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India's Primary Energy Evolution: Past Trends and Future Prospects

ABSTRACT This paper assesses India's primary energy mix and changes in consumption and production to identify factors causing these changes and their likely economic and emission impacts. A rising GDP growth rate and the changing structure of the economy during 1980–2013 resulted in a significant growth in energy consumption, though with little apparent impact on the primary energy mix, with coal and oil dominating at unchanged levels. Despite growth in energy consumption, India's primary energy consumption per capita remains low as compared to the world averages. Industrialization, urbanization, and the energy mix are key factors that will influence growth in India's energy demand. Going forward, India's primary energy consumption is expected to grow at a rate outpacing China's. Coal will continue to dominate the energy mix, though it will lose some market share to gas and renewables. India's energy and emission intensities have declined over time but mostly due to improving energy efficiency and not due to a change in the energy mix. With the energy mix not changing, the gains from greater shares of more energy- and carbon-efficient fuels are likely to remain limited. Significantly for India, domestic production has been sluggish in responding to energy demand growth, and imports are likely to continue rising, placing a significant burden on the macro economy. A higher GDP growth path and a green growth path are explored to understand their implications for the energy policy environment, improvements in energy and carbon intensities, import dependency, and domestic production.

Keywords: *India, Energy Demand, Energy Production, Energy Intensity, Energy Forecasts, Carbon Emissions, Energy Imports, Green Growth*

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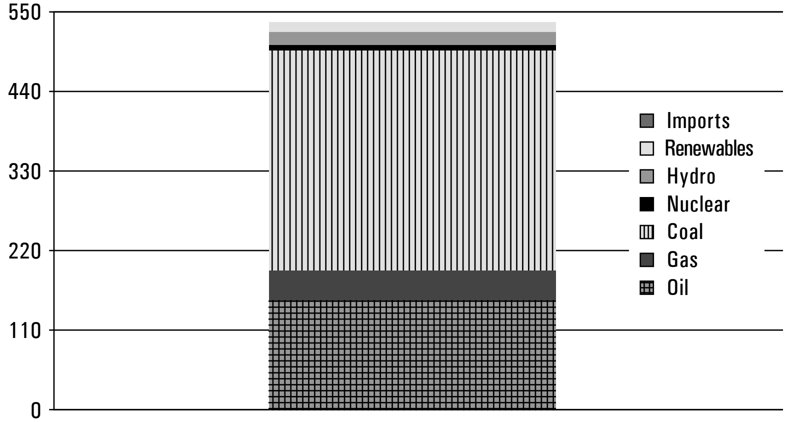
The large increases in energy consumption that have accompanied rising population and economic growth in India have been shaped by a variety of environmental factors and policy choices. India faces a stubborn energy mix that seems unlikely to change very much over the next two decades, with growth in population and GDP driving up energy consumption. This growth in demand calls for increased consumption of fossil fuels. In addition, despite growing domestic production of both fossil and non-fossil fuels, imports will continue to rise. This is likely despite an expected, rapid ramp-up in renewable energy and nuclear power generation, apart from gains in energy intensity.

This paper presents a forecast of India's energy demand and future based on the results of the *BP Energy Outlook 2035* (BP 2015a). Section 1 briefly describes the growth in India's primary energy demand and supply since 1980. Section 2 is a brief review of the prevalent energy demand modeling techniques and the existing forecasts of energy demand in India and the world. Section 3 presents the approach and methodology used in the *BP Energy Outlook 2035*, followed by the results for India in a reference, base case. Section 4 presents two alternative scenarios, constructed to assess the impact of higher GDP growth and that of a greater penetration of renewable energy and higher energy efficiency. The impact of the three scenarios is described in terms of energy demand, carbon emissions, and import dependency. Section 5 concludes the paper.

1. Growth of Energy Demand and Supply in India

India's energy consumption has grown by 5.5 percent per annum since 1980, on par with the fastest growing economies in the world, particularly in Asia. Amongst fossil fuels, consumption of oil has grown by 5.3 percent per annum, coal by 5.6 percent per annum, and gas by 11.7 percent per annum during 1980–2014. Growth in non-fossil fuels has been led by renewables, which started from almost negligible generation in 1990 to 61.5 terawatt-hours (TWh) by 2014, while nuclear generation in the power sector has grown by 8.1 percent per annum and hydro by 2.6 percent per annum during this period. In all, 93 percent of the total increase in consumption was met by fossil fuels, with coal contributing the largest at 57 percent of the total increase between 1980 and 2014, followed by oil at 28 percent and gas at 8 percent (Figure 1). Non-fossil fuels together added just 7 percent of the increase in consumption during this period.

FIGURE 1. India: Increase in Energy Consumption, 1980–2014 (Mtoe)



Source: BP (2015b). Mtoe = million tons of oil equivalent.

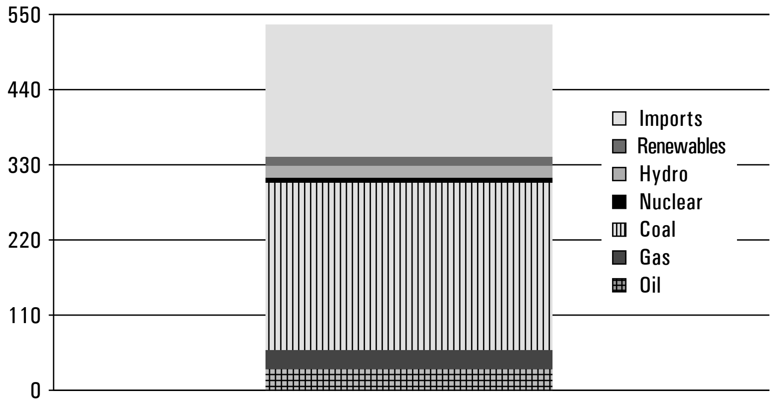
India's share of global demand during these 34 years has risen from 1.5 percent of the global energy consumption in 1980 to 4.9 percent by 2014, making its way from the tenth largest energy consumer in the world in 1980 to the fourth largest by 2014. India still remains the second largest non-OECD (Organization for Economic Cooperation and Development) energy consumer, behind China.

India's energy production, however, has grown only by 4.2 percent per annum during this period. As a result, 36 percent of the increase in domestic consumption has been met by rising fossil fuel imports (Figure 2). Fossil fuels account for 89 percent of the increase in domestic production, with coal accounting for 71 percent of the total increase between 1980 and 2014. This is followed by oil accounting for 10 percent and gas accounting for another 8 percent. Non-fossil fuels together add a total of 11 percent to the increment in domestic energy production during 1980 and 2014.

1.1. Energy Demand and Energy Mix Implications

Over the last few years, even with economic growth slowing down in India, energy consumption has remained robust. GDP growth slowed down from 7.4 percent per annum during 2000–10 to 6.1 percent per annum during 2010–14, but energy consumption growth went up from 5.6 percent per annum to 5.8 percent per annum. As a result, improvements in the energy intensity of GDP also slowed down. The fuel mix had implications for CO_2 emissions from energy use. More significantly, the sharper slowdown in

FIGURE 2. India: Increase in Energy Production and Imports, 1980–2014 (Mtoe)



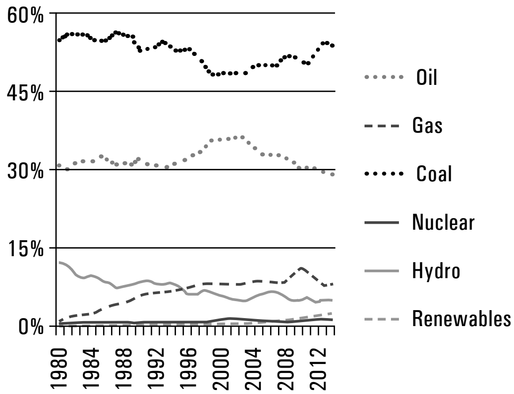
Source: BP (2015b).

domestic production as compared to consumption implied that the share of India's energy consumption met by domestic sources fell to 57 percent by 2014, the lowest on record.

The energy sector is generally slow-moving, and changes in consumption and production are a result of lumpy investment decisions and only gradual improvements in efficiency. As a result, India's energy sector at one level appears largely unchanged since 1980, with coal and oil still dominating the energy mix. The broad averages, however, mask a significant shift away from coal and toward oil until 2000, and the subsequent recovery in coal's share in the early part of this century (Figure 3). The competition between coal and oil in the last century has now been played out between coal and gas over a much shorter period. A rapid rise in gas consumption during 2005–10, followed by a decline during 2010–14, was offset by equivalent changes in coal consumption. However, an increase followed by a decline in gas production during the same intervals was not matched by an equivalent trend in coal production.

