ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

LBNL Report

Modeling Clean and Secure Energy Scenarios for the Indian Power Sector in 2030

Nikit Abhyankar[a],
Amol Phadke[a],
Jayant Sathaye[a],
Ranjit Bharvirkar[b],
Alissa Johnson[a],
Ranjit Deshmukh[a],
Cathie Murray[c],
Bob Lieberman[c],
Ajith Rao[c]

[a] Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division
[b] Itron Inc.
[c] Regulatory Assistance Project

May, 2013

This work was supported by the Climate Economics Branch, Climate Change Division, U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Table of Contents

ABSTRACT

Recent developments in renewable energy (RE) related to upward revisions to potential estimates, declining costs, and improved performance have created new opportunities for using RE to cost-effectively meet energy security challenges in India. Under the "Modestly Secure and Clean" scenario, 40% of energy needs in 2030 are met by wind (15%), solar (10%), other RE (5%), and energy efficiency (10%) at a cost comparable to the "Baseline" scenario where only 10% of the electricity demand is provided by these resources and will lead to elimination of coal imports. If the rapid drop of solar prices continues, an electricity mix where 60% of the demand is provided by these sources can be achieved at comparable costs. Given the seasonal and diurnal complementary nature of solar and wind resources in India, and high-level of correlation with the load shape, such a mix is both cost effective and technically feasible.

1 Introduction

According to Central Electricity Authority, over April 2011-March 2012 period the energy shortage was 8.5% and peak demand shortage was 11.1% (CEA, 2012a). A multitude of factors has led to much lower generation capacity coming on line during the 11th plan as compared to the target. Coal imports are likely to range ~140 million tonnes according to the Coal Ministry and the Planning Commission (ET, 2012; Ratnajyoti Dutta, 2012). The recent rise in global coal prices that have increased beyond $100/tonne yields an import bill of ~$14 Billion for just 2012-13. In case the domestic coal supply is not able to meet these projections and coal prices continue rising, the import bill will continue to grow. From the perspectives of an ongoing chronic power shortage and a future potentially large energy import bill, it is imperative that all cost-effective domestic resources need to be considered for meeting the power demand and ensuring sustained rapid GDP growth.

2 Renewable Energy Potential

In recent months, there have been several re-assessments of potential energy reductions from energy efficiency and increased availability of renewable energy resources such as wind and solar indicating an alternative energy mix could cost-effectively achieve the dual objectives of rapid/substantial reduction (or even complete elimination) of power shortage and the energy import bill.

It is well known that India is rich in its solar resource. A number studies and published reports in indicate that India receives on average 2,300-3,200 hours of sunlight a year with daily incidence ranging from 4 to 7 kWh/m^2, aggregating to an equivalent energy potential of about 6 million BkWh of energy per year (Sharma, Tiwari, & Sood, 2012). Applying constraints pertaining to land-use/cover show solar power potential ranging from ~11,000 GW to 200-250 GW (Ramachandra, Jain, & Krishnadas, 2011; Sukhatme, 2011).

Wind technology and analysis tools have evolved and improved significantly since the nineties. Several recent reports indicate that the potential for wind energy is significantly more. At a 20 percent capacity factor, the various studies estimate 2,505 GW onshore, 1,324 GW, and 2,075 GW (Hossain, Sinha, & Kishore, 2011; Lu, McElroy, & Kiviluoma, 2009; Phadke, 2012). Similar wind potential re-estimation studies were done for the US and China, which found that their potentials were also significantly higher than their original official estimates - increased from 14,106 BkWh to 21,024 BkWh for the US and from 520 BkWh to 4,170 BkWh for China.

It is necessary to acknowledge a unique aspect of wind energy. Unlike various other conventional power generation sources (e.g. coal, natural gas, solar PV/thermal), only a small portion of the land area within a designated "wind power plant" is disturbed either permanently or temporarily with the rest of the land area being available for alternative uses including but not limited to farming, cattle-raising, and others. NREL (2009) estimates that less than 3% of the wind power plant area is disturbed during the construction/commissioning phase of the project and less than 3% of the wind power plant area is permanently disturbed (Denholm, Hand, Jackson, & Ong, 2009).

The projected Indian energy needs for 2032 (end of 15th Plan) are in the range of 3880 to 4800 BkWh. The estimated wind energy potential ranges from 2900 to 4390 BkWh and solar potential ranges from 380 to 24,400 BkWh. In other words, the estimated wind and solar potential is ~1 to 6 times that of the projected 2032 energy needs of India suggesting that availability of renewable resource is not likely to be a fundamental constraint when planning India's energy portfolio for the future.

3 Trends in Costs and Performance of Various Technologies

Wind costs are declining both due to a reduction in capital costs and improvements in performance. According to a study of 81 turbine transactions (worth 24,000 MW) in the US, capital costs of turbines were decreasing from 1990s to 2001, steady until 2004, rising again through 2009, and declining again through 2011 (Wiser, Lantz, Bolinger, & Hand, 2012).

Ongoing improvements in wind technology (e.g. higher hub-heights and larger rotor diameters) have led to increasing total energy output and in turn their capacity utilization factors, especially in lower wind speed sites (Wiser et al., 2012).[1]

Solar costs have also been rapidly declining. The lowest successful bid for solar PV in the second round of the Jawaharlal Nehru National Solar Mission 2011 auction resulted in the price of Rs 7.49 per kWh (~USD 0.15), which was 38 percent lower than the average price set in the first round of the 2010 auction (Rs 12.16 per kWh) (Deshmukh, Gambhir, & Sant, 2011; Pearson, n.d.). Average solar costs are falling mainly due to the reduction in prices for PV modules. According to the Solarbuzz retail module price index, module prices in the U.S. and EU have reduced by almost 60 percent over the last 5 years, both due to technology improvements and other factors such as eliminating silicon shortages and increased competition (Barbose, 2011; Deshmukh, 2011; Solarbuzz, n.d.).

