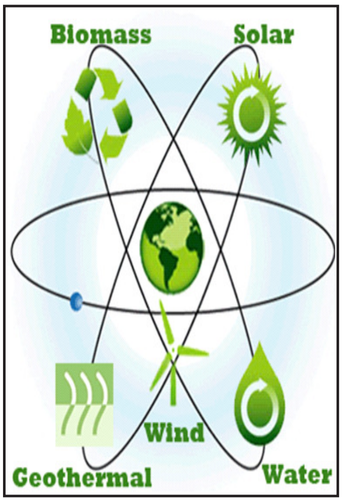
ECONOMIC ISSUES 12

CHALLENGES OF TRANSITION FROM FOSSIL FUELS TO GREEN REGIMES



ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT

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Challenges of Transition from Fossil Fuels to Green Regimes

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ASIAN INSTITUTE OF TRANSPORT DEVELOPMENT

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CHALLENGES OF TRANSITION FROM FOSSIL FUELS TO GREEN REGIMES

Foreword

In the year gone by, the world adopted Agreement on Climate Change and recognised the irreversible threats to human society and planet due to looming climate change. One of the important goals of the Agreement is to promote use of sustainable energy. In the developing countries, this would require transition from use of fossil fuel to green energy resources. It is not an easy path. In this monograph, Prof. Sengupta provides alternative ways to achieve the stated goal based on empirical analysis. Prof. Sengupta is an internationally acclaimed scholar and researcher in the area of environmental economics. This monograph makes an important contribution to the discourse on the subject.

K. L. Thapar
Chairman

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The United Nations (UN) has established a Green Fund for the mitigation and adaptation to climate change, but this single broadly targeted fund may not be enough for the purpose of the huge task. More initiatives might be required at the level of the union of a number of countries who are united for geo-political or linguistic-cum-cultural as well as political-economic reasons to accelerate the process of mitigation-cum-adaptation in the context of climate change. The author, along with Satya Brata Das, an Energy Journalist of Cambridge Strategies in Edmonton, Alberta, in Canada proposed in a paper (2015) entitled *From the Fossil Fuel Present to a Low Carbon future* the creation of a dedicated climate fund within the Commonwealth. It was published by Cambridge Strategies, Edmonton.

Change can be induced by moral suasion as well as by the anxiety for survival. This series of *economic issue* points out at the conceptual level, how capital for the proposed fund can be mobilised and illustrates how it can be usefully applied to accelerate India's transition from a high-carbon economy to a low-carbon future, with minimal disruption to the social order while allowing for robust economic growth.

To effect the transition from a fossil fuel regime to a low-carbon regime, the author proposes to convert the entire rental income from any natural resource (like Hotelling's rent from fossil fuels) into new assets of renewable energy technologies by way of their taxation and investment of the tax proceeds for the development of the latter as what is called backstop technologies. It also offers a scalable model for effective international action in the context of assisting other developing countries in a similar transition from fossil fuel to a green electrical energy regime, mobilising resource rents from big fossil fuel resource rich countries.

Abbreviations

BU	–	Billion Units
CAGR	–	Cumulative Annual Average Growth Rate
CEA	–	Central Electricity Authority
CO2	–	Carbon dioxide
CSP	–	Concentrated Solar Power
C-WET	–	Centre for Wind Energy Technology
DNI	–	Direct Normal Irradiance
GCCSI	–	Global Carbon Capture and Storage Institute
GDP	–	Gross Domestic Product
GHG	–	Greenhouse Gases
GHI	–	Global Horizontal Irradiance
GOI	–	Government of India
GW	–	Gigawatt
GWp	–	Global Warming Potential
IEA	–	International Energy Agency
IPCC	–	International Panel for Climate Change
MNRE	–	Ministry of New and Renewable Energy
MTOE	–	Million Tonnes of Oil Equivalent
OECD	–	Organization for Economic Cooperation and Development
OLS	–	Ordinary Least Square
PFCE	–	Private Final Consumption
R&D	–	Research and Development
RE	–	Renewable Energy
T&D	–	Transmission and Distribution
TERI	–	The Energy and Resources Institute
UN	–	United Nations
WISE	–	World Institute of Sustainable Energy

Chapter 1

Background

The world is not only depleting its fossil fuels and other non-renewable resources, it is also exhausting its renewable resources by over-exploitation at rates exceeding their respective rates of regeneration as driven by the dynamics of the ecosystems. The waste absorptive ability, including that of the greenhouse gases (GHG) by the ecosystems by degrading them, is also a renewable fund service resource of our global common. This common resource is being degraded by injecting more GHGs into the atmosphere than what the forests and oceans can absorb by the processes of carbon sequestration and the drive of ocean currents. It is, in fact, the rate of resource depletion and waste flows into the sink of ecosystems exceeding their capacities of resource regeneration and waste degradation by the natural ecosystem. The attitude of “anything goes” in the name of commercial success is the impelling force behind the exhaustion of resources and degradation of the environment, and its profound effect on the climate of the biosphere we share.

Climate change is going to be the case of the greatest market failure in the history of the human economy. It is now amply clear that the capitalist institution of the market, in spite of policy intervention, cannot generate enough forces that can contain the huge adverse effects of this market failure. Capitalist values that drive the market-based system and its institutions, if left unchecked, would make us oblivious of the finiteness of our ecosystems and their capabilities and the impact of the entropy law on our economic and social processes.

It is, therefore, nothing surprising that the assessment of the fifth Intergovernmental Panel on Climate Change (IPCC) affirms that it is far too late to “stop” climate change – even if “stopping” such change were within the capacity of humans. Indeed, even if all fossil fuel use were to stop now (entirely hypothetical presupposition), the greenhouse gases (GHGs) already extant in the atmosphere over the last 150 years will continue to bring rapid mutations in the health of the biosphere. The latest IPCC's synthesis report for policymakers makes it abundantly clear that the best chance of taking meaningful action is long behind us. The report tells us in effect that we cannot prevent catastrophic climate change because we cannot turn back the tide of industrial history. Yet, even as we move vigorously to curb carbon emission and find ways to adapt to inevitable climate change, a pivotal challenge remains: how to fundamentally change the way our species uses fossil fuels, our ways of life and our value systems that would change our scale and the pattern of demand and use of natural resources. We have also to find out how the gains of the use of fossil fuels in terms of rental flow can be used for the transition to make it cost effective. It is, in fact, high time we considered how we could transit from a fossil fuel-based system to the one based on renewable energy, the potentials of some of which are huge and can bring about with new technologies and try to draw up the road map to the Third Industrial Revolution that is talked about (Rifkin, 2011).

Chapter 2

Difference in Perspectives of the Developed and the Developing Countries:
Growth for Inclusion vs Climate Control

It is well known that an event like climate change and, in fact, any environmental degradation affects the poor and the vulnerable more adversely than the rich. Yet, there arises a great deal of tension between the developed and the developing countries at any summit on climate change in arriving at a consensus regarding the action plan for containing climate change and adaptation to it. The rich countries refuse to address the fundamental problem of global inequity and to accept the view that the issues of poverty removal and those of control of climate change have important complementarities and not fundamentally conflicting. A fast removal of poverty through high growth in developing countries would soon have high income effect on demand for higher environmental quality including environmental standards for controlling climate change and also enhancing the ability of mobilising financial resources to finance such control. However, in the stage of transition and development, developing countries have a serious choice problem of allocating financial resources between growth and environmental protection. The developed countries, on the other hand, stubbornly resist any change in their ways of life dominated by wasteful consumerism. The pre-existing capitalist market has a vested interest in keeping up effective demand for such consumerist market-promoted goods and their wasteful use, irrespective of their long-term impact on the environment due to their essentially myopic view on societal well-being.

Again, at another level as development promotes per capita income, people's social rate of discounting the future is lowered, the macroeconomic interest rate declines with decline in the marginal productivity of capital with greater scale deployment of capital, on the one hand, and decline in the rate of pure time preference on the other. This lowering of the discount rate facilitates a higher scale of investment at the level of micro-management, as it would facilitate clearances of investment projects including the ones for greening the environment through mitigating GHGs and adaptation to climate change. Lowering the interest or discount rate would contribute to the improvement of the net present value of projects as well as raise the probability of their internal rate of return (IRR) exceeding the lower discount rate. This effect of the lowering of the discount rate would, in fact, be reflected in the acceptability of a higher payback period by financiers and higher rating of such green environmental and infrastructural projects.

As both the developed and the developing countries need to realise the complementarities between high growth and the control of climate change, the moral suasion of the individual countries for coming together and taking co-operative action becomes important. We can possibly reduce the total financial needs for such a sustainable programme of development through greater international cooperation in research in the areas of science and technology, technology transfer and financial cooperation. Financial resource flow from common wealth or the global UN climate fund can release the financial resources for other apparently competing but fundamentally complementary uses for growth and infrastructure development and expansion of human capability through better education and public health services. The logic of such reallocation of global resources would be that the benefit of a climate fund would accrue to the whole global community while the national development process would largely benefit the people at country level.

We would like to elaborate here that we do not mean an 'either or' approach in our fuel choice during the transition from a fossil-fuel regime to a green-energy one. These should include both the optimum use of fossil fuel for generating the resource rent arising from their exploitation and mobilising them for investment in the development of the back-stop technology of renewables-based energy as well as in various energy conservation technologies across the carbon dioxide-intensive sectors of an economy through their modernisation. We propose the conversion of fossil assets into clean energy resource developing assets not by stopping altogether the extraction of fossil fuels but by using the capital fund created out of resource rent arising from their extraction. There should, of course, be every effort at converting the existing fossil fuels through beneficiation and other technical measures into cleaner ones for particularly generating electrical energy. Fossil fuel production and use and the development of renewable and alternative energy should occur simultaneously and in a planned co-ordinated manner, making the two tracks of the energy sector development processes complementary [See Hartwick (1977) for the conceptual foundation of such a strategy of sustainable development applicable in the context of energy-using resource rent from fossil fuel. See also El Sarafi (1994) for the required proper accounting of income from depletable resources, which would warrant such investment use of resource rental for generating income in perpetuity or benefit in terms of sustained energy supply in future].

The need for transforming the global economy and society to control climate change and clean up the environment at local and global levels has led to the development of the vision of a new industrial era based primarily on the development of renewables and hydrogen to replace fossil fuels in the electricity and the transport sector. Since the sources of the supply of renewables (particularly the new renewables, i.e. excluding large storage hydro) and the load centres of demand are widely dispersed and subject to fluctuations, the development of an energy internet of a smart grid for the flow of power from new renewables is an imperative.

Focus and Scheme of the Monograph

The discussion on the analysis of this prospect in the context of greening India's electricity sector, ending up with the presentation of a policy brief in this monograph, focuses on the potential role of the renewables in the development of India's power system. It goes into the details of resource-wise estimates of the potential of power capacity as assessed recently, their determinant factors, and the constraints or challenges in their development. It also discusses some of the cost trends and shows how the true cost of the main competing coal thermal power compares with those of such new renewable resource-based supply. It also provides some illustrative financial resource requirement on the generation side of the development of the new renewables based power. It concludes by making observations on the attainable level of penetration of the new renewables and policies that need to be in place for this purpose within the horizon of 2031-32 including the relevance of the commonwealth climate fund to achieve such goals.

Chapter 3

Role of Renewables and Third Industrial Revolution

The role of renewables has come into the focus of the discussion on mitigating a further accumulation of GHGs and controlling their resulting adverse impacts on the climate system of the planet. As the combustion of fossil fuel energy resources has been the dominant source of the emission of the major anthropogenic GHG CO_2, the mitigation of the GHG emission centred on that of CO_2 emission and the use of fossil fuel. Since the scale of using fossil fuel, in turn, depends on the scale of economic activities and the pace of growth, and since economic growth is connected with the growth of employment and the pace of poverty removal, the choice of strategy and policy for the mitigation of climate change has to take into consideration these concerns of macroeconomic development.

In order to appreciate the economy-energy-sustainability connection and explore the options to get out of the current state of unsustainable energy growth, it is important to look back very briefly at the history of development since the industrial revolution in Western Europe. The experience of the industrial revolution can be viewed not merely as a process of explosion of labour productivity facilitated by the use of machine and technology permitting the division of labour, but essentially as a process triggered by the discovery of new energy resources along with the associated transport and communication technologies which had a great revolutionary impact on the process of the division of human labour – the social organisation of production. All these had radically transformed human society by reducing spatial distance and effecting a wide diffusion of knowledge, information and technology. The first revolution revolved around coal and steam power and the second one around hydrocarbons – oil and gas – and electricity, the latter as a converted clean highly efficient energy for final use as fuel. The first industrial revolution gave us steam power and the steam engine, which led to the emergence of railways, a factory economy and steam-powered printing technology. The second industrial revolution was characterised by the discovery of the use of hydrocarbons, leading to the innovation of the internal combustion engine. This converged with the development of electrical communication. The two together brought the automobile revolution and the use of clean electric power, replacing steam power in the industry, commerce and transport. All these led further to the emergence of the power grid, telecommunication networks of telegraph, telephone, radio, television, etc., having a vast impact on the organisation and efficiency of society and economy in delivering human welfare.

Both the first and second industrial revolutions were, however, driven by the development of fossil fuels, which are non-renewable in the human time scale and involve a high intensity of pollution arising due to essentially the highly entropic nature of economic processes of production. In view of the implication of climate change, desertification, a physical and chemical degradation of soil and water bodies and air and atmospheric pollution, the concern has developed for saving the world and humanity by creating an ecologically sustainable economic order. The search and thrust of research in science and technology are now for the discovery and development of carbon-free or carbon-neutral renewable resources and that of communication technology like the Internet, which can ultimately permit phasing out the fossil fuels and GHGs and other harmful emissions altogether in a third industrial revolution. The third industrial revolution would essentially involve shifting from fossil fuels to renewable energy resources of solar, wind, geothermal, tidal, biomass, water, etc. and organising such energy production in a decentralised manner in small- and medium-scale enterprises and sharing energy output through a wide network of the energy Internet. The latter would require the development of a wide network of a smart grid aided by a wide information flow through the energy Internet and their digitised co-ordination for demand-supply matching and automated energy sharing [Rifkin 2011, The Third Industrial Revolution (en.wikipedia.org as on Oct 9, 2013)].

While clean energy production and use have been growing fast in the recent years, the world is still grappling with the problems of the second industrial revolution and resolving them mainly through focusing on the issue of energy efficiency both in its end use in the non-energy sectors (energy conservation) and in the supply of primarily electrical energy by reducing conversion loss, auxiliary loss and T&D losses. The other way by which the countries are trying to get out of the current problem of pollution and unsustainable fossil fuel use has been by reducing the share of fossil fuels (coal and oil) in gross electricity generation, and by raising that of natural gas or coal bed methane (cleanest of the fossil fuels), nuclear, micro-hydroelectricity, biomass and wastes and other abiotic renewables like wind, solar, geothermal and tidal. People are resisting the development of new hydro-storage because of its adverse impact on the river ecosystems, although it provides by itself a clean energy resource like water. The development of bio-liquids and electric vehicles has also been initiated in some countries and the governments are setting goals to support the advancement of new vehicle market.

