Supplementary Material – Model Summaries

"Informing India's Energy and Climate Debate: Policy Lessons from Modelling Studies"

Prepared by the Centre for Policy Research (CPR) and the International Institute for Applied Systems Analysis (IIASA)

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Note: *Summaries for each study were prepared by Navroz K Dubash, Radhika Khosla, Narasimha D Rao and K Rahul Sharma for the CPR-IIASA report "Informing India's Energy and Climate Debate: Policy Lessons from Modelling Studies", available at http://cprindia.org/research/reports/informing-india%E2%80%99s-energy-and-climate-debate-policy-lessons-modelling-studies. They are based on CPR and IIASA's review of the reports cited with additional clarification sought through correspondence with the report authors.*

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1. **LCSIG: Report of the Expert Group On "Low Carbon Strategies for Inclusive Growth"**

Model Description:

A multi-period activity analysis model (AIM) of the Indian economy built on input output tables of 2003-04. The model selects household consumption and savings, among other variables, to maximize overall utility from consumption. The model determines macroeconomic outputs, including investment, production, energy inputs and emissions. The specification of energy sector characteristics is largely exogenous to the model.

Scenarios:

The model runs two scenarios for 2007-2030:

1. "Baseline Inclusive Growth" (BIG) with inclusive growth policies as outlined in the 12th Five Year Plan, modelled through government spending. No carbon emission constraints or specific measures to reduce the emission intensity of the economy are introduced in the BIG scenario **(referred to as the Reference Scenario in the research report).**
2. "Low Carbon Inclusive Growth," (LCIG) which adds on low carbon measures using the parameters listed as Key Input Parameters to facilitate low carbon growth **(referred to as Single Policy Scenario in the research report).**

Key Results:

- Low carbon strategies require additional cumulative investment worth USD 834 billion, 50% higher than in the baseline scenario. GDP growth rate falls from 7.03% to 6.87% across the scenarios.
- From BIG to LCIG, total emissions drop from 5271 MT to 3830 MT and per capita emissions from 3.6 to 2.6 tonnes/capita.

Report Used

Planning Commission, "The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth.", Planning Commission, Government of India, New Delhi, India. Available online at http://planningcommission.nic.in/reports/genrep/rep_carbon2005.pdf (2014).

Modelling Timeframe: 2007 to 2030

Outcome Variables

	Variable	BIG[1] Scenario	LCIG[2] Scenario
Economic Outcomes[3]	Gross Domestic Product Growth Rate (CAGR)	7.03%	6.87%
	Gross Domestic Product in Rs Billion 2007 prices in - 2007 - 2030	 48,330 230,550	 48,330 222,729
	Investment in the Energy Sector		Additional investment of 1.5% of GDP amounting to USD 834 billion (2011 prices)[4]
	GDP Loss in the Low Carbon Scenario		3% of GDP or USD 1,344 billion (2011 prices)[5]
Emissions[6] and Energy Outcomes	Annual Emissions (MT) in 2030	5271	3830
	Per Capita Emissions (T of CO2) in 2030	3.6	2.6
	Emissions intensity (gms of CO2/$ GDP 2007-PPP) in 2030[7]	330	250
	Energy Intensity (kgoe/$ GDP 2007-PPP) in 2030	0.071	0.071
	Total energy requirement (MToE) in 2030	1146	1108

[1] BIG – Baseline Inclusive Growth scenario
[2] LCIG – Low Carbon Inclusive Growth scenario
[3] The Low Carbon Committee Report also includes data on the growth rate of private consumption (CAGR) at 5.75% for the BIG scenario and 5.75% for the LCIG scenario.
[4] The additional investment required is cumulative over the modelling period (Data obtained upon request from a report co-author on 28 January 2015)
[5] The loss in GDP is cumulative over the modelling period (Data obtained upon request from a report co-author on 28 January 2015)
[6] Includes only Carbon Dioxide
[7] Emissions Intensity numbers have been converted from kilograms to grams

	Coal (MTOE)	546.0	445.0
	Oil (MTOE)	406.0	330.0
	Gas (MTOE)	168.0	187.0
	Nuclear (MTOE)	8.0	73.0
	Hydro (MTOE)	11.0	20.0
	RE (MTOE)	6.0	54.0
	Total Electricity Supply in 2030 (TWh) (by fuel type below)	**3371**	**3466**
	Coal (TWh)	3038	2200
	Gas (TWh)	95	128
	Nuclear (TWh)	32	280
	Hydro (TWh)	131	230
	Solar (TWh)	8	275
	Wind (TWh)	50	279
	Biomass (TWh)	13	70
	Others (TWh)	3	3