Auctions are enabling the price discovery of RE and capturing the cost savings for consumers as observed in India's Jawaharlal Nehru National Solar Mission, California's Renewable Standard Portfolio procurement, and Brazil's RE procurement. Brazil's Ministry of Energy supervised auctions also show a trend in declining wind prices. The 2011 auctions resulted in an average price of 99.5 Reals per MWh (USD 63.75 per MWh) for 1928 MW of wind capacity, 23% lower than the 2010 average price of 130 Reals per MWh (USD 80.75 per MWh), and 33% lower than the 2009 average price of 148 Reals per MWh(USD 91.93 per MWh). Contracts are of 15-20 year durations (Trabish, H, n.d.).

In sharp contrast to the trends in costs of wind and solar technologies, the global prices of coal and natural gas have started becoming increasingly volatile since early 2000s and spiking as high as ~$180/tonne for coal and ~$10/MMBtu for natural gas in 2008 (BP, 2010). China's switch

---

[1] These reductions in capital costs and technology improvements have been noted by the Central Electricity Regulatory Commission. See - Central Electricity Regulatory Commission, November 2011, "Explanatory Memorandum for Draft Terms and Conditions for Determination of Tariff for Renewable Energy Sources".

from a net exporter of coal to a net importer coupled with India's growing imports may lead to higher and more volatile coal prices over the next few years.

4 International Developments in Energy Mix Modeling and Goal Setting

As jurisdictions have improved their understanding of the techno-economic potential of their indigenous renewable resources, these resources have taken a more prominent position in national and regional energy strategies and targets.

Recent updates to China's technical exploitable wind resource assessment resulted in a significant increase in estimates, to over 2500 GW of onshore wind. The Chinese government has proposed a low-carbon development path, and wind power development has now become one of the primary strategies to achieve this path. In 2011 China's Energy Research Institute and the International Energy Agency completed the "China Wind Energy Development Roadmap 2050." This roadmap anticipates that installed wind capacity will reach 200 GW by 2020, 400 GW by 2030 and 1000 GW by 2050. Wind power is expected to ramp up to meet 17G% of electricity demand (IEA, 2011). The US has also increased its understanding of the wind resource potential in the last decade and has set a target of 300 GW by 2030, or 20% of installed capacity (USDOE, 2008).

The European Union has set an economy-wide de-carbonization goal of reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050. The resulting "20/20/20 by 2020" legislation sets a binding target of 20% for carbon abatement, a binding target for renewables (20% end-use economy wide, which implies a target of approximately 35% for electricity), and a non-binding target for energy efficiency (20% of end-use) by 2020. The National Renewable Energy Action Plans (NREAPs) submitted to the Commission were the member states' proposals for how they plan to comply with the renewables requirement. When the plans are aggregated the total wind capacity by 2020 is anticipated to be 213 GW and total solar (PV and CSP) is expected to be 92 GW (Beurskens & Et al, 2011). The EU Commission recognizes that meeting these ambitious goals will not be adequate to reach their 2050 targets. A roadmap analysis was recently completed and points to a need for and feasibility of increased renewable targets:

"The analysis of all scenarios shows that the biggest share of energy supply technologies in 2050 comes from renewables. Thus, the second major pre-requisite [after efficiency] for a more sustainable and secure energy system is a higher share of renewable energy beyond 2020. In 2030, all the de-carbonization scenarios suggest growing shares of renewables of around 30% in gross final energy consumption" (EU, 2011).

5 Scenario Analysis

The analysis is performed by developing a least cost capacity expansion model in GAMS for the Indian power sector. It minimizes the discounted total (investment and operational) cost of the power system subject to the constraints on resource availability. Model assumptions and data are given in annexure 1.

Three scenarios of renewable energy capacity addition and energy efficiency programs are created as described in the following table. The peak demand (505 GW) and energy needs (3245 TWh) are constant across all three scenarios in 2030.

5.1 Baseline Scenario (12th Plan up to 2022 and then hold growth trends constant)

This scenario simulates the capacity additions as envisaged in 12th plan up to 2022. For non-coal plants, the growth trend is kept constant until 2030 while capacity addition from coal plants beyond 2022 is adjusted to meet the remaining demand. Electricity demand is as projected by the Power and Energy Working Group report for 12th plan up to 2022. It is assumed to grow at similar growth rates thereafter.

5.2 Modestly Secure and Clean Scenario (RE+EE Share = 40% by energy by 2030)

This scenario assumes that clean energy sources provide 40% of total energy needs in 2030. Specifically, wind provides 15%, solar provides 10%, and other RE (i.e. small hydro, biomass and waste to power) provides 5% of energy by 2030. Energy efficiency programs save 10% of energy.

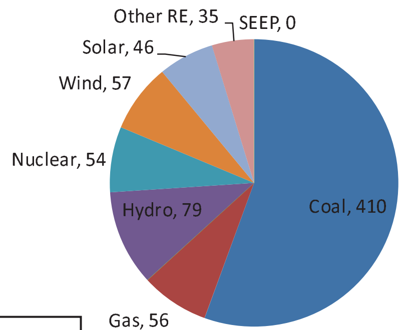
5.3 Aggressively Secure and Clean Scenario (RE+EE Share = 60% by energy by 2030)

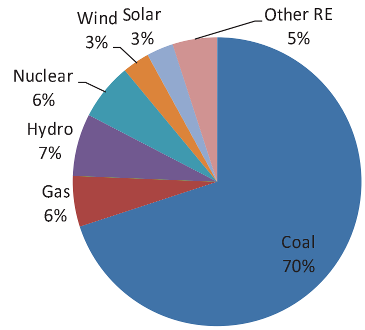
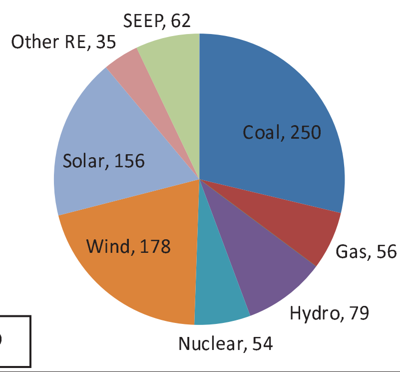
This scenario assumes that clean energy sources provide 60% of total energy demand in 2030. Specifically, wind provides 25%, solar provides 15%, and other RE (i.e. small hydro, biomass and waste to power) provides 5% of energy by 2030. Energy efficiency programs save 15% of energy.

