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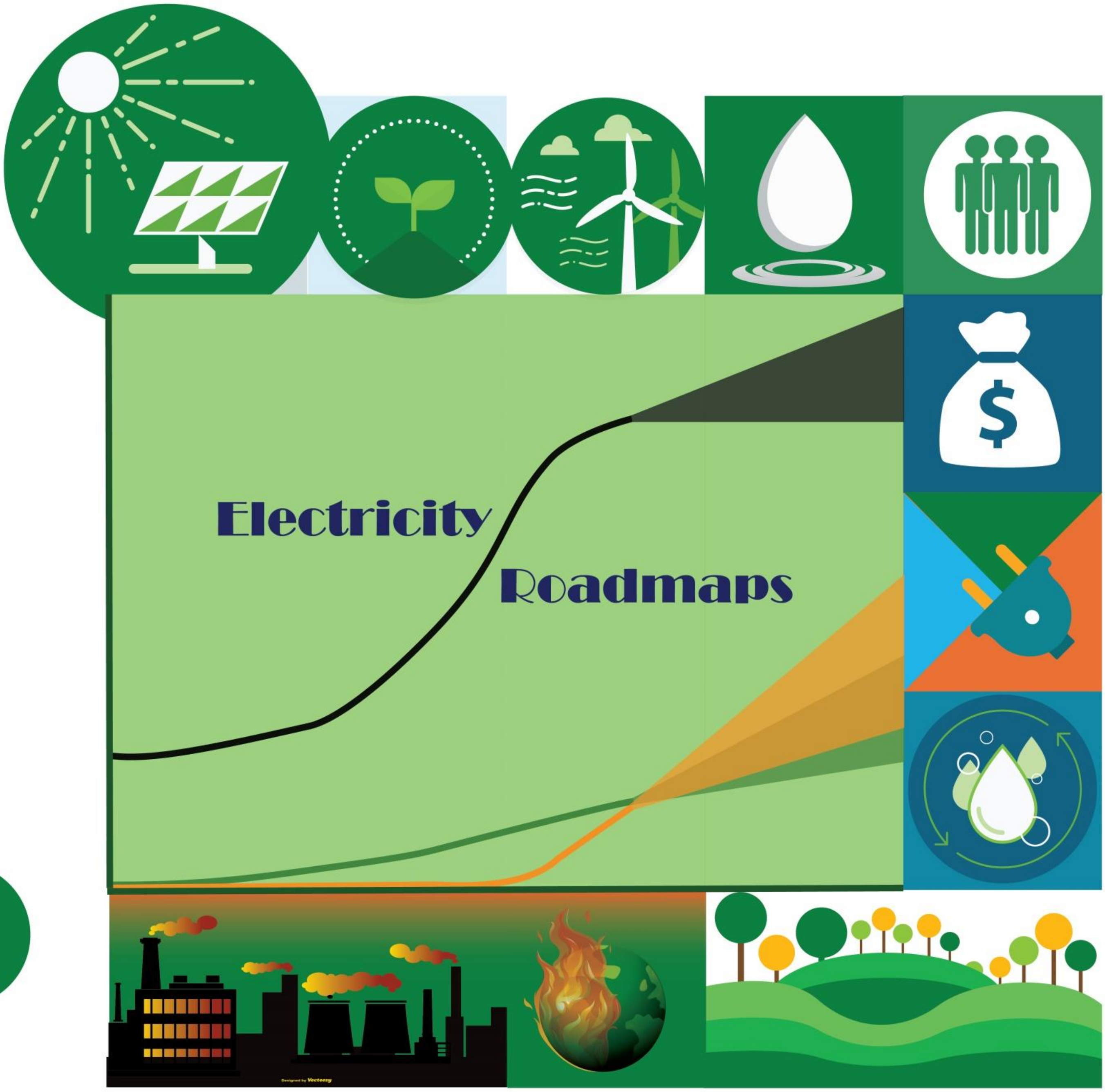
ELECTRICITY TRANSITION ROADMAPS

Comparative Evaluation of Long-Term Low Carbon Electricity Transition Roadmaps for India



Supporting Information

Comparative Evaluation of Long-Term Low Carbon Electricity Transition Roadmaps for India: A Supply Side Assessment

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Center for Sustainability, Policy & Technology Management

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Organizations:

Shakti Sustainable Energy Foundation seeks to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following areas: clean power, energy efficiency, sustainable urban transport, climate change mitigation and clean energy finance.

Center for Sustainability, Policy & Technology Management (SusPoT) is a not-for-profit Think-&-Do Tank incorporated with a mission to assist decision makers, practitioners and civil society to develop and pursue inclusive transformative pathways towards sustainable societies. SusPoT conducts multi-disciplinary system analytics based policy research to develop inclusive strategies for sustainable clean energy transition in India.

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<u>Supporting Information</u> to

Comparative Evaluation of Long-Term Low Carbon Electricity Transition Roadmaps for India: A Supply Side Assessment

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Technology Assessment: Data Sources and Assumptions

Table 1A: Climate Footprint for different electricity sources (Life Cycle GHG emissions - kg CO2-eq./MWh)

Source	Mean	Reference Details / Comments
Coal	1082	Mallapragada et al., 2019)
Gas	586	Mallapragada et al., 2019
Nuclear	12	(Schlömer et al., 2014)
Hydro	41	(Kadiyala, Kommalapati, & Huque, 2016b) Impoundment type Large (I-L) Dams (>30MW)
Wind	16	(Kadiyala, Kommalapati, & Huque, 2016a) Performance values of Onshore (ON), Large (L) Wind Turbines (0.25 and 5 MW)
Solar	30	(Leccisi, Raugei, & Fthenakis, 2016) Ground-Mounted Photovoltaic systems – Mix of thin films and C-Si PV

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Table 2A: Water Footprint for different electricity sources (Life Cycle Water Consumption - m^3/MWh)

Source	Mean	Reference Details / Comments
Coal	2.34	Own estimations based on (Meldrum et al., 2013) for fuel cycle and power plant life cycle data; (Chaturvedi et al., 2017) for power plant operations; Opencast mining is assumed for coal fuel cycle as it accounts for more than 93% of coal mining in India (CCO, 2017); 90% Re-circulating type cooling systems, 1% Dry cooling systems and 9% Once through type sea water based cooling systems are assumed (IRENA & WRI, 2018). Note: we account for freshwater consumption only in this indicator, so all sea water based power plants (9%) are assumed to operate without any freshwater consumption for cooling systems.
Gas	1.00	Own estimations based on (Meldrum et al., 2013) for fuel cycle and power plant life cycle data; (Chaturvedi et al., 2017) for power plant operations; 83% Re-circulating type cooling systems, 17% Dry cooling systems are assumed (IRENA & WRI, 2018).
Nuclear	2.09	Own estimations based on (Meldrum et al., 2013) for fuel cycle and power plant life cycle data; (Chaturvedi et al., 2017) for power plant operations; 40% Re-circulating type, 20% freshwater + 40% sea water based Once through cooling systems are assumed (IRENA & WRI, 2018). Note: we account for freshwater consumption only in this indicator, so all sea water based power plants (40%) are assumed to operate without any freshwater consumption for cooling systems.
Hydro	17.57	The data is assumed from Three Gorges Dam (Scherer & Pfister, 2016)
Wind	0.01	(Meldrum et al., 2013)
Solar	0.24	Own estimation: Power plant life cycle data – Average of C-Si and thin films median values from (Meldrum et al., 2013); Operations – India specific data from (IRENA & WRI, 2018) (80 L/MWh)