Key Input Parameters

Category	Parameter	Sub-Parameter	BIG Scenario	LCIG Scenario
Economic Parameters[8]	Total Factor Productivity growth (TFPG)	Agricultural Sector	1%	1%
		Non Agricultural Sector	1.5%	1.5%
		Renewable Energy Technologies	-	Owing to the falling costs of renewable energy technologies, the TFPG of this sector is higher than 1.5% up to 2025
Energy Parameters	Autonomous Energy Efficiency Improvement (AEEI)	Energy inputs into production activities for coal, petroleum products, natural gas and electricity	0.5%	1.5% from 2015 onwards
		Power Sector	-	1%
		Electricity used in the Power Sector	-	0.5%

[8] Inclusive growth modelled through government expenditure (and as per the targets of the 12th Five Year Plan) for both scenarios

Additional Sector Specific Inputs and Constraints (only for LCIG scenario)

Electricity Supply	T&D Loss in the Electricity sector	The AEEI of 0.5% assumed for the power sector reflects a T&D loss reduction from 20% to 10%
	Coal based Electricity generation	Restricted to increase by 1.6% from 2015 onwards. Additional generation from coal takes place from super critical plants with 20% higher fuel efficiency and 25% higher capital cost
	Hydro and Nuclear based Electricity generation	The development of hydro and nuclear power is accelerated
	Share of renewables in Electricity generation	Increases from around 7% at the end of the 11th Plan (2012) to18% by 2030
	Share of Non-fossil based power in Electricity generation	Increases from 20% in 2012 to 33% in 2030
Transport	Freight using Railways	Increases by 2.5% per year, from 1/3rd in 2011 to almost half in 2030
	Fleet Efficiency norms for motorised vehicles	Doubles by the year 2030
	Marginal budget shares of petroleum products	Decreased by 0.2% from 2015
	Reduction in petroleum use in transport	Reduces by 1.5% per year and replaced by 60:40 ratio of LNG and Electricity starting 2015
Electricity Demand	Marginal demand of electricity by households (Appliance efficiency)	Reduces by 2% per year starting 2015 resulting in a 30% reduction by 2030
	ECBD compliance for buildings (alternative service activity introduced to reflect this)	Increases from 1% to 3.4% by 2030
Carbon Sequestration		Increases from 185 million tons of Co_2 in 2011 to 270 MT of Co_2 in 2030 to reflect the goals of the National Mission for Green India to increase green cover by 5 million hectares & improve the quality of forest on another 5 million hectares by 2020.

2. NCAER: "Climate Change Impact on the Indian Economy – A CGE Modelling Approach"

Model Description:

A recursive dynamic computable general equilibrium (CGE) model that simulates the Indian economy for the period 2003-04 to 2030-31, based on the 2003-04 India Social Accounting Matrix (SAM). A carbon tax is the primary low-carbon policy mechanism, with an option to recycle revenues. Some salient assumptions include those on labour force growth, foreign savings growth, total factor productivity growth (TFPG), and autonomous energy efficiency improvement (AEEI).

Scenarios:

Three scenarios are presented in the report for 2003/04 to 2030/31 - A Reference Scenario **(referred to as the Reference Scenario in the research report)** and two Carbon Tax scenarios – Revenue Positive (such that the additional revenue contributes towards an expansion of investment) and Revenue Neutral (such that there is no additional revenue as the gain in revenue from carbon taxes is neutralised by reduction in direct taxes) – each with tax rates of $10, $20, $40 and $80 or a total of 8 model runs. **(Revenue neutral scenarios with carbon taxes of $10, $40 and $80 referred to as Weak, Intermediate and Stringent Policy Scenarios respectively in the research report).**

Key Results:

- In the Revenue Neutral Scenario for carbon taxes of $10 and $80, the decline in GDP in 2030-31 as compared to the Reference Scenario is 0.94 and 5.31 percentage points respectively. The decline in GDP for the $10 and $80 Revenue Positive scenarios is slightly higher at 1.01% and 6.20%.
- Emissions intensity declines negligibly as carbon tax increases from $10 to $80.

Report Used

National Council of Applied Economic Research (NCAER), " Climate Change Impact on the Indian Economy – A CGE Modelling Approach.", NCAER, New Delhi, India (2009).