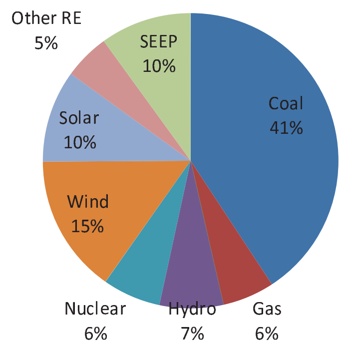
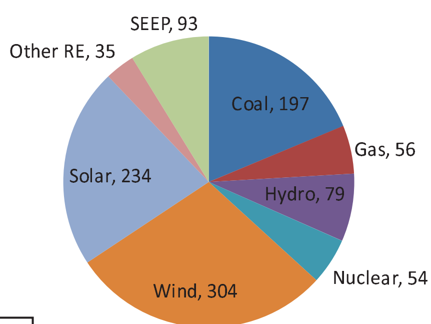
6 Key Results

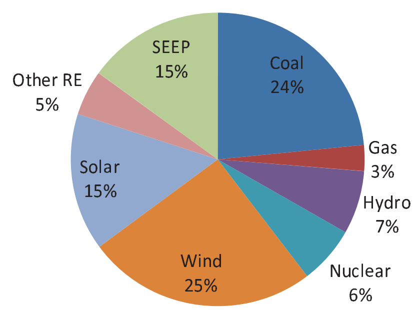
The total installed capacity in the clean energy scenarios is substantially more than that in the Baseline scenario because the coincidence of renewable energy resources with peak demand is lower than that of the schedulable conventional plants.

Table 1: Shares in Installed Capacity and Net Energy Generation in 2030

<table>
<tr><th></th><th>Installed Capacity in 2030 (GW)</th><th>Share in Net Energy Generation in 2030
(Same across all three scenarios at 3245 TWh)</th></tr>
<tr><td>Baseline</td><td>

Total = 738</td><td>
</td></tr>
<tr><td>Modest</td><td>

Total = 809</td><td>
</td></tr>
<tr><td>Aggressive</td><td>

Total = 960</td><td>
</td></tr>
</table>

The total cost of generation of the modest clean energy scenario is only 2% higher than that of the 12th plan scenario while that of the aggressive clean energy scenario is 10% higher than the 12th plan scenario. Energy efficiency off-sets the higher cost of renewable energy sources in both clean energy scenarios. Given the variable nature of renewable energy generation, additional flexible capacity (e.g. gas turbines) are more likely to be needed in order to maintain stability of the grid. Based on the merit order dispatch modeling, the integration costs range between 4% and 7% of the total generation cost and are accounted for in this analysis.

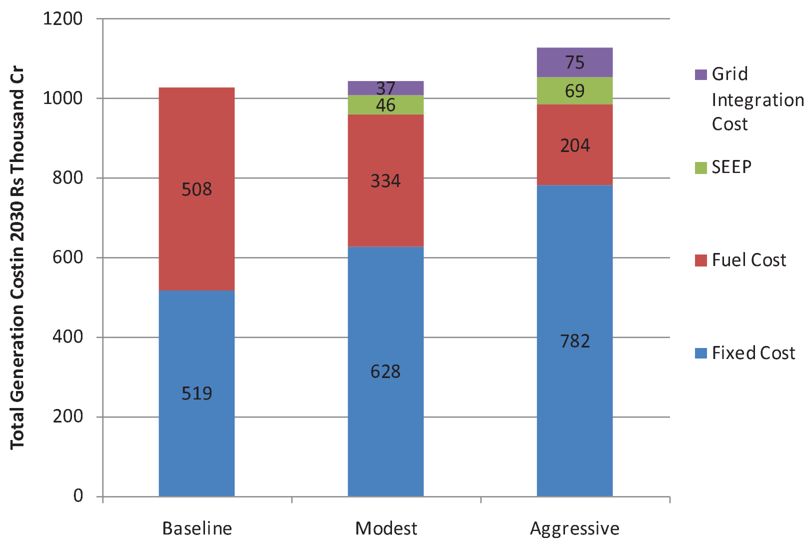


Figure 1: Total Generation Cost in 2030 (Rs Thousand Crore)

Given that the total cost of generation in the clean energy scenarios is only marginally higher than the 12th plan costs, average cost of energy at bus-bar for the Modest scenario is approximately the same as that of the Baseline scenario and 5% higher in the Aggressive scenario.

Clean energy scenarios would reduce the fuel consumption significantly and would be able to hedge the risk of any fuel price shock or supply disruption thereby enhancing country's energy security. Under the Aggressive scenario coal consumption in 2030 is at the same level as in 2013. Under the Modest scenario, annual coal consumption is reduced by ~60% by 2030.

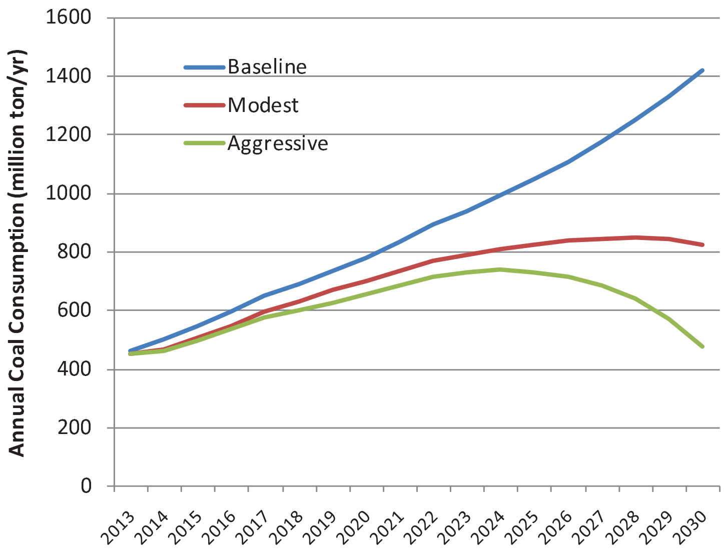


Figure 2: Annual Coal Consumption by Power Sector (million tons per year)

In this analysis, coal price is assumed to be the average price of the domestic coal (~$40/tonne). The international (import) price of coal is much higher (~$120/tonne), albeit with higher calorific value and lesser ash content. The savings due to avoided coal imports for different shares of imported coal in total coal consumption in 2030 are shown in the following table.