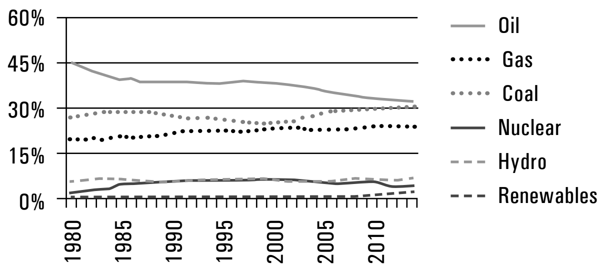
In comparison, the global energy mix has evolved gradually but definitively away from fossils (Figure 4). Oil has steadily lost market share since the first oil crisis in the 1970s, and continues to do so by the virtue of its consumption growth lagging overall primary energy consumption growth. The market share of coal, which seemed to have peaked in the mid-1980s as industrial growth in OECD slowed down, has had a renaissance on the back of China's rapid industrial growth before peaking at the beginning of this decade. Gas and nuclear have slowly gained market share with rapid

FIGURE 3. India: Primary Energy Shares, 1980–2014 (%)



Source: BP (2015b).

FIGURE 4. Global: Primary Energy Shares, 1980–2014 (%)



Source: BP (2015b).

growth rates, albeit in very small volumes. In general, the share of fossil fuels appears to be converging, with the current shares varying between 23 percent of the total primary energy for gas and 33 percent for oil, while the share of non-fossil fuel energy forms varies between 2.5 and 7 percent.

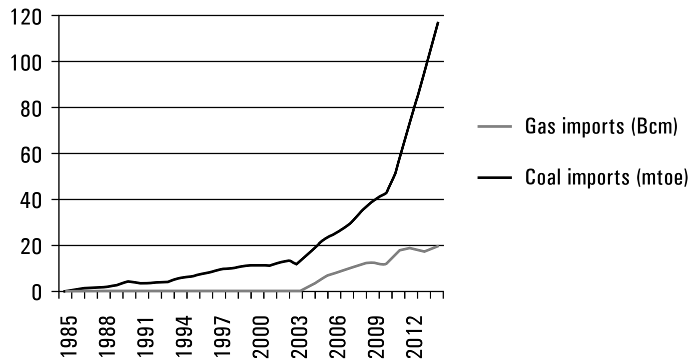
1.2. Rising Import Dependency

India's net energy imports increased by 5.5 percent per annum during 2010–14, as compared to 4.8 percent per annum in the first decade of the century. While coal led the trend, with imports rising by 28.6 percent per annum during this period, gas and oil imports rose by 12.4 percent per annum and 4.9 percent per annum, respectively. Underlying this rapid increase in coal imports were developments in domestic gas production during this period and the tight Asian liquid natural gas (LNG) market. As domestic gas production collapsed in India in 2010, energy demand shifted to imports (Figures 5 and 6). LNG, on the other hand, entered a three-year lull in supply growth in 2011 and, along with the 2011 Fukushima nuclear disaster, pushed Asian LNG demand (and prices) to record highs, making gas imports much more expensive than coal imports. The result was the dramatic increase in coal imports by India during 2010–14.

1.3. Higher Energy Intensity and Emissions

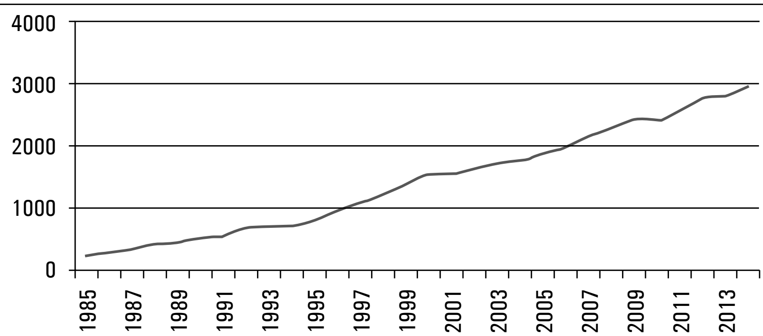
Energy markets are sluggish in their response to economic drivers. Consequently, while GDP growth slowed down, energy consumption growth remained stable, thus slowing down improvements in India's energy intensity

FIGURE 5. India: Coal and Gas Imports, 1985–2014



Source: BP (2015b); Bcm = billion cubic meters.

FIGURE 6. India: Oil Imports, 1985–2014 (thousand barrels/day)

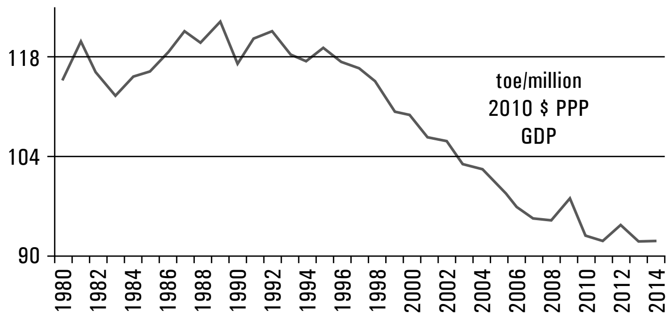


Source: BP (2015b).

(measured as units of energy per unit of GDP) as well. From a reduction of 1.6 percent per annum during 2000–10, energy intensity fell by only 0.3 percent per annum during 2010–14 (Figure 7). These gains in the first period occurred when GDP growth was much faster than the increase in energy consumption; GDP rose by 7.4 percent per annum during 2000–10, while energy consumption increased by 5.6 percent per annum. In the following four years (2010–14), GDP growth came down to 6.1 percent per annum, while energy consumption growth increased to 5.8 percent per annum, leading to a much slower decline in energy intensity per annum.

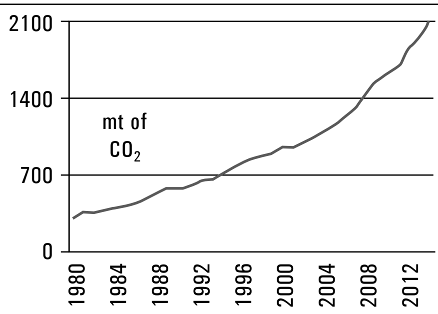
The growth in CO_2 emissions from energy consumption accelerated in India—from 5.6 percent per annum during 2000–10 to 6.2 percent per annum during 2010–14 (Figure 8). This implies that the carbon intensity of energy

FIGURE 7. India: Energy Intensity, 1980–2014 (tons of oil equivalent (toe) per million $ of 2010 PPP GDP)



Source: BP (2015b).

FIGURE 8. India: CO_2 from Energy Use, 1980–2014 (metric tons)



Source: BP (2015b).

consumption was broadly unchanged during 2000–10, but then increased over the period 2010–14 as coal gained shares from gas rapidly.

2. Energy Modeling Approaches

Modeling techniques in the energy sector are mostly applied to modeling energy demand, while energy supply models are usually simple aggregations of individual supply sources. Each supply source, in turn, is usually projected on the basis of resource availability and likely utilization rates. The likely decline rate of the supply source of fossil fuels also brings another factor to a supply forecast model.

The literature on energy demand modeling is rich and varied. Econometric, top-down modeling and bottom-up, end-use modeling are the two prevalent approaches for modeling in the energy sector. The end-use or engineering models taking a bottom-up approach estimate demand based on equipment saturation, efficiencies, and usage. This section provides a very brief description of the more widely applied energy demand modeling techniques, followed by a review of the recent energy sector modeling exercises in India, with the latter using the survey reported by Navroz Dubash et al. (2015).

2.1. Econometric Modeling of Energy

Top-down econometric models are aggregate models of the economy based on past trends used to predict relationships between the sectors of the economy (IPCC 2001). Technological change is usually incorporated exogenously in the model, rather than explaining it within it. For example, autonomous energy efficiency improvement describes the rate at which sectors require less energy over time to produce a given level of output (MIT 1997). Econometric models then apply differing rates of change among sectors and regions based on historic data or future assumptions. In general, top-down models are useful for forecasting in cases where historical development patterns and relationships among key underlying variables hold constant for the projection period (Hourcade et al. 1996).

Top-down models are often used when there is little information available on equipment stocks (Zarnikau 2003). The econometric methods require a consistent set of information over a reasonably long duration and are hence easier to execute for individual sectors. There is a large literature on specific functional forms for econometric analysis of short-run electricity demand (Batancourt 1981). Other papers have examined the demand for electricity in India by developing a logarithmic linear econometric model, wherein a relationship between electricity consumption and variables such as income, price of electricity, and price of diesel, among others, was developed to estimate short-run and long-run elasticities (Bose and Shukla 1999). Systems-based approaches include residential, industrial, and total electricity demand estimation in the United States using both a partial adjustment approach and a simultaneous equations approach (Kamerschen and Porter 2004). In estimating residential energy demand, energy prices, disposable income, and other attributes of the consumers are usually incorporated. Crucial here is having a long enough data series that allows for a sufficiently large number of variables and rich functional forms to be used.