Modelling Timeframe: 2003-04 to 2030-31

Outcome Variables[9]

Category	Variable	Reference Scenario	RP$10[10]	RP$20	RP$40	RP$80	RN$10	RN$20	RN$40	RN$80
Economic Outcomes	*GDP Growth Rate (CAGR) for the period 2003-04 to 2030-31*	*8.75%*	*8.70%*	*8.67%*	*8.61%*	*8.49%*	*8.71%*	*8.68%*	*8.62%*	*8.53%*
	Gross Domestic Product in PPP USD Billion in 2030-31 (2003/04 prices)	27368.53	27091.85	26878.31	26464.05	25672.6	27110.72	26924.3	26552.03	25914.19
Emissions[11] and Energy Outcomes	Annual Emissions (MT) in 2030-31	4000.05	3965.49	3931.48	3876.23	3756.2	3965.49	3931.48	3876.23	3756.2
	Per Capita Emissions (MT of Co2) in 2030-31	2.77	2.75	2.72	2.69	2.6	2.75	2.72	2.69	2.6
	Emissions intensity (kg of CO2/$ GDP in PPP) in 2030-31	0.14616	0.14637	0.14627	0.14647	0.14631	0.14637	0.14627	0.14647	0.14631
	Energy Intensity in KgoE per USD of GDP in PPP 2030-31	0.0397	0.04	0.0398	0.04	0.0399	0.0399	0.0399	0.0397	0.0397

[9] All derived variables have been depicted in *Italics*.
[10] RP = Carbon Tax implemented with Revenue Positivity and RN = Carbon Tax implemented with Revenue Neutrality. The four scenarios within each category of RP or RN are depicted as $10, $20, $40 and $80 corresponding to the value of the carbon tax.
[11] Includes Carbon Dioxide and Nitrous Oxide

Key Inputs Parameters

Nine special sectors are introduced in the SAM including hydroelectricity, non-hydroelectricity, nuclear electricity, mechanised road transport, non-mechanised road transport, water transport, air transport, biomass and natural gas.

Category	Parameter	Value
Economic parameters	Total Factor Productivity growth (TFPG)	3%
Energy Parameters	Autonomous Energy Efficiency Improvement (AEEI)	1.5%
Electricity Supply	It is unclear from the report if renewables have been included in the model	
Electricity Demand	NA	

3. **TERI WWF: "The Energy Report – India. 100% Renewable Energy by 2050"**

Model Description:

A MARket ALlocation (MARKAL) model of the Indian energy sector. This is a linear programming model that selects energy supply options to minimize system cost based on a detailed representation of the energy sector from resource conversion to demand. CO2 emissions are an output but also can be included as a potential constraint in system optimization.

Scenarios:

Two scenarios are presented in the report for 2001 to 2051:

1. Reference Energy Scenario (REF) considers only current trends and policies, as determinants of projected energy demand and supply. Includes fossil-based, nuclear and renewable forms of energy. **(referred to as the Reference Scenario in the research report)**
2. 100% Renewable Energy Scenario (REN). In this scenario Fossil fuels and nuclear-based technologies are phased out and replaced, wherever possible, with renewable options. No new capacity additions of fossil fuel or nuclear technologies are considered, unless already under construction. Aggressive energy efficiency improvements are included. **(referred to as Single Policy Scenario in the research report)**

Key Results:

By 2051, as much as 90 per cent of India's total primary energy supply could technically be based on renewable sources in the REN scenario and cumulative CO2 emissions in the REN scenario are about one-third of those in the REF scenario.

Report Used

TERI. The Energy Report – India: 100% Renewable Energy by 2050. New Delhi: WWF India, 2013.
http://awsassets.wwfindia.org/downloads/the_energy_report_india.pdf

Modelling Timeframe: 2001 to 2031[12]

Outcome Variables

	Variable	Reference	100% RE Scenario
Economic Outcomes[13]	*Total annual undiscounted system cost (billion USD PPP 2007)*	*4468*	*5069*
	Total annual undiscounted investment in technology (billion USD PPP 2007)	*1419*	*1494*
Emissions[14] and Energy Outcomes	Annual Emissions (MT) in 2031[15]	5440	3550
	Per Capita Emissions (T of CO2) in 2031	*3.57*	*2.33*
	Emissions intensity (kg of CO2/$ GDP in PPP) in 2031	*0.261*	*0.171*
	Total energy requirement (MToE) in 2031 (by fuel type below)	**2149**	**1343**
	Coal (MTOE)	1167.2	833.6
	Oil (MTOE)	836.0	258.0
	Gas (MTOE)	68.0	72.9
	Nuclear (MTOE)	32.5	42.7
	Hydro (MTOE)	41.3	41.3
	RE (MTOE)	4.0	94.6

12 The study provides data for 2001-2051. Date for 2001-2031 has been selected to enable comparison between studies.
[13] Converted to USD PPP 2007 using appropriate conversion factors. The study specifies that majority of the additional investment in the REN scenario will be required between 2036-51
[14] Includes only Carbon Dioxide.
[15] Data obtained upon request from a report co-author on 24 February 2015.