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Table 3A: Land Transformation for different electricity sources (Life Cycle Land Transformation – (10^3) m2/GWh)

Source	Mean	Reference Details / Comments
Coal	0.46	All data from (Fthenakis & Kim, 2009); Opencast mining is assumed for direct land transformation during mining stage as it accounts for more than 93% of coal mining in India (CCO, 2017)
Gas	0.28	(Fthenakis & Kim, 2009)
Nuclear	0.09	(Jacobson, 2009)/(Mitavachan & Srinivasan, 2012)
Hydro	1.88	The average of lower estimate from (Mitavachan & Srinivasan, 2012) and Higher estimate from Lake Powel Reservoir (Fthenakis & Kim, 2009); Indirect land transformation 14 m2/GWh (Fthenakis & Kim, 2009)
Wind	0.12	Own estimations based on (Fthenakis & Kim, 2009). As multiple land use types can coexist with wind farms, we assume that wind turbines use 5% of the wind farm areas; For Indirect land transformations, we assume 6 m^2/GWh (Fthenakis & Kim, 2009)
Solar	0.49	Own estimations: Land area 2 ha/MW (Mitavachan & Srinivasan, 2012, 2017); Capacity Factor: 19% (CERC, 2016; MNRE, 2016); Lifetime 25 years; Indirect land transformation - 1% of onsite land use (Murphy, Horner, & Clark, 2015)

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Table 4A: Air Pollution for different electricity sources (Life Cycle Particulate Matter Emissions – kg PM10-eq./MWh)

Source	Mean	Reference Details / Comments
Coal	1.030	Minimum values from (Mitavachan & Srinivasan, 2017) is taken; Note: The historic emissions of coal power plants in India are very high due to minimal pollution regulation (3.125 kg PM10-eq./MWh; (Srinivasan et al.., 2018). With setting-up of a new regulation standard by Government of India in 2017, we assume that the coal power emissions might get reduced with the effective implementation of the same in the coming years. Hence, we assume lower value instead of the higher one.
Gas	0.757	(Hertwich et al., 2015)
Nuclear	0.030	(Gagnon et al., 2002; Frischknecht et al., 2007)
Hydro	0.113	The average of Reservoir 1 and Reservoir 2 values from (Hertwich et al., 2015) are used as proxy because of non-availability of data
Wind	0.027	(Hertwich et al., 2015)
Solar	0.079	The average of Min and Max values from (Hertwich et al., 2015) – Ground Mounted thin film and C-Si technologies

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Table 5A: Levelized Cost of Electricity for different electricity sources (INR/kWh)

Source	Mean	Reference Details / Comments
Coal	5.14	All data from (Pachouri et al., 2019). We assume the average values from 2025 for all the electricity sources (the mid-year of our assessment time period 2020-2030).
Gas	6.24	
Nuclear	3.96	
Hydro	4.81	
Wind	2.69	
Solar	2.42	

References

Pachouri, R., Spencer, T., & Renjith, G. (2019). Exploring Electricity: Supply-Mix Scenarios to 2030. TERI. https://www. teriin. org/sites/default/files/2019-02/Exploring% 20Electricity% 20Supply-Mix% 20Scenarios% 20to, 202030.

Table 6A: External Costs for different electricity sources (INR/kWh)

Source	Mean	Reference Details / Comments
Coal	8.12	All socio-environmental costs from (Rafaj and Kypreos, 2007); the social cost of GHG emissions are calculated by assuming $86 per ton$CO_2$ from (Ricke et al., 2018); All data is inflation adjusted to 2020 values and we assume the currency conversion of 1$ = 70 INR and 1 EUR = 80 INR. Note: For renewables, we account for carbon costs associated with embodied emissions, among others.
Gas	5.14	
Nuclear	0.73	
Hydro	0.37	
Wind	0.22	
Solar	0.31	

References

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Ricke, K., Drouet, L., Caldeira, K., & Tavoni, M. (2018). Country-level social cost of carbon. Nature Climate Change, 8(10), 895-900.

Table 7A: Employment generation potential for different electricity sources (Jobs Generated across life cycle value chains of the electricity sources - Job-Years/GWh)

Source	Mean	Reference Details / Comments
Coal	0.63	All data from (Reddy, 2016)
Gas	0.27	
Nuclear	0.60	
Hydro	0.80	
Wind	1.76	
Solar	3.40	

References

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India Roadmaps Meta-Analysis

Figure 1A: Format used for data collection from modeling studies.

Metadata collection format from Individual studies
1. General Information
Study Title
Month/Year
Lead Authors
Institute (s)
Funding / Commisioning Body
Scope (Only Electricity; +Heating/Transport OR Entire Energy System)
Source (URL)
2. Scenarios
Reference Scenario (Yes/No)
No. of Alternative Scenarios
Scenarios Nomenclature
Base Year
Study Timeline
3. Modelling Approach
Name of the Model used (e.g., TIMES, MESAP...)
Type of Model (e.g., Simulation, Market Equilibrium..)
Any other key details?

