team Leader	IRADe-PR-22, 2009
Three-tier Systems for Climate Negotiations	Ministry of External Affairs	Project Leader	IRADe-PR-21, 2009
Methane Emission and Pump Test Study from Landfill Zusammenarbeit, GIZ	United States Environmental Protection Agency	Project Leader	IRADe-PR-19, 2009
Analysis of GHG Emissions for Major Sectors in India: Opportunities and Strategies for Mitigation	Centre for Clean Air Policy, USA	Project Leader	IRADe-PR-16, 2009
Analysis for CCS Technology in Indian Power Sector	Department of Science and Technology, DST	Project Leader	IRADe-PR-15, 2009
Demand, Supply and Subsidy Analysis for Indian Fertilizer Sector	Department of Fertilizer	Project Leader	IRADe-PR-14, 2009
Extension of Minimum Support Price, MSP: Fiscal and Welfare Implications	Planning Commission	Project Leader	IRADe-PR-13, 2008
Gender Analysis of Renewable Energy in India: Present Status, Issues, Approaches and New Initiatives	ENERGIA	Project Leader	IRADe-PR-12, 2009
Demand for Natural Gas in the Indian Fertilizer Sector	Stanford University, USA	Project Leader	IRADe-PR-11, 2007

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Project Name	*Funding Organization*	*Capacity*	*Year completed/status*
Evaluation of Franchisees System in Assam	Rural Electrification Corporation	Project Leader	IRADe-PR-10, 2007
Evaluation of Franchisees System in West Bengal	Ministry of Power	Project Leader	IRADe-PR-09, 2007
Natural Resource Accounting, NRA Goa Phase-II	Central Statistical Office	Project Leader	IRADe-PR-08, 2007
Gender Oriented Energy Policy	ENERGIA	Project Leader	IRADe-PR-07, 2006
GHG Reduction Potential, Sectoral Baselines and Opportunities for CDM Projects	Ministry of Environment and Forests	Project Leader	IRADe-PR-06, 2006
The Energy Poverty and Gender Nexus in Himachal Pradesh, India: The Impact of Clean Fuel Access Policy on Women's Empowerment	ENERGIA and Department for International Development	Project Leader	IRADe-PR-05, 2005
Consequences of Electricity Pricing Reforms on Agriculture	Stanford University	Project Leader	IRADe-PR-04, 2004
Impact of Fuel Scarcity and Pollution on Rural Poor, a comparative analysis of vulnerable groups in HP	SANEI, Global Development Network	Team Leader	IRADe-PR-03, 2003
India's National Circumstances for Addressing Climate Change, NATCOM	Ministry of Environment and Forests	Project Co-Leader	IRADe-PR-02, 2003
Gender & Climate Change, COP 8	United Nations Development Programme	Project Leader	IRADe-PR-01, 2003

16.5 PROJECTS IN LOCAL AND GLOBAL ENVIRONMENT ISSUES AND SUSTAINABLE DEVELOPMENT

Project name	*Funding orgainsation*	*Capacity*	*Year completed/status*
• Assessment of Landfill Gas and Pre Feasibility Study at Okhla Landfill Gas Utilization as domestic fuel	US Envt. Protection Agency	Project Leader	2009
• Analytical Approaches for Climate Negotiations	Ministry of External Affairs	Project Leader	2009
• Climate Change Impacts and Vulnerability of Himalayan Ecosystems: A study of Uttarakhand	Ministry of Environment and Forests	Project Leader	2009
• Analysis of GHG Emissions for Major Sectors in India: Opportunities and Strategies for Mitigation	CCAP, Washington	Project Leader	2009
• Road Map of Carbon Capture and Storage, CCS Technology Development in India	DFID/BHC	Project Leader	2009
• Demand, Supply & subsidy analysis forIndia Fertiliser sector	Ministry of Fertiliser	Project Leader	2009
• Natural Resource accounting, NRA Goa	Central Statistical Office, CSO	Project Leader	2007
• Natural Resource Accounting, NRA Goa Phase-II under SEEA Frame Work	Central Statistical Organization, New Delhi	Project Leader	2006
• Rural Pollution and health Gender Perspective	EERC/UNDP	National Project Leader	2003
• Environmental Management Capacity Building Technical Assistance Project	World Bank	Chairperson, National Programme	2003