	Total Electricity Supply in 2031(GW) (by fuel type below)	**793.6**	**720.4**
	Coal (GW)	511.7	266.4
	Gas (GW)	37.5	21.2
	Nuclear (GW)	48.0	63.0
	Hydro (GW)	160.0	160.0
	Solar (GW)	0.0	87.0
	Wind (GW)	30.0	84.4
	Biomass (GW)	0.0	32.0
	Others (GW)	6.4	6.4
	Total Final Energy Demand (TWh) (by sector below)	**16558.1**	**12465.1**
	Industry (TWh)	7314.0	5348.8
	Buildings[16] (TWh)	4081.4	3686.0
	Agriculture (TWh)	674.4	430.2
	Transport (TWh)	4488.4	3000.0

Key Input Parameters

Note: Large number of inputs parameters included in the model and not presented here. For more details, refer to the original report.

[16] Includes residential and commercial sectors and energy needs for lighting, cooking, space conditioning, refrigeration, water heating and operating other electrical appliances.

4. **Shukla et al.: "Energy-Emissions Trends and Policy Landscape for India"**

Model Description: An integrated assessment modelling (IAM) framework that includes GCAM, a global IAM that links energy, agriculture/land use and climate systems, with soft links to an energy partial equilibrium MARKAL model for India, an end-use demand module and a time-snapshot energy accounting model (AIM-ExSS). The unique feature is the link to a global IAM, and therefore the construction of scenarios based on global climate stabilization targets.

Scenarios:

Six scenarios (a BAU and 5 policy scenarios) are presented in the report for 2005 to 2050 as below. To facilitate comparison with other studies, data upto 2030 has been obtained for all the scenarios throughout the working paper. Of the policy scenarios, scenarios 1, 4 and 5 have been selected, with the intent of identifying weak, intermediate and high stringency low-carbon policies, as defined by total emissions in 2030.

1. BAU – No new policy targets **(referred to as the Reference Scenario in the research report).**
2. Scenario 1 – Weak Policy Reference Case with no Forcing Level targets **(referred to as Weak Policy Scenario in the research report).**
3. Scenario 2 – Stringent Policy Reference Case with no Forcing Level targets.
4. Scenario 3 – Forcing Level target of 2.8 W/m^2 in 2010.
5. Scenario 4 – Weak policy until 2020 followed by cooperation (through Global GHG tax) to 2.8 W/m^2 **(referred to as Intermediate Policy Scenario in the research report).**
6. Scenario 5 – Stringent policy until 2020 followed by cooperation (through Global GHG tax) to 3.2 W/m^2 **(referred to as Stringent Policy Scenario in the research report).**

Key Results:

The model generates energy sector and emissions pathways for different scenarios. Key outcomes are shown below.

Report Used

Shukla, P. R., Garg, A., and Dholakia, H. H., "Energy-Emissions Trends and Policy Landscape for India.", Allied Publishers (2015).

Modelling Timeframe: 2005 to 2030

Outcome Variables[17]

	Variable	Reference	Scenario 1	Scenario 5	Scenario 4
Economic Outcomes	No economic outcomes or investment data reported				
Emissions[18] and Energy Outcomes	Annual CO2 emission in 2030 (MT)[19]	4531.3	4475.1	3864.9	3420.5
	Per Capita Emissions (T of CO2) in 2030[20]	*2.86*	*2.82*	*2.44*	*2.16*
	Emissions Intensity	NA			
	Primary Energy Supply (MTOE)[21] (by fuel type below) in 2030[22]	***1598.1***	***1594.6***	***1515.3***	***1437.8***
	Coal (MTOE)	*878.4*	*859.5*	*728.2*	*651.1*
	Oil (MTOE)	*256.8*	*256.0*	*266.6*	*262.7*
	Gas (MTOE)	*133.3*	*146.6*	*178.2*	*181.4*
	Nuclear (MTOE)	*147.9*	*147.9*	*155.2*	*155.2*
	Hydro (MTOE)	*72.8*	*72.8*	*72.8*	*72.8*