	Base Scenario						Alternative Scenario I					
4. Key Assumptions	Base Year	2020	2030	2040	2050	Data Source	Base Year	2020	2030	2040	2050	Data Source
Key Targets (e.g., CO2 reduction; SDGs)												
Renewables (Main Source - Solar/Wind/others)												
Coal (Main Techology - Sub-Critical/Super-Critical/CCS)												
Nuclear (Technology type)												
Demand Side Management (If yes, which options?)												
Any other key assumptions?												
5. Electricity Demand (in TWh)	Base Year	2020	2030	2040	2050	Data Source	Base Year	2020	2030	2040	2050	Data Source
Total Electricity Consumption												
Residential												
Industry												
Transport												
Others												
6. Electricity Supply Data (in TWh)	Base Year	2020	2030	2040	2050	Data Source	Base Year	2020	2030	2040	2050	Data Source
Total Electricity Generation												
Coal (Sub-critical/Super-critical; includes CCS-Yes/No)												
Coal-CCS												
Nuclear												
Hydro												
Wind-Onshore												
Wind-Offshore												
Solar-PV												
Solar-CSP												
Natural Gas (includes CCS-Yes/No)												
Natural Gas-CCS												
Oil/Diesel												
Bioenergy (biomass/biogas)												
Small/Micro-Hydro												
Any other Renewables (Geothermal, Ocean...)												
Storage (overall)												
Pumped Hydro Plant												
Battery Storage												
Hydrogen												
Synthetic Natural Gas												
Any other Storage types (mention explicity, if yes)												
7. Electricity Supply Data (in GW)	Base Year	2020	2030	2040	2050	Data Source	Base Year	2020	2030	2040	2050	Data Source
Total Installed Capacity												
Coal (Sub-critical/Super-critical; includes CCS-Yes/No)												
Coal-CCS												
Nuclear												
Hydro												
Wind-Onshore												
Wind-Offshore												
Solar-PV												
Solar-CSP												
Natural Gas (includes CCS-Yes/No)												
Natural Gas-CCS												
Oil/Diesel												
Bioenergy (biomass/biogas)												
Small/Micro-Hydro												
Any other Renewables (Geothermal, Ocean...)												
Storage (overall)												
Pumped Hydro Plant												
Battery Storage												
Hydrogen Production Plant												
Compressed Air Storage Plant												
Any other Storage types (mention explicity, if yes)												
8. Key Recommendations (just keywords / main points)												
9. Any Comments												

I. Energy [r]evolution - A Sustainable World Energy Outlook

Citation: Greenpeace, GWEC, Solar Power Europe. Energy [r]evolution: A sustainable world energy outlook. 2015.

1. General information

The study 'Energy [r]evolution - A Sustainable World Energy Outlook 2015: 100% renewable energy for all' was published by Greenpeace International, Global Wind Energy Council and SolarPowerEurope in September 2015. This is the 5th edition of Energy [r]evolution project report, an initiative Greenpeace International is working on since 2005. German Aerospace Center and Institute of Engineering Thermodynamics, Systems Analysis and Technology Assessment, Germany are significant contributors to modeling the scenarios in the study.

2. Thematic background

The first Energy [r]evolution scenario was published by Greenpeace International back in May 2005. Since then, multiple country-wise energy [r]evolution scenarios have been published. While the scenarios presented in energy [r]evolution reports have been labeled as 'fanciful' or 'unrealistic' at times, many of them have been the most accurate in predicting the future developments in the energy sector, especially the growth in renewable power generation. Energy [r]evolution 2015 also presents ambitious pathways for providing the entire energy requirements for the World by renewable energy sources. 'The 2015 edition of the global Energy [R]evolution features: 1) a 100% renewable energy scenario for the first time; 2) a basic Energy [R]evolution case with a final energy share of 83% renewables which follows the pathway for the E[R] published in 2012; and 3) and the IEA´s World Energy Outlook 2014 Current Policies scenario extrapolated out to 2050- which serves as a reference case.'(p.9)

3. Methodology

The scenarios presented in the study are targeted towards the goal of providing 100% renewable energy for all. A technology-driven bottom-up approach has been exercised while stylizing the scenarios. Amongst the key drivers are GDP and population growth rates, renewable energy deployment. **Mesap/PlaNet** Simulation models were used to generate energy supply scenarios. It is an energy-system toolbox which analyses energy supply, demand, costs, and impacts for a region-specific or global energy system. Rather than employing the conventional cost optimization approach, separately defined development paths have been integrated into the model database and energy balances are calculated.

Some data has been taken from the IEA database 2014 for initializing the model. Demand projections in this study are based on the projections presented in energy [r]evolution 2012 and a part of World Energy Outlook 2014. In addition to that, certain assumptions about the improvement in the lifestyle of people, energy efficiency and variations in results due to rebound effect have been made.

4. Scenarios/ pathways

Energy [r]evolution 2015 presents three scenarios for the World to project the possible pathways for energy systems. The **Reference Scenario (REF)** is primarily based on the current policies (2014 policies) adopted and implemented by the countries in the energy and climate sector. It is based upon the ‘Current policies’scenario presented in the ‘World Energy Outlook 2014’ published by IEA. The reference scenario is the outcome of the extension of the current trends being followed. This scenario does not consider any added policy interventions to combat climate change and curb greenhouse gas emissions. IEA’s current policies scenario gives projections only up to the year 2040. Reference scenario extrapolates those values to 2050. The major objective of developing this scenario is to provide a base case for comparison of two energy [r]evolution scenarios presented in the study.

The **Energy [R]evolution (E[R])** scenario is an extension/modification of the Energy [R]evolution scenario presented in the 2012 study. Two primary objectives of this scenario are: 1) Reduction in global CO_2 emissions, to limit the temperature rise of the earth below 2^oC; 2) Complete elimination of nuclear energy from the energy sector, due to environmental concerns. Thus, the scenario aims at achieving significant decarbonization of the energy sector by implementing a feasible set of policies by 2050. E[R] scenario assumes maximal use of available use of energy-efficiency practices, as well as increased adoption of renewable energy resources in heat and electricity generation. The results show that the final energy share of renewables shall be close to 83% with this scenario.

A more ambitious scenario called the **Advanced Energy Revolution (ADV E[R])** scenario has been presented, for the first time in this study. It advocates for 100% decarbonization of the energy sector, thus meeting all the energy demand by renewable energy only. There are specific differences between the two E[R] scenarios. Both the scenarios consider the same energy consumption levels, as well as zero share of nuclear energy in the mix. However, an accelerated introduction of renewable energy resources has been assumed, so that there will be no coal or gas/oil power plants in the power sector. Apart from that, a major shift in the transportation sector is assumed. Use of biofuels and battery-powered vehicles are considered. This demands for high capacity addition, in electricity and storage sector. Due to the aggressive adoption of renewables, fully decarbonized energy system by 2050 is represented in this scenario.

5. Infrastructural changes within the Indian power system

One of the major objectives of Energy [R]evolution scenarios is to entirely phase-out nuclear energy from the power sector by 2050. This is a major change in the infrastructure of the power system. In the E[R] scenario, a relatively small share of coal and gas power plant still exists in the mix, but in Adv E[R] scenario, the electricity supply is fully renewable-based. Due to the lack of these conventional dispatchable plants, to provide the baseload, a high installed capacity of biomass-based and wind power plants is required. A significant amount of natural gas plants are also expected to be replaced by hydrogen-based power plants. The share of renewables, mostly solar and wind, is assumed to grow at a very high rate so that they compensate for the retiral of fossil-based power plants. Due to low capacity factors and intermittent nature of these sources, a mix of readily present and fundamentally novel grid operation concepts will have to be exercised to maintain grid balance.