Finally, there is also the initiative of developing carbon capture and storage technology, which would prevent the emission of CO_2 to enter into the atmosphere. Although deploying clean technologies in the first decade of the present century shows their growth rate to be varying across countries, mostly in the range of 27-56 per cent, according to the Global Carbon Capture and Storage Institute (GCCSI) data base 2011, the world is still largely dependent on fossil fuels. In the last decade, fossil fuels supplied 50 per cent of the new energy demand, oil 94 per cent of the total fuel requirement of the transport sector and non-hydro power from renewables has supplied only 3 per cent of the final energy produced in 2009 in the world.

This trend of development has resulted in the steady rise in the CO_2 emission by G20 countries and the world over the last decade. In spite of a slight decline in 2009 due to global recession, the emission level in 2010 reached a record high of 30.6 gigatonnes, 5 per cent more than the previous peak in 2008. Besides, it is to be noted that 80 per cent of the projected emissions are to come from the infrastructural investments already made. In view of this, the ushering in of a third industrial revolution as conceptualised and described above at an early date has to be induced by deliberate policy initiatives and international energy co-operation. This would be achieved mainly through energy conservation and an accelerated introduction of non-hydro renewables, and the development of the energy Internet for energy sharing through a smart grid among others.

Chapter 4

Energy Scenario in India:
Towards an Ecologically Sustainable Energy Economy

It is still really a far cry for India to reach the stage of ushering in a third industrial revolution unless it is supported by the kind of funding that would be available from some Climate Fund at the UN or, say, the Commonwealth level. While there has been the emergence of the renewables as a beginning to play a more than negligible role in supplying the growing new power demand, the most challenging task in the revolutionary era is going to be the development of the energy internet through the smart grid of power and information flow. The development of new renewables has been particularly significant as a source of off-grid power generation in remote areas as it could save substantively the transmission and distribution (T&D) cost.

India has, however, made important progress in conserving energy by raising the end-use efficiency and efficiency of energy conversion and supply by reducing losses. This has also contributed to the reduction of the carbon intensity of GDP and also to the saving of capital requirement in a capital-scarce country like India. The energy system of India primarily consists of the energy carriers – fossil fuel, hydro and nuclear resources, and biomass, combustible biomass and wastes, which are largely non-traded resources, having a share of 24.5 per cent in the total primary energy supply. There are also other new renewable resources whose current use has a relatively small share in the total energy balance, but which can emerge as significant resources in the not so distant future in India's future energy balance in view of the recent decline in their cost of investment and the trend in growth of their capacity.

The primary commercial energy supply of India has grown from 675 mtoe in 2009 to 788 mtoe in 2012, at an annual average rate of 5.29 per cent, according to the energy balance-sheets of the

International Energy Agency (IEA). The growth of electrical energy, on the other hand, grew from 980 billion KWh in 2009-10 to 1,179 billion KWh in 2013-14 at an annual average rate of 4.73 per cent, according to the Energy Statistics of the Government of India for 2013-14. The composition of the fuel mix of primary commercial energy and that of energy resource mix for the gross generation of electricity are given in the Tables 1 (for 2013-14) and 10 (for 2009), mainly based on the Energy Statistics 2015 edition of the Central Statistical Organisation (CSO) of the Government of India.

Table 1: **Composition of Primary Commercial Energy as on 2013-14 for the Entire Economy (%)**

Coal	62.75
Oil	30.05
Natural Gas	1.62
Total Fossil Fuel*	95.55
Hydro	1.90
Nuclear	1.46
New Renewables	1.08
Total Carbon free fuel	4.45
Total	100

Source: GOI 2012, Energy Statistics 2012

*Includes the share of non-utility in thermal power

The most important feature of this composition of mix for the overall energy system or the electricity generation in India has been the dominance of fossil fuels with a high carbon footprint. The driving force behind the observed pattern of growth of the power sector, which provides the major opportunity of fuel substitution, has been energy security to provide support to India's high growth of GDP and energy security to households in terms of access to electricity by supply-side initiatives in the energy industry. The relative endowments of the availability of the alternative fuels and their cost competitiveness have been the major determinants of such choice of fuel composition.

Chapter 5

Macroeconomic and Environmental Unsustainability: Pattern of India's Energy Resource Use

The Period 1989-90 to 2010-11

The high dependence on fossil fuels has, however, become unsustainable not only because of the high share of the carbon footprint in the total ecological footprint, but also because of (a) other adverse environmental externalities from which all the energy resources suffer to a greater or lesser extent and (b) macroeconomic unsustainability due to heavy financial requirements for imports of all the three fossil fuels arising from their growing eco-scarcity.

The share of imports in the total apparent consumption of coal, oil and natural gas has risen over time and reached the levels of 22.7 per cent, 78.5 per cent and 27.3 per cent, respectively, in 2013-14 due to the growth of demand outpacing supplies from the domestic sources (see Figure 1). The import prices of all the three fossil fuels have also grown in nominal dollar and rupee terms and real rupee terms over the last two decades, although recently these prices, particularly of oil, have come down sharply. In the nominal dollar and rupee terms, the import prices have grown annually over the two decades 1989-90 to 2010-11 at the respective annual average rates of 2.67 per cent and 7.06 per cent for coal, and 6.47 per cent and 14.39 per cent for oil. The import price of gas in nominal dollar and rupee terms grew at an annual average rate of 3.85 per cent and 4.51 per cent, respectively, in the period from 2004-05 to 2010-11.

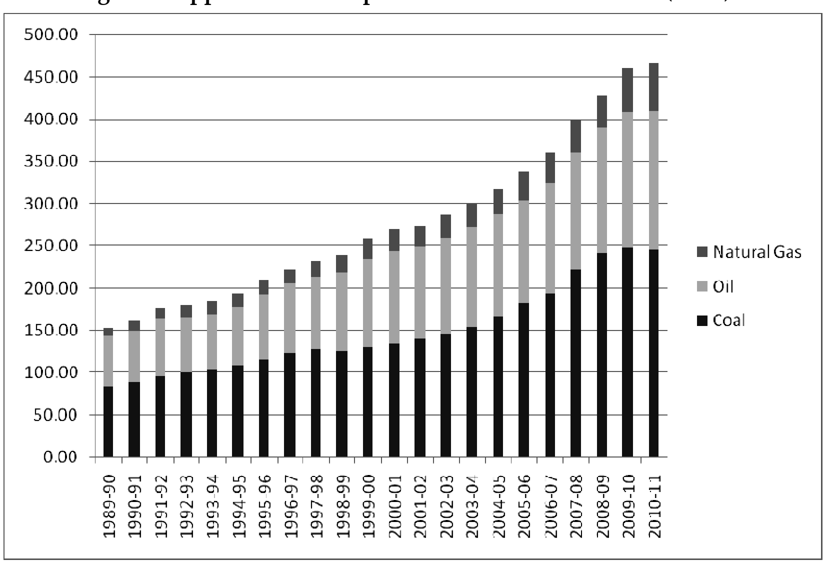
While the combined growth of net imports of fossil fuels has been 8.79 per cent per annum over the period under reference, its share in total apparent consumption has increased at 3.25 per cent per annum (see Table 2 and Figure 1). This continued growing share of physical imports continued in the post 2010-11 period as well.

Table 2 Apparent Consumption of Fossil Fuels in India (mtoe)

Year	1989-90	1994-95	1999-00	2004-05	2010-11	Growth (percent)
Apparent Consumption	153.32	193.45	258.95	318.15	466.61	5.36
Net Imports	26.85	41.63	79.80	101.86	164.35	8.79
Share of Net Imports (per cent)	17.50	21.50	30.85	32.02	35.20	3.25

Source: Author's own calculations based on energy and trade statistics from the various government data sources.

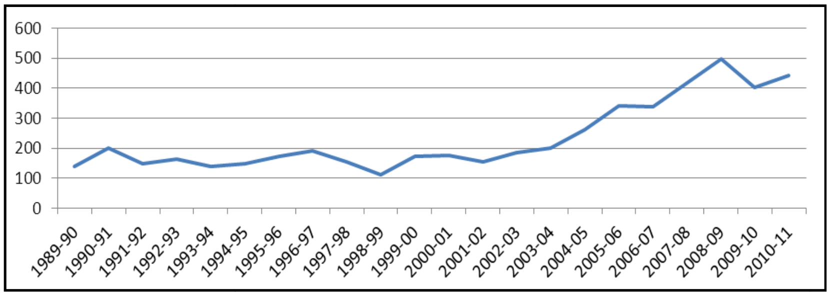
Figure 1: Apparent Consumption of Fossil Fuels in India (mtoe)



Source: Author's Own Calculations

It may be further noted that the unit price of total fossil fuels in the oil equivalent unit has increased in nominal dollar and rupee terms at 15.05 per cent and 19.92 per cent per annum, respectively [see Figure 2 (a)].

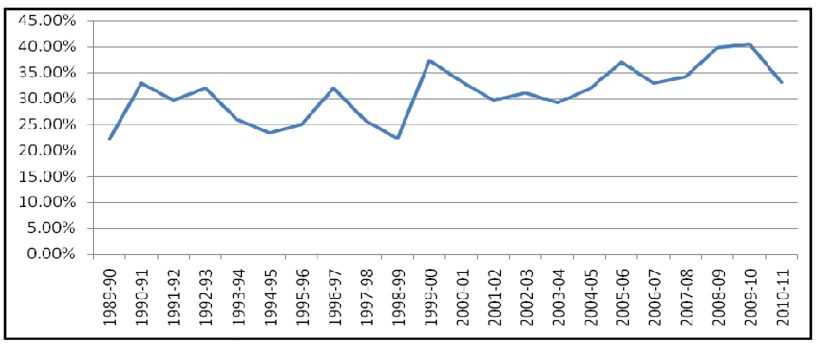
Figure 2(a): Trend of Prices per Tonne of Oil Equivalent for Fossil Fuels Combined in India



Source: Author's Own Calculations

As a result of the price rise, as indicated above, India's total net import energy bill has grown at an alarming rate of 19.92 per cent per annum in nominal dollar terms, leading to an increase of almost 55 times in the past two decades.

Figure 2(b): Percentage Share of Energy Import Bill in India's Total Exports



Source: Author's Own Calculations

As a result of all these factors, the total energy import bill has also been growing over time as a percentage of India's total export earnings, which reached 38 per cent in 2010-11 [see Figure 2(b)]. This has become a source of concern for the macroeconomic sustainability of the pattern of growth of energy use in India, particularly in view of the sharp decline in the rate of growth of IT-related service export earnings to 10 per cent per annum and of the slowing down of the inflow of foreign direct investment in recent years.

Is There Any Change in the Condition of Macroeconomic Sustainability in the Current Decade?

Post 2010-11 price and trade scenario in energy

In view of the fact that the international oil price has crashed in 2014-15, has the prospect of macroeconomic sustainability of India's energy consumption pattern changed? Table 3 shows that net imports of coal and crude oil have increased over the last four years 2010-11 to 2013-14 with 2010-11 as the base, while petroleum product exports have increased only marginally. This has meant the rise of coal and oil imports net of petroleum exports in oil equivalent unit from 148.9 million tonne in 2010-11 to 204.25 million tonne in 2013-14 at the annual average rate of 11.11 per cent per annum. The price effect of the crash of international oil prices has very likely played a role in such growth of demand to be met from import sources.

Table 3: Imports of Coal and Oil (2010-11 to 2013-14)

Year	Net Import of Coal (mill tonne)	Net Import of Crude Oil (mill tonne)	Net Import of Petroleum Products (mill tonne)	Total oil equivalent Import
2010-11	67.04	163.6	-42.26	148.9
2011-12	100.83	171.73	-44.99	167.41
2012-13	143.34	184.8	-47.63	194.33
2013-14	166.29	189.24	-51.14	204.25

However, we have not been able to generate sufficient export revenue over these years, and this has resulted in a serious problem of financing of imports of energy and a depreciation of exchange rate. Table 4 shows that while the value of net import of oil (in current Indian rupee) has increased from Rs 2,935 billion in 2010-11 to Rs 6,185 billion in 2013-14, the net non-oil export earnings from all sources has been only negative in all the years from 2010-11 to 2013-14. This indicates the seriousness of macroeconomic crisis, which got manifested in the depreciation of the dollar value of the rupee, from US$1= Rs 45.6 in March 2011 to US$1= Rs 62.5 in March 2015.

However, the redeeming feature of the currency balance situation for India has been the crash of international oil prices in 2014-15, the Brent oil price, in fact, declining from $107.48/barrel in March 2014 to $55.89/barrel in March 2015. This has caused the rupee import price of oil to decline from Rs 64.65 per barrel to Rs 34.93 per barrel i.e. by 46 per cent approximately in one year.

Table 4: Export and Import of Oil and Non-oil Traded Items of India during 2010-11 to 2013-14 (Rs. Billion)

Year	Exports		Imports		Net Import	Net Export
	Oil	Non-Oil	Oil	Non-Oil	Oil	Non-Oil
2010-11	1887.8	9541.4	4823.0	12012.0	2935.2	-2470.6
2011-12	2679.1	11980.0	7431.0	16024.0	4751.6	-4044.0
2012-13	3308.0	13035.0	8919.0	17773.0	5611.0	-4738.0
2013-14	3803.0	15156.0	9987.0	17092.0	6184.0	-1936.0

Such a sharp fall in the oil price indicates its volatility, which is the major indicator of international energy prices rather than stable low real prices of oil and energy in the international market in the coming years. Such price volatility would again point to the importance of search for the substitutability of fossil fuels like oil by other renewables. Rising coal imports as shown in Table 3 reinforce further the need for an accelerated introduction of new renewables replacing coal to have a sustained macroeconomic balance and financing of energy consumption.

The promotion of the growth of exports, including those of services, and attracting foreign investment are thus now critical for strengthening the macroeconomic fundamentals in the interests of sustaining the growth of energy use for providing energy security to a high-growth economy. It is, in fact, important that direct forest investment be guided through government policies to flow into the areas of energy conservation through modernising both energy and non-energy industries and that of new renewables-based energy industry. The macroeconomic sustainability issues and policy considerations cannot be divorced from energy security and sustainability issues in a heavily energyimporting country like India. The substitution of fossil fuels by renewables assumes, in such a context, greater significance as it would reduce the pressure of energy imports on the balance of payments of the country.