[17] All derived variables have been depicted in *Italics*.
[18] Includes only Carbon Dioxide
[19] Data obtained upon request from a report co-author on 29 January 2015.
[20] Data obtained upon request from a report co-author on 29 January 2015.CO_2 Per Capita for all scenarios calculated as = Total CO_2 (scenario)/Population(2030) using data provided by the report.
[21] RE is a combination of renewable/clean energy (inclusive of hydro power) and bio energy. Data converted from TWh to MTOE as follows: 1 TWh = 0.086 MTOE (Source: IEA).
[22] Data obtained upon request from a report co-author on 29 January 2015. RE is a combination of biomass and non-biomass renewables. Data converted from exajoules (EJ) to MTOE as follows: 1 EJ = 23.885 MTOE (Source: IEA).

	RE (MTOE)	*108.8*	*111.7*	*114.2*	*114.5*
	Total Electricity Supply in 2030 (TWh)[23]	**3383.4**	**3378.4**	**3383.4**	**2820.6**
	Coal (TWh)	2124.2	2052.4	2124.2	1238.3
	Gas (TWh)	195.1	195.1	195.1	26.8
	Nuclear (TWh)	282.4	282.4	282.4	282.4
	Hydro (TWh)	388.9	388.9	388.9	388.9
	Biomass (TWh)	0.8	0.8	0.8	21.9
	Others (TWh)	392.2	458.9	392.2	862.4

Key Input Parameters

Note: Large number of inputs parameters included in the model and not presented here. For more details, refer to the original report.

[23] Data obtained upon request from a report co-author on 29 January 2015. Data converted from EJ to TWh as follows: 1 EJ = 277.78 TWh (Source: IEA). Coal values include coal with and without CCS; gas values include gas with and without CCS; biomass includes biomass with and without CCS; oil includes oil with and without CCS and Others include non-biomass renewables, including geothermal, ocean, solar (PV and CSP), wind (Onshore and Offshore). Individual renewables shares not available. Data on Coal and Gas have been reversed from the original document based on clarification issued by a co-author of the report on 10 February 2015.

5. **CSTEP: "A Sustainable Development Framework for India's Climate Policy-Interim Report"**

Model Description:

The study integrates inputs from the LEAP model (bottom-up, accounting model) for transport and the TIMES (optimization) model for the power sector, and combines them into scenarios using the India Energy Security Scenarios (IESS) scenario analysis tool to generate energy sector pathways with sectoral detail. The unique feature of the model is to generate scenarios based on sustainable development criteria, including inclusive growth and energy security considerations.

Scenarios:

Two scenarios are presented in the report for 2012-2030:

1. Business as usual (BAU) – takes into account ongoing policy strategies of the government **(referred to as the Reference Scenario in the research report).**
2. Policy Scenario – assumes greater policy efforts towards sustainability objectives of energy security, inclusivity and cleaner air. Carbon mitigation is considered a co-benefit of such a sustainable development pathway **(referred to as Single Policy Scenario in the research report).**

Key Results:

- The Policy scenario results in an energy demand of 10,000 TWh in 2030, compared with 12,500 TWh for the BAU. Fossil free sources increase to 13% in the policy scenario.
- The electricity demand in 2030 is expected to be 3000 TWh. Fossil free sources contribute to 40% of total generation by 2030 in the policy scenario. Renewable sources contribute to 20% of electricity demand.

Report Used

Centre for Study of Science, Technology and Policy (CSTEP), " A Sustainable Development Framework for India's Climate Policy: Interim Report.", CSTEP, Bangalore, India. Available online at http://www.cstep.in/uploads/default/files/publications/stuff/30683f0adbd6f81820ab9a37eb55c7b0.pdf (2015).

Modelling Timeframe: 2012 to 2030

Outcome Variables[24]

	Variable	BAU Scenario	Policy Scenario
Economic Outcomes	No economic outcomes presented in the current version of the report		
Emissions[25] and Energy Outcomes	Annual Emissions (MT) in 2030[26]	4686.0	3872.0
	Per Capita Emissions (MT of CO2) in 2030[27]	3.58	2.96
	Emissions intensity (kg of CO2/$ GDP PPP) in 2030	*0.356*	*0.286*
	Energy Intensity (kgoe/$ GDP PPP) in 2030	NA	
	Primary Energy Supply (MTOE) (by fuel type below) in 2030[28]	***1474.5***	***1307.6***
	Coal (MTOE)	*819.7*	*588.8*
	Oil (MTOE)	*398.5*	*356.9*
	Gas (MTOE)	*120.3*	*129.1*
	Nuclear (MTOE)	*24.3*	*91.1*
	Hydro (MTOE)	*19.3*	*20.9*
	RE (MTOE)	*103.9*	*141.4*