Table 2: Avoided Coal Imports and Saving by 2030

	Modest				Aggressive			
Cumulative avoided coal consumption relative to Baseline (million ton)	3,239				4,842			
Share of imported coal in the avoided consumption relative to Baseline	20%	30%	40%	50%	20%	30%	40%	50%
Cumulative coal imports up to 2030 million tons	648	972	1,295	1,619	968	1,453	1,937	2,421
International price of coal ($/ton) (Assumed constant from 2013 to 2030)	120	120	120	120	120	120	120	120
Domestic coal price in 2030 ($/ton) (increases from $40 in 2013 to $59 in 2030)	59	59	59	59	59	59	59	59
Cumulative saving up to 2030 Rs Thousand Cr	213	320	427	533	318	477	636	795

Annual carbon dioxide emission reductions under the Modest and Aggressive scenarios are 900 million tons/yr (40%) and 1500 million tons/yr (66%), respectively.

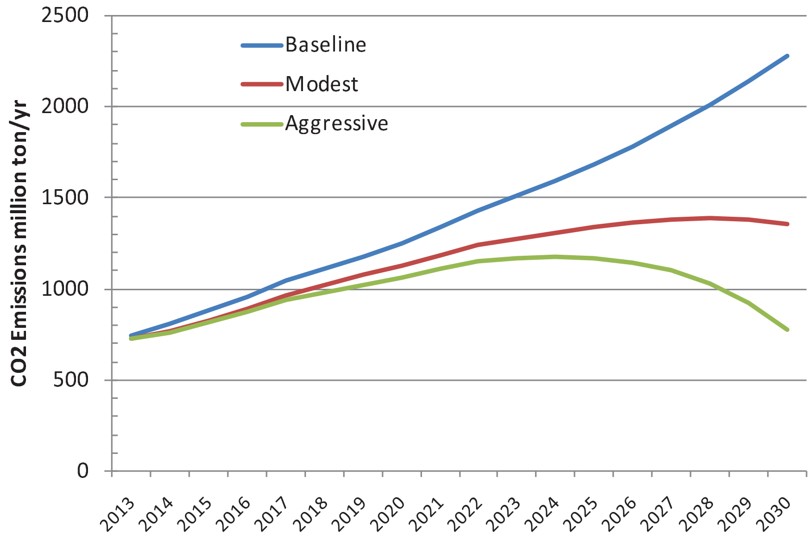


Figure 3: Total CO2 Emissions from Power Sector

Technical Feasibility of Integrating Large-scale Renewables – International Experience

According to the recently published International Panel on Climate Change's Special Report on Renewable Energy (2011), despite the variable electrical output of renewable energy sources such as wind and solar, there are being successfully integrated into existing electric systems all around the world. In four countries (Denmark, Portugal, Spain, and Ireland), wind energy in 2010 was already able to supply up to 20% of annual electricity demand. Based on multiple comprehensive renewable energy integration studies from EU and the US, IPCC (2011) finds that *"accommodating wind electricity penetrations of up to (and in a limited number of cases, exceeding) 20% is technically feasible, but not without challenges."* A meta-analysis of these studies conducted by (Holttinen et al., 2009) estimates that the incremental cost of for wind penetration up to 20% is less than INR 0.30/kWh.

Seasonal and Diurnal Availability of Solar and Wind Energy and Demand Patterns in India

Wind and solar generation have complementary temporal profiles and also have a good correlation with demand. Based on the analysis of hourly projected demand in 2030, we find that large scale addition of solar and wind reduces the requirement for intermediate-load (typically, gas) and base-load plants (typically, coal), does not require significant back up generation support, and is technically feasible to integrate in the electricity mix.