Smart grids enabled with ICT technology shall play a crucial role in maintaining the balance of the grid, by incorporating demand-side management and large-scale electricity storage options together to provide the required flexibility to the grid. Due to the uncertainty over economic & technical feasibility of storage technologies, the study also propones for redesigning current transmission network and forming a super-grid network with options such as HVAC and HVDC transmission lines, for increased reliability and low transmission costs. To implement the changes suggested, an investment close to 5,370 billion US$ is required in E[R] scenario, and 7,220 US$ in Adv E[R] scenario.

6. Discussion/ recommendations of relevant policies

From the overall study, the authors conclude that bringing the Energy [R]evolution into existence, active political actions are necessary. Technological and financial barriers can be efficiently dealt with. Policy barriers and political decisions can rather prove to be the hurdles in the implementation. The study presents the following policy interventions as part of the conclusion.

- Phase-out of fossil fuel and nuclear power plants entirely
- Protection of current forest reserves and restoration of forests
- Entering into a legally-binding agreement on dealing with the issue of climate change
- Shifting subsidies away from fossil fuels and providing financial support to renewable technologies for increased adoption.
- Providing innovative solutions to deal with greenhouse gas emissions and take some actions on the ground by 2020.
- Educating industrialists and consumers about energy efficiency practices and empowering them to adopt the practices through easier financial mechanisms.
- Adoption of successful policy models from neighboring countries.

II. World Energy Outlook

Citation: International Energy Agency IEA. World Energy Outlook. 2019.

1. General information

International Energy Agency published its 2019 edition of annual energy insights report ‘World Energy Outlook 2019’ in November 2019. World Energy Outlook team developed the study in Directorate of Sustainability, Technology and Outlooks (STO) in collaboration with other offices of IEA. WEO 2019 edition emphasizes the importance of Africa in the world’s energy future. Hence, this study contains dedicated sections for Africa apart from the global energy scenarios and projections.

2. Thematic background

World Energy Outlook is one of the most comprehensive reports which provides key data and figures on global as well as regional and country-level scale and also provides key insights and recommendations on trends of energy supply and demand. First edition of WEO was published back in 1977, while the annual publications began in 1997. WEO does not indicate projections. Instead, it attempts to present different future energy scenarios by varying key drivers. WEO covers the entire energy system spectrum ranging from oil, coal to electricity and renewables. WEO 2019 presents three scenarios, each one different from the other in the policies interventions assumed and therefore the resulting futures.

According to the authors, scenarios ‘highlight the gap between where the energy world appears to be heading, given certain starting assumptions on policy, and where it would need to go in order to meet key energy and environmental objectives in full.’

3. Methodology

IEA has developed its own simulation model, called as **World Energy Model (WEM)** which is a large-scale simulation model. The model essentially covers three modules - energy supply, energy demand and energy transformation. WEM depends on IEA’s own database. Thus it is a very ‘data-intensive’ model. At its core, it attempts to do energy balance from supply to the demand via the energy transformation agencies. In the simulation modeling, specific costs for technologies play a vital role. WEM makes use of Logit and Weibull functions to determine the share of technologies in the mix.

A simplified schematic diagram from the official WEM documentation suggests that WEM takes CO_2 prices, policies implemented, technology-options, and other socioeconomic drivers as the assumptions, and energy flows, CO_2 emissions and required investments are obtained as the output of the model. A detailed explanation of the methodology used for modeling the scenarios is described in the official WEM document. For example, energy demand is calculated using econometric models based on historical data and socioeconomic drivers.

4. Scenarios/ pathways

World Energy Outlook 2019 presents three scenarios for the future energy systems up to 2040. Scenarios can be stylized by using more than one approaches. Current Policies Scenario (CPS) and Stated Policies Scenario (SPS) assume specific policy interventions to be in place and then determine the energy supply and demand projections based on those assumptions. Sustainable Development Scenario (SD) on the other hand, sets a goal of reducing greenhouse gas emissions and limiting the global temperature rise well below 2^{o} C and determines the possible ways to achieve the goal.

Current Policies Scenario (CPS) is designed to determine the global energy scenario if the current trends of energy use are continued till 2040, and only current policies in practice are implemented. This scenario only considers the government policies which were in effect in the mid-2019. Global energy demand is assumed to rise by 1.3% per year up to 2040. CPS is primarily designed as a base scenario or the baseline for comparison with the remaining two scenarios.

Stated Policies Scenario (SPS), as the name suggests, considers the intended or stated policies by the government on climate change. Although there is much uncertainty about the implementation of these policies, this scenario attempts at finding out what can be the global picture if all the countries abide by their stated policies, in or outside the NDCs signed in COP21. Global energy demand rises by 1% per year according to the SPS scenario. A cautious approach in the assumptions has been exercised to account for the possibility of change in the policy interventions in future. Results show that even with the stated policies by the countries, the world does not meet the sustainability goals by 2040.

Hence, **Sustainable Development Scenario (SD)** was designed to meet the sustainable energy system goals. SD not only encompasses SDG7 goals (universal energy access goals) and Paris agreement objectives but also intends to address the problem of air pollution and related loss of human lives. Using WEM analysis, integrated least-cost energy pathways or strategies are developed in order to achieve the decided policy and sustainability goals.

5. Infrastructural changes in Indian power system

The study concerns with entire energy system dynamics on the global scale. Therefore, the infrastructural changes in the power sector have not been discussed explicitly. However, as the scenarios predict high adoption of renewables in developing countries such as China and India, the power system infrastructure or the grid infrastructure needs to strengthen the flexibility. As per the SPS and SD scenarios, India is expected to experience a huge increase in electricity demand and therefore must ensure very high peak ramping requirements. According to the SD scenario, flexibility requirements for India increase six-fold.

WEO2019 specifically discusses the importance of battery storage technology in India. Battery technology is highly efficient and fastest option to provide the required grid flexibility. Due to the expected high increase in electricity demand and uptake of solar PV technology in India, battery technology is best suited to strengthen the flexibility of the Indian power sector. India can also provide a large market, which brings economies of scale into the picture. SPS scenario projects installed capacity of 200GW by 2040 with cheaper batteries employed. Addition of this battery capacity will also have an impact on coal-based plants. New coal-based capacity will not be added if solar PV + battery combination is efficiently exercised.

6. Discussion/recommendations of relevant policies

Two out of the three scenarios presented in the study are based upon the current policies being implemented and the policy objectives mentioned in country NDCs. However, the Sustainable Development Scenario, while developing a pathway to meet the sustainable energy goals, advocates some policy interventions, which serve as additives to the policies mentioned in CPS and SPS scenarios. Some of the interventions from SDS and SPS are mentioned below.