2.2. Bottom-up Energy Modeling

Bottom-up modeling focuses on counting equipment and stocks and adding up energy consumption by analyzing the efficiency and frequency of use of the equipment. These models allow for more comprehensive analysis by aggregating demand across sectors, regions, and fuels. Total energy demand is then a product of activity levels and energy intensity (energy used per unit of economic output) or process efficiency (energy demand per physical output). These models incorporate the development of new technology and processes that improve the efficiency of energy-using equipment and usually forecast demand based on the engineering costs of a wide range of technologies (IEA 1997; IPCC 2001).

Bottom-up models often make use of the vintage stock concept to project demand or supply into the future. In other words, they model future energy use based on costs, timing, and the market shares of technologies or the vintages of equipment and stocks. These models often use simulation and back-casting to project into the future and are most suited in cases where new technologies are penetrating the market or new policies are changing preferences and behavioral patterns.

However, such models are weak in incorporating feedback between the structural evolution of a particular sector and overall economic development patterns, such as the influence of consumer non-energy behavior and changes in the size and spread of various sectors of the economy.

2.3. Energy Modeling in India

Energy modeling and analysis in India have largely been based on a bottom-up, optimization approach (Pandey 1998; Sengupta 1993; Shukla and Kanudia 1997). Several bottom-up and input–output studies, though aggregate in nature, have modeled energy at the sector level (Table 1) (Pachauri 2002; Pandey 1998; Shukla and Kanudia 1997; Tiwari 2000).

The Asian-Pacific Integrated Model or AIM-end-use model (Shukla 1996) was set up for a 40-year horizon from 1995 onwards by minimizing discounted energy system costs at the end-use, sub-sector level. The Market Allocation (MARKAL) model, originally developed for Canada (Berger et al. 1992), has also been adopted for India (Pandey 1998; Shukla and Kanudia 1997). Garg et al. integrate the top-down AIM-end-use model with the bottom-up MARKAL model to provide insights into the implications of mitigation commitments on the energy and technology mix, energy costs, mitigation costs, and the competitiveness of Indian industries (Garg et al. 2001). A stochastic Indian MARKAL model (Loulou et al. 1997) reflects long-term uncertainties in technology and fuel substitution within the Indian context. Most studies focus only on technical and economic variables influencing energy use, without including other social, demographic, and structural and transitional dynamics at the household level that impact energy use and development, particularly in a developing country (Pandey 2002).

The Dubash review quoted earlier and most other studies have been motivated by climate change and environmental considerations. A number of these studies also highlight issues around energy security, both nationally and in the form of household access to energy. For instance, the objectives of the modeling elements of studies from the World Bank (2011) and

TABLE 1. Recent Energy Modeling Studies in India

Study	*Approach*	*Type*	*Reference*
Expert Group on Low Carbon Strategies	Activity analysis model	Top-down	Planning Commission (2014)
The Energy Report—India	MARKAL location model	Bottom-up	TERI (2013)
Energy Emissions—Trends and Policy Landscape	Integrated assessment model	Hybrid	Shukla et al. (2015)
A Sustainable Development Framework for India's Climate Policy	Integrated energy model	Bottom-up	CSTEP (2015)
Energy Intensive Sectors of the Indian Economy	World Energy model	Bottom-up	World Bank (2011)
India Energy Security Scenarios	Excel-based simulation	Bottom-up	NITI Aayog (2015)

the Delhi-based TERI (2013) are to quantify the impact of sector-specific mitigation activities on greenhouse gas (GHG) emissions. Energy security and the rising share of imports in meeting domestic energy demand are considered in the Planning Commission's work (2014).

2.4. Other Global Energy Models

There are a number of other global energy projects that present energy consumption and supply forecasts, differentiated by regions and fuels, using the same approach as this paper. Key amongst these are the International Energy Agency's (IEA) annual *World Energy Outlook*, the US Energy Information Administration's (EIA) annual *International Energy Outlook*, and the Shell Scenarios. Again, this list is only indicative of the vast literature and products available to researchers and analysts.

The Shell Scenarios are described as "ask(ing) 'what if?' questions to explore alternative views of the future and create plausible stories around them. They consider long-term trends in economics, energy supply and demand, geopolitical shifts and social change, as well as the motivating factors that drive change" (Shell 2014). The Scenarios present alternative narratives of how and where the demand and supply of energy are driven by a complex interplay of politics, economics, social development, and technology change. More significant than the demand and supply forecasts that result from the exercise is the impact that these alternative narratives have on energy growth paths and the way they help identify the fault lines in the world energy situation that governments and businesses need to be cognizant of.

As compared to the Shell Scenarios, the forecasts from the IEA and EIA are closer in approach to this paper. The *International Energy Outlook* of the US Government's EIA presented two oil prices and two global GDP growth cases in its recent edition to examine a range of potential interactions of supply, demand, and prices in world energy markets. The model adjusts energy demand and supply growth to balance the market in each scenario (EIA 2013). The *World Energy Outlook* of the IEA available at the time of writing this paper contains three scenarios. The IEA emphasizes that none of the scenarios is a forecast—they are not designed to predict likely outcomes but to explore possibilities under different policy assumptions (IEA 2014). The "New Policies Scenario" (NPS) assumes that announced national policy objectives are fully implemented, while the "Current Policies Scenario" assumes very little change in policy. An aspiration forecast is also presented in the "450 Scenario" that sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting the concentration of GHGs in the atmosphere to around 450 parts per million of CO_2. IEA identifies the NPS as its central case.

3. India's Energy Future: Approach, Methodology, and Results

This paper and its assessment of India's energy future differ from previous studies in three ways. First, being prescriptive in nature, most of the studies cited earlier develop baseline and alternative scenarios as different cases, with the baseline being a "more-of-the-same" type projection based on the past, while alternative scenarios build in more aggressive policy reforms. One outcome of such a distinction is that each policy reform can be evaluated in terms of its impact. The baseline forecast in this paper, on the other hand, takes into account the likely policy reform process and builds in autonomous technology development, recognizing that policies do change and evolve over time, and that the natural progression of technology development works through the system. Thus, for example, the government's targets for wind, solar, and coal production in India are recognized while making policy assumptions for the future.

Second, the paper contextualizes India's energy demand, especially energy imports, against the overall global demand and supply of energy. This allows for adjusting demand on a yearly basis depending on the excess demand volumes for oil, gas, and coal, and the availability of these resources for import in regional markets. For the oil market, this assessment is based on the global oil balance, while for coal and gas, the regional supply scenario provides a boundary for import volumes. Although energy prices are not explicitly taken into account in the country-level forecasts, this balance provides an indication of the tightness of the market.

Finally, the India-centric studies listed earlier account for efficiency improvements and technology changes based on domestic industrial conditions and best-in-class experiences from the rest of the world. This forecast is global by design and approaches efficiency improvements and technology changes based on global trends and their transmission through global trade. For instance, improvements in vehicle efficiencies are reproduced around the world, with the automobile industry meeting demand in the OECD countries from manufacturing facilities in the non-OECD countries that allows for countries like India to benefit from these efficiency improvements. Similarly, policy developments in the OECD countries, such as strengthening

Euro emission standards in the European Union (EU), imply that non-OECD manufacturing facilities also need to improve product efficiencies.

3.1. Methodology

The forecast presented in this paper does not rely on a single, all-encompassing, general equilibrium model of the global energy economy. Such models do exist and can be very useful in highlighting the interdependencies within the energy system and identifying some of the potential unintended consequences of policy interventions. However, their complexity and high maintenance cost (in terms of the time and data required to keep them up-to-date and calibrated against the real world) limit their usefulness as tools for forecasting a “most likely” outcome.

The approach taken here, which is similar to that taken by the IEA and EIA work (IEA 2014; EIA 2013), is to apply a range of modeling strategies across different sectors and geographies and then aggregate the results in an accounting framework that ensures that everything balances. On the demand side, the forecast comes from a hybrid of top-down, econometric modeling and activity-level models applied in conjunction with a bottom-up aggregation of energy consumption in individual units based on their utilization rates. The final outcome relies heavily on expert judgment, applied to the most up-to-date data that is available, with modeling tools used, where possible, to inform and support that judgment.