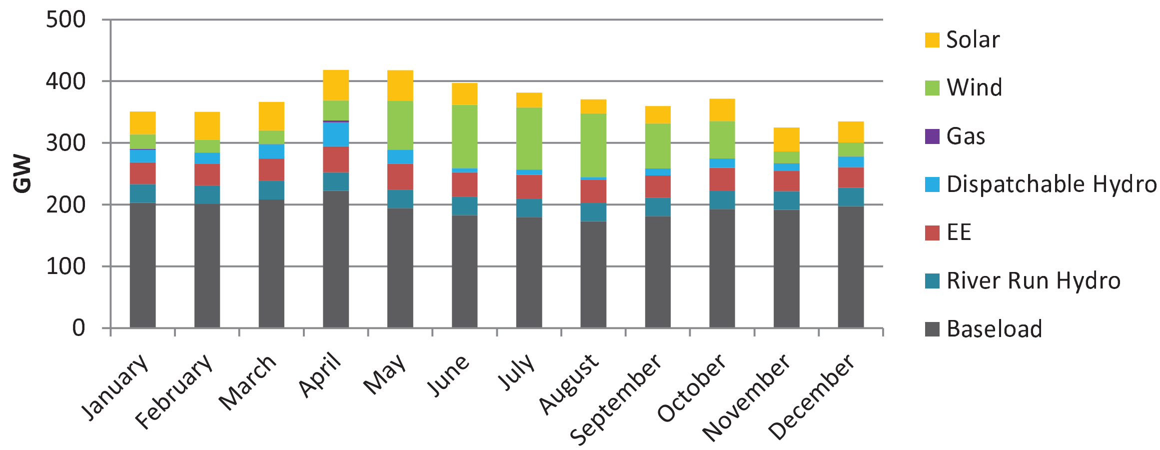


Figure 4: Seasonal profile of generation and demand for "Modest" Scenario

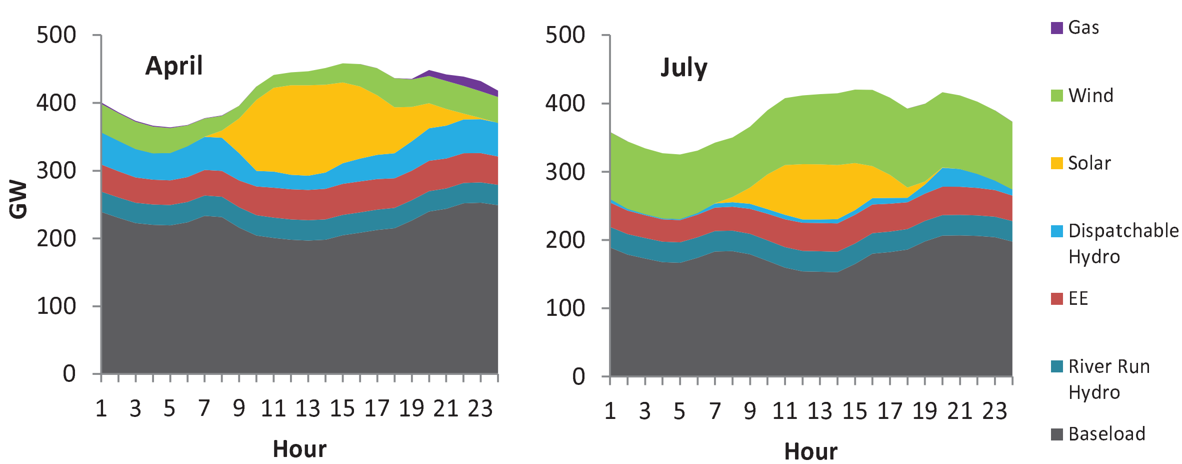


Figure 5: Average hourly demand and generation for "Modest" Scenario

7 Conclusion

The preliminary analysis presented in this note shows that a cleaner and more secure future for the Indian power sector is feasible. Due to the falling costs of the renewable energy technologies and cost-effective energy efficiency programs, the incremental costs of the clean energy scenarios are only minor. A preliminary simulation of the grid dispatch also indicates that the integrating large scale additions of solar and wind power is technically feasible. The clean energy scenarios offer substantial emissions and other environmental benefits; more importantly, clean scenarios significantly enhance the country's energy security by reducing the power sector's exposure to the imported fuel. More analysis and modeling effort is needed to fully understand the costs, benefits and risks in the clean scenarios; our work in the near future would focus on answering these questions.

8 Annexure 1: Key Model Assumptions, Data Sources and Supplementary Results

8.1 Key Model Assumptions

8.1.1 Peak Demand Projections

Demand is projected per the power and energy working group report in the 12th five year plan up to 2022. Similar growth rates are applied thereafter.

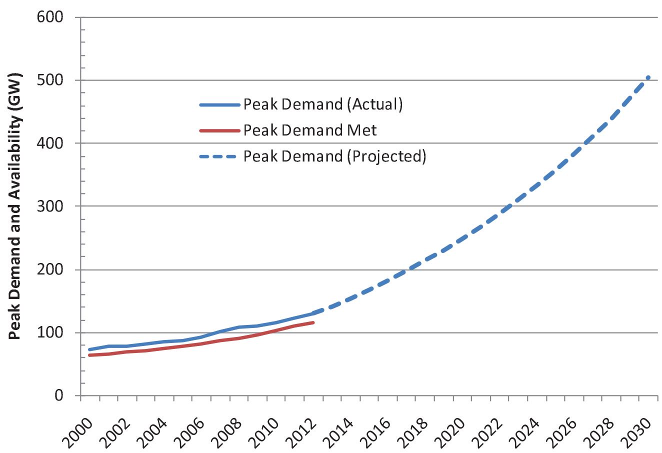


Figure 6: Actual and projected peak electricity demand (GW) and availability at bus-bar

(Data Sources: (CEA 2007; CEA 2009; CEA 2011; CEA 2012; Planning Commission 2012; Authors' calculations)

8.1.2 Planned Capacity Additions and Energy Efficiency Programs

Large additions to the country's electricity generation capacity have been planned in the next two plans including aggressive targets for renewable energy sources. A total of 72 GW of renewable capacity has been slated to be added by 2022 translating to total investments of nearly Rs 400 Thousand Cr (MNRE, 2007, 2010a, 2010b).[2]

There is also renewed interest in implementing large scale energy efficiency programs nationally as well as at the utility level. In addition to the standards and labeling program, the Bureau of Energy Efficiency will be launching the Super Energy Efficient Appliance Deployment Program (SEEP) in 2012.

[2] Note that this includes the 20 GW of grid connected solar projects by 2022 under the National Solar Mission.

8.1.3 Renewable Energy Resource Potential and Levelized Costs

Table 3: Potential and Cost of Renewable Energy Sources in India

Resource		Potential in India (GW)	Installed Capacity as of March 2012 (GW)	Average Cost of Generation** Rs/kWh	
				2012	2030
Wind		2,505*	17.4	3.62 (@35% CUF) 4.23 (@30% CUF)	3.60 [b] (@35% CUF) 4.20 [b] (@30% CUF)
Small Hydro		15	3.30	3.56	3.1
Biomass + Cogeneration		23.7	3.10	3.20	4.9[c]
Solar	PV	20-30 MW/sq km	0.94	7 – 8 [a]	4.5
	Thermal		-	9.9	6.4

(Data Sources:(MNRE, 2010b; Phadke, 2012))

Notes:

* At 100m hub height and >20% capacity factor. Source: Phadke, A., R. Bharvirkar, and J. Khangura (2012) - Reassessing Wind Potential Estimates for India: Economic and Policy Implications. Berkeley, Lawrence Berkeley National Laboratory.

** Cost of generation is estimated using norms specified in CERC Terms and Conditions of Tariff determination for Renewable Energy Sources, 2012.