[24] All derived outcome variables been depicted in *Italics*.
[25] Includes only Carbon Dioxide
[26] Data obtained upon request from a report co-author on 29 January 2015.
[27] Data obtained upon request from a report co-author on 29 January 2015. Emissions per Capita has been computed by dividing the Total CO2 emissions by population data provided by the report.
[28] Data obtained upon request from a report co-author on 29 January 2015. RE is a combination of solar, wind and bio energy. Data converted from terawatt-hours (TWh) to MTOE as follows: 1 TWh = 0.086 MTOE (Source: IEA).

	Total Electricity Supply in 2030 (TWh) (by fuel type below)[29]	**3000.0**	**2744.0**
	Coal (TWh)	2405.0	1682.0
	Gas (TWh)	105.0	102.0
	Nuclear (TWh)	99.0	371.0
	Hydro (TWh)	224.0	243.0
	Solar (TWh)	50.0	237.0
	Wind (TWh)	93.0	280.0
	Biomass (TWh)	27.0	71.0
	Others (TWh)	-3.0	-242.0
	Final Energy Demand (TWh) (by sector below) in 2030[30]	**11502**	**9774**
	Industry (TWh)	5871	5350
	Buildings (TWh)	2470	2088
	Agriculture (TWh)	590	548
	Transport (TWh)	2571	1788

Key Input Parameters

Note: Large number of inputs parameters included in the model and not presented here. For more details, refer to the original report.

[29] Data obtained upon request from a report co-author on 29 January 2015. Solar includes solar PV and CSP; wind includes onshore and offshore wind; others forms the electricity balancing requirement with the addition of electricity imports and reduction of electricity exports. A negative number implies net exports.
[30] Data obtained upon request from a report co-author on 29 January 2015. Includes domestic and commercial lighting and appliances, green building design and envelope savings, and cooking.

6. **World Bank: "Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development"**

Model Description: An engineering-based bottom-up energy sector model for scenario analysis in India. The model contains sectoral representation of demand and supply, excluding agriculture and non-commercial biomass. System capacity expansion is specified for the scenarios. Power system capacity is dispatched in merit-order to minimize costs.

Scenarios:

Three scenarios are presented in the report for 2007 to 2031. Detailed information on scenarios 1 and 3 has been received from report co-author on 29 January 2015 and therefore this fact sheet includes data for scenarios 1 and 3 only.

1. Scenario 1, alternatively called Five Year Plans scenario, assumes full implementation of the Five Year Plans and other projections and plans by the government of India **(referred to as the Reference Scenario in the research report)**
2. Scenario 2, alternatively called delayed implementation, more closely follows historical performance in implementation of the Five Year Plans
3. Scenario 3, or all-out stretch scenario, adds to scenario 1 additional steps to increase energy efficiency and low-carbon energy sources **(referred to as Single Policy Scenario in the research report)**

Key Results:

- Low carbon strategies employed in Scenario 3 lead to a reduction in annual CO_2 emissions in 2031 from 4686 MT to 3872 MT between Scenarios 1 and 3.
- Implementation of low carbon strategies in Scenario 3 lead to an increase in overall investment cost for Life Extension, Efficiency Improvement, and New Capacity in Grid-Supplied Electricity in 2031 from 8,600 to 9,100 (Rs. Billion NPV-2007) between Scenarios 1 and 3.

Report Used

World Bank, "Energy Intensive Sectors of the Indian Economy – Path to Low Carbon Development", The World Bank Group, Washington D. C., USA. Available online at http://www.esmap.org/sites/esmap.org/files/India_LowCarbon_FullReport.pdf (2011).