- Adoption of energy efficiency technologies should be the primary alternative to reduce emissions.
- Phasing out incandescent light bulbs by 2020.
- Voluntary and mandatory star ratings for household appliances.
- Upgrading the transmission & distribution network and limiting the T&D losses in the system to 15%.
- Increased use of supercritical technology in coal-based power plants.
- Efforts to be made to expedite approval and land acquisition for energy projects.
- Opening of coal, oil and gas sectors to private players.
- Exercising policies in favour of accelerating the deployment of the renewables
- Increased focus on battery storage technology to provide flexibility to the power system
- Promotion of direct use of renewables in building and transport sector as well as to supply the heating requirements.
- Strengthening the PAT mechanism and continuing the scheme after 2020.

III. Quality of Life for All: A Sustainable Development Framework for India's Climate Policy

Citation: Center for Study of Science, Technology and Policy CSTEP. Quality of Life for All: A Sustainable Development Framework for India's Climate Policy. 2015.

1. General Information

The study 'Quality of Life for All: A Sustainable Development Framework for India's Climate Policy' was published in August 2015 by Center for Study of Science, Technology and Policy (CSTEP). 'This study proposes an analytical framework to assess India's growth and emissions trajectory through a people's lens'.(p.1 Introduction)

2. Thematic background

The study was published months before India submitted its Intended Nationally Determined Contribution (INDC) at COP21. The study was carried out to devise a roadmap for improving the overall quality of life in India. Thus, multiple aspects of the quality of life, such as air quality, availability of freshwater and clean cooking fuel, improved energy and food security, better energy efficiency have been considered in the study. The authors argue that India should make a commitment to sustainable development rather than only focusing on greenhouse gas emissions, and the climate strategy ought to be devised accordingly. Two scenarios have been presented in the study to demonstrate that sustainability will also eventually lead to a reduction in GHG emission.

3. Methodology

NITI Aayog of India has developed an open-access web/excel based tool called **India Energy Security Scenarios (IESS) 2047** which allows users to simulate various scenarios for energy supply and demand with different mixes of technologies. This study is built on the IESS 2047 tool. A TIMES-MARKAL model (bottom-up energy system model based on constrained optimization) is used to evaluate several combinations of technologies and policies. A schematic of the model is shown in Figure 1.

Two scenarios, namely the **Business-As-Usual (BAU) scenario** and **Sustainable Development (SD) scenario** have been stylized using the model, and their implications on various sectors have been determined.

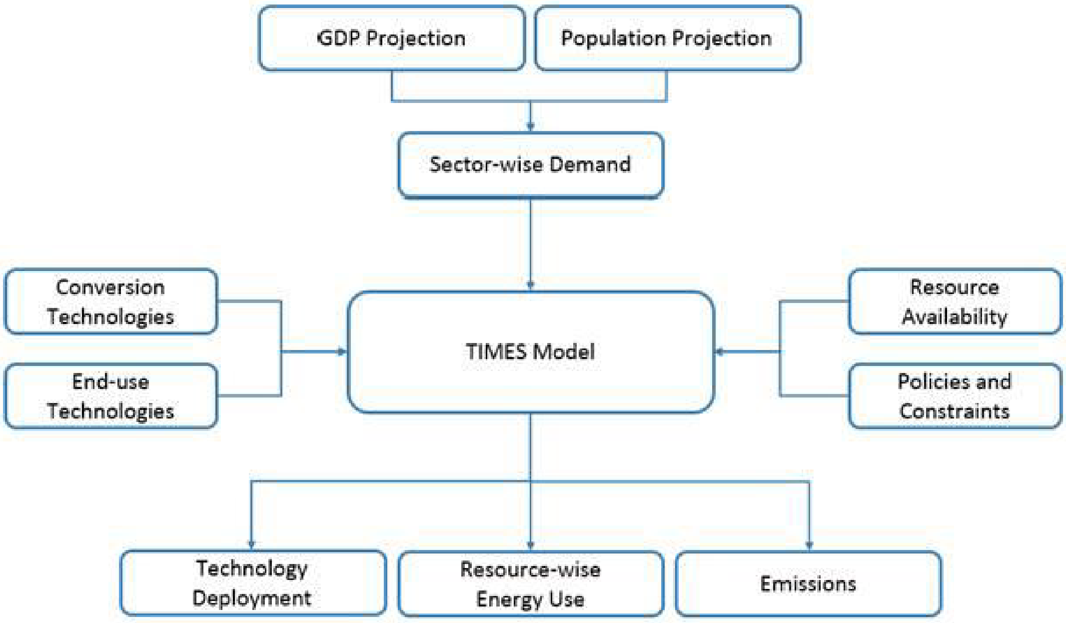


Figure 1: Representation of TIMES-MARKAL model used (p.1)

4. Scenarios/ Pathways

Business-As-Usual (BAU) scenario is a reflection of current policies and trends in the year 2030. BAU scenario shows that the overall primary energy demand of the country in 2030 grows around threefold of the value in 2012 due to the sustained industrial growth. As more electrification of the end-use applications takes place, electricity demand in 2030 will be four times that of in 2012. Similar statistics have been presented in the study for other sectors such as health, cooking, air pollution. This scenario serves as the reference scenario for comparison with Sustainable Development scenario.

Sustainable Development (SD) scenario is designed to improve the factors associated with the living condition of the citizens and increasing the quality of life for people. Various sustainability indicators such as energy security, local air pollution, inclusivity have been analyzed, and policy interventions are suggested to improve those indicators. For example, the primary energy demand in 2030 in the SD scenario is 22% less than the BAU scenario, due to the implementation of energy efficiency measures and modern cooking practices. Many indicators across the sectors have been examined, and the results are presented in the study.

5. Infrastructural changes in the Indian power sector

The study does not describe the changes in the infrastructure of the power sector in any of the sections. Only the changes in the electricity generation mix in the SD scenario have been described. In the SD scenario, around 33% of the electricity is generated from non-fossil sources. Renewables contribute 15% of the total generation. A significant increase in the installed capacity of renewables is required to achieve this situation.

6. Discussion and recommendation of relevant policies

Several policy interventions have been described in the study to achieve SD scenario. Some of them are as follows:

- High penetration of energy-efficient appliances in residential and commercial buildings
- Improve access of LPG to rural areas
- Improving the energy efficiency of industries through methods such as process switching or recycling
- Increase the share of public transport.
- Increase the share of rail-based freight and passenger transport in the country
- Promoting clean technologies such as electric vehicles.

IV. Electricity Generation in India: Present State, Future Outlook and Policy Implications

Citation: Tiewsoh LS, Jirásek J, Sivek M. Electricity generation in India: Present state, future outlook and policy implications. Energies 2019;12:1361.