Chapter 6

Carbon Free Abiotic Conventional Energy Resources in the Road Map to Sustainable Energy for India: Hydro and Nuclear

Nuclear and hydro resources in large storage are two options that can contribute to the green development of energy. The prospect of the nuclear route of energy development depends on our success at the stage of the breeder reactor and that in developing the thorium-uranium cycle so that we can use our huge stocks of thorium reserves. The availability of a suitable site for nuclear reactors is an important constraining factor. The capacity forecasts for this sector have chronically erred grossly on the higher side than what could be achieved. Analysts at the Department of Atomic Energy have claimed that the capacity would require to be raised to 275 GW by 2052 from the current level of 4.78 GW in 2013-14 to wipe out all the shortages of power supply from all other sources together. This is unlikely to happen unless there is a breakthrough in technology development and application in the Indian nuclear industry.

The recent projections based on the current ongoing nuclear project capacities give an addition of 4.8 GW, while pre-project activities have started for 10.5 GW from domestic sources and for another 8 GW from the sources of foreign collaboration (particularly the Russian collaboration). In view of these developments, the Twelfth Five Year Plan has boldly set the target of raising the share of nuclear in gross electricity generated from 3.17 per cent in 2011-12 to 5 per cent in 2016–17 and 12 per cent in 2031-32. While it is too early to assess the situation of a successful prospect of nuclear development, we need of course to engage in trade for buying both the uranium resource and the capital equipment of light water reactor so that we are in a position to successfully experiment with the uranium-thorium reactor in the next phase of the cycle of nuclear power development.

So far as hydro energy is concerned, India has a potential of generating 150 GW from the large storage of hydro resources and another 15 GW of small hydro generation potential, according to the assessment of the Central Electricity Authority (CEA) and Ministry of New and Renewable Energy (MNRE) (WISE 2014, Chapter 11), respectively. The hydro capacity installed was, however, 40.53 GW in 2013-14. The share of all kinds of thermal power (i.e. steam, gas, diesel, etc) together in the total gross generation of power in the utility system increased from 51 per cent in 1950 to 70.6 per cent in 1990-91, 82 per cent in 2011-12, and 85.6 per cent (including the shares of non-utility) in the same year 2011-12, while that of hydro-electricity declined from 49 per cent in 1950 to 27.1 per cent in 1990-91 and 12.4 per cent in 2011-12 and 11.4 per cent in 2013-14. As non-utility, i.e. power generation has mostly been thermal based, there has thus emerged a serious imbalance of a hydro-thermal mix in the gross generation of power from the point of view of efficiency for meeting the varying load of power demand. Hydropower is, in fact, known to be the most convenient and efficient resource in meeting fluctuating peak load.

The reasons of the declining share of hydro have been due to the long gestation lag of storage dam projects and various socio-ecological constraints of such projects like displacing human settlements, degrading the ecological landscape due to inundation of the catchment and dam area, disturbances in the riverine water flow with consequent adverse impact on flora and fauna in the upstream as well as the downstream. This option is, in fact, fraught with too many socio-political and political-economic problems arising from too much disturbance in the local and regional ecosystems due to environmental externalities as well as due to the destabilisation of human settlements.

The Twelfth Plan, however, envisages a decline of share of thermal power to 61 per cent with coal at 58 per cent and gas at 3 per cent and that of hydropower marginally declining to 11 per cent. This would mean a definite expansion of the absolute size of the hydropower system in the growing capacity of the overall system. However, the decline of share of natural gas, which is the cleanest component of fossil fuels, is not satisfactorily explained in the plan document.

Chapter 7

New Renewable Energy Resources

Carbon Neutral Biomass and Combustible Wastes as New Renewables

If all the conventional sources of commercial energy resources have limitations in providing environmentally and macro-economically sustainable electrical energy supplies, we have to look for other options of biotic and abiotic renewable resources for the purpose. Biomass constitutes about a quarter of the total primary energy supply as of today in India. In 2009, the primary energy supply in the form of combustible biomass and wastes in India was 164.278 mtoe which was 24.45 per cent of the total primary energy supply. It is only a negligible fraction (0.69 per cent approx. in 2009) of such biomass including wastes that was converted into electricity. Most of such biomass fuel is used in conventional country chullah (oven) for cooking, causing problems of serious health hazards for women and children in lower-income groups exposed to such emissions.

These biomass resources themselves can, however, be converted into clean gas fuels like biogas by way of gasification in bio-digest. Such gaseous fuel can be further converted into electricity to meet the requirements of households or agricultural operations of the rural sector. It is possible to organise, for example, both family-sized and community-sized plants if a critical minimum dung of animals or other biomass can be mobilised for the plant for biogas generation, involving voluntary cooperation of all the stakeholders in an incentive compatible way (Parikh and Parikh 1977). Such biogas may be further converted into electric power at small scale for local decentralised offgrid supply in rural areas.

There are, in fact, two important biotic resources of power which need to be considered for the supply of electricity:

(a) biomass and bagasse (the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice), and (b) other wastes for conversion into electrical energy. Biomass Resource Atlas India and WISE Report 2011 (See Wise 2014, Chapter 11, Table 11.4), show that the biomass generation and its surplus potential to be 54 million tonne, and 13.9 billion tonne per year, respectively. This would permit about 18 GW of biomass power. The waste resource of bagasse from the sugar industry has an additional potential of power co-generation of 5 GW. Apart from these, the master plan of National Bio-energy Board puts further power generation potential of 386 MW of electric energy from urban liquid waste in 2012, which may go up to 462 MW by 2017 and 4,566 MW from urban solid waste by 2017. All these provide an estimate of 7.025 GW of potential power from biomass and combustible waste resources together (see Table 5).

Abiotic Source of New Renewable Energy (RE)

Finally, it is the abiotic energy resources of wind and solar radiation, geothermal heat and tidal waves, which would constitute the major energy resources in the new industrial era. Both biomass resources and abiotic wind, solar light energy and micro-hydroelectricity can provide not only to fill any shortfall of power supply from the conventional sources to meet the demand, but may constitute a major source of supply of electricity for supporting economic growth and universal access to electricity for all. The major shortcoming of our rural electrification programme for giving access to power for villagers in India has, however, been suffering from shortcomings of lack of electricity distribution infrastructure, lack of strength of the grid extended to cover villages in large areas and also inadequate supply of power to flow along the distribution infrastructure. As the generation of power based on both biotic and abiotic renewable resources can be decentralised, these technologies may permit both supply to the grid in case such generation is grid connected or can provide off-grid supply to local consumers if the grid development or extension to the concerned areas becomes infeasible due to physical or logistical constraint or high cost. The new-renewables can, in fact, be a source of not only greater energy security by providing the consumers wider access to power and thereby greater equity in its distribution but also facilitating improvement in the quality of power supply in rural India.

Solar Power Potential and the Challenges of its Realisation

As India is endowed with abundant sunshine, solar radiation has emerged as an important source of both electrical and thermal energy. Solar thermal heating of water had emerged an economically viable competitive option for quite some time in India, while the solar photovoltaic (PV) electricity had been quite costly until recently, its cost of generation varying in the range of Rs 10 to 13 per KWh. However, the cost of solar PV electricity has been recently coming down quite fast due to technological improvement through R&D and increasing deployment of solar PV technology. The KPMG report (2012) predicted that both solar PV and solar roof-top power technology would be cost-competitive with grid power by the end of the Twelfth Plan. Most parts of India, however, receive solar radiation of 4 to 7 KWh per square metre per day. As several parts of India receive good radiation, the Expert Group on Low Carbon Strategies for Inclusive Growth of the Planning Commission (See Planning Commission, 2011); set the solar potential at over 500 GW assuming 1 per cent of land area of India available for such use involving some diversion of land for the erection of solar panels.

There are other expert views like that of the World Institute of Sustainable Energy (WISE), which puts the estimate of potential in the range of 700 to 1,000 GW, assuming an additional possibility of setting up grid connected solar power capacity in several states, roof-top solar power generation and solar pumping of water facility. Unlike in the case of wind, solar power generation would, however, involve such use of land for constructing the solar panels that may cause some diversion of land use. The potential of solar power would, therefore, depends on the temporal and spatial distribution of strength of solar radiation and the land space availability for solar power for other than roof top generation, solar pumping, etc.

In order to pre-empt any problem of food security due to diversion of land use, the WISE, however, assumed, in its estimates of solar energy potential, the use of only wasteland for solar power generation. Land requirement for solar PV plants has been estimated to be 2.013 hectare per MW of installed capacity and that for Concentrated Solar Power (CSP) has been taken to be 2.43 hectare/MW of capacity. Given that solar radiation in terms of measures of Global Horizontal Irradiance (GHI) with the productivity of 5.2 KWh/m sq/day and Direct Normal irradiance (DNI) with the productivity of 4.73 KWh/ metre sq / day on the average in India, such estimates of solar irradiance or availability of light energy in short waves are supposed to provide economically viable power with potential of 851 GW of SPV power or that of 710 GW of CSP power.

We assume here that a given land can be used for either of the solar technology, but not for both at the same time. However, such estimates of solar power potential vary widely across states, depending on the land area available and the measures of solar irradiance i.e. availability of solar short wave light energy for conversion into electric power. While Rajasthan and Jammu & Kashmir have solar PV potential of 137 GW and 124 GW, respectively, West Bengal and Bihar have, on the other hand, a potential of 4.5 GW and 9.3 GW, respectively. It may further be noted here that the roof-top SPV power panels and solar pumps would be able to generate power, in addition to what can be obtained by the utilisation of waste land.

It may not, in fact, be necessary to utilise fully the waste land as a significant development potential of solar power can be harnessed by roof-top solar PV system and solar projects on irrigation canals. Gujarat recently developed a 1 MW SPV project on the Narmada canal near Chandrasan. Such projects optimise land use by putting solar panel on the land available on the banks of the irrigation canals, thereby also reducing the evaporation of canal water by 30 per cent.

The success of the Gujarat project warrants an exploration of further lengths along the banks of canals for harnessing SPV power in India. In the off-grid solar power development, the roof-top solar PV for the commercial and residential sectors and solar pump-set for agriculture are going to be the two most important applications of solar technology. The potential of the total roof-top SPV has been estimated to be 254 GWp and that of water pumps at more than 37 GWp. The recently assessed solar potential of power development as indicated in the literature is given in Table 5.

It is also to be noted here that apart from Solar PV, solar thermal technologies of concentrated solar power technologies of various kinds (like Solar Tower, Parabolic Solar Trough, Solar Dish Stirling, etc.) have been developed and are currently in practice globally, though not in India. These thermal solar power technologies essentially provide thermal energy, which can either be used for generating power by raising steam or for space and water heating transferring the thermal energy harnessed from sunlight using these technologies through heat exchangers. Since the potential of solar power and that based on other new renewables is a function of the state of technology and the extent of its deployment, which brings down the plant and equipment cost, it is an ever changing and dynamic one. Table 5 provides estimates of potential in terms of electrical power capacity as assessed by the experts on the basis of the state of technology development and costs.

A major source of constraint in the way of developing solar power potential has been, first of all, that CSP technology is not available in India. Secondly, it is the constraint of manufacturing capacity of solar photovoltaic cells, which poses a major hurdle in the way of development of SPV. We have now an annual capacity of ingots and wafer production of 15 MW, solar cells 848 MW, and solar modules of 1932 MW as in 2014 in India. In view of the target of realisation of solar PV development of 4-5 GW by 2017 and the ultimate high potential of SPV development of 852 GW in the long run, the equipment manufacturing sector for the SPV and innovations in the development of more efficient solar cells made out of new materials in a larger scale would require high priority in financial resource allocation and policy thrust in providing right incentives for such development. While solar cells are being currently made of materials like thin film silicon or materials based on Cd-Te, etc., the newly emerging cell technologies are being based on new materials like Gallium arsenide, organic semiconductors, Dye - sensitised cells, and nanotechnology solar cells which have higher technical and cost efficiency. Promoting new material based cell technology is imperative for India's utilisation of the full potential of SPV power.

Wind Energy Potential and Challenges of its Development

Wind energy potential depends on the strength of wind flow and the hub height of the wind tower at which the wind energy can be harvested. India has a long coastline of more than 7,600 km where wind flow is favourable for wind power generation. Such power can be generated both onshore and offshore. For wind energy, the estimates of potential would obviously depend on the hub height and the spatial distribution of strength of the wind flow and that of its power generation potential per unit of land area across different regions of India, although generation of wind power in a land area does not cause any major land use diversion. While the Eleventh Plan document shows the wind power potential to be 45,195 MW as assessed for March 31, 2007, this has been reassessed by the Centre for Wind Energy Technology (C-WET) to be 49,130 MW in 2010 at 50 m hub height, with 9 MW/km^2 land requirement and 2 per cent of land availability for such purpose for all states other than the Himalayan ones and 0.5 per cent land availability for others. The Lawrence Berkeley Laboratory gave separate independent estimates to be 2006 GW at a 80-metre hub height and 3,121 GW at a 120-metre hub height and higher land availability in the range of 7 per cent to 11 per cent in various states of India. For a higher capacity utilisation factor with greater than a 25 MW unit, the potential would, however, be in the range of 543 GW to 1,033 GW. The offshore wind potential can further provide an additional 15 GW at less than 60-metre hub height in India.

We present in Table 5 the potential of such power capacity based on wind and other renewables based on the estimates of various expert groups and its cumulative achievement till March 2012 along with their respective capacity utilisation factors. In spite of all the limitations of the new and renewable energies, the total potential of generation of electrical energy from such sources is thus really huge while only a miniscule fraction of it has been really exploited.

The geographic distribution of wind energy potential is quite unevenly distributed over space, season and the time of the day. Tamil Nadu and Gujarat have a substantial share of the potential of wind power of the country, which was originally underestimated by the C-Wet and officially published statistics. While TERI estimated Gujarat's onshore potential to be 1,162 GW at an 80-metre hub height, taking the availability of both crop and non-crop land together for setting up wind power installations, WISE, on the other hand, estimated Tamil Nadu's wind power potential using the GSI-based approach to be 196 GW at a 80-metre hub height. These two states would thus generate around 1,300 GW at the full utilisation of their onshore potential, which is many times higher than what Table 6 shows i.e. just 15 GW. Besides, India has a long coastline of 7,600 km, where wind flows make abundant wind energy resource available. The relatively low labour cost along coasts makes offshore power generation a favourable option; the high cost of offshore construction, on the other hand, pushes up the cost.

So far as the equipment manufacturing capability is concerned, India has emerged as a manufacturing hub of wind energy equipment, with a number of foreign firms participating in the industry here. At present, the industry has a consolidated production capacity of equipment for the development of 11,000 MW. In future, the size and capacity of wind turbines are expected to go up while the size of the existing units remains relatively low. The turbine capacity in India ranges between 225 KW and 2,500 KW, compared to 7,580 KW as the global maximum. The hub height ranges in India from 41 metres to more than 120 metres, the global maximum being 135 metres. The rotor diameter ranges between 28 metres and more than 110 metres, the global maximum being 127 metres. As larger-sized plants and equipment are deployed in the future, the equipment efficiency is expected to go up and cost of both installation and generation per unit of gross generation of electrical energy is expected to go down, making the wind option further competitive.