[a] Solar PV costs as seen in the second round of the competitive bidding for National Solar Mission.

[b] Drop in the wind turbine costs is not significant since it is a mature technology. However, the operations and maintenance costs of the old fleet keeps increasing over years.

[c] Drop in the capital cost of biomass projects is not significant since it is a mature technology. However, the fuel price (biomass) and operations and maintenance costs keep increasing over year thereby raising the cost of generation over years.

8.1.4 Capital Costs

8.1.4.1 Conventional Projects

Capital cost of conventional projects is assumed to remain constant until 2030.

Fuel	Capital cost (2012) (Rs Cr/MW)
Coal	4.5
Natural Gas	3.5
Diesel	3.0
Hydro	6.0
Nuclear	8.0

8.1.4.2 Renewable Energy projects

The source of capital costs of renewable projects in 2012 is the Central Electricity Regulatory Commission (CERC) Tariff Regulations issued in February 2012. Capital cost for solar PV projects has been adjusted to meet the results of the recently concluded competitive bidding for phase II of the National Solar Mission. The winning bids had the average costs in the range of Rs 7-8/kWh. Post-2012, the capital cost is assumed to follow the trajectory projected in the US Energy Information Administration's (EIA) Annual Energy Outlook 2010. Capital cost of solar thermal projects with storage is assumed to cost 50% more than the capital cost of projects without storage.

RE Technology	2012 (Rs Cr/MW)	2030 (Rs Cr/MW)	% Change
Wind (80m hub height)	5.75	5.73	-0.4%
Small Hydro	6.12	4.75	-22%
Biomass + Cogeneration	4.30	2.84	-34%
Waste to Power	8.00	6.00	-25%
Solar Thermal (with storage)	12.63	7.58	-40%
Solar PV	8.10	5.01	-38%

8.1.4.3 Energy Efficient Appliances

Incremental investment in SEEP is taken as the incremental capital cost of efficient appliances. Retail price of the BAU appliances and efficient is determined after a short market survey in 2011-12. Average capital cost of efficient appliances is assumed to increase at 2% per annum.

End Use	Average Cost of the Appliance - 2012 (BAU) (Rs/Unit)	*Incremental* Cost of Super Efficient Appliance - 2012 (Rs/Unit)
FTLs (T5+electronic choke)	185	215*
Fans	1,000	250**
AC	20,000	6,890**
Refrigerators	10,535	4,000**
TV	12,000	1,175**
Motors [a]	30,000	3,457***
Agricultural Pumps [a]	11,000	4,000*

Notes:

[a] For Motors and agricultural pumps, prices for best available appliances in India are used.

* Indicates differential in average retail prices.

** Refers to the differential in manufacturing costs only. The differential in retail prices might be a little higher.

*** This is the weighted average incremental cost over different capacities of motors ranging from 2.2 kW to 37.5 kW.

Data Sources:

- Lawrence Berkeley National Laboratory - Cost of super-efficient TVs and ACs
- Adwait Pednekar (Prayas Energy Group) - Cost of super-efficient fans
- US Technical Support Document for Refrigerator Standards Rulemaking – Cost of super-efficient refrigerators.

8.1.5 Capacity Utilization Factors

Capacity Utilization factors for the renewable energy projects are taken as approved in the CERC tariff regulation 2009. Utilization of thermal projects is adjusted to meet the energy demand.

Technology	Capacity Utilization Factor (or PLF)
Coal	50-90%
Gas (CCGT)	40-70%
Diesel	10%-60%
Nuclear	47%
Hydro	35%
Wind	20-35%
Small Hydro	40%
Biomass + Cogeneration	80%
Waste to Power	20%
Solar Thermal (with thermal storage)	27%
Solar PV	22%

8.1.6 Heat Rates

Heat rates for conventional and biomass projects are taken from the CERC tariff regulations 2009.

Technology	Heat Rate (kCal/kWh)
Coal / Lignite	2300
Natural Gas (CCGT)	1800
Diesel	1900
Biomass + Cogeneration	3800

8.1.7 Other Assumptions

8.1.7.1 T&D Loss

Transmission and Distribution loss is conservatively assumed to be 20% in 2012. It is assumed to reduce to 15% by 2022 and to 12% by 2030.

8.1.7.2 Fuel Prices

Fuel prices are set at the long-run marginal costs in 2012. Coal, biomass and natural gas prices are assumed to increase by 2% per annum while diesel prices are assumed to increase by 4% per annum. Prices for 2012 and escalation rates are shown in the following table.

Fuel	Delivered price in 2012		Annual Price Escalation
	Rs/Ton	**($/MMBtu)**	
Coal (Average of domestic coal)	2000	2.5	2%
Natural gas (Average of domestic and LNG)	-	6.0	2%
Diesel	-	15.0	4%
Biomass (Average of CERC approved prices)	1736	2.5	2%

CO_2 Emissions Factors

CO_2 emissions factors are taken from the CEA emissions database v5 (2010). Specific emissions for the thermal projects are listed in the following table.

Technology	CO_2 emissions (kg/kWh)
Coal / Lignite	1.04
Natural Gas (CCGT)	0.43
Diesel	0.59

8.1.8 Local Pollutant Emission Factors

Emission factors for local pollutants like SO_x, NO_x, and Black Carbon (Soot) are given in the following table. They have been taken from Ohio State University's study on anthropogenic emissions from energy activities in India.[3] Since local pollution is the problem usually associated with coal power plants, we have applied these emission factors only to coal fired power plants.

[3] Source: http://www.osc.edu/research/archive/pcrm/emissions/thermalemissions.shtml

Pollutant	Emission Factor
SOx (g/kWh)	7.4
NOx (g/kWh)	8.0
Black Carbon (Soot) (g/kg of coal consumption)	0.08
Suspended Particulate Matter (SPM) (g/kWh)	2.5

8.2 Supplementary Results

The total installed capacity in the clean energy scenarios is more than that in the Baseline scenario. This is because the coincidence of renewable energy resources with peak demand is lower than that of the schedulable conventional plants.