The transport sector’s demand for fuels is modeled in two different ways. First, a technology-rich, “bottom-up” model is used to simulate the evolution of vehicle fleets, based on a range of parameters that enter into vehicle choice decisions, including importantly the constraints imposed on auto manufacturers in the environmental performance of their vehicles (for example, Corporate Average Fuel Economy Standards in the United States, tailpipe CO_2 per km emission standards in the EU). Second, an econometric analysis of the relationship between transport fuel demand and incomes and fuel prices provides the basis for a “top-down” projection, given assumptions about the growth of income and changes in prices. The results from these two different modeling strategies are compared and expert judgment is applied through an iterative process of discussion to agree on a final set of numbers for the projection of transport fuel demand. Some of the key results from the modeling exercise are the following:

- The global vehicle fleet (commercial vehicles and passenger cars) more than doubles from around 1.2 billion today to 2.4 billion by

2035. Most of that growth is in the developing world (88 percent), since some OECD markets are already at saturation levels.
- Fuel economy gains are likely to accelerate over the period to 2035, with vehicle fleet fuel economy forecast to improve by 2.1 percent per annum between 2013 and 2035, having improved by about 1.5 percent per annum over the past decade of 2003–13.
- Transport fuel demand will continue to be dominated by oil (89 percent share in 2035), but the share of non-oil alternatives will increase from 5 percent in 2013 to 11 percent in 2035, with natural gas being the fastest growing transport fuel (6.3 percent per annum).

Industrial demand is based on the levels of economic activity represented by GDP, an assessment of the energy-intensive sectors within each region, and availability and competition between alternative fuels. For instance, China's industrial demand is based on likely trends in the share of industry in GDP in China, competition between coal and gas for market share, and likely trends in meeting energy intensity and GHG reduction targets in the economy. The fading impact of industrialization is apparent in the split of primary energy consumption by sector. Industry has been the fastest growing sector since 2000, averaging at 2.7 percent per annum, but projected growth slows to 1.4 percent per annum.

Power generation is the one sector where all fuels compete, and so it plays a major role in how the global fuel mix evolves. The demand for primary fuels for power generation is based on generation-capacity augmentation in all regions and for all fuels, on policy trends, and on regulatory changes likely to comply with GHG targets and technology improvements in electricity generation. The last factor is especially important for forecasting the generation of electricity from renewable sources, where reduction in the cost of generation through achieving economies of scale, learning by doing, and autonomous efficiency improvements result in significant achievements. The outcome by 2035 is a more balanced and diversified portfolio of fuels for power generation. Coal remains the dominant fuel, accounting for more than a third of the inputs to power generation, but that share is down from 44 percent today and the gap between the shares of coal and of other fuels narrows significantly.

Supply forecasts are more bottom-up. The projection of nuclear power in India is a good example. This is based on current data on projects under construction and planned, and on announced policy targets, all subject to expert overview of the likelihood of plans being implemented and targets being met. Forecasts for the supply of fossil fuels are based on adding up likely decline rates of existing producing regions, balanced with the likely demand for each fuel so as to be able to mimic price effects. These are then moderated by the proved reserves base[1] and expectations of changes in market structure due to policy reforms that may encourage greater exploration and production activity. For instance, the confluence in the United States of abundant resources with supportive policy and market structure—the world's largest rig fleet, access to extensive pipeline networks, and deep financial markets—that led to the rapid growth in energy production in the United States is unlikely to be replicated as widely anywhere else in our forecasts.

Given the considerable inertia in the global energy system, the long life of assets, and the long lead times on new builds, the key ingredients for a good forecast are the most up-to-date data to establish the starting point and initial momentum of the system and people with deep knowledge of how the individual parts of the system work and how they connect with one another.

3.2. Forecasts and Comparison with Other Studies

Table 2 contains the details of the BP forecast and comparisons with other publicly available projections over the period 2013–35. The BP Energy Outlook forecasts are within the range of these publicly available forecasts.

TABLE 2. BP Forecast Compared with Other Global Forecasts, 2013–35

	Primary energy consumption annual growth rate during 2013–35 (%)				*Shares in 2035 (%)*			
	BP	*IEA New Policies*	*IEA Current Policies*	*EIA*	*BP*	*IEA New Policies*	*IEA Current Policies*	*EIA**
World	1.5	1.2	1.5	1.6	100.0	100.0	100.0	100.0
Oil	0.8	0.5	0.9	0.9	27.4	28.0	29.1	28.5
Biofuels	3.2	1.5	1.4		0.7	10.7	10.0	0.0
Gas	1.9	1.6	1.8	1.7	26.4	22.7	21.6	22.8
Coal	1.1	0.5	1.6	1.6	27.1	26.0	29.2	27.9
Nuclear	1.9	2.5	1.9	2.7	4.9	6.3	5.4	6.9
Hydro	1.8	2.0	1.8		7.1	2.8	2.5	0.0
Renewables	7.0	7.5	1.8	2.7	6.4	3.5	2.3	14.0

Sources: Authors' estimates, BP (2015a), IEA (2014), EIA (2013).
Note: EIA forecasts are for 2010–35. Biofuels are included in renewables here.

1. The BP *Statistical Review of World Energy* defines "proved reserves" as "Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing conditions."

We see weaker growth in OECD energy demand than others, while our projections for non-OECD growth are stronger than most. Compared to the IEA scenarios (which are not forecasts but assessments of potential outcomes based on defined sets of policy assumptions), our outlook lies above the IEA's "New Policies Scenario," which assumes that the announced national energy conservation and efficiency policy objectives are fully implemented, and close to the "Current Policies Scenario," which assumes no change in existing polices. This probably reflects our differing views on the outlook for rapidly industrializing economies and the speed with which China, in particular, can move to a less energy-intensive growth path.

3.3. Building Blocks for Policy Analysis for India

Population growth and increases in income per capita are the key drivers behind growing demand for energy, so the assumed path for these variables is a critical input for our forecasts. The population projections are taken directly from the United Nations Population Division, Revision 2010. By 2035, India's population will exceed 1.5 billion, which means an additional 250 million people will need energy.

The economic growth assumptions are based on projections provided by Oxford Economic Forecasting and sit well within the range of forecasts for the global economy that are available. The GDP numbers are expressed in real 2011 US dollars and Purchasing Power Parity (PPP) exchange rates. Using PPPs instead of market exchange rates, to convert currencies makes it possible to compare the output of economies and the welfare of population in real terms (using the same prices for the same goods in all countries and all years).

Over the outlook period, the global GDP is expected to more than treble, with India contributing nearly 13 percent of the total world's GDP growth. India's per capita GDP is assumed to increase by 166 percent over 2013–35, growing at an average of 4.6 percent per annum. On this measure, by 2035, India's per capita income would be just above where China's is today, and less than half of the current EU level.

Given these assumptions for population and income growth, both the level of energy demand and the fuel mix are heavily influenced by policy. The primary focus of India's policy throughout the 2013–35 period is assumed to remain the securing of affordable and reliable energy to support economic development. But there is also an increasing emphasis on clean energy, driven both by local environmental concerns and India's desire to play its

TABLE 3. Energy Policy Assumptions for India, 2013–35

	Current status	*Policy assumption*
Gas	Administered prices with some incentives for exploration and production	Gradual price deregulation by 2025
Coal	Target of 1 billion tons of production by 2020	Coal production reaches 1 billion tons by 2027
Solar	Target of 100 GW by 2022	80 GW by 2035
Wind	Target of 100 GW by 2022	110 GW by 2035
Nuclear	Target of 63 GW by 2032	27 GW by 2035

Source: Authors' estimates. GW = gigawatt.

TABLE 4. India: Energy Demand Elasticities

	Elasticity with respect to GDP		*Annual Growth Rate (%)*	
Demand	*2015–25*	*2025–35*	*2015–25*	*2025–35*
Oil	0.67	0.62	4	3
Gas	0.98	0.44	6	2
Coal	0.63	0.63	4	3
Nuclear	1.48	0.75	9	4
Hydro	0.50	0.68	3	4
Renewables	1.76	1.28	10	7
Total	**0.72**	**0.65**	**4**	**3**
GDP (PPP)			6	5

Source: Authors' estimates.

appropriate part in addressing global climate change issues. Some specific policy assumptions are illustrated in Table 3.

Given India's stage of economic development, energy demand is expected to remain closely linked to economic growth. That linkage weakens gradually as the economy matures, and this weakening is reinforced by policy efforts to improve efficiency (including, for example, the removal of energy subsidies). The effects can be seen in the elasticity of energy consumption with respect to GDP (that is, the ratio of energy growth to GDP growth), which has averaged 0.85 over the past decade and is assumed to decline to 0.72 over the next decade and to 0.65 in the final decade to 2035. Table 4 provides more detail by fuel type.