It is further expected that innovations in wind turbine technology, both onshore and offshore, would continue to take place the world over to reduce material requirement for plant and equipment, making them lightweight and raising the life of equipment and improving the operation of the control system of the plant. A greater development of skill and knowledge of wind turbine manufacturing and operation is also important to drive further the dynamics of wind energy in the renewable energy industry.

Overall Potential of New Renewables and Green Electrical Energy

As already mentioned in the light of the discussions in the preceding sections, we have chosen to present the figures of Table 5 as the currently assessed potential, which may increase in future because of the dynamic nature of the whole concept of potential as argued above. These have been drawn from WISE (2014). The estimates of the potential of wind and solar power, which we have used for our further analysis as given in Table 5, do not include the

CSP potential of solar power and are based on only SPV potential on the assumption that certain land cannot be used for both the types of solar technology, namely, SPV and CSP. The estimate of solar potential goes up to 1,050 GW, according to WISE 2014, if we allow land to be shared between the two technologies, although we have not used these latter estimates for our future projections as the CSP technology is not available in India. Besides, WISE 2014 has presumed the offshore wind energy potential to be 380 GW, which we have ignored because of high costs and risks associated with its development as a reliable energy source. The estimates of potential new renewables-based power and green power have been accordingly taken to be 3,254 GW and 3,404 GW, respectively (See Table 5). We have further provided the investment and generation costs of all the technologies for estimating the financial resource requirements and assessing the relative competitiveness of the different technologies although these are undergoing changes on the lower side for the renewables over time.

Table 5: Potential of Green New Renewable Power Potential GW

Technologies	Potential GW	Capacity Factor	Generation Billion KWH	Cumulative Capacity GW March 2012
SPV	850	0.2	1489.2	1.579605
SPV pump & panel over banks of canal	322	0.2	564.144	
Wind onshore	2006	0.25	4393.14	15.864622
Wind offshore	15	0.25	32.85	
Biomass	18	0.6	94.608	3.99187
Cogeneration from bagasse	5	0.6	26.28	
Waste to energy	7	0.6	36.792	0.078368
Other sources: geo thermal & ocean	16	0.2	28.032	
Small Hydro <25 MW	15	0.2	26.28	2.975535
Total new renewables	3254		6691.326	24.49
Large Hydro >25 MW	150	0.2	262.8	38.99
Total Green Power	3404		6954.126	643.48

Source: WISE (2014)

*The table does not show the roof top solar power potential of 254 GWP and concentrated solar power (CSP) of 710 GW as separate items.

Chapter 8

Natural Resource Requirements of the New Renewables and Pressure on Eco-systems

We have generated, later in this monograph, different scenarios of electrical generation in future based on a model with the twin objectives of (a) providing energy security to India's growth process, and (b) fast greening of India's power sector. To combine two objectives, we have considered alternative fuel-mix for power generation in the different scenarios. In view of the much higher impact of coal thermal power vis-à-vis the options of new renewables any increase in the share of new renewables effected through policy initiatives has been balanced by a corresponding decline in the share of coal thermal generation of power. In this context, we have reviewed not only the comparative environmental impact of coal vis-a-vis new renewables, but also reviewed the true socio-economic cost of coal thermal power, which is substantially higher than its financial cost. Our model of the latter section is based on this comparatively high physical impact of coal thermal power and higher true cost of coal than the financial one. We, therefore, digress below to review the comparative requirements of natural resources and the environmental pressure on the ecosystems of the different power generating technologies and the true cost of coal.

Land Use

All modes of power generation involve some use of land, which is a scarce and politically most sensitive natural resource today in India. However, the land requirement of coal thermal projects has been substantively greater than that for the new renewables-based power generation technologies. The saving of land requirement by switching to renewables from coal thermal is an important environmental benefit of such fuel substitution. The land requirement would vary between 0.25 hectare and 0.4 hectare per MW of coal thermal power generation for the project site itself. Given the projected growth of capacity addition of 66.6 GW in the five-year period 2012-17 to that of 158.6 in the Fifteenth Plan period 2027-32 (assuming 8 per cent growth in capacity per annum), the total requirement of land for acquisition over this 20-year period would thus be varying in the range of 19,647 hectare to 46,703 hectare in the respective periods as worked out by WISE 2014. These do not include any share of land requirement for coal mining and transportation for supply of coal to the power plant. The renewable energy-based generation has, on the other hand, much less land use when we compare the total life cycle requirement for the different technologies. Besides, renewable energy-based generation does not cause any irreversible damage of land as in the case of mining and land can be re-used after the life of the project in 25 years, with the same level of primary productivity as earlier.

Besides, unlike coal thermal generation, abiotic resource-based power generation, solar or wind have no environmental impacts like those of emission, deforestation, or damage to crops, grasslands or forests, and no additional lands like coal-handling at ports, transport, townships, etc. As renewable energy-based generation like wind or solar is modular, it does not require contiguous pockets of land. Rooftop solar generation or solar pump sets would not require additional land. Even if we think of scaling up solar or wind generation, we may focus on harvesting the resources of solar radiation or wind at a large scale for conversion into electricity in areas where they are more abundantly available. For example, the environmental and social cost of solar power development in arid and semi-arid areas would be low where population pressure is low and the opportunity cost of land-use diversion is also low due to low primary productivity of land in such areas. In the case of wind, one has to identify location, season and timing of the day with abundant wind flow onshore as well as offshore, which may have a low opportunity cost in terms of diversion of land-use, warranting scaling up of wind generation.

It may also be noted that as modern IT permits the operation and maintenance of such renewable energy technology projects from a distant location, no additional land is required on a significant scale for housing and the attendant infrastructure. Besides, as renewable energy generation takes place in small and dispersed units, there is no requirement of large-scale acquisition of land, involving diversion of its use and ownership, which might become a source of social tension (WISE 2014).

Impact on Water, Forests and Pollution

The renewable energy-based generation of power – based, particularly, on solar and wind – does not require any significant amount of water as compared to coal thermal. Wind power is water-neutral, while water is required for cleansing solar PV panels. But such requirement is small except in desert areas where dust storms pollute the panels.

While the coal-based thermal projects get delayed because of the constraint of forest clearance for developing linked mines, there is no environmental impact on forests for solar or wind-based generation if these projects are located outside the forests as these have no externalities of pollution, noise or thermal effects, creating any damaging impact on wild-life and habitats. In case any such projects are developed inside a forest, the adverse impact may be controlled by the conditions of the grant of forest clearances. In the case of wind turbines, there would be some requirement of such clearances for transporting of large blades and heavy-duty cranes for the setting up of or dismantling the plant. The counterpart requirements for setting up the solar PV panels are minimal or negligible. The environmental impact of any large solar thermal electricity projects for power generation would also be of a much smaller order as there would be no requirement of transportation of energy resources such as coal or evaluation of waste like fly ash or hot water. Besides, renewable energy-based technologies can supply power to forest-based commodities through micro-grids, which would have no adverse impact on the forest eco-system.

Air Pollution

Finally, the renewable energy-based technologies have no environmental impact through air pollution in the case of solar PV, solar thermal, wind or small hydro. In the case of biomass combustion or gasification based power generation, there would be some adverse impact on air quality. This can be controlled if there are non-overlapping areas of biomass supply. Besides, there are technologies like bio-methanation, which have far lower particulate emission as in the case of natural gas-based power generation.

Saving of Financial Costs as Relative Advantage of RE Technologies vis-à-vis Coal Thermal

One of the major environmental-cum-financial benefits of substitution of fossil fuels by new renewables is going to be in the form of substantive reduction in the requirements for transporting fossil fuels by railways and road transportation and, therefore, substantive saving of capital investment for the development of mines, railways, ports, etc. that would have been otherwise required. Besides, the secondary fuel requirement of oil for the current 116,000 MW of coal thermal power generation yielding 693 billion units of electricity requires an expenditure of Rs 6,300 crore per annum only on oil at the assumed subsidy rate of diesel at Rs 45 per litre, while the renewables do not require any such subsidiary fuel. The savings out of such costs of transport and oil are, in fact, important benefits of such substitution, which are not recognised, in the current methodological practice of cost-benefit analysis. This becomes particularly important when the pricing of oil and railway tariffs contains substantive subsidy elements since the tariff of power based on such subsidised input prices would not reflect the true cost of the concerned technology.

Chapter 9

How to Compare the True Resource Costs of Technology Options?

The correct methodology for the choice of technology among alternatives does, in fact, require the comparison of the true socio-economic costs of power generation, i.e. the one that does not contain any hidden subsidy and internalises all costs of environmental externalities over the lifetime of the projects, which are substantive in the case of coal vis-à-vis any RE technology. It is, in fact, the stream of net differences between the true costs of coal thermal and any competing alternative RE technology, which is to be considered as the stream of net savings of costs or net benefits arising from the technology substitution over the life of the project. The net present value of the stream of such cost savings at an assumed rate of discount (say 10 or 12 per cent) is going to be the deciding criterion of the merit ordering between the two. By all such binary merit comparison, we can finally arrive at the complete merit ordering of all the RE options along with the coal thermal technology, the latter being the dominant generation technology of power in India today.

Hidden Costs of Subsidy of Thermal Coal

The real challenge here involves the estimation of both the hidden subsidy in coal thermal power and in the replacing technology, on the one hand, and the costs of environmental and social externalities of the different power generation technologies on the other. The subsidies in a technology route may take the forms of under pricing of the fuel input, capital subsidy, tax waiver, or concessional tax rate on capital equipment, etc., by way of government intervention and regulation (e.g., price control) in the fuel, finance capital or equipment market, or into the other markets of sectoral products linked through input-output relationships. As the range and forms of subsidy – direct and indirect – is quite large in India it is a difficult task to ascertain the hidden subsidies precisely. The World Institute of Sustainable Energy (WISE), Pune made an attempt to calculate the hidden subsidy for 19 thermal power projects in India (WISE 2014).

The method of calculating hidden subsidy was to calculate (a) the levelled cost of generation of power without internalising any benefit of subsidy, (b) adjusting for the monetised value of all incentives levelised for the unit of generation of power provided by the central and state governments, and (c) finally, comparing the total cost of generation without internalising any benefit of subsidy with the actual cost of generation of power with the impact of subsidy as per the books of account. The difference between the two would provide an estimate of the hidden cost of subsidy per unit of generation. The levelled cost of the Kota thermal power station was, for example, found to be Rs 2.63/KWh, as per the actual internalisation of benefits of subsidy per unit of generation and escalated to Rs 3.08 with its internalisation. The subsidy was thus estimated to be Rs 0.45 per unit of generation for the project at a 10 per cent discount rate for Kota. The same was found to be Rs 0.94 per KWh of gross generation of energy for the Talcher Super Thermal Power Plant. For the 19 power projects of the WISE study 2014, the weighted average subsidy was estimated to be Rs 0.68 per KWh of gross generation. For the current installed capacity of coal thermal power generation, the total amount of hidden subsidy would work out to be Rs 561 billion per annum or US$ 10 billion per annum without taking any share of subsidy to the railways for coal transportation.

Costs of Environmental Externalities

Beside the cost of hidden subsidy, the internalisation of the cost of environmental externalities is another important step for arriving at the true comparative costs of the various technological options of power generation including the coal thermal and the renewables. The monetisation of environmental damage cost is difficult because of the non-traded character of eco-services whose gain or loss is to be captured in such costs of externalities. In recent years, some international studies like Extern - E (Bickel and Friedrich 2004) made some progress in this direction particularly in the context of power generation. Paul Epstein and his co-authors showed the methodology of working out the costs of environmental impact over the entire life cycle of coal from the stage of coal mining, extraction, transportation, washing and combustion for power generation causing damages to the landscape, massive deforestation, degradation of air quality due to emissions of methane, NOx, SO_2, PM 2.5, CO_2 and mercury and other carcinogenic emissions. Besides, there would be damage to the local hydrology due to the arising of effluents containing sludge and drainage of other highly acidic wastes.

All these externalities are identified as per Extern - E methodology and then classified into three categories: (a) quantifiable and monetisable, (b) quantifiable but difficult to monetise, and (c) finally those which are qualitative. Different methods are employed for estimating these damage impacts of the different types. These impacts are further grouped into two groups: (i) impacts of use of energy resources in power generation on climate, and (ii) direct impact on public health. The cost implications of these two types of impact in value terms of loss of income or asset are worked out which are finally internalised to obtain the true resource cost of power generation. All public health impacts due to mortality are to be estimated using the mortality adjusted statistical value of life (SLV). Similarly, the public health impact due to increased morbidity is to be estimated by the disability adjusted life expectation and statistical value of life. Since accidents in mines and coal transportation and increased morbidity due to health hazards to which mine workers are exposed are to be recognised in the social cost of power generation, these estimates are to be based on the risk of accident or morbidity to which workers are exposed and the SLV. Since the mortality risks are particularly uncertain, there has to be high and low estimates of such elements of social cost. Epstein and his colleagues have found the estimate of the cost of environmental externalities of coal thermal power generation in

US$ 2008 to be 17.8 cents / KWh or INR 8.39 per KWh as a point estimate in the entire range of possible variation from Rs 9.36 / KWh to Rs 26.89 / KWh. In the Indian context, Shukla and Mohapatra (2008), on the other hand, estimated such costs of externality only due to air pollution and water pollution in coal thermal power generation over the life cycle of coal which is Rs 3.15 per KWh, the components of air pollution and water pollution damage costs being Rs 2.09 and Rs 1.09 per unit of KWh, respectively.

There is, however, a wide variation in the estimates of such studies on the costs of externalities because of the variations in assumptions depending on the country or case specificities of the plant or project context. However, there is a broad agreement among the results of the different studies in respect of the dominance of the cost of health, as it has been found to be the single-largest element in the total cost of externalities.

It is, however, to be noted that the above estimates by Epstein and his colleagues (2011) suffer from the limitations of assigning numerical values to non-monetisable impacts, choice of discount rate in the valuation of eco-system damage, etc. Such imperfections are, however, inevitable. The greater the volume of data available for a wide range of case-specific situations, one can make a better choice of the cost-price factor in the context of evaluating a specific new project and for ascertaining the true cost competitiveness of coal vis-a-vis other renewables-based technology.

However, as an illustration of the application of methodological principle of obtaining the true cost of coal thermal generation, which can be used as a benchmark for the assessment of the relative merit of any new renewables-based generation technology, we may point out that such a normative benchmark price of coal-based power tariff should be the sum of the following three components:

(a) A base tariff of power comprising the fuel cost including the conventional fixed and variable (mainly fuel) cost on a normative basis. (See Table A5 in the Appendix for the details of assumptions and the tariffs for alternative assumptions of blend of the domestic and imported power grade coal).

(b) Hidden cost of subsidy at the alternative discount rates.

(c) Cost of externalities.