1. General Information

The article ‘Electricity Generation in India: Present State, Future Outlook and Policy Implications’ was published in MDPI April 2019 edition. Lead authors of this article are L.S. Tiewsoh, Jakub Jirasek and Martin Sivek from Department of Geological Engineering at the Technical University of Ostrava, Czech Republic. The research was funded by the Ministry of Education, Youth and Sports of the Czech Republic. The study mainly focuses on electricity supply and demand in India.

2. Thematic Background

India is a fast developing country, with a GDP growth rate as high as 7% per year in recent past. Due to the rapid growth expected in the near future, electricity demand for the country is also expected to be very high. In that regard, forecasting the demand for electricity becomes crucial for planning purposes. Currently, the bulk of the power produced in India comes from fossil fuel sources such as coal and natural gas. Penetration of renewables in India is increasing rapidly, but renewables still hold a low share in the overall generation.

The study attempts to forecast the demand scenarios for India up for the year 2030 using data and statistics available in the public domain. Multiple scenarios have been presented considering the various possibilities of energy savings measures employed. Scenarios also present two supply-side situations - 1) high renewables growth 2) high fossil-fuel share. The results of these scenarios are compared and used to suggest policy interventions.

3. Methodology

LEAP (Long Range Energy Alternative Planning) tool was used for forecasting both the supply and demand of the electricity for the country. This tool is developed at the Stockholm Environment Institute. It employs bottom-up end-use accounting methodology on the demand side, while on supply side, it uses simulation and optimization methods to model the electricity sector. For demand projections for India, the model was divided into multiple sectors such as industrial sector, residential sector, agricultural sector, etc. The future energy demand for each sector is then calculated using past data and specific exogenous inputs such as GDP and population. Two major assumptions from the demand side, which lead to different scenarios are - High energy savings and high industrial growth with low energy savings.

From the supply side, two pathways have been set - High Renewables and Gas scenario where penetration of renewables is expected to increase rapidly. On the other hand, Low Renewables and Gas scenario prefers coal-based power plants.

4. Scenarios/ Pathways

As mentioned earlier, four scenarios have been designed by combining supply-side and demand-side pathways or situations. **High Renewable and Gas production (HRG)** scenario has a large emphasis on generation from renewables, nuclear and gas power plants. It assumes that the targets set by Govt. of India are fulfilled by 2022, and the adoption of renewables continues to grow at the same rate. **Low Renewables and Gas (LRG)** scenario, unlike the HRG scenario, assumes that the growth of renewables slows down after 2022 and focus is again shifted to fossil-fuel-based power plants. Addition of nuclear and natural gas power plants has also been considered in this scenario.

Energy Savings (ES) scenario is designed from the demand point of view. This scenario assumes that a high amount of investment is directed towards energy-efficiency alternatives across the sectors. For example, the attractiveness of green buildings to domestic and commercial buildings form a part of this scenario. On the other hand, **High Industry Growth (HG)** scenario assumes that investments are made towards expansion and capacity building purpose of industries, rather than energy-efficient measures. The scenario is specifically designed in a way to consider the inefficient practices in the industry, to demonstrate two extremes from the demand perspective.

5. Infrastructural changes within the Indian power system

The study forecasts electricity demand and supply scenarios using several models up to 2030. In all the scenarios, it is observed that coal remains to be one of the significant, if not the most significant contributor to the electricity generation mix. Only in HRG scenario, the generation from renewables surpasses coal. There is an increase in renewables capacity in India, along with nuclear energy which is seen as one of the better alternatives to strengthen the country's energy security. A discussion on the infrastructural modifications that the overall grid or the power sector has to undergo to cope with the changes in the energy mix has not been carried out in the study, explicitly or implicitly. However, to maintain the supply-demand balance of the grid in HRG scenario, where renewables constitute 1/4th of the overall electricity generation, demand-side interventions as well as strengthening storage technology, e.g. battery, pumped hydro are the alternatives that will be needed to be exercised.

6. Discussion/ recommendations of relevant policies

As mentioned in earlier sections, the study is majorly a forecasting exercise rather than a discussion on achieving specific goals. Therefore, the study does not make aims to make policy recommendations explicitly. The 'discussion' section, however, mentions some interventions that should be carried out in order to achieve the scenarios presented. Some of them are described below.

- Subsidization of relatively weaker and expensive sectors of electricity to achieve an optimal outcome
- Determining appropriate differential tariff to promote renewable energy resources
- Employing advanced measures to ensure the safety of nuclear power plants.
- Creating awareness amongst citizens about the safety of nuclear power plants through regular and transparent communication.

V. Pathways to Deep Decarbonization in India

Citation: Shukla P, Dhar S, Pathak M, Mahadevia D, Garg A. Pathways to deep decarbonization in India. SDSN-IDDRI; 2015.

1. General Information

The study 'Pathways to Deep Decarbonization in India' is a part of the global Deep Decarbonization Pathways Project, which is an initiative of Sustainable Development Solutions Network (SDSN) and Institute for Sustainable Development and International Relations (IDDRI). The country report for India was published in September 2015, with IIM Ahmedabad, CEPT University Ahmedabad and UNPE DTU partnership being the major contributors to the report. The study is aimed at finding pathways for low-carbon development for India. It encompasses the entire energy system of the country.

2. Thematic background

Deep Decarbonization Project is an international initiative, working with research teams from 16 countries which constitute about 70% of the total global GHG emission. The project has the primary aim to demonstrate the scenarios to these countries for transition in their energy systems and achieve a low-carbon economy. Development goals for the respective countries are also considered while designing the scenarios.

The study presents two deep decarbonization scenarios for India - 'conventional' and 'sustainable'. The 'Conventional' scenario follows a 'forward-looking neoclassical economic paradigm' while 'Sustainable' scenario is based on the sustainability goals for the country in the year 2050. (p.3) Reference scenario for forecasting the current trends has not been included in the study.

3. Methodology

The model used have been described to have a 'horses for courses' approach, which means adopting different approaches to solve different problems which arise out of sectoral and regional diversity. A soft-linked integrated modelling mechanism has been used, which implies that multiple models have been used to address multiple problems, and they are linked together with exogenous data and not with mathematical equations. This facilitates having both top-down and bottom-up approaches together to obtain the results for a scenario. However, this type of model ought to be used carefully, as it may lead to internal inconsistencies and not having a convergent solution.

AIM CGE/ GAMS model, ANSWER-MARKAL model and AIM ExSS model are interlinked via information exchange. Out of which MARKAL is a bottom-up optimization model which optimizes energy system costs. Sectoral drivers and databases are fed exogenously to this interlinked model. A back-casting framework has been adopted for scenarios assessment to align national development goals with global climate target.