(continued)

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Project name	*Funding orgainsation*	*Capacity*	*Year completed/status*
• Cap-21: Capacity Building for Introduction of Environment Economics into Decision Making for Sustainable Development	UNDP, New York and New Delhi	National Project Coordinator	2001
• Environmental Accounting for India	UNU/IAS	Team Member	2003
• Climatic Impact on agriculture in India	World Bank	Team Leader	1997
• Sustainable consumption patterns of India	UNDP	Individual Consultant	1997
• A Natural Resource Accounting Framework for NTGCF: A Tool for Sustainable Development	CIDA, Canada	Team Member	1997
• Poverty, Environment and Development Nexus	HRD, UNDP	Individual Consultant	1996
• Economic Instruments for Climate Change	Indo-Canada Link Project	Team Leader	1996
• Environmental and Natural Resource Accounting for India	UN-ESCAP	Team Leader	1996
• IPCC WG-III SAR Decision Making Framework	IPCC	Team Leader	1995
• Trade and Environment Linkages- A Case Study of India	UNCTAD, Geneva	Team Leader	1995
• Metropolitan Environment Improvement Program	World Bank	Team Member	1995
• Income Group-wise Consumption Patterns, India	UNDP-WRI	Team Leader	1994

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Project name	*Funding orgainsation*	*Capacity*	*Year completed/status*
• Environment Mission for South Africa	IDRC, South Africa & Canada	Team Member	1994
• Natural Resource Accounting	UNDP	Team Member	1993
• Consumption Patterns, North–South	UNCED/Earth Summit Rio	Team Member	1992
• Climate Change and India's Energy Policy Options	Rockefeller Foundation	Team Leader	1992
• Consumption Patterns, SAARC Group, IPCC Strategies	Climate Action Network/Ministry of Environment	Team Leader	1991

16.6 PROJECTS IN ENERGY SYSTEMS

Project name	*Funding organization*	*Capacity*	*Year completed/status*
• Gender Analysis of Renewable Energy in India	ENERGIA	Project Leader	2009
• Evaluation of Remote Village Electrification Programme	MNRE	Project Leader	2009
• India's Initial National Communication to the United Nations framework Convention on Climate Change	Ministry of Environment and Forest	Project Leader	2009
• Evaluation of Solar Thermal Demonstration Programme	MNRE	Team Leader	2009

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Project name	*Funding organization*	*Capacity*	*Year completed/status*
• Evaluation of Solar Photovoltaic Programme	MNRE	Team Leader	2009
• Natural Gas demand for fertilizer sector in India	Stanford University	Team Leader	2007
• Evaluation of Franchises System: Assam, West Bengal and Rajasthan	REC	Project Leader	2007
• Evaluation of Franchisees System: Assam, West Bengal and Nagaland	Ministry of Power	Project Leader	2007
• Techno- economic Assessment of Bio energy in India	TIFAC	Project Leader	2006
• Integrated Study of Diesel Substitutes from Oil Seeds in India	Petroleum Federation of India	Project Leader	2006
• Gender Oriented Energy Policy	Energia International, Netherlands	Project Leader	2005
• Electricity pricing reforms and agriculture in India	Stanford University	Project Co-Leader	2005
• The Energy Poverty and Gender Nexus in Himachal Pradesh, India: The Impact of Clean Fuel Access Policy on Women's Empowerment	SANEI, World Bank	Project Leader	2005
• Impact of fuel Scarcity and Pollution on Rural Poor: A case Study of Himachal Pradesh	DFID/ENERGIA	Project Leader	2005
• Pilot Demonstration Project on Renewable Energy in Jeevika Village of SEWA	Self Employed Women's Association, SEWA, Gujarat	Project Leader	2005