Assuming a range of coal blend varying between all domestic coal and 90 per cent of imported coal in the blend, we obtain the estimates of tariff ranging between Rs 3.78 /KWh and Rs 5.86 / KWh in the Indian context. The cost of hidden subsidy, as estimated by the WISE 2014 for a set of Indian coal thermal projects, has been found to be in the range of Rs 0.45 per KWh and Rs 1.55 per KWh for private sector plants at a 10 per cent discount rate weighted average estimates being Rs 0.58 per KWh. From the study of Epstein *et al* (2008) we obtain, on the other hand, the cost of externalities of a coal thermal plant to be lying in the range of Rs 4.43/ KWh to Rs 12.65/KWh. The true socio-economic cost is thus estimated to be lying between Rs 8.79 and Rs 19.09 per KWh. The component of the cost of environmental externalities thus constitutes a major share of 50-66 per cent of the economic resource cost of power generation (see Table 6).

It is nothing surprising that a comparison of the range of variations of true cost of coal thermal power with the normative cost of generation based on new renewables as given in Table 23 makes it clear that the new renewables-based power technology should be the preferred social choice as it involves lower socio-economic resource cost. The major reason behind this true cost competitiveness of renewables based power is the opportunity of saving of substantive costs of externalities and of the hidden subsidies of coal thermal generation that is offered by such substitution of technology. This clearly emphasises the need for a new policy direction in reducing our dependence on coal for power generation and raise the share of the new renewables in the gross generation of power.

Table 6: True Cost of Coal Thermal Power

Range of Genuine Cost of Coal Thermal Electrical Energy

Items of C	Lower Limit	Upper Limit	Mean Value (unweighted average of min. & max.)
Share of imported coal (per cent)	0	90	
Variable cost (Rs/KWh)	2.2	4.2	
Fixed cost (Rs/KWh)	1.58	1.66	
Total estimated cost based tariff (Rs/KWh)	3.78	5.86	4.82
Variable cost as per cent of tariff	58.2	71.67	
Hidden cost of subsidy on sample observation of 19 power projects (private ownership basis), discount rate 10 per cent, (Rs/KWh)	Min. over sample	Max. over sample	
	0.45	0.94	0.695
Cost of externality (Rs/KWh)	4.40	12.64	8.52
Total true cost (Rs/KWh)	8.63	19.44	14.035

Assuming 1 cent = Rs 0.47 (wherever conversion was required to be used).

The tariff estimates of the above table have been estimated on the basis of the assumptions given in Appendix Table A5.

One may, however, argue that the quoted costs of renewables based on the tariffs fixed by the Central Regulatory Commission may contain some hidden costs of subsidies in these emerging technologies. While there may be some elements of hidden subsidies in the new renewables-based power generation, the costs of environmental externalities are supposed to be negligible at least in the case of abiotic resources of wind, solar and as well as micro hydroelectricity. It is only the biomass-based power generation that would involve some externalities which are still likely to be quite small as compared to coal thermal because of the advantage of carbon recycling in the case of the former.

Chapter 10

Present Technology Scenario of the Power Industry of India

The landscape of the power industry and its growth in the era of post-liberalisation and economic reform is depicted in Table 7. In the first decade of this century, when the Electricity Act of 2003 was passed and the new electricity policy was issued by the Government of India, an institutional framework was provided for the creation of large capacities in thermal, gas and hydro projects. Coal was allocated for captive use to such large plants. The civil nuclear deal with the US facilitated the prospect of growth of large-scale nuclear capacities as well. All these were premised on the fast growth of the power sector based on conventional energy resources and technology so that the requirement of faster economic growth for poverty removal could be provided the energy support (see Maithaini and Gupta, 2015).

As Maithani and Gupta (2015) correctly observe, such growth along the conventional route faced serious problems over these years, due to environmental and forest clearances, infrastructure and logistical constraints, lack of adequate financial resource flow – particularly bank credit, increasing costs of imported fossil fuel energy, and a popular perception of high accidental and health risks of nuclear power particularly in the post-Fukushima incident eras. People's resistance made, in fact, the choice of politically acceptable locations quite a difficult task. All these have caused slippage in the actual realisation of the targeted growth in power capacities in the Tenth and Eleventh Plans. While the government of India is addressing these issues, the challenges are likely to be constraining the growth in the current plan as well. The main source of difficulty, as we notice below, has been the inadequate availability of the concerned primary resources of fossil fuels and people's resistance against both hydro and nuclear projects for environmental reasons. Before going into the discussion on possible future relative roles of the conventional and the new renewable resources over the time horizon up to 2031-32, we now have a look at the capacity structure and resource-wise composition of the electricity industry for working out the roadmap towards a radically different capacity and technology structure of the Indian electricity industry as would be envisaged by the Third Industrial Revolution.

Table 7 gives the distribution of the installed capacity of the Indian electricity industry across technologies in March 2012 and March 2014 showing their recent pattern of growth, while Figure 3 shows the technology-wise composition of such capacities as on March 2014. It is important to note that the installed capacities of both thermal utility power and grid-interactive renewable power reached the level of 200 GW and 31.7 GW, respectively, both improving their respective shares to 70 per cent and 11.1 per cent in the total installed power capacity of the country as on March 2014. Of the total renewable power capacity, which is mostly grid interactive power, the major share has been that of wind energy amounting to 65 per cent, followed by biomass and bagasse and waste which had a share of 15 per cent, the share of small hydro has been about 12 per cent only and solar PV had the lowest share of around 8 per cent, at the end of March 2014 (see Table 8b and Figure 4).

This scenario is, however, fast changing due to a substantive fall in cost of solar PV power and it is becoming competitive with conventional resource-based grid power. This is reflected in the fact that solar power capacity grew at the rate of 56 per cent between March 2013 and March 2014, while the capacity of both wind and biomass and combustible waste based power increased at the rate of 11 per cent approximately in the same one-year period. The small hydroelectricity capacity grew at a moderate rate of 4.7 per cent in that year. As a result, both capacity and the gross generation of new renewables-based power grew at 12-13 per cent in that year (see Table 8a).

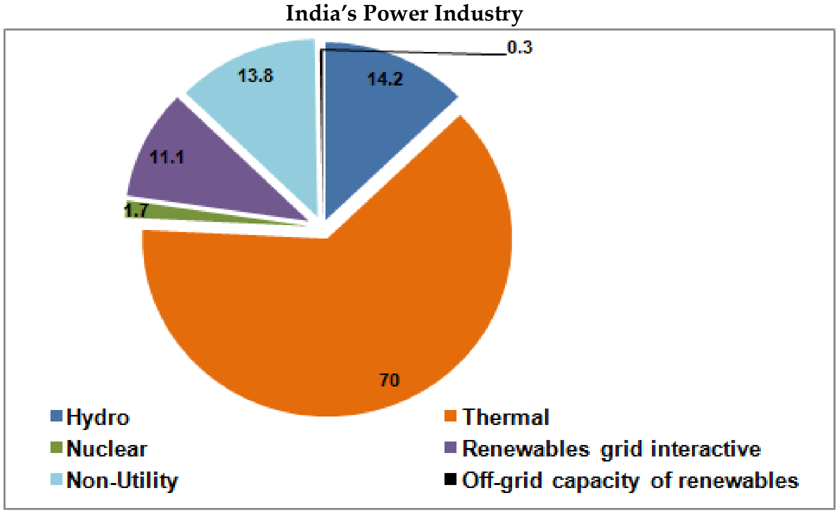
Table 7: Installed Capacity of India's Electric Power Industry (GW)

Sector and mode	March 2011-12	Share in March 2011-2012	March 2013-14	Share in March 2013-2014	CAGR 2005-06 to 2013-14
Total Utility (a+b+c)	199.96	84.3	245.259	85.9	7.84
(a) Hydro	38.99	16.4	40.531	14.2	2.55
(b) Thermal	131.70	55.5	199.947	70.0	9.46
(c) Nuclear	4.78	2.0	4.780	1.7	3.99
(d) Renewables grid interactive	24.49	10.3	31.692	11.1	13.70*
Non-Utility	36.50	15.4	39.375	13.8	6.97
Total installed capacity (incl. grid interactive)	236.39	99.6	284.634	99.7	
Off-grid capacity of renewables	0.90	0.4	0.900	0.3	
Grand Total	237.30	100.0	285.534	100.0	7.72

* Cumulative Annual Average Growth Rate (CAGR) for 2011-12 to 2013-14.

Source: GOI 2012, Energy Statistics 2013, 2014, 2015 and GOI 2012, 2013, Twelfth Five Year Plan and other Planning Commission Sources

Figure 3: Source-wise Composition of Installed Capacity of India's Power Industry



In any case, the pace of progress of introducing new renewables to replace fossil fuels has been very slow till now.

Apart from the high costs of such technologies, the lack of entrepreneurship in the deployment of such capital and technology, lack of institutional support at the grassroots level, poor focus on training and management for using and maintaining such new technologies and the lack of awareness of rural community have been important additional barriers to progress in this direction. This is why we believe that climate funds like the one of Commonwealth Climate Fund, as proposed, can be a valuable instrument in accelerating the pace of such progress.

Table 8a: Growth of Installed Capacity of New Renewables Power in GW

Resource	March 2012-13	March 2013-14	Growth rate (per cent) 2012-13 to 2013-14
Biomass	3.6	4.0	11.4
Waste to Energy	0.1	0.1	11.5
Wind	19.1	21.1	10.9
Small Hydro	3.6	3.8	4.7
Solar	1.7	2.6	56.1
Total Grid interactive	28.1	31.7	12.9
Off grid power	0.9	0.9	0.0
Grand total new renewables	29.0	32.6	12.9

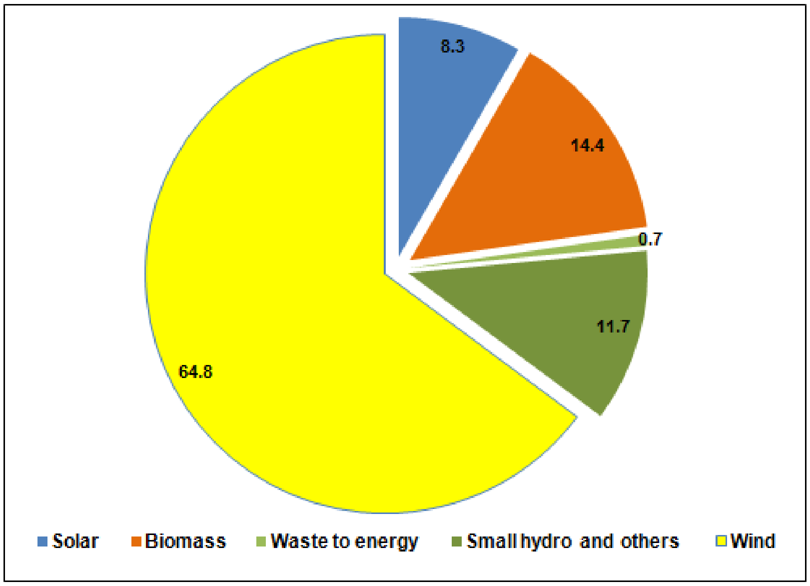
Source: Energy Statistics, Government of India 2015

Table 8b: Total Installed Capacity and Resource-wise Composition of the New Renewables in India in GW

Resource	Grid in GW, March 2014	Off-grid in GW, March 2014	Total in March 2013-14 (in GW)	Share in March 2013-14
Solar	2.632	0.085	2.717	8.332822
Biomass	4.013	0.695	4.708	14.43906
Waste to energy	0.107	0.132	0.239	0.732994
Small hydro and others (aerogen hybrid systems)	3.804	0.002	3.806	11.67270
Wind	21.136		21.136	64.82243
Total	31.692	0.914	32.606	100

Source: Energy Statistics, 2015

Figure 4: Resource wise Composition of New Renewables Based Installed Power Capacity



Chapter 11

Projections on Primary Commercial Energy Requirements and CO_2 Emissions of India in the Long Run

Objectives and Assumptions

In view of the potential of power generation by the alternative resources of solar, wind and other new renewable energy technologies, we now would like to find out how fast India can achieve the transformation of its energy economy with the objectives of achieving: (a) energy security for supporting India's high and inclusive growth and to provide universal access of people to electricity; (b) macroeconomic sustainability by reducing the import dependence of India's energy sector; (c) environmental sustainability and sharing the moral responsibility of saving the planet.

We have developed a simple econometric-cum-spreadsheet model of projection of future energy scenarios of India for the terminal years of 2021-22 and 2031-32, giving the requirement of gross generation and installed capacity of electrical energy, based on the different resources and the associated financial requirements for such transformation. The model is based on assumptions regarding realisable targets of new renewables to replace fossil fuels taking into account India's potential of new renewable resources, on the one hand, and India's experience and current state of development of such renewables-based energy technology on the other. However, the answer to the moot question will finally depend, among others, on the financial resources that may be available from the various Climate Funds and other sources.

Indeed, as we shall see, the infusion of project-based capital from the various climate-related fund sources will accelerate India's development, so that it evolves into an environmentally sustainable system to support 8 per cent GDP growth rate. At the same time, the international funding will help India to approach the goal of raising the share of new-renewables to 17.7 per cent or green power to a level of 30 per cent share by 2031, according to the business as usual scenario and a second scenario of accelerated introduction of new renewables raising its share to 30 per cent by 2031 and that of green power (i.e., including that of large hydro share) to 43 per cent of gross generation requirement.

The latter scenario will, in fact, permit India to attain a share of green power to 75 per cent by 2050. While the business as usual scenario is based on the National Action Plan on Climate Change, as resulting in the current pace of penetration of new renewables, the second scenario represents a policy-driven scenario of accelerated introduction of new renewables in power generation in view of their potentials and the ability to realise them, as discussed earlier. In our generation of scenarios of projection, these alternative assumptions have been further combined with real energy price increase (at the rate of 0 or 3 per cent per annum) over the real price level of commercial energy as in the base year of 2009. We have thus ended up with four scenarios of electrical energy development for these combinations of assumptions, as given in Table 9.

Table 9: Scenarios of projections of commercial energy requirements in the form of electricity for 8 per cent GDP Growth rate with base year 2009

Item	Description
Scenario 1: Baseline or BAU	0 per cent annual rise in real energy price, baseline share of new renewables in the gross generation of electrical energy
Scenario 2	3 per cent annual rise in real energy price over the base year, baseline share of new renewables in gross generation of electrical energy
Scenario 3	0 per cent annual rise in real energy price over the base year, accelerated introduction of new renewables in gross generation of electrical energy
Scenario 4	3 per cent annual rise in real energy price over the base year, accelerated introduction of new renewables in gross generation of electrical energy.

Development of a projection model based on such combinations of assumptions or scenarios, as described above, involved the use of the results of an econometric model of sectoral energy demand behaviour, which is supposed to be a function of in real energy price and the concerned sectoral income or sectoral GDP. On the supply side, higher efficiency in the electricity industry has been assumed for the different time horizons especially in respect of transmission and distribution. Besides, the alternative scenarios of fuel mix for the gross generation of power reflected such different shares of the carbon free new renewable resources for power generation that any increase in the share of the new renewables is off-set by an equivalent decline in the share of coal thermal power generation. Such substitution of fuel resources is justified specially on the ground of true high cost of coal thermal power (see Tables 13 and 14). Table 15 further gives us the composition of gross generation of the new renewable electrical energy – like solar, wind, biomass based power, etc. for any of our scenarios of projection.