4. Scenarios/Pathways

The study presents two scenarios; both are low-carbon or deep-decarbonization pathways stylized on different carbon budgets considered. There is no BAU or reference scenario mentioned in the study. Both scenarios extend from 2010 to 2050 and are focused only on reducing CO_2 emissions of the country. Also, both the scenarios assume that global agreement of achieving temperature rise below 2^oC still exists and all countries participate following the CBDR principle.

'Conventional' scenario focuses mainly on the growth of the economy. Its assumes that economic growth is the central objective, with the existence of perfect markets in place, and transition to a low-carbon economy will be achieved through a 'carbon tax' imposed on the economy. Thus, it argues that economics eventually will drive energy, power, industry and other sectors towards decarbonization. It assumes that a 'cap and trade' mechanism or 'carbon tax' exists and is applicable globally. The scenario is highly urban-centric and does not provide enough attention to sustainable rural development. The underlying idea of the scenario that economics shall lead to deep decarbonization is somewhat similar to the current trends observed or practised in the country.

'Sustainable' scenario uses the back-casting mechanism. The scenario is focused on sustainability as the name suggests, and considers economic, social and environmental goals into consideration together. Thus, a sustainable goal is mapped to the year 2050 and action roadmap is designed accordingly to fulfil the goal. The sustainable scenario strives at creating a 'low carbon society' rather than merely a 'low carbon economy.' (p.14) The sustainable scenario is not urban-centric s opposed to the conventional scenario. In short, the sustainable scenario aims at increasing the overall social welfare and not just the economic welfare of society.

5. Infrastructural changes in the Indian power sector

Even though both the scenarios have the same objective, due to the divergence in the means to achieve the objective, different infrastructural changes in power sectors are expected. High uptake in renewable sources such as wind and solar technology is common for both scenarios. For the conventional scenario, as the carbon tax is assumed to be in place, demand-side interventions are not expected to have a significant share in reducing emissions. Therefore, supply-side interventions are focused upon in this scenario. Share of nuclear power generation increases up to 34% in 2050 as per conventional scenario. Due to the carbon tax, prices of nuclear power would achieve parity with coal-based power and nuclear power plants would play an important role in supplying the baseload as a significant increase in electricity demand is expected in this scenario. Apart from nuclear, carbon capture and storage (CCS) technology will also play a crucial role in reducing carbon emissions from power plants.

Sustainable scenario considers total societal welfare and hence does not favour nuclear power due to its environmental hazards which are well-known. Therefore, nuclear power generation is expected to rise up to only 16% in this scenario. For the sustainable scenario, CCS and renewables are major pillars for achieving 'low-carbon society'. This scenario also aims at implementing low emission measures such as improving transmission network, implementation of demand-side management, etc.

6. Discussion and recommendation of relevant policies

The study discusses two deep-decarbonization pathways for India. Some of the key interventions to achieve those pathways are mentioned below.

- Early deployment of renewable technologies and energy-efficiency techniques to avoid a high share of nuclear and CCS technologies in the energy mix
- Urgent scaling up of global carbon finance for rapid technology transfer required to realize the pathways
- Promotion of clean commercial energy sources in rural areas
- Devising innovative carbon finance instruments
- Creating domestic markets for innovation and faster adaptation of low carbon technologies
- Developing regional cooperation for efficient use of resources available.

VI. Low Carbon Development Pathways for a sustainable India

Citation: Parikh J, Parikh K, Ghosh PP, Khedkar G. Low Carbon Development Pathways for a Sustainable India. IRADe New Dehli, India 2014.

1. General Information

The study 'Low Carbon Development Pathways for a sustainable India' was published in January 2014 by the organization Integrated Research and Action Development (IRADe), with World Wide Fund for Nature - India and Centre for Environment Education (CEE) as primary partners. The study has been supported by other organizations as well. The study has the objective of envisioning low-carbon goals for India. It is 'a result of a two-year discussion process, in which Indian and German civil society organizations have come together in order to promote possible approaches for low-carbon development scenarios in a society which still faces a high degree of poverty.'(p.III)

2. Thematic background

India being a developing country has many pressing issues yet to be solved, a high amount of poverty and lack of energy access to name a few. On the other hand, the menace of climate change is known to affect the developing countries more than developed. Therefore, India holds much interest in getting a global agreement amongst all countries to act on climate change. The study presented focuses on sketching out low-carbon pathways while recognizing the developmental goals for India. The study attempts at answering the following questions:

i) What is the Visionary Development pathway, and how to realize it?

ii) How can carbon budget adhere to the developmental ambitions?

iii) Which technologies shall be employed, in which sectors to achieve a low-carbon pathway?

In order to do that, four scenarios have been presented in the study ranging from the Business-As-Usual scenario to the low-carbon development scenarios. The study happened to be 'a first-of-its-kind to address development concerns in a climate-modeling framework.'(p.iv)

3. Methodology

The study presents four scenarios, as mentioned earlier. A step-by-step approach has been adopted in stylizing the scenarios. Initially, a reference or **Dynamics-As-Usual** scenario is developed by considering the household energy consumption as the major driver. Then, considering human development to be the major driver, **Visionary Development** scenario has been designed, with developmental measures and goals considered accordingly. Two low-carbon pathways have been designed further, based on the specifications of India's carbon budget share.

The study makes use of IRADe macroeconomic model. The model is a dynamic multi-sectoral, linear programming model based on the input-output framework. The matrix used is the Social Accounting Matrix for India 2003-04, presented by Saluja and Yadav. Investments in different sectors such as energy, power, industry sectors are calculated internally in the model. The model is then solved using the General Algebraic Modeling System (GAMS) programming tool. However, the model has its limitations on some of the assumptions it makes, such as the prices taken to be constant at 2003-04 values, considering GHG emissions only from CO_2 and neglecting other sources, etc.

4. Scenarios/Pathways

Dynamics-As-Usual (DAU) scenario is a projection of the current trend of energy use and emissions in the year 2050. It serves as a reference scenario, for comparison with other scenarios presented. The government consumption growth rate is considered to be 7% over the period of analysis. Only the policies and schemes initiated before 2005 have been considered in the scenario. Results of the scenario show that the growth of the power sector is mainly based on supercritical coal-based technology.

Visionary Development Scenario (VD) aims at achieving development thresholds and improving well-being indicators by 2050. This scenario discusses overall development goals, rather than energy or emission targets, using multiple development indicators such as life expectancy, access to electricity, clean cooking, schools, sanitation facilities, etc. The indicators were chosen by The Institute for Human Development (IHD). The scenario thus finally aims at achieving HDI value 0.905 for India by 2050 and presents policy interventions and measures to achieve the goal.

Low-carbon Development Scenarios (LC) can be considered to be one step further to the Visionary Development Scenario. They attempt at examining the possibilities and the consequences of low-carbon pathways for India. Two such scenarios have been presented (LC1 and LC2) wit different carbon budgets considered. Note that these scenarios/pathways also include development thresholds considered in VD scenario. LC1 scenario takes 156 Gt CO_2 as the carbon budget till 2050, while LC2 scenario considers the carbon budget to be 133 Gt CO_2 till 2050.