Modelling Timeframe: 2007 to 2031

Outcome Variables[31]

	Variable	Scenario 1	Scenario 3
Economic Outcomes	Investment Costs for Life Extension, Efficiency Improvement, and New Capacity in Grid-Supplied Electricity in 2031 (Rs. Billion NPV-2007)	8600	9100
Emissions[32] and Energy Outcomes	Annual Emissions (MT) in 2031[33]	4686	3872
	Per Capita Emissions (T of CO2) in 2031[34]	*3.58*	*2.96*
	Emissions Intensity (kg of CO2/$ GDP PPP)	*0.304*	*0.251*
	Primary Energy Supply	NA	
	Total Electricity Supply in 2031(GW)[35] (by fuel type below)	**609.2**	**585.9**
	Coal (GW)	359.5	299.2
	Gas (GW)	33.0	30.0
	Nuclear (GW)	13.1	13.1
	Hydro (GW)	138.7	158.7

[31] All derived outcome variables been depicted in *Italics*.
[32] Includes only Carbon Dioxide
[33] Excludes the agricultural sector
[34] Data obtained upon request from a report co-author on 29 January 2015. CO2 Per Capita in 2031 for all scenarios calculated as = Total GHG (scenario)/Population (2031) using data provided by the report.
[35] Data obtained upon request from a report co-author on 29 January 2015. All numbers converted from MW to GW. Others includes Other Thermal.

	Solar (GW)	0.0	20.0
	Wind (GW)	45.0	45.0
	Biomass (GW)	17.9	17.9
	Others (GW)	2.0	2.0

Key Input Parameters

Category	Parameter	Scenario 1	Scenario 3
Economic Parameters	CAGR of GDP till 2030-31	7.6%	7.6%
	Total Factor Productivity growth (TFPG)	NA	
Energy Parameters	Autonomous Energy Efficiency Improvement (AEEI)	NA	
Electricity Supply	Grid generation life extension & efficiency enhancement	As defined in Five Year Plans	Enhanced program
	New grid generation capacity expansion	As defined in Five Year Plans	Additional 20 GW of solar and 20 GW of imported hydro
	Technical loss reduction in transmission and distribution	From 29% in 2005 to 15% in 2025	Accelerated by 10 years to 2015
Electricity Demand	Demand side measures in industry, household, non-residential, transport	Projected based on historical trends and government energy efficiency targets	Additional energy efficiency measures in each sector

7. **IESS: "India Energy Security Scenarios 2047: Sector Specific Insights"**

Model Description: An energy accounting model for energy strategy analysis that constructs different scenarios of energy security and policy effort at a sectoral level, and presents energy sector and emissions pathways in an interactive web tool.

Scenarios:

Seven pathways are presented in the IESS 2047 online tool, of which the details of four pathways are presented in this document. The scenarios were selected to identify a Reference (baseline), and three policy scenarios that characterize 'weak', 'intermediate' and 'stringent' low-carbon policy scenarios.

1. Determined Effort Scenario: All demand and supply choices at Level 2 **(referred to as the Reference Scenario in the research report)**
2. Maximum Energy Security Scenario: Determined Effort or Level 2 choices on the demand side **(referred to as the Weak Policy Scenario in the research report)**
3. Maximum Energy Security Scenario: Heroic Effort or Level 4 choices on the demand side **(referred to as the Intermediate Policy Scenario in the research report)**
4. Minimum Emissions Scenario: Level 4 choices on the demand side and supply calibrated to ensure minimum emissions **(referred to as the Stringent Policy Scenario in the research report)**

Key Results: The model is intended to provide a tool for scenario analysis rather than produce specific results. Outcomes related to the chosen scenarios are shown below.

Report Used

Planning Commission, " India Energy Security Scenarios 2047: Sector Specific Insights.", Planning Commission, Government of India, New Delhi, India. Available online at http://indiaenergy.gov.in/doc/Report_Final.pdf (2014).

Modelling Timeframe: 2012 to 2032[36][37]

Outcome Variables[38]

	Variable	Determined Effort Scenario	Maximum Energy Security Scenario: Determined Effort	Maximum Energy Security Scenario: Heroic Effort	Minimum Emissions Scenario
Economic Outcomes	Economic outcomes or expenditure outcomes to be included in future versions of the tool				
Emissions[39] and Energy Outcomes	Annual Emissions (MT) in 2032	5674.0	5186.0	4717.0	4071.0
	Per Capita Emissions (T of CO_2) in 2032	3.7	3.4	3.1	2.7
	Emissions Intensity (kg of CO_2/$ GDP PPP)	*0.301*	*0.275*	*0.250*	*0.216*
	Primary Energy Supply (MTOE)[40] (by fuel type below) in 2032	***1542.7***	***1435.3***	***1286.7***	***1175.8***
	Coal (MTOE)	*768.36*	*654.7*	*608.3*	*478.4*
	Oil (MTOE)	*437.58*	*404.6*	*311.4*	*311.4*
	Gas (MTOE)	*153.31*	*145.6*	*149.7*	*124.2*
	Nuclear (MTOE)	*-*	*-*	*-*	*-*
	Hydro (included in RE) (MTOE)	*-*	*-*	*-*	*-*