We have, in fact, targeted 35 per cent share of new renewable in 2031-32, in view of the consistency with the presumed attainability of 15 per cent share by 2021-22. The latter is justified by the recent experience of accelerated fast growth of capacities, particularly in Solar PV and Wind leading to a share of 6.65 per cent for the new renewable in gross generation of electrical energy of India in 2013-14. We have based our projection of shares in the total gross generation of the four main types of new renewables: (i) solar PV, (ii) wind, (iii) biomass and (iv) small hydro and others within new renewables in their total gross generation of electrical energy for future up to 2021-22 on their respective relative growth of capacities between 2012-13 and 2013-14, which had been 56 per cent for solar PV, 11 per cent for wind and biomass, and about 4.7 per cent for small hydro-electricity and others, as given in Table 8(a). It has been further assumed that while solar and wind capacity would be added by +2GW each year between 2021-22 and 2031-32 (following an idea of Maithani and Gupta 2015), the capacities of biomass and micro hydroelectricity based power would continue to experience the same relative growth of capacities as experienced up to 2021-22 in the following ten-year period up to 2031-32. These assumptions along with the respective capacity utilisation factors led to the shares of individual technologies in the gross generation requirement of renewables-based power for the two terminal years as presented in Table 12. Figures 5(a), 5(b) and 5(c) show how the energy resource mix of gross generation of electrical energy would change between 2009 and 2031-32 as per scenario 1 and 3 and also as per scenario 2 and 4.

Table 10: Technology-wise Gross Generation Mix (%) (Scenario 1 and 3)

Year	Gross Gen BU	Coal (%)	Gas (%)	Oil (%)	Hydro (%)	Nuclear (%)	Renewable (%)
2009	979.87	70.00	11.50	1.70	13.00	2.30	1.50
2021	1537.28	60	14.00	1.30	13.00	2.30	9.40
2031	2577.99	50	16.00	1.00	13.00	2.30	17.70

Table 11: Technology-wise Gross Generation Mix (%) (Scenario 2 and 4)

Year	Total BKWh	Coal (%)	N.Gas (%)	Oil (%)	Hydro Storage (%)	Nuclear (%)	Renewables (%)
2009	979.87	70.00	11.50	1.70	13.00	2.30	1.50
2021	1537.28	54.40	14.00	1.30	13.00	2.30	15.00
2031	2577.99	32.70	16.00	1.00	13.00	2.30	35.00

Figure 5(a): Technology-wise Composition of Gross Generation of Electricity in India 2009 (in shares of billion units)

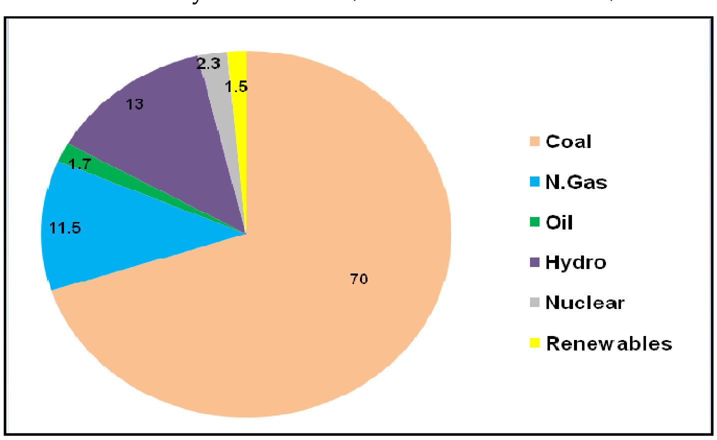


Figure 5(b): Projected Technology-wise Composition of Gross Generation of Electricity in India 2031 (Scenario 1 & 3), in shares of billon units

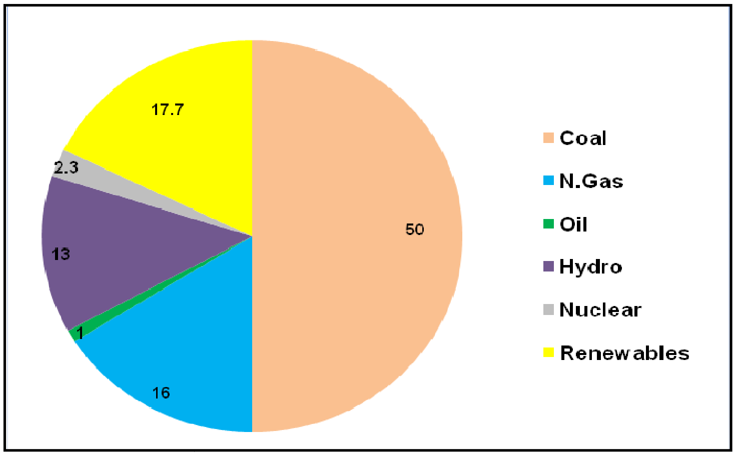


Figure 5(c): Projected Technology-wise Composition of Gross Generation of Electricity in India 2031 (Scenario 2 & 4), in shares of billion units

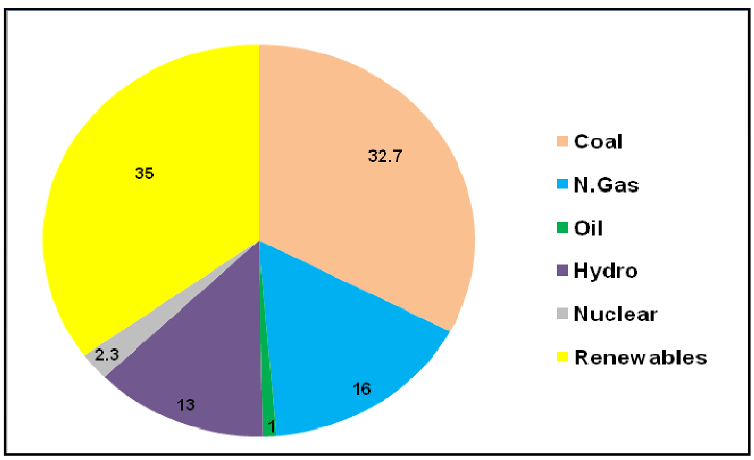


Table 12: New Renewable Resource-wise Gross Generation Mix (Per Cent All Scenarios)

Year	Total BKWh	Solar PV (%)	Wind (%)	Biomass (%)	Small hydro, etc. (%)
2009	14.70	3.10	56.27	30.91	9.71
2021	230.59	50.00	32.00	15.00	3.00
2031	902.30	38.00	29.00	30.00	3.00

Model based Projections of Different Future Power Energy Scenarios and Role of the New Renewables

The Model and Results of Future Gross Generation Requirements of Electrical Energy in India and CO_2 Emissions

We have presented the econometric model of final energy demand at sectoral level and also its results in units of MTOE in the Appendix of this monograph (see Table A1 of the Appendix). As the derivation of sectoral demand depends on the sectoral pattern of growth, the model assumed the elasticity of sectoral GDP with respect to aggregate GDP in its top down approach as given in Table A2 sectoral GDP. In order to derive the demand of final energy in the form of electrical energy, the appendix gives the assumptions along with its basis regarding the growth of the share of electricity in the total final energy use by the different non-energy sectors (see Table A3). Finally, the Appendix also provides the assumptions of the growth of supply side efficiency over the time horizon up to 2031-32 as given in Table A4, which are considered feasible to attain as per the report of the Expert Group of the Integrated Energy Policy of Planning Commission of 2006.

The demand for electrical energy as per our sectoral econometric model aggregated over sectors would lie between 2.057 trillion and 2.577 trillion units by 2031-32, of which the share of new renewables would vary between 364 billion KWh and 902 billion KWh (see Table 18). The installed capacity requirement for such new renewable power is, in turn, projected to lie between 193 GW (Sc.1) and 381 GW (Sc.3) across the scenarios in the terminal year 2031-32, which should be perfectly feasible to install in view of the fact that the potential of new renewables at the present stage of technology development has been assessed by the experts to be 3,404 GW. The results of the econometric model of demand projection as discussed in the Appendix yielded the total final energy demand as aggregated over the sectors and that of final energy in the form of electricity for the different scenarios and the different terminal years for 8 per cent GDP growth are presented in Tables 13 and 14 respectively. Table 15 provides the final energy intensity of GDP as implicit in these projections.

Table 13: Total Final Energy Demand. mtoe

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En. price rise and Accld. Renewables
2009	246.1	246.1	246.1	246.1
2021	437.80	361.50	437.80	361.50
2031	768.10	526.70	768.10	526.70
CAGR (%)	5.31	3.52	5.31	3.52
GDP elast.	0.66	0.44	0.66	0.44

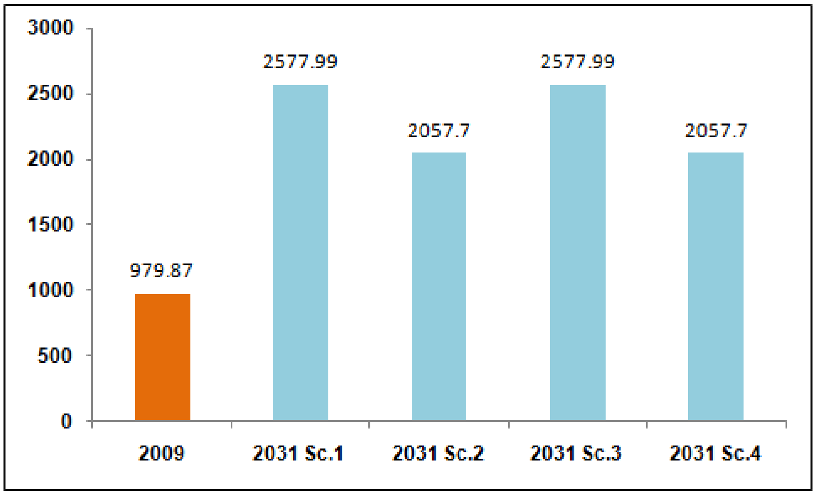
Table 14: Total Final Electricity Demand, Billion KWh

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En. price rise and Accld. Renewables
2009	650.00	650.00	650.00	650.00
2021	1229.00	1084.00	1229.00	1084.00
2031	2111.00	1684.00	2111.00	1684.00
CAGR (%)	5.50	4.42	5.50	4.42
GDP elast.	0.69	0.55	0.69	0.55

Table 15: Commercial Energy Intensity for 8%GDP Growth Scenarios

Year	Real Price of Energy Index Change of 0 per cent	Real Price of Energy Index Change of 3 per cent
2009	0.066	0.066
2021	0.047	0.039
2031	0.038	0.026

Figure 6: Total Gross Generation Requirement of Electricity in Billion Units



These results strongly indicate that India is already moving along a final energy-saving growth path. These further show the growing potential of energy conservation in the end-using sectors in future that are likely to be realised, if the present sector-specific behavioural relationship of electrical energy consumption particularly with growth of sectoral income or GDP and real energy price facing a sector remains unchanged. We shall observe later in the following discussions the impact of such energy conservation potential through real price change for energy and its implications in respect of CO_2 emissions at the macro level.

Given the growth of supply side efficiencies, as assumed in the Appendix, the projections of final demand for electrical energy as given in Table 14 for 8 per cent GDP growth further yield the projections of Tables 16, 17, 18 and 19. They present, respectively, the total requirements of Gross Generation of electrical energy, those based on conventional resources and technologies, new renewable resources and directly on Wind and Solar energy resources only. Figure 6 gives the total gross generation requirement for 2009 and for the terminal year 2031-32 for all the scenarios.

Table 16: Total Gross Generation Requirement of Electricity (in BU)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc 2 Real En. Pr. Rise 3 per cent	Sc 3 Acc ld Renewables	Sc 4 3 per cent Real En.price rise and Accld. Renewables
2009	979.87	979.87	979.87	979.87
2021	1537.28	1326.25	1537.28	1326.25
2031	2577.99	2057.70	2577.99	2057.70
CAGR (%)	4.50	3.43	4.50	3.43
GDP elast.	0.56	0.43	0.56	0.43

Table 17: Total Conventional Gross Generation Req. of Electricity, Billion KWh

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En. price rise and Accld. Renewables
2009	965.17	965.17	965.17	965.17
2021	1392.78	1201.58	1306.69	1127.31
2031	2121.69	1693.49	1675.69	1337.51

Table 18: Growth of New Renewables Gross Generation Requirement, Billion KWh

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	14.70	14.70	14.70	14.70
2021	144.50	124.67	230.62	198.96
2031	456.30	364.25	902.39	720.27

Table19: Growth of Wind and Solar Generation Requirement, Billion KWh

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	9.302	9.302	9.302	9.302
2021	118.490	102.227	189.085	163.147
2031	310.284	247.665	613.562	489.782

The issues relating to energy security and environmental sustainability lead us further to enquire into the implications of the above projections in respect of CO_2 emission as well as the requirement of total installed capacity and financial resources for investment. We have worked out both the current CO_2 emissions and lifecycle CO_2 emissions in any particular terminal year as per the different scenarios. The coefficients of current and life cycle CO_2 emission of power generation as per the different power generation technologies are indicated in Table 20. The norms for current CO_2 emission have been assumed as per CEA norms, while for that of life cycle emission coefficients the IPCC norms have been assumed. The current CO_2 emissions and life cycle CO_2 emissions of gross generation of electrical energy as per these assumptions are presented in Tables 21 and 22 for the different scenarios for different terminal years.