The potential for India's own fossil fuel production to meet energy demand growth is constrained by its resource endowments. The forecasts of production are based on existing proved reserves, likely extraction and decline rates, and the prospects for finding and developing new reserves—all conditional on expected policy reforms (Table 5).

TABLE 5. India: Growth of Energy Supply

	Proved Reserves	*2015–25 Annual Growth Rate (%)*	*2025–35 Annual Growth Rate (%)*
Oil (billion barrels)	5.74	−2	0
Gas (trillion cubic meters)	1.43	1	5
Coal (billion tons)	60.60	4	3
Total		**5**	**3**

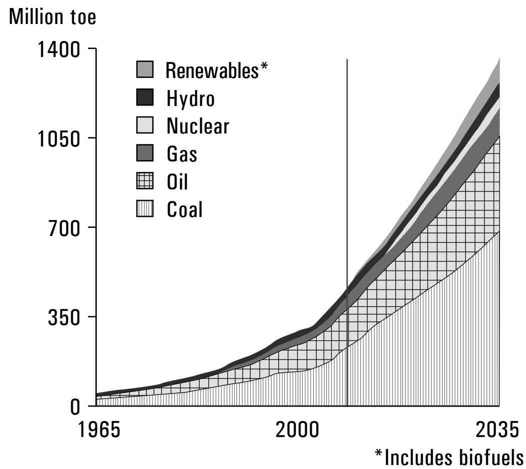
Source: BP (2015a).

3.4. Reference Case

Based on these assumptions, India's primary energy consumption is expected to grow by 128 percent between 2013 and 2035, achieving an average growth rate of 3.8 percent per annum (Figure 9). That is almost double the average rate of growth for non-OECD energy markets; India's share of global energy demand would rise to 8 percent in 2035, still some way behind China (at 26 percent), but ahead of Russia (5 percent) and Brazil (3 percent).

Despite the rapid growth in total energy consumption, India's per capita consumption of energy will remain relatively low in 2035; less than half the global average. To put this in perspective, in terms of per capita energy use, India, in 2035, will be roughly where South Korea was in 1978 or Thailand in 1995. India's energy intensity (the amount of energy consumed per unit

FIGURE 9. India: Projected Growth of Energy Consumption, 2013–35 (Mtoe)



Source: BP (2015a).

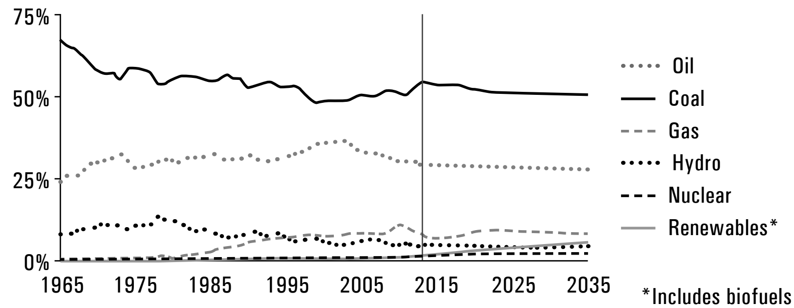
of GDP) will also remain low, declining by 1.6 percent per annum. India's economic development is expected to be much less energy-intensive than China's recent experience.

In these projections, India's energy mix continues to evolve slowly, with fossil fuels accounting for 87 percent of the demand in 2035, down from 92 percent today (and compared to a global average of 81 percent in 2035). Coal continues to dominate the energy mix, accounting for 51 percent of the energy consumption in 2035, though it does lose some market share, notably to renewables and nuclear (Figure 10). Coal would account for nearly half of the growth in India's energy consumption by 2035.

The consumption of fossil fuels more than doubles over 2013–35, with natural gas up 145 percent, oil up 117 percent, and coal up 112 percent. Renewables and nuclear grow even more rapidly, expanding by 564 percent and 363 percent, respectively. Large-scale hydroelectricity shows the slowest growth, but still achieves a very respectable 98 percent increase in output.

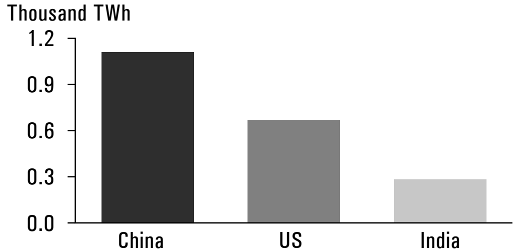
India's own energy production meets just over half of the increase in energy consumption, growing by 117 percent (3.6 percent per annum). Amongst fossil fuels, only coal is able to keep up with the growth rate of demand, with production expanding by 119 percent. Gas production also grows (by 78 percent) but less rapidly than consumption, and oil production declines. Coal remains the dominant fuel produced in India with a 66 percent market share in 2035. Renewables in power overtake oil as the second largest, increasing from 3 percent to 11 percent in 2035, as oil drops from 12 percent to 4 percent. India would contribute the third largest increment to renewable energy generation during 2013–35 in the world (Figures 10 and 11).

FIGURE 10. India: Projected Primary Energy Shares, 1965–2035 (%)



Source: BP (2015a).

FIGURE 11. Projected Renewable Energy Growth, China, the United States, India, 2013–35 (TWh)



Source: BP (2015a). TWh = terawatt-hours.

3.5. Policy Implications

The projections described earlier pose two key policy challenges. First, with energy demand growth outpacing the expansion of domestic energy supply, India's dependence on imported energy increases. India's energy production as a share of consumption would decline from 59 percent today to 56 percent by 2035 as imports would rise by 143 percent. Oil imports would rise by 161 percent and account for 61 percent of the net increase in imports, followed in volumetric terms by increasing imports of coal (by 96 percent) and gas (by 270 percent). This would place a significant burden on the macro economy as India currently consumes 4.3 percent of the total world oil consumption and 7 percent of the total trade in oil. By 2035, India's share of the world's oil consumption would rise to 7 percent, while it would account for 11 percent of the total imports. India's share of the global LNG trade would increase from 6 percent today to 8 percent in 2035.

The second key challenge is the growth of carbon emissions. While India's energy intensity of GDP would decline by 1.6 percent per annum by 2035, India's slow-moving energy mix means that the carbon intensity of India's energy consumption would decline only modestly by 0.3 percent per annum by 2035. The net result is that CO_2 emissions from energy use would more than double, averaging a growth of 3.5 percent per annum. Over the final decade of the projection, from 2025 to 2035, India would account for more than a third of the growth in global GHG emissions, adding more than twice as much CO_2 as China during that decade. However, this would still allow India to meet its stated goal of reducing CO_2 intensity of GDP by 20 percent by 2021, a year later than the target date (UNFCCC 2011).

4. Alternate Cases

There are, of course, many uncertainties surrounding any projection of India's energy future. To illustrate this, two alternative cases are described in the following subsections. One explores the implications of assuming a higher GDP growth path. The other examines the possibility of a "greener" growth path with greater gains in energy efficiency and a stronger push on renewables. Neither of these examples is a full-blown scenario. They represent a rough form of sensitivity analysis in which we adjust a few key parameters relative to our reference case. We do not attempt to assign any probabilities to these cases—they are simply designed to illustrate the range of possibilities for India.

4.1. Implications of a Higher GDP Growth Path

If India aspires to higher GDP growth than the assumed growth rates in the base case described earlier, what might happen? What would be the impact of assuming GDP growth of, say, 7.5 percent per annum during 2013–35 while keeping the relationship between economic growth and sectoral energy demand the same as in the reference case? Total energy demand growth would increase to around 5 percent per annum (Table 6, "High" case). Both oil and gas would grow slightly faster than 5 percent, and coal slightly slower.

This case results in CO_2 emissions growing at 4.7 percent per annum, which would be a concern in a world that is increasingly likely to be carbon-constrained. Moreover, if India's own production of fossil fuels remains at

TABLE 6. India: Energy Consumption Growth and Shares, 2013–35 (%)

	Annual average growth, 2013–35 (%)			*Share of primary energy (%)*			
	Base	*High*	*Green*	*2013*	*Base*	*High*	*Green*
Oil	3.6	5.2	2.2	29	28	31	28
Gas	4.1	5.4	3.6	8	8	9	10
Coal	3.5	4.4	–2.0	55	51	49	21
Nuclear	7.2	8.0	7.6	1	3	2	4
Hydro	3.1	3.9	3.5	5	4	4	6
Renewables	9.0	9.8	16.0	2	6	5	31
Total	**3.8**	**5.0**	**2.4**	**100**	**100**	**100**	**100**

Source: BP (2015a) and authors' calculations.

the reference case level, higher domestic demand in this higher GDP growth case would result in a significant increase in energy imports.