Table 4: Installed Capacity (GW) in 2030

	Baseline	Modest	Aggressive
Coal	410	250	197
Gas	56	56	56
Hydro	79	79	79
Nuclear	54	54	54
Wind	57	178	304
Solar	46	156	234
Other RE*	35	35	35
SEEP	0	62	93
Total	**738**	**809**	**960**

*Note: Other RE sources includes small hydro, biomass and waste to power.

The "Baseline" scenario is dominated by coal accounting nearly 70% of the net generation in 2030. Gas plants provide about 6% of total electricity requirement making the share of fossil fuel in electricity generation nearly 76% in 2030. In the "Modest" and "Aggressive" scenarios, electricity generation from fossil fuels by 2030 drops to 47% and 27%, respectively.

Table 5: Net Energy Generation (TWh or billion kWh) at bus-bar in 2030

	Baseline	Modest	Aggressive
Coal	2270	1322	760
Gas	185	185	93
Hydro	226	226	226
Nuclear	206	206	206
Wind	99	492	819
Solar	97	328	492
Other RE	162	162	162
SEEP	0	325	487
Total	**3245**	**3245**	**3245**

Although clean energy scenarios result in increase in a substantial increases in additional investments, the average cost of generation is almost the same as the Baseline scenario.

Table 6: Total Additional Investments between 2013 and 2030 (Rs Thousand Crores)

	Baseline	Modest	Aggressive
Coal	1,193	552	340
Gas	125	125	125
Hydro	323	323	323
Nuclear	496	496	496
Wind	227	922	1,644
Solar	273	848	1,266
Other RE	130	130	130
SEEP	0	34	52
Total	**2,768**	**3,431**	**4,377**
Average Capital Cost (Rs Cr/MW)	5.14	5.58	5.69

Although the additional investment is higher in the "Modest" and "Aggressive" scenarios, their total cost of generation in 2030 (including fuel and other costs) is only marginally higher than the "Baseline" scenario.

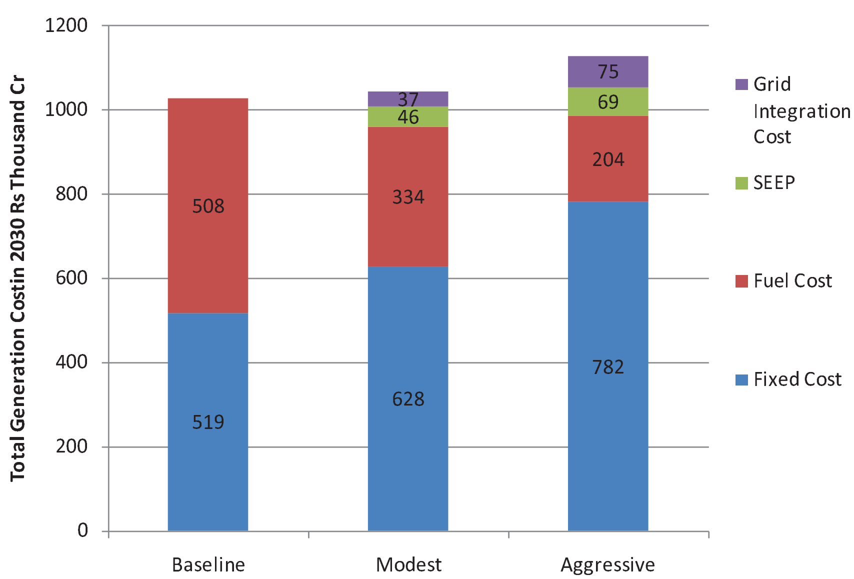


Figure 7: Total cost of generation (Rs Thousand Cr) in 2030

The total cost of generation of the "Modest" and "Aggressive" scenario relative to the "Baseline" scenario is 2% and 10% higher, respectively. Energy efficiency, being the cheapest resource, offsets the higher cost of renewable energy sources in both clean energy scenarios.

The variable nature of renewable energy generation requires additional flexible capacity (like gas based combustion turbines) in order to integrate them into the grid. The incremental cost for grid integration of renewables in the clean energy scenarios is estimated (based on the merit order dispatch modeling) to range between 4% and 7% of the total generation cost.

The average cost of energy at bus-bar in the "Modest" and "Aggressive" scenarios is only marginally higher as compared with that in the "Baseline" scenario.

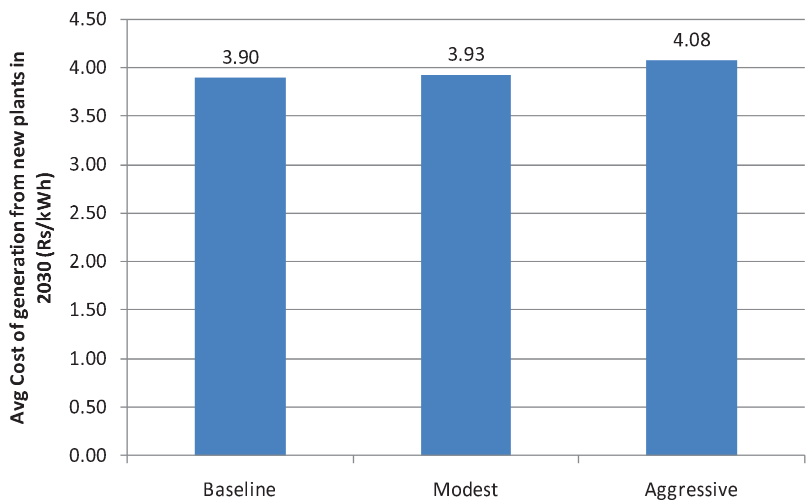


Figure 8: Average cost of generation from new plants at bus-bar in 2030 (Rs/kWh)

Secure and Clean energy scenarios can result into large reductions in emissions of CO_2 and local pollutants (like SO_X, NO_X, Black Carbon and Suspended Particulate Matter) from power sector. Such reductions in local pollutants will have immense environmental and public health benefits.