[36] The IESS model provides output data upto 2047. However 2032 data has been sourced from the online tool for this study to facilitate comparability with other studies.
[37] All derived outcome variables been depicted in *Italics*.
[38] All data from IESS web-tool, accessed on 31 January 2015
[39] Includes only Carbon Dioxide
[40] RE is a combination of renewable/clean energy (inclusive of hydro power) and bio energy. Data converted from TWh to MTOE as follows: 1 TWh = 0.086 MTOE (Source: IEA).

	RE (MTOE)	*178.33*	*230.5*	*217.2*	*258.3*
	Others (MTOE)	*5.16*	*-*	*-*	*3.44*
	Total Electricity Supply (TWh) (by fuel type below) in 203241	**3218**	**3084**	**2878**	**2352**
	Coal (GW)	1811	1811	1811	774
	Gas (GW)	250	250	250	110
	Nuclear (GW)	116	116	116	146
	Hydro (GW)	231	231	231	270
	Solar (GW)	138	263	138	263
	Wind (GW)	240	304	240	452
	Biomass (GW)	-	-	-	-
	Others (GW)	432	109	92	337
	Final Energy Demand (TWh) (by sector below) in 2032	**12446**	**12446**	**10427**	**10427**
	Industry (TWh)	6236	6236	5809	5809
	Buildings[42] (TWh)	2679	2679	2001	2001
	Agriculture (TWh)	631	631	439	439
	Transport (TWh)	2900	2900	2178	2178

[41] Data from IESS web-tool, accessed on 31 January 2015. Coal includes domestic coal and imported coal-based generation (for reference: 771 TWh and 2451 TWh respectively); solar includes solar PV and CSP; wind includes onshore and offshore wind; others includes small hydro, biomass and biogas, waste to electricity, and imports.

[42] Includes domestic and commercial lighting and appliances, green building design and envelope savings, and cooking

Key Input Parameters

Category	Parameter	Least Effort Scenario	Maximum Energy Security Scenario: Determined Effort	Maximum Energy Security Scenario: Heroic Effort	Minimum Emissions Scenario
Economic Parameters	CAGR of GDP till 2030-31	7.4%			
	Total Factor Productivity growth (TFPG)	NA			
Energy Parameters	Autonomous Energy Efficiency Improvement (AEEI)	NA			

Sector-wise Inputs Parameters (defined for Levels 1 to 4 of 'Policy Effort' for each sector in the report)

Category	Parameter	Description
Energy Demand	Transport	Transport parameters include, Domestic Passenger Transport Demand (in Km per person per year), Domestic Transport Passenger Mode (Air, Rail, Road), Domestic Freight Transport Demand (in billion ton-Km), and Domestic Freight Transport Mode (Air, Rail, Road)
	Cooking Energy	Cooking energy parameters and requirements (in TWh) include rural and urban consumption of LPG, Electricity, PNG, Biomass, Coal, Kerosene and Biogas for cooking and the efficiency of cooking devices using respective fuels.
	Buildings	Buildings energy parameters and requirements (TWh) include efficiency of residential lighting and appliances, efficiency of commercial lighting and appliances and building envelope optimization.
	Industry	Industry parameters include efficiency improvements in cement, fertilizer, aluminium, iron and steel, pulp and paper, textile, chlor alkali and other sectors through Perform-Achieve-Trade (PAT) scheme penetration.
	Agriculture	Agriculture includes energy demand from irrigation (TWh), energy demand from mechanisation (MT of diesel), choice of fuel for irrigation (solar, diesel, electricity).
	Telecom	Telecom includes electricity consumption (TWh) in the telecom sector and shifts from diesel to solar.
Energy Supply	Renewable Energy	Renewable Energy includes Solar PV(MW), CSP (MW), Onshore wind power (MW), Offshore wind power (MW), and SHP (MW).
	Clean Energy	Clean energy includes nuclear power, large hydroelectric power, bioenergy (includes biomass residue production and end use, first and second generation biofuels, algae biofuel production), energy from waste.
	Conventional Energy	Conventional Energy includes Gas (Domestic gas production and gas power stations), Coal (Domestic coal production, coal power stations and efficiency of coal power stations), Domestic oil production, carbon capture and storage, Electricity imports and Transmission and distribution losses