Today, India imports a little over 40 percent of its energy consumption. By 2035, that would have risen to 44 percent in the base case and to 54 percent in the high GDP growth case. In volume terms, the net imports of fossil fuels would exceed to 900 Mtoe in 2035 in the high case, as compared to around 600 Mtoe in the reference base case. That level of imports is not infeasible—global supply flows could accommodate India's requirements, albeit with pressure on fuel prices. In this high growth case for India, China and India together would be importing around a quarter of the world's oil production and more than 40 percent of the world's LNG. In terms of oil trade, 16 percent of the global oil exports would find their way to India. The major challenge for this alternative case would, of course, be the question of whether the Indian economy could afford the import bill.

4.2. Implications of Green Growth

India is committed to playing its part in addressing the risk of climate change. Under what conditions is it possible that India's carbon emissions in 2035 would be no higher than they are today? The arithmetic of this case is relatively simple; finding a feasible policy set that could credibly deliver it is much more challenging. As compared to the reference base case, this greener alternative requires a much faster decline in energy intensity and a much more rapid shift from fossil to non-fossil fuels.[2]

The "green" case assumes that energy intensity declines at 3 percent per annum. This is quite a stretch for India, given that it starts already at a relatively low level, but similar rates of decline sustained for at least ten years have been seen in other rapidly developing Asian economies (for example, Taiwan, the Philippines). The result is total energy demand growing at just 2.4 percent per annum (Table 6).

This case also assumes that India's renewables grow at the same rate (16 percent per year) as in the EU over the past 20 years, and that both nuclear and hydroelectricity achieve production growth rates that sit between the base case and high case rates. Finally, among fossil fuels, gas is assumed to gain a larger share of primary energy, while oil maintains the same share as in the base case. That leaves coal being squeezed out, with quite a dramatic decline in its share of energy to just over 20 percent by 2035.

2. To keep the analysis simple, we have ignored the potential for carbon capture and sequestration in this case. If that technology were available to be deployed at scale, it would allow a larger share for coal to be consistent with the goal of stabilizing carbon emissions.

This case delivers zero growth in carbon emissions from energy use. It also sharply reduces net energy import requirements. The decline in coal demand leaves the level of coal consumption in 2035 below the current level of coal production, thereby eliminating the need for net coal imports. There would still be a requirement to import oil and gas, but overall, net energy imports in 2035 would be about half the base-case level and a third of the high-case level.

This alternative "green" case has much to commend it in terms of outcomes. However, it is clearly built on some very challenging assumptions. To illustrate the challenge, consider the policy interventions that have been required in the EU to secure the rapid and sustained growth of renewables. The Renewable Energy Directive 2009 established a binding target of 20 percent for the share of renewables in EU's final energy consumption by 2020. Individual EU countries then committed to a range of differentiated targets to achieve this EU aggregate goal and submitted National Renewable Energy Action Plans, which laid out sectoral targets and policy measures. A simple measure of the degree of policy support for renewables is the estimated amount of subsidy that has been paid to renewable energy sources. The most recent report for the European Commission (De Vos et al. 2014) cites a figure of €40 billion for renewable energy support in 2012.

5. Conclusion

Rising GDP and the changing structure of the economy in India have resulted in a significant growth in energy consumption over the past 30 years, even as the energy mix appears to be stubbornly dominated by fossil fuels. However, the significant shifts in the energy mix, away from coal and toward oil until the 2000s and the subsequent recovery in coal's share, followed by a period of competition between coal and gas, illustrates the potential for change. This change is most affected by the changes in domestic production, especially of gas and renewables.

Going forward, India's primary energy consumption is expected to grow at a rate outpacing most large developing countries. Coal will continue to dominate the energy mix, though it will lose some market share to gas and renewables. Other implications of this slow-moving energy mix are observed in overall energy intensity and carbon emissions. While India's energy intensity and emissions have declined over time, these gains are mostly due to improving energy efficiency. However, with a relatively inflexible energy mix, the gains from improving the share of more energy- and carbon-efficient fuels would remain limited. More significantly for India, domestic production has been sluggish in responding to energy demand growth, and imports are likely to continue rising. This increased share of energy imports as a percentage of GDP would place a significant burden on the economy.

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Comments and Discussion*

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I have three sets of points I would like to make. The first looks at the alternative causal narratives of different trends—the first part of Kaushik's paper. What is behind the elevator description of this going up and coming down? The second is to reflect a little bit on the models. I am not a modeler. I think that they are useful and constructive to engage with, but in general, I also remain skeptical. Anupam and I have done a little division of labor, and he will deal with models. And third, what are the big questions we are trying to answer and how?

First on the elevator part. Kaushik's presentation was quite rich and did better justice to the material than the paper, because the paper went into a lot of detail about trends in different time periods but you did not really get a sense of the larger narrative. What are the explanatory factors? Why do we see something going up at this point and going down at the other point? The narratives are important because that is what really sticks in your mind and it also signals the policy direction. It is what allows a policy conversation, and a lot of my comments are going to be about how we use analysis like this for policy because that is, presumably, the interest of this forum.

First, the paper has some really great stories, but I would like to actually see more of these. My favorite was the one about how post-Fukushima we saw a spike in gas prices, driving gas up to unaffordable levels and, therefore, an increase in coal imports. In another presentation by Kaushik, I heard him tell a fascinating story a couple of years ago: While the Europeans pumped a lot of money into renewable energy, the Americans instead invested in shale, essentially driving down the price of coal in the United States, which then went in and undercut all the renewables in Europe. That kind of story is actually what makes these trends really interesting, and I would encourage the revision of this paper to bring about some of those larger storylines a little bit better.

* To preserve the sense of the discussions at the IPF, these discussants' comments reflect the views expressed at the IPF and do not take into account revisions to the original conference paper in response to these and other comments, even though the IPF Volume itself contains the revised paper. The original conference version of the paper is available on www.ncaer.org.

In addition, I felt there was a bit too much of reliance on unicausal stories. So, for example, oil or gas goes down because there is a decreased investment without actually explaining why that is. But, of course, there is a complex political economy behind that, which anybody who reads even the front page of the financial papers in India knows. For example, there is a story about the credibility of governance and pricing arrangements in gas and the sanctity of contracts: What kind of price is obtained for gas and what is the basis for that price? Something similar is now going on in power purchase agreements based on coal power. Moreover, if you want to think about coal in India, you cannot really think about coal prices without thinking about the implicit subsidy that the railways provide to passenger rail on the back of freight cost, which then has implications for the competitiveness of our coal. These kinds of larger stories could, thus, at least be alluded to, even in a secondary way, that is, what lies behind this lack of investment.

An overarching point: early in the paper, it would be nice to get a little bit more of a sense of what are the big questions we are trying to answer. Are we saying it is really about imports of fuels? Are we saying it is about the mechanisms of encouraging investment? I did not really feel that I got that from the beginning of the paper.

Turning on to the models, my issue with a lot of modeling studies is that they sort of quite blithely embrace the fallacy of false concreteness. There is a number that is put out there, and you are not really sure how credible that number is. By way of example, I am going to take up with Kaushik an issue on one number related to the "green scenario" that Kaushik put out. Under the "green scenario" of the BP study, the per capita energy consumption rises by only 1.5 percent as compared to a 4.5 percent increase in the base case. That, *a priori*, makes it sound like India should be very wary of the climate negotiations. But if you dig into it a little bit, it turns out that the green scenario has been constructed to assume zero growth in carbon from energy over the next 20 years! That is not a realistic scenario which anybody talks about, nor is it on the table for India in climate negotiations. So, you have to have the context and assumptions right, otherwise scenarios and model results can be misleading.

One reason I find it hard to engage with a lot of modeling studies is perhaps that they are so complex; it is very difficult to get a sense of the reasoning behind various assumptions. So, I benchmarked this study against seven studies we looked at in a CPR analysis[1] to get a sense of some of the differences in the underlying assumptions and how well they are explained.

1. http://www.cprindia.org/research/reports/informing-india%E2%80%99s-energy-and-climate-debate-policy-lessons-modelling-studies.

The most important assumption, of course, is about GDP growth rates. Depending on the nature of the model, GDP is either endogenously or exogenously assumed. The studies we looked at, which are domestic studies, assume that over the next 15 years, the average GDP growth will be somewhere between 7 and 8.75 percent a year, with no lower end cases below 7 percent. I think that actually the BP paper is much more sensible with a GDP growth rate assumption of around 4.6 percent. Interestingly, nobody is really occupying the middle ground, which is probably where we will end up if we are lucky. So, that obviously makes a huge difference. There is an interesting sidebar here: International studies uniformly have lower growth rate assumptions than national studies because the national studies feel they have to shoot for an aspirational target. Of course, in the process, we might be shooting ourselves in the foot in climate negotiations because it looks like we are going to be a huge share of the future problem, because high GDP growth typically requires higher emissions, when, in fact, we are going to be a much smaller share of the problem if we have more reasonable assumptions.