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Project name	*Funding organization*	*Capacity*	*Year completed/status*
• Consequences of Electricity pricing reforms on agriculture	Stanford University, California, USA	Team Member	2005
• Impact of fuel Scarcity and Pollution on Rural Poor, a comparative analysis of vulnerable groups in Himachal Pradesh	South Asia Network of Economic research Institutes, SANEI/Global Development Network	Project Leader	2005
• Projections for Petroleum Products, Natural gas and substitutes upto 2030	PriceWaterHouseCoopers, New Delhi Petroleum Federation of India	Project Co-Leader	2005
• Client Survey for Energy Trust Funds of World Bank	ESMAP/ASTAE-World Bank	Project Leader	2004
• Gender as a Key Variable in Energy Interventions in Developing Countries: Are We Asking the Right Questions?	DFID, UK, Engineering Knowledge and Research Programme	Project Leader	2004
• Sustainable Urban Transport: Case Studies of Mumbai and Delhi	SIDA/Asian Institute of Technology	Project Leader	2002
• Financial Performance of SEB: An Analysis	11th Finance Commission, Govt. of India. New Delhi	Team Leader	2000
• Environmentally Sound Energy Development Strategies, Phase-II: for India	UNEP Centre for Energy and Environment, RISO, Denmark	Team Leader	1996
• Structural Transformation Process Towards Sustainable Development	INFRAS, IAE Switzerland	Team Leader	1995

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Project name	*Funding organization*	*Capacity*	*Year completed/status*
• Environmentally Sound Energy Development Strategies, Phase-I: for Maharashtra	UNEP Centre for Energy and Environment, RISO, Denmark	Team Leader	1994
• Demand Side Management in the Electricity Sector	EMCAT/USAID	Team Leader	1994
• Compressed Natural Gas in Transport Sector	PACER, ICICI, US/India	Team Leader	1991
• Survey of High Tension Industries in Maharashtra	Energy Management Centre, Ministry of Power, New Delhi	Team Leader	1991
• Rural Energy Systems	IDRC, Canada	Team Leader	1990
• Long Term Issues in Indian Power Sector	World Bank/Planning Commission, Govt. of India	Team Leader	1989
• Super Conductors in Power Systems	Department of Science and Technology	Team Leader	1988

16.7 Ph.D./M.Phil. Thesis Guided in Energy, Environment, Climate Change and Sustainable Development

Name	*Thesis title*	*Year of completion*
Ph.D. Theses		
Debabrata Chattopadhyay	Economic Operation of the Power System in India	1996
Saumen Majumdar	Energy and Economic Linkages: Imports, Investments, Efficiency and Pricing Issues	1996
Piyush Tiwari	Economics of House Markets in India	1996
Santha Kavi Kumar	Modelling and Analysis of Climate Change Impacts for India	1998
Raghavendra Rao	Policy Modeling of the Oil and Gas Sector in India	1999

(continued)

(continued)

Name	*Thesis title*	*Year of completion*
Satya Narayana Murthy	Energy, Environment and Sustainable Development	2000
Hari Priya	Taking Stock of Nature: Accounting for Forest Resources in India	2000
B.A.N. Sarma	Modelling Frameworks for Electric Generation and Transmission Planning	2000
Anoop Singh	Energy and Environmental Policy Modeling	2001
Mudit Kulshreshtha	Long-term Supply Strategies for Commercial Energy Sector in India	2002
Barnali Nag	Economic and Policy Analysis of CO_2 Emissions in India	2004
Sarika Rathi	Urban and rural environmental issues in India	2007
Haimanti Biswas	Rural Pollution, Gender and Health	2009
M. Phil. Thesis		
D. Bag	The Economics of Pesticides Application in Agriculture and Environmental Damage	2000

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https://doi.org/10.1007/978-981-19-9756-3

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