5. Infrastructural changes in the Indian power sector

The power sector is an area of focus, mainly for Low-carbon Development Scenario, as the power sector contributes more than 50% to the overall CO_2 emissions. VD scenario projects an increased share of supercritical power plants in the mix to reduce emissions. However, the desired emission reductions are not achieved merely by the introduction of supercritical plants. A major shift towards renewable energy resources is proposed in LC scenarios. LC1 scenario considers solar PV with and without storage as the primary alternative to achieve the required emission reduction. LC2 scenario, being even more stringent on the carbon budget goes one step further, considers a lower capacity of supercritical plants and an increased share of solar thermal with storage, hydro and natural gas plants.

6. Discussion and recommendation of relevant policies

Low-carbon Development Pathway discusses several interventions for reducing emissions across sectors. Some of them are mentioned below.

- Entire replacement of subcritical technology by supercritical technology, to curb the coal consumption and CO_2 emissions.
- Increase in the use of renewable energy sources, at a minimum rate of 5% per annum.
- Shifting freight transport from roads to railways, to reduce the petroleum import and the energy as well as carbon footprint of the freight transport sector.
- Exploring fuel alternatives for petrol, diesel etc. such as CNG, electric vehicles.
- Promoting energy efficiency schemes such as PAT scheme, especially in energy-intensive industries such as cement, steel industry.
- Increasing the use of energy-efficient of household appliances such as LED bulbs
- Promoting shift to non-motorized transport in cities.

VII. Evaluating India's climate targets: the implications of economy-wide and sector-specific policies

Citation: Singh A, Karplus VJ, Winchester N. Evaluating India's Climate Targets: The Implications of Economy-Wide and Sector Specific Policies; Report 327 2018.

1. General Information

The study 'Evaluating India's climate targets: the implications of economy-wide and sector-specific policies' was published by MIT's Joint program on the Science and Policy of Global Change in march 2018. Arun Singh, Niven Winchester and Valerie Karplus are the lead authors of this study. The joint program is a collaboration between the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR) at MIT, which primarily works on analysis and assessment of climate and environmental policies. This study particularly focuses on analyzing the impacts of India's proposed INDC targets.

2. Thematic Background

India has been one of the fastest-growing countries amongst all the developing nations in the world, with GDP growth rate consistently hovering around 7%. As the economy grows, the electricity sector shall also experience steep growth. On the other hand, India's INDC as submitted in COP21 asks for a 33% reduction in CO_2 intensity by 2030 as compared to 2005 level, and a 40% share of non-fossil based electricity by installed capacity by 2030. The INDC targets can be achieved through multiple mechanisms such as carbon-tax mechanism, Renewable Purchase Obligations (RPO), cap-and-trade scheme, etc. These mechanisms differ from each other in their sectors of application and the consequences on the economy. The study tries to answer the question 'which strategy should be employed to achieve NDC targets?' by simulating a model of the Indian economy and the welfare impacts. Moreover, the sensitivity of outcomes of declining solar & wind power prices and their implications are examined.

3. Methodology

A multi-sector applied general equilibrium model for the Indian economy, which links CO_2 emissions and energy production with economic activities has been used. The model allows having feedbacks within the sectors. Households, firms and government are represented in the model. The overall economy has been divided into 18 sectors based on GTAP-power database. The energy sector is described in detail in 12 of them, such as electricity, coal, oil, gas, etc. Each sector is then represented as a nested production function. Other external parameters required for the model, such as cost function, elasticity values for production functions, GDP multipliers have been taken from multiple sources.

The model is formulated as a mixed complementarity problem in the Mathematical Programming System for General Equilibrium Modeling and General Algebraic Modelling System (GAMS), which is then evaluated using PATH solver to formulate three scenarios.

4. Scenarios/ Pathways

The study initially generates a reference scenario for the year 2030 using forward calibration simulation. Apart from the reference scenario, three other scenarios considering different policy interventions in each of them to achieve the NDC targets of India have been designed. **Emissions-Intensity scenario** has been designed keeping the CO_2 emission reduction target of the NDC in as the focus area. An economy-wide cap-and-trade or emissions trading scheme has been considered as the instrument through which the target is achieved. Using the model, the impact of the targets on sectoral emissions and electricity mix, as well the corresponding carbon price is identified. Results of this scenario show that by implementing the proposed cap-and-trade scheme, emissions intensity reduces by 28% from 2011 levels.
The **Non-Fossil scenario** emphasizes on achieving the target of 40% installed capacity of renewables by 2030, as mentioned in the NDC. The policy instrument considered in this scenario is Renewable Portfolio Standards (RPS) or for Indian situation, Renewable Purchase Obligation (RPO). A third scenario, **the Combined scenario** has also been presented in the study which considers joint efforts on both the fronts, which is how the targets will be achieved in practice.

5. Infrastructural changes in the Indian Power sector

The study is primarily carried out to analyze the impacts of targets on the economy and is therefore, not a technology-oriented study. Thus, there are no specifics in the study regarding what infrastructural changes in the power sector shall be observed or will be needed to achieve the NDC targets through stated policy instruments. However, as mechanisms such as cap-and-trade scheme are applied, some changes in the electricity mix are bound to happen. In the Emissions-intensity scenario, the share of coal and natural gas power plants decreases significantly in the mix, nuclear and hydropower are operated at their maximum capacity, and a massive increase in solar PV installations take place. The non-fossil scenario also predicts a similar situation where large quantities of renewables are introduced in the mix, and overall electricity price increases.

6. Discussion and policy recommendations

Discussion carried out in the studies regarding policy instruments is summarized below.

- Cost of carbon emission in Emissions-intensity scenario is lower as compared to the reference scenario, while it is very high in Non-fossil scenario.
- Emissions-intensity scenario and Non-fossil scenario both result in a significant increase in the price of electricity, which may cause emissions to shift to other sectors.
- Combining carbon tax and RPO is a low-cost solution and should be implemented.
- Designing suitable policies for solar and wind may reduce their costs further, and more aggressive decarbonization policies then can be employed.

VIII. A More Sustainable Energy Strategy for India

Citation: Ahluwalia MS, Gupta H, Stern NH. A more sustainable energy strategy for India. 2016.

1. General Information

The study ‘A More Sustainable Energy Strategy for India’ was published by the Grantham Research Institute on Climate Change and the Environment in July 2016. The research is funded by The Grantham Foundation and UK ESRC. The main interest area of the study is to find out low carbon scenario for India.

2. Thematic Background

The Paris agreement signed by 175 countries in 2015 is considered as one of the crucial steps taken