Then there are policy assumptions. A lot of these numbers are just extremely hard to defend. Why does BP assume 80 gigawatts of solar energy by 2035? India's low carbon study projects 3 gigawatts of solar energy by 2030 in its baseline scenario, presumably based on current capacity, which is, frankly, ridiculous, and 110 gigawatts of solar by 2030 in its low carbon policy scenario. Which of these numbers do we take seriously and why? There has to be a much more of a reasoned process, and I think that the paper has to spend a little bit more time explaining why particular numbers are used and the rationale behind them, and contextualize them a little bit more.

Another example related to the assumptions is that the elasticity of energy consumption falls from 0.85 to 0.65 percent by 2035 in the BP paper. Now, what if we actually manage to get manufacturing to increase? Will we then see this decline in energy elasticity? It is not really clear.

So, where do these modeling results take us? I put the BP paper up on the left with CPR's summary of primary energy on the right from the model scenario comparative analysis that we undertook. I scaled this so the scale is approximately the same, and you will see that the primary energy required according to BP is of the order of about 1100 million tons of oil equivalent or MTOE (in 2035), that is, well below even the lowest case in the modeling comparison study, which is between 1200 and 1600 (by 2030–32). That is a pretty big difference. How does a policy maker take this seriously? What does he or she do with it? This point is underscored when you look at a single number like carbon. CPR's model comparison basically shows that

Indian emissions might double or triple by 2030. Again, a pretty big range. How do you enter a negotiation space or plan domestic policy if you do not know whether your emissions will double or triple during a 15-year period?

Hence, how do we move beyond this? I think the paper really needs to dig into some of these underlying assumptions and give some sense of what the outcomes really turn on. All the analysts are doing their work in silos. Let us have some common assumptions leading to common reference cases and then you can build some sensible policy cases. When this paper is revisited, we could best use this enormous amount of material and really world-class modeling to extract some of the stories perhaps a little better than the authors currently do, tell us a little bit more about the assumptions, and focus it better around a few key questions.

Let me just end with one last point. Energy policy debates are no longer just about supply side issues, such as can we increase our coal to 1,000 million tons or not? They are also about achieving different objectives, such as energy access, energy security, assured energy for growth, local environmental quality (in particular air pollution, which is becoming a big deal), and global environmental protection. There are potential synergies and tradeoffs across all these things. Until the models get to the point where they can start helping you think about those synergies and tradeoffs, their utility is going to be limited. Maybe the paper can reflect upon that too.

Anupam Khanna

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I would like to thank Shekhar and NCAER for inviting me to discuss this paper. I want to state right away that my comments will be on the draft paper itself, which is slightly different from the presentation Kaushik just delivered. I think the presentation addresses one or two of my earlier concerns, so I will skip those. I also want to congratulate NCAER for including this topic in the IPF because it addresses, or at least I hope it will by the time we are done with it, the "missing middle" problem that Dr Bardhan referred to in his talk earlier. Over the last six years since my return to India, I find that about 80 to 90 percent of the research seminars and analytic work that I read coming out of India is on either macro–macro or micro–micro and very little on the middle where the policy tyre hits the road. A lot of events I have attended are full of aims and exhortations, with zero analysis about the instruments in the middle, including policy incentives and programs where public money is actually being spent.

I will list very quickly the paper's contents and my take on them. The first topic, which Navroz has already talked about, covers the demand and supply of primary energy since 1980. The discussion in the paper is mainly descriptive. The authors have got some proximate correlates about oil and gas, but these provide no insight and the implications that are drawn out are pretty obvious. There is no model or any analysis which relates energy mix, import dependence, or energy intensity. There is no counterfactual or any drilling down on their drivers. The Indian energy system is, in some ways, very, very simple because we are so starved of energy. We have a demand side, which is pretty much going with a certain set of drivers; a supply side, which is essentially autonomous; and then we have a huge import trade to bridge the gap. I found the paper somewhat confusing wherein the authors ascribe the production levels to the consumption because I do not think there is any direct relationship and almost all the analytic work that has been done to date does not really make that connection.

There is another big omission in the first part of the paper about what went up and what went down, what Navroz called "the elevator story." The authors need to talk about what has been happening to the international markets. While one slide describes the status of all commodity markets for the past decade, the next one is about what has been happening to the energy market. So, if one is going to talk about oil versus gas, he needs to know what happened to the relative prices of oil and gas which substitute for each other in many ways. Not only that; one has to worry about what happened to oil and gas globally versus what happened in Asia. We all know that while the oil market is global, the gas market is actually still regionally fragmented, with at least three different regions showing distinctive pricing. Another part that was somewhat confusing in the paper relates to the demand side, though I think the elements are there and perhaps a little more work can rectify the problem. The story that the table tells in five-year segments is that the drivers of consumption seem to be changing, resulting in big changes and shares of primary energy. Some of this had to do with prices. Another part had to do with other factors. What were they? For example, the point that is made here, if you compare what happened in the late 1990s versus the early 1990s, is that coal only contributed about a third to the increment in primary fuel consumption in the latter period, as opposed to typically what had been its incremental contribution (about half). Why was that? Why did oil come in so high? Is it all about the transport demand, the point noted by Kaushik?

The other big problem with all of this is the huge data inconsistencies. I am not talking just about the assumptions and estimates of elasticities, for instance, which even in the best of studies have wide differences.

There appears to be a limited factual basis even on very fundamental questions such as what has the consumption been in recent years and what is actually the power demand? Does the electricity consumption data include all the varieties of captive power or not? What are motor vehicles contributing in terms of the demand for oil? All these are highly variable. If you give me a result you want, I can pretty much derive it with suitable methodological frameworks and assumptions and rig the model in a way to give you that. So, I think there is a basic issue with both overly simple and overly complex models. This type of model is good for exploratory purposes, but when one is doing serious policy analysis, he needs to think about the analytic framework and choose an approach to fit the purpose.

There are two or three well-established approaches in this regard. The paper refers to the scenario approach, for example, what the other global energy major Shell does, or what the security agencies in the United States versus what the energy agencies (for example, IEA or US Department of Energy) do, which tend to go more along this route, albeit with key differences in the details. The other big tendency today in terms of modeling is that most of the models that Kaushik referred to tend to be highly mechanistic and very deterministic in terms of economic mechanisms, even though they have certain stochastic elements in terms of either parameters or economic shocks. The shortcomings of this approach have been amply documented, and there is a new trend which is trying to get a better fix on the reality by incorporating two things, technology and behavioral change, into these models. I believe that would make a big difference in terms of some of the policy conclusions.

Navroz has already expressed his skepticism about energy models. I think I have also pointed out that there are so many moving parts and assumptions that you have to be careful about how you interpret these results or how seriously you take them. But, at the same time, one does need some way of making decisions or at least getting comfort from these decisions. One may not know what might happen in a particular area but he might want to pose the question: "What if?" For this, I mentioned that one option was the scenario approach, but there are other complementary ways as well. Consider what occurred in the United States. In the late 1970s, that is, during the time immediately after the first energy crisis, there was a lot of preoccupation with numbers. On going back and reading the literature, one discovers that after some time, they realized that this preoccupation with numbers was actually getting in the way of serious policy. So, I think one of the most innovative things that occurred was the establishment of the Energy Modelling Forum. Many of the well-known names in energy policy analysis today, such as

Jim Sweeney, Bill Hogan, John Weyant, and many others from different institutions, were participating actively in the discussion. The idea here was to get all the modelers to engage with each other and basically make them talk not about "computerese" and numbers but key issues, and find out the differences. Of course, to make that a serious exercise, given the vastness and complexity of the US energy system, they ended up having to take up particular themes. I went back and looked at the papers from 1982 onwards, which describe the first seven years of the forum, and I was amazed by the relevance for us of the six or seven topics in another age on another continent that were actually used as a way of getting the models to talk to each other so that one could offer consistent advice to policymakers. The topics I have shown in the slide—energy in the economy, coal in transition, electricity demand, aggregate elasticity of energy demand, and oil and gas supply—are what I have been trying to persuade Navroz and a couple of other people, including Gireesh, to work on seriously.

I want to highlight just a few more major gaps. One of the biggest gaps in energy modeling for a geographically large country such as India, which applies to other countries too, is the issue of transport of energy. I just want to point out that two years ago, the biggest issue in terms of energy in India was the fact that we could not get coal to our power stations. I do not think anybody would disagree with that. This problem has, in fact, been persisting for at least 20 years, and we have not dealt with it. It is not that other countries have not had this problem. China faced exactly the same sort of situation in 1989. But their government dealt with it. The point is that unless one delves into the requisite analysis in some depth, many of the things that we talk about, including imports and moving coal to these power stations (50 percent of our rail freight today just entails moving coal for power), cannot be meaningfully framed in policy terms. Even if we say simplistically that we can import all the power and supply it to power stations, we will find it impossible to do so. The energy policy goes totally haywire. Gireesh can take this up in his remarks and perhaps also address the transmission dimension.