Table 7: Reduction in CO2 and Local Pollutant Emissions from Power Sector

Scenarios	Emissions in 2030 (million tons/yr)					Cumulative reduction in emissions between 2013 & 2030 (million tons)				
	CO_2	SOx	NOx	Black Carbon (Soot)	SPM*	CO_2	SOx	NOx	Black Carbon (Soot)	SPM*
Baseline	2280	18	20	0.11	6	-	-	-	-	-
Modest	1363	11	11	0.07	4	4956	42	45	0.26	14
Aggressive	777	6	7	0.04	2	7722	62	67	0.39	21

Note: * SPM stands for Suspended Particulate Matter

9 References

Barbose, G. (2011). Tracking the Sun IV: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2010. *Lawrence Berkeley National Laboratory: Berkeley, CA*, 61.

Beurskens, L. W. M., & Et al. (2011). Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States. Retrieved from http://www.ecn.nl/docs/library/report/2010/e10069.pdf

BP, B. P. (2010). *BP statistical review of world energy*.

CEA. (2007). *Report on Seventeenth Electric Power Survey of India*. Central Electricity Authority.

CEA. (2009). *Growth of Electricity Sector in India from 1947-2009*. Central Electricity Authority.

CEA. (2011). *Load Generation Balance Report 2011-12*. Central Electricity Authority.

CEA. (2012a). Monthly Energy Report (March 2012). Central Electricity Authority. Retrieved from http://www.cea.nic.in/reports/monthly/executive_rep/mar12/29-30.pdf

CEA. (2012b). *Load Generation Balance Report 2012-13*. Central Electricity Authority.

Denholm, P., Hand, M., Jackson, M., & Ong, S. (2009). *Land-use requirements of modern wind power plants in the United States*. National Renewable Energy Laboratory Golden, CO. Retrieved from ftp://ftp.manomet.org/WildlifeandEnergy/Literature_8July10/NREL_Land_Use_2009.pdf

Deshmukh, R. (2011). Analysis of International Policies in the solar Electricity sector: Lessons for India. Retrieved from http://escholarship.org/uc/item/3ph2h5gq.pdf

Deshmukh, R., Gambhir, A., & Sant, G. (2011). India's solar mission: procurement and auctions. *Economic & Political Weekly*, *166*(28), 22–26.

ET. (2012, March 17). Budget 2012-13: More coal imports likely following duty reduction. *The Economic Times*. Retrieved from http://articles.economictimes.indiatimes.com/2012-03-17/news/31204906_1_coking-coal-shortage-coal-ministry

EU. (2011). Communication from the [European] Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy Roadmap 2050. Retrieved from http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf

Holttinen, H., Meibom, P., Orths, A., Van Hulle, F., Lange, B., O'Malley, M., … Estanqueiro, A. (2009). *Design and operation of power systems with large amounts of wind power: Final report, IEA WIND Task 25, Phase one 2006-2008*. VTT Technical Research Centre of Finland. Retrieved from http://www.vtt.fi/inf/pdf/tiedotteet/2009/T2493.pdf

Hossain, J., Sinha, V., & Kishore, V. V. N. (2011). A GIS based assessment of potential for windfarms in India. *Renewable energy*, *36*(12), 3257–3267.

IEA. (2011). *Technology Roadmap: China Wind Energy Development Roadmap 2050*. International Energy Agency.

Lu, X., McElroy, M. B., & Kiviluoma, J. (2009). Global potential for wind-generated electricity. *Proceedings of the National Academy of Sciences*, *106*(27), 10933–10938.

MNRE. (2007). *Eleventh Plan Proposal Document. New Delhi, Ministry of New and Renewable Energy*. Ministry of New and Renewable Energy, Government of India.

MNRE. (2010a). *Jawaharlal Nehru National Solar Mission*. Ministry of New and Renewable Energy, Government of India.

MNRE. (2010b). *Renewable Energy in India: Progress, Vision and Strategy*. Ministry of New and Renewable Energy, Government of India.

Pearson, N. (n.d.). India's "Astonishing Auction" pushes down global solar price. *Bloomberg*. Retrieved from http://www.bloomberg.com/news/2011-12-02/india-s-solar-power-bid-prices-sink-to-record-consultant-says.html

Phadke, A. (2012). Reassessing wind potential estimates for India: economic and policy implications. Retrieved from http://escholarship.org/uc/item/7551z3z3.pdf

Planning Commission. (2012). *Report of the Working Group on Power and Energy for Twelfth Plan (2012-17)*. The Planning Commission of India.

Ramachandra, T. V., Jain, R., & Krishnadas, G. (2011). Hotspots of solar potential in India. *Renewable and Sustainable Energy Reviews*, *15*(6), 3178–3186.

Ratnajyoti Dutta. (2012, February). UPDATE 1-India 2012/13 coal import needs seen 140 mln T-source. *Reuters*. Retrieved from http://in.reuters.com/article/2012/02/28/india-coal-idINL4E8DS5AA20120228

Sharma, N. K., Tiwari, P. K., & Sood, Y. R. (2012). Solar energy in India: Strategies, policies, perspectives and future potential. *Renewable and Sustainable Energy Reviews*, *16*(1), 933–941.

Solarbuzz. (n.d.). India's "Astonishing Auction" pushes down global solar price. *SolarBuzz*. Retrieved from http://www.solarbuzz.com/facts-and-figures/retail-price-environment/module-prices

Sukhatme, S. P. (2011). Meeting India's future needs of electricity through renewable energy sources. *Current Science(Bangalore)*, *101*(5), 624–630.

Trabish, H. (n.d.). How did wind beat the price of natural gas in Brazil. *Greentech media*. Retrieved from http://www.greentechmedia.com/articles/read/how-did-wind-beat-the-price-of-natural-gas-in-brazil

USDOE. (2008). 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to US Electricity Supply. Retrieved from www.nrel.gov/docs/fy08osti/41869.pdf

Wiser, R., Lantz, E., Bolinger, M., & Hand, M. (2012). Recent developments in the levelized cost of energy from us wind power projects. *Presentation, February*. Retrieved from http://eetd.lbl.gov/ea/emp/reports/wind-energy-costs-2-2012.pdf