Table 20: CO_2 Emission Coefficients – Current and Lifecycle Emissions

Technologies	Emission	Lifecycle
Coal	1.04	0.82
Gas	0.6	0.49
Oil	0.66	0.49
Hydro	0	0.024
Nuclear	0	0.012
Solar PV	0	0.048
Wind	0	0.012
Biomass	0	0.23
Small hydro, ocean, geothermal	0	0.024

Source: IPCC 2014, and Energy Statistics 2014, GOI

Table 21: Total CO_2 Emission in Million Tonne

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	629.151	629.151	629.151	629.151
2021	876.812	756.448	806.220	695.547
2031	1280.477	1022.051	914.764	730.146
CAGR (%)	3.283	2.230	1.716	0.679

Figure 7: Total CO_2 Emission in Million Tonne

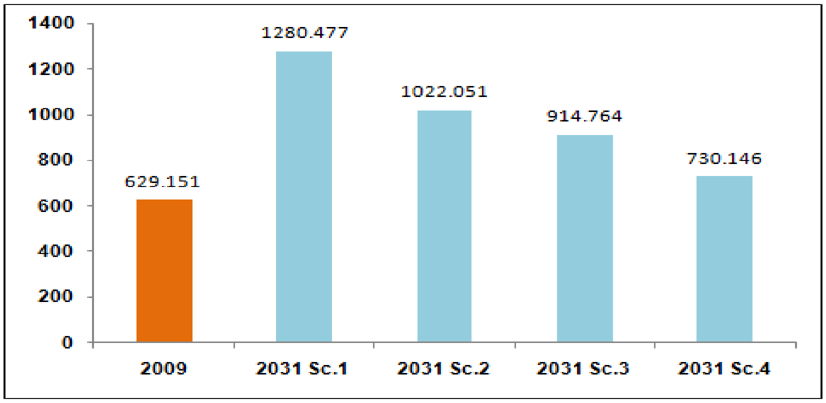
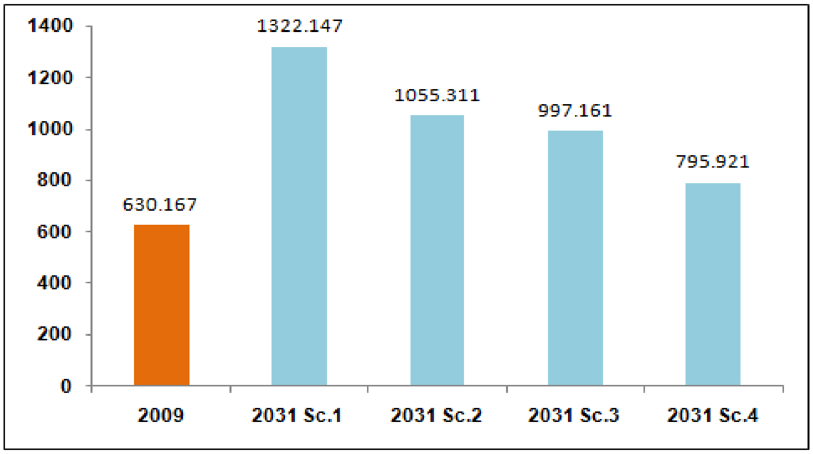


Table 22: Total Life Cycle CO_2 Emission in Million Tonne

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	630.167	630.167	630.167	630.167
2021	885.924	764.309	820.761	708.093
2031	1322.147	1055.311	997.161	795.921
CAGR (%)	3.426	2.371	2.108	1.067

Figure 8: Total Life Cycle CO_2 emission in Million Tonne



As per the projections of the study as outlined above, the total current CO_2 emission, which is thus supposed to be responsible for the carbon footprint, would rise from around 629 million tonne in 2009 to somewhere in the range of 730 (Sc.4) to 1280 (Sc.1) million tonnes in 2031-32 for 8 per cent GDP growth depending on the assumptions of the other policy variables of real energy pricing, and the share of new renewables in the fuel mix of power generation, etc. However, it is important to note that the CO_2 emissions out of generation of electrical energy only are thus projected to grow at an annual average rate lying between. 0.679 per cent (Sc.4) and 3.283 per cent (Sc.1) for the different scenarios (see Table 21).

So far as the abatement of CO_2 emission is concerned, the substitution of coal by new renewable, as per our results of projection, has been found to be marginally more effective than raising the real energy prices. However, if we combine the rise in real energy price with the raising of the share of new renewables, it can reduce both the absolute level of CO_2 emission from 1280 million tonnes to 730 million tonnes in 2031-32 and the annual growth rate of current CO_2 emission from 3.283 per cent (BAU, Sc.1) to 0.679 per cent per annum (Sc.4) (See Table 22). Table 22 gives the life-cycle emissions for all the scenarios for the same terminal years showing similar trends of change (see Figure 8).

Projected Requirements of Installed Capacities of Generation of Power and Financial Resources

For any given scenario of our projection, the requirement of installed capacity would depend on the capacity utilisation factors, which vary across energy resources and technologies. The capacity utilisation factor further varies widely for the new renewables because of the uncertain time distribution of availability of energy resources vis-à-vis that of load demand. These capacity utilistion factors of the different technologies have been assumed to be as given in Table 23 and used for the purpose of projection of the installed capacity requirement for the different scenarios in the different terminal years. These are reported for the total system, new renewables based generation and for the sub-system of solar and wind power in Tables 24, 25 and 26. The implications of these capacity projections in respect of financial resource requirements for the build-up of the capacity over the time horizon 2012 to 2022 as well as from 2012 to 2032 have been respectively presented in Tables 27A & 27B, 28A & 28B and 29A & 29B in the units of INR Thousand Crores and US dollar Billions separately. The investment cost per unit of generation capacity for the various technologies and their levelled generation cost, which have been used for estimating these capital resource requirements have been presented in Table 23. While Figures 9 and 10 have shown the capacity requirements of the total system, and those of solar and wind only, in view of the growing relative importance of the latter among the new renewables over the period 2009 to 2031-32 for all the four scenarios. Figures 11 and 12, on the other hand, depict the picture for the subsystem of solar and wind power.

Table 23: Investment Cost and Generation Cost

Technologies	Capacity Utilization Factor	Capital Cost INR/MW, 2012	Capital cost in US$ million/MW, 2012	Unit cost of Generation Rs./KWh	Unit cost of Generation US cents/ KWh
Coal	0.8	6.75	1.25	2.57	4.75
Gas	0.7	3.24	0.60	2.78	5.15
Oil	0.7	2.16	0.40	2.81	5.20
Hydro	0.2	8.10	1.50	4.46	8.25
Nuclear	0.6	8.10	1.50	2.16	4.00
Solar PV	0.2	11.50	2.13	11.42	21.15
Wind	0.25	5.75	1.06	4.85	8.98
Biomass	0.6	4.20	0.78	5.32	9.85
Small hydro, ocean, geothermal	0.2	6.60	1.22	4.21	7.80

Source: WISE 2014, Energy Statistics, US Energy Information Administration, 2019 levelled Cost, Annual Energy Outlook 2014 the cost of Solar is now much lower than as indicated in this Table.

Table 24: Growth of Total Capacity Requirement, GW

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	199.960	199.960	199.960	199.960
2021	359.719	310.340	388.515	335.192
2031	650.702	519.379	775.440	618.971

Figure 9: Growth of Total Capacity Requirement, GW

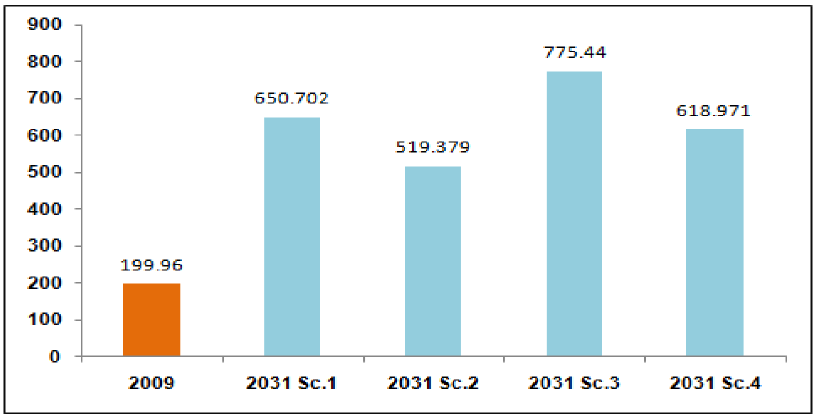


Table 25: Growth of Capacity Requirements of New Renewables, GW

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	24.490	24.490	24.490	24.490
2021	68.951	59.487	110.031	94.937
2031	192.729	153.834	381.107	304.222

Table 26: Growth of Capacity Requirements of Wind and Solar Power, GW

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2009	17.444	17.444	17.444	17.444
2021	62.353	53.795	99.502	85.853
2031	161.476	128.888	319.306	254.889

Figure 10: Growth of Capacity Requirements of Wind and Solar Power, GW

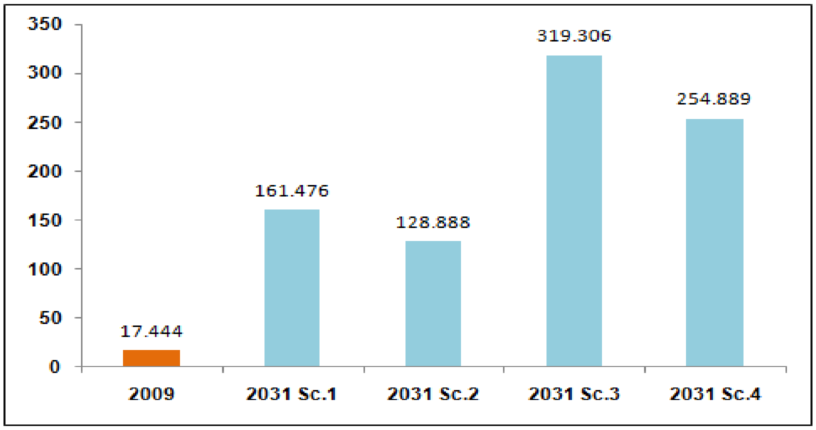


Table 27a: Requirement of Funds for Total Capacity Build-up (INR Billion)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	13157.830	9536.650	16044.860	12421.160
2012 to 2031	3446.278	2487.502	4620.969	3508.627

Figure 11: Requirement of Funds for Total Capacity Build-up, 2012-31 (INR Billion)

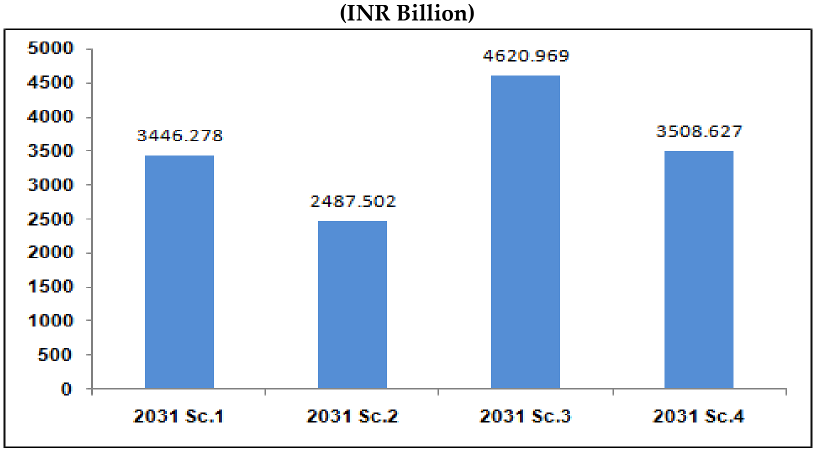


Table 27b: Requirement of Funds for Total Power Capacity Build-up (US$ Billions)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	243.664	176.605	297.127	230.021
2012 to 2031	638.200	460.648	855.735	649.746

We want to make it, however, clear that these projections are not predictions of India's future energy scenario, but represent certain alternative energy scenarios which may be considered to be quite feasible for India to attain under reasonable conditions in view of, particularly, the very high potential of abiotic new renewable resources that exist as indicated in the above sections.

These model results solution would also indicate that how low carbon and environmentally sustainable India's growth and energy development can be possible within the time horizon up to 2031-32 depending, mainly, on abotic new renewable energy resources of wind and solar.

Table 28a: Requirement of Funds for New Renewables Capacity Build-up (INR Billion)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	4864.88	3968.06	8581.10	7203.51
2012 to 2031	14952.02	11639.62	30994.66	24447.00

Table 28b: Requirement of Funds for New Renewables Capacity Build-up (US$ Billion)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	90.090	73.483	158.909	133.398
2012 to 2031	276.889	215.548	573.975	452.722

Table 29a: Requirement of Funds for Wind and Solar Power Capacity Build-up (INR Rs Billion)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	4862.62	4045.10	8411.46	7107.54
2012 to 2031	13881.72	10859.45	28519.16	22545.02

Figure 12: Requirement of Funds for Wind and Solar Power Capacity Build-up (INR Rs Ten Billion 2012-31)

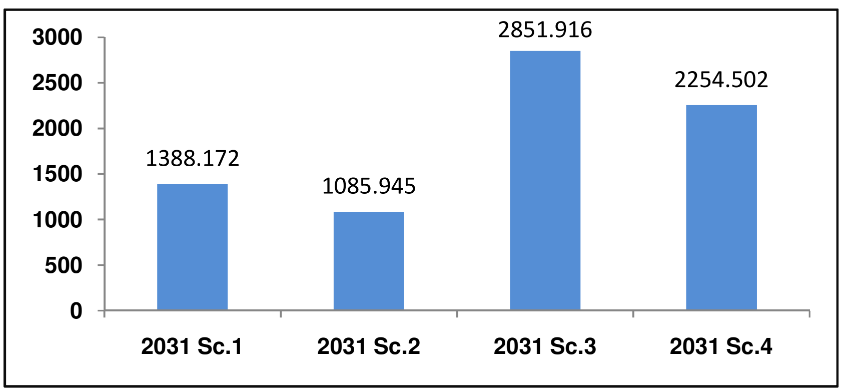


Table 29b: Requirement of Funds for Wind and Solar Power Capacity Build-up (US$ Billion)

Year	Sc 1 Base line: No En Price rise and BAU share of Renewables	Sc2 Real En. Pr. Rise 3 per cent	Sc 3 Accld Renewables	Sc4 3 per cent Real En.price rise and Accld. Renewables
2012 to 2021	90.049	74.909	155.768	131.621
2012 to 2031	257.069	201.101	528.133	417.500

One issue may, however, be raised regarding the technical and project implementation feasibility and financial viability of such pattern of growth of electrical energy in the Indian context as it contains a large component of addition of power capacity based on the new renewables. Such capacity addition is projected to be in the range of 35 GW to 86 GW over the time horizon up to 2021-22 and in the range of 129 GW to 357 GW for the time horizon up to 2031-32 depending on the scenario from the base capacity of 24.5 GW in 2012. The corresponding financial requirement for such generation capacity creation over the time horizon up to 2031-32 would vary in the range of 1164 to 3100 thousand crore of INR or 216 to US$ 453 Billion. On the other hand, this would lead to the saving of life time CO_2 emission in the range of 267 to 526 million tonne and that of current CO_2 emission in the range of 258 to 550 million tonne depending on the scenario.

It may be pointed out here that the estimated projections of financial resource requirement, as given in the Tables 27a and 27b to 29a and 29b, represent only the requirement of generation investment for the purpose of building up the required installed capacity and do not include any share of the financial resource requirement of the corresponding required strengthening of the transmission and distribution system. The latter would be inevitably involved as smart grid development is almost a basic prerequisite of the development of the new renewables due to variability of both the load demand and instantaneous supply of such non-storable renewable resources like wind and solar. Besides, our cost projections of the different scenarios do not include the share of investment for energy conservation, which is supposed to follow any real energy price increase. India has, in fact, a huge potential of electrical energy conservation at low price, which needs to be realised.

However, the projection of investment requirement for the build-up of generation capacity should not as such pose any big constraint in these days of globalisation and global capital crossing national boundaries with much greater ease. The real challenge would, however, arise in attracting entrepreneurship and funds in particular choice option of generation technology due to low credit rating of many of such projects in India at least to begin with. Such rating may be affected not only by risk involved due to technology and business environment of the project, but also by the macroeconomic and country level policies in the context of attracting foreign capital.

To overcome such constraints, it may be important to develop new initiatives for alternative sources of finance like regional infrastructural banks, multilateral banks, and climate funds like the one proposed in this monograph. Apart from direct financing of electricity projects based on renewables, these sources may help the concerned projects by extending credit enhancing facilities by appropriate guarantee or counter-guaranteeing the rating enhancement.

Chapter 12

Conclusion

Policy Brief: Challenges of Generation and Transmission of Power in the Era of Renewables-based Power

What further is required to introduce a big bang change in fuel policy for generating electricity by making a structural shift in technology in favour of new renewable resources? Large Solar and wind capacities need to be created for faster transformation of India's fossil fuel based electricity industry into a green one. The development of new renewables would require large-scale availability of financial resources of the order of US$ 450 billion (Sc. 4) over a 20 year period. The requirement of energy conservation following the real energy price rise, as envisaged for the concerned scenario, has also to be made available from the financial system to make the full potential of life-time CO_2 emission saving of the order of more than 500 million tonnes vis-à-vis the BAU Scenario 1 in 2031-32.

In the area of R&D for technology development, what is required is a policy thrust in favour of development of CSP and offshore wind energy development in the Indian context. India needs to accelerate her manufacturing capacity of equipment for new renewable technologies and also give high priority to human resource development for the new RE industry through wider introduction of new renewables technology education as these are of crucial importance to make the potential of RE capacity of India to be realizable. However, the major challenge for faster RE penetration in the Indian power industry would mainly relate to the following in the area of Transmission and Distribution:

(i) Reconfiguring, restructuring and upgrading the Indian power grid.

(ii) Grid balancing for meeting the high demand for power intensive industries like steel, aluminium, cement, paper, railway traction etc, with major energy resource of new renewables, which would require firm supply from large point sources of hydropower and natural gas.

(iii) Grid-scale energy storage.

(iv) Upgrading the Indian grid as smart one for automated coordination for smooth two-way flow of electricity and information regarding power demand and capacity. It is also required for the relevant coordination and integration of the different activities of the sector across regions and state boundaries in the context of transmission of power and coordination of flow of power dispatches from the various junctures.

(v) Strengthening of the information system for energy for every 15 minutes or minute-by-minute power demand and availability of power capacity and basic RE resources. While the existing power system is quite geared to making load forecasting and managing supply accordingly, the forecasting of supply from fluctuating and uncertain sources of wind and solar energy, which all pose challenges on demand-supply management.

The efficiency of operation of such a system involving renewables would depend on the choice of models for forecasting on the supply side. There are not only the problems of uncertainty but also of accuracy in the prediction of the new supply side variables. The larger the area of such forecasts and shorter the time horizon of forecast (gate closure time), the higher is generally the accuracy of the forecast.

The development of RE with the utilisation of its full potential would thus require development and strengthening of the power grid and transmission system of India, as per the above listing, in order to achieve better planning for dispatch and coordination of power flow. Such complementary requirement of development on the T&D side would require financial resources on the top of the above projection of US$ 450 billion over the 20-year horizon. Climate fund can step in to provide support to such requirements.

Although it has often been argued that the RE technologies offer the opportunity of decentralised off-grid production and supply, but such opportunities may often be highly inadequate for realizing the full potential of wind and solar energy in India, in view of the divergence between the spatial distribution of high load centres and those of potential sites of RE plants. Both the developments of smarter grid for evacuating grid connected RE over long distances as well as development of storage technologies for local distribution are necessities for greening our electricity industry. It is, however, important to realize what are the constraints or barriers in the ways of achievement of the goals of the Third Industrial Revolution by way of substitution of fossil fuels by carbon-free or carbon-neutral energy resources and how to remove them. This substitution is not to be viewed as a short-term objective but a long-term one by way of converting resource rent of the extracted fossil fuels into capital assets, as repeatedly emphasised in the monograph, created for the development of knowledge and infrastructural capital and new kinds of plant and equipment.

Besides, one major issue, in this context, would be the cost effectiveness of the transition to the new industrial order through the technological and socio-economic transformation. As new renewables-based technologies would be knowledge intensive and as the patented knowledge market is highly imperfect and monopolistic, the capital cost may become finally quite high, standing in the way of cost effectiveness and the distribution of capitalism in the new order. So far as the inclusiveness of the development process is concerned, wide sharing of knowledge, transfer of technology and control of price of the knowledge capital by governmental intervention become important for both the sharing of benefits of the new industrial revolution between the rich and the poor and between the developed and the developing countries. International cooperation among member UN or Commonwealth countries in joint research on science and technology and in sharing and transferring technologies across borders would only enable the developing countries to leapfrog to a higher stage of development characterised by the new order. The intellectual property right regime would be of critical importance in such knowledge sharing and delivering the R&D output to the users at affordable prices and in converting the knowledge into a global public good at the earliest. The financial cooperation through UN or Commonwealth Climate Fund would be such arrangement as catalytic for such required cooperation.

Concluding Remarks

The combined objective of growth for poverty removal and climate stabilisation by appropriate mitigation measures inevitably leads to a big challenge of setting up large new capacities in new renewables to ensure their substantively larger share in gross power generation to replace coal through the transformation process, as discussed, in the long run. The target addition to capacities for new renewables only as implied by the projections of Table 25 would be in the range of 170 GW to 280 GW (approx.) as per base-line Business As Usual scenario 1 and the most CO_2 emission abating scenario 4, the corresponding financial resource requirement being in the range of US$ 280 to 450 Billion for setting up only the generation capacity over the 20 year period. These requirements of fund do not consider any share of financial resource requirement for energy conservation in the non-energy sector and that of transmission and distribution for the required strengthening of the grid. Some critics may consider such targets to be infeasible and impractical. There is some basis for such charges in view of the political economy of India, which throws up the challenge of going by political consensus on decisions relating to economic and environmental matter in a large pluralistic society governed by its political democracy as given by the Indian Constitution. However, the admission of these charges would amount to giving up the continually stated policy objectives of the Government of India of growth for poverty removal and sharing the responsibilities of climate stabilisation through evolutionary transformation of fossil fuel regime into that of clean carbon-free one in the power industry. In fact, this is not a challenge which can't be met as argued and illustrated above if there is political will, and consensus on technical and financial cooperation at the global or regional or at sub global level like the Commonwealth. The world has enough savings to finance such requirements of a large developing country like India, the largest emitter in Commonwealth.

However, the issue would be: how to begin and who is to take an initiative. All these require moral suasion and cooperation among the member countries of any network believing in the broad objectives of such development. Hence, the fossil fuel rich country like Canada (particularly its vast energy reservoir province of Alberta) can take a role in moral leadership and initiate a process of setting up a fund through a severance tax imposed on fossil fuels. This would raise the prices of fossil fuels inducing some energy conservation as well as enable mobilisation of financial resources for the climate fund. The fund can be set up at an appropriate mechanism of the deployment of such resources for supporting the candidate projects on generation, transmission and distribution and some on electricity conservation.

We have provided an example of such candidate projects from India. If the idea is acceptable, it would require further detailed work on the design of such climate fund for both financial resource generation and its devolution for effecting the transformation of fossil fuel wealth into new kind of carbon fuel technology and energy producing asset. This requires a new initiative and leadership towards a world free of poverty and carbon related pollution, which is the goal of the Third Industrial Revolution.

Appendix

A Basic Model of Demand Analysis and Projection: The Income and Price Model of Energy Demand

For analysing the energy consumption behaviour at sectoral level and overall economy level, we pose a simple model, which assumes that demand for energy (EDD^i) of each sector i of the economy is a function of its income (I^i) and the real energy price (RPE^i) it faces. The partial income elasticity of demand and the partial price elasticity are assumed to remain constant over the projection period. This gives us a demand function of the form:

$$EDD^i = A(I^i)^{\alpha}(RPE^i)^{\beta},$$

$$i = \ Overall\ economy, industry, \ldots residential$$

Here, α, is the income elasticity of energy demand

β, is the price elasticity of energy demand

A, is the technology parameter

α, β and A are constant over the entire projection period.

For the purpose of econometric estimation, the above model can be transformed into a double log linear model of the form:

$$\log\,(EDD_t^i) = \log(A) + \alpha * \log\left(I_t^i\right) + \beta * log(RPE_t^i) + \varepsilon_t^i$$

$$i = \ Overall\ economy, industry, \ldots residential$$

ε_t^i is the random error component and conforms to the assumptions of the classical regression model.

Data and Sources

The econometric estimation of the model for the overall economy and for each sector requires data on energy demand, GDP that indicates the level of income or value added and the real energy price index. The nominal energy price is calculated using the fuel shares and the corresponding WPI of fuels faced by a given sector or by the aggregate economy. The real energy price is calculated by deflating the nominal price by the GDP deflator. The Private Final Consumption (PFCE) is used as an indicator of income for the residential sector. The model is estimated using data from 1990-2009. The data for energy demand is obtained from the Energy Balances of the non-OECD countries published by the IEA. The data for GDP and PFCE are obtained from the National Account Statistics, and the data for WPI prices are obtained from the RBI database and the website of the Office of the Economic Adviser.

Estimation

The standard time series techniques cannot be applied since data for only twenty years are available, which are inadequate for the purpose. The model is estimated using the method of Ordinary Least Square (OLS) and the standard errors are adjusted for auto-correlation and hetero-elasticity using HAC standard errors and co-variance by Newey and West. A dummy for the years of post-2004 period has been included in the models to account for a level shift in the data, which is possibly due to certain changes in methodology in energy consumption calculation by the IEA. Each model is initially run with both the dependent variables and the dummy. If, however, a variable is found to be insignificant, then it is dropped and the model is re-estimated. The model specification and estimated coefficients are given in Table A.1 in the Appendix. The Table further gives the partial GDP elasticity of electricity demand and the partial price elasticity for each sector as derived therefrom.

Table A.1: The Estimates of the Basic Model for Partial GDP Elasticity (α) and Partial Price Elasticity (β) for Final Energy Demand

Sector	Estimate of partial GDP elasticity (α)	Estimate of partial price elasticity (β)
Overall Economy	0.7 (0.00)	-0.51 (0.00)
Industry	0.4 (0.05)	-0.6 (0.00)
Transport	0.97 (0.00)	-1 (0.00)
Agriculture	1.95 (0.00)	-0.51 (0.016)
Other Services	0.63 (0.00)	-
Residential	Pre-2004 (0.72)	-
	Post-2004 (0.5)	
[-] used when the coefficient is insignificant		

Source: Author's Own Calculations

Energy Intensity Projections

Once the models have been estimated, the projections can be made if we have the values of the independent variables. The projections are made taking the year 2009-10 as the base. The projections using the Basic Model are made assuming two growth scenarios and two price scenarios. The growth scenarios assumed are one with 8 per cent GDP growth rate from 2010-2046 and the other with 6 per cent GDP growth rate from 2010-2046. The sector wise GDP projections are made by calculating the elasticity of sector wise GDP with respect to the overall GDP of the economy and then finding the corresponding growth rates of the sectoral GDP according to the various scenarios. The Appendix Table A2 gives the overall GDP elasticity of sector wise GDP or PFCE for the respective 5 sectors including the residential one based on the data for the period from 1990-2009 and also provides the sector-wise growth rates for 8 per cent GDP growth rate scenario. The text Table 16 provides the projections of the total final commercial energy demand using the sectoral GDP growth projections as per Table A2 below and the real energy price as per the assumptions of the concerned scenarios over the time horizon up to 2031 -32.

Table A.2: Elasticity of Sectorial GDP or Income with respect to Macro GDP and the Sectorial Growth Rates GDP or PFCE for 8 per cent Macro GDP Growth Rate

	Industry	Transport	Agriculture	Other services	Residential
Overall GDP Elasticity of Sector wise GDP/PFCE	1.06	1.15	0.424	1.27	0.846
Sectorial growth rate for 8 per cent aggregate growth rate	8.48	9.2	3.39	10.16	6.77

Source: Author's Own Calculations

To ascertain the growth of final electrical energy demand from that of final demand for commercial energy, we have further assumed the sector-wise share of electricity in the final energy use in different terminal years as given in Table A3. These projected shares have been based on the historical experience of use of this modern clean fuel electricity in various advanced countries of the OECD with high Environmental Performance Index published by Yale Centre for Environmental Law & Policy for 2012.

Table A3: Assumptions for Sector wise Electricity share in Final Energy Demand for 2010-2046

Share of Electricity in year	Industry (%)	Transport (%)	Agriculture (%)	Other Services (%)	Residential (%)
2009	26.11	2.08	59.46	27.16	32.09
2021	30.21	2.95	60.00	35.44	35.31
2031	33.63	4.00	60.00	42.34	38.00

Source: Author's Own Calculations

These percentage shares of electricity in total energy demand have given us the absolute level of sectoral final use of electricity and thereby the aggregate final use of electricity by the non-energy sector of the economy as given in Table 17 in -chapter 11. The gross absolute level of electricity to be generated for the economy over the future time horizon would be derived therefrom by taking due account of losses due to transmission, distribution and auxiliary losses. As we expect the supply side efficiency of electricity industry to improve over time, Table A4 shows the decline of losses on account of auxiliary and T&D losses as a percentage of gross generation, which should be considered plausible. The gross generation requirement of electrical energy has been derived on the basis of the supply side efficiency parameters as given in Table A4.

Table A4: Assumptions for Auxiliary and Transmission and Distribution Losses

Year	Auxiliary and T&D losses
2009	28.33 per cent
2021	20 per cent
2031	18 per cent

Table A5: The Basic Assumptions for Normative Coal Thermal Tariff Calculation

No.	Parameter	Value
1	Capacity utilisation factor	80 per cent
2	Auxiliary consumption	10 per cent
3	Capital cost of power project	Rs 507 lakh
4	Salvage value	10 per cent of capital cost
5	Debt fraction	70 per cent
6	Interest rate on term loan	13.50 per cent
7	Depreciation for first 12 years	5.28 per cent
8	Depreciation for next 13 years	2.05 per cent
9	Discount rate	11.08 per cent
10	O&M cost	Rs 14.59 lakh/MW
11	O&M cost escalation	5 per cent a year
12	Return on equity	15.50 per cent
13	Interest on working capital	12 per cent
14	Station heat rate	2425 kcal/KWh
15	Calorific value of fuel (imported)	5500 kcal/kg
16	Calorific value of fuel (domestic)	4000 kcal/kg
17	Fuel cost (imported)	Rs 6000 / tonne
18	Fuel cost (domestic)	Rs 2200 / tonne
19	Escalation in fuel cost	5 per cent a year

Source: Coal in India: Time for a Verdict, World Institute of Sustainable Energy (WISE), 2014, Pune

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