Finally, I want to say that the energy agenda is much wider. This includes issues not just on the supply side but also on the demand side. I think the biggest bank for the buck of national effort comes from energy efficiency, not just technical but also allocative efficiency economy-wide. The issues of transport, renewable energy, and technology development also need to be considered. The imperative of energy access lies at the core of this. Lastly, there is an entire dimension that we have not talked about, which relates to many initiatives being taken by the government to promote energy efficiency and the use of renewables. A lot of money is being spent or programmed to spend, but there is hardly a single study which actually looks at the effectiveness of such programs. I could only find one study done by Anand Sudarshan only recently. In other countries, many innovative programs continue to be introduced and evaluated, such as "cash for coolers" (and refrigerators and air conditioners) in Mexico, rationing to affect long-term behavior in Brazil, the CFL distribution process, and better information on energy labels. All these are highly pertinent to India, but I think we need to look seriously at what works and what does not before we pour a lot of money into such programs.

General Discussion

Vijay Joshi asked Navroz Dubash his view on the conclusion of the Indian Planning Commission's 2005 study on "Low Carbon Strategies for Inclusive Growth," that a low carbon growth strategy would reduce India's average GDP growth rate to 2030 by only 0.15 percentage points below the study's baseline growth scenario. Was that credible?

Navroz Dubash replied that the exact number was lower GDP growth over 2007 to 2030 by 0.16 percentage points, resulting in the 2030 GDP being lower by 3.33 percent. This was not particularly credible, though it would be a wonderful result if it were to come true. Deeper analysis of the work suggests that the low carbon strategy involves a series of questionable assumptions including about energy efficiency gains from appliances and the growth rate of renewable energy. There appear to be only five or six concrete changes between the two scenarios, but it was not clear if the model was fully accounting for either their costs or their gains. For example, it does not account for cobenefit gains in air pollution reduction, which should ideally be assessed. He was not sure how far policy should be based on it exclusively.

Rajnish Mehra noted that in a general equilibrium model, a change in the GDP growth rate also changes the discount rate, which is a function of the growth rate. So we get this small change in GDP that the Planning Commission study got if we keep the cost of capital constant. Mehra also wondered, referring to the graph on nuclear energy in India in the paper, why a country that is highly dependent on imported energy and has access to fairly good nuclear technology does not generate more of its power through fission.

Kaushik Deb replied that every additional nuclear power plant built anywhere has been more expensive than the last one. At its best, when it was about 6–7 percent of the global energy mix, nuclear energy was present in only nine countries, but has been losing market share since then. When renewables accounted for 6 percent of the global energy mix, they were present in 93 countries, with costs declining constantly with increasing deployment scale. Similarly in India, renewables have turned out to be much more cost effective and less challenging. Mehra commented that taking into account the imputed cost of global warming would improve the relative cost comparison of nuclear technology, at least with fossils. France had shown that.

Agreeing with Mehra, Deb commented that nuclear works best where governments are able to execute challenging decisions, and perhaps not that much attention is paid to the difference between financial and economic rates of return. So, countries like China and Russia have achieved renewables growth, but India, characterized by considerable reliance on the private sector for generation, finds it difficult to bridge these rates of return. Since no private insurer is typically willing to insure a nuclear power plant, this has to be socialized, which makes nuclear difficult in countries that depend largely on markets and where execution of top-down mandated targets is difficult. Nuclear power has been declining in every OECD country, including France and Japan, though the latter is rebooting some plants that were operational before the Fukushima disaster, but at a much lower scale of operation. These, and similarly the US nuclear plants, are unlikely to be replaced, though their life may be extended for a couple of decades.

Anupam Khanna noted that nuclear is typically never an integral part of economic or financial modeling but is incorporated exogenously in almost every energy model, except very specifically in determining conditions under which nuclear energy would be competitive. Similarly, renewables in India typically tend not to be part of energy models, and these are exogenously brought in with one set of results if market clearing mechanisms are used and another when social goals are sought to be achieved such as accelerating the process of adopting renewables. Energy modeling is heavily guided by the heavy reliance on "expert inputs," also the case for this paper. Dubash added that all the domestic Indian models overproject the nuclear capacity to be between 15 and 42 gigawatts of nuclear power by 2030, though only 2 gigawatts have been added in the last decade. There appears to be an official number for nuclear power, basically 60 gigawatts, and it seems that no official pronouncement can go down below that.

Shekhar Shah asked Dubash to comment on the future of renewables in India, given the survey he had done. Can India achieve the government's recent target of adding 100 gigawatts of solar energy by 2022?

Gireesh Pradhan (chair) averred that he was thoroughly in awe of economists but wanted to point out that India is currently in a state of scarcity amidst plenty. Installed capacity is almost 270,000 MW against a peak demand yesterday of 127,000 MW, and yet we had a shortage of 2 percent. We have concentrated a lot on the supply side, mostly using coal, and this will remain the focus in the short and medium terms. So, the capacity is there, but we are not able to meet the current demand, and, furthermore, 36 percent of Indians have no access to electricity, so there is a big question of India's energy security. The other problem that the government needs to tackle is the poor financial health of distribution companies, which makes the entire power sector extremely shaky. The power sector has a huge debt overhang and is adding losses of some ₹40,000 crores every year.

On climate change, Pradhan felt that there was no need to be defensive, with India being at just 920 KWh per capita as against a global average of 2,800 KWh and its CO_2 emission far less than China's. On solar, the present government increased the previous goal of 20,000 MW of grid connected solar to 100 GW by 2022, part of an overall goal of 175 GW of renewables by then, comprising in addition to solar, 60 GW from wind, 10 GW from biomass, and 5 GW from small hydro. The approach on solar is to take advantage of short gestation lags and install large plants, assuming that the substantial funding and land acquisition needed will be available. The problem will be when large amounts of renewable power have to be integrated into the grid, requiring ancillary services and balancing to transmit power from multiple sellers to multiple buyers in a complex environment where service reliability must be assured and the standards for the actual grid connection must be established and maintained.

Shah picked up on Khanna's mention of the Energy Modeling Forum (EMF) at Stanford University and suggested setting up a similar forum in India to bring together leading experts and decision-makers from government, industry, universities, and other research organizations to study important energy and environmental issues. Would that be doable?

Khanna added the Stanford EMF remains very active, though it has moved on to next generation issues. He felt that Dubash had already started framing the key issues for such a forum in India by reviewing six or seven significant studies in this area. But maintaining such a forum necessitates a lot of commitment from the members beyond just meeting at regular conclaves. It requires a serious commitment to putting data together and ensuring its authenticity and availability, some of the things that also came out during the first few rounds of the EMF.

Dubash fully agreed that something like the Stanford EMF was needed in India, though his own group was more an intelligent consumer of models not a producer. Even consumption was not easy, which is why they had done the review of models. And there would be serious institutional and other challenges in setting up a forum, since there are a handful of organizations in India who do these models, and the utility of these models entails some kind of a U-curve. South Africa has only one serious modeling group, which nobody really contests, so it is at one end of the U. We are somewhere in the middle with the multiplicity of Indian models, but none quite at the definitive level required to build a serious dialogue, and also not yet at the point at the other end of the U when we can ensure the sensible use and value of the multiple models. Dubash said that they had requested NITI Aayog to play a strategic, cross-ministerial, long-term role in energy modeling and policy dialogue—they already have an in-house spreadsheet-based model that can form the foundation for such dialogue. He felt that setting up this kind of a forum would not come about automatically and would need a sustained and systematic collective action.

Khanna felt that the NITI spreadsheet model was good for some dialogue but was not really a model. He mentioned that the US Department of Energy's Pacific Northwest National Laboratory (PNNL) in Washington State had undertaken some work on an Asian energy forum, but the problem was the scarcity of people. And international efforts may be crowding out others. At the very least, this will require considerable leadership, commitment, and buy-in.

Shah noted that Arvind Panagariya would be delivering the IPF lecture that evening, and the suggestion about an energy forum at NITI could be conveyed to him. He referred to a similar exercise in a forum on growth macro-modeling undertaken by the erstwhile Planning Commission that was run by Commission Member Kirit Parekh with several institutions involved whose work was also funded by the Commission. These met regularly to present their model results and to build a dialogue around them. He mentioned that this forum added considerably to NCAER's capacities in macro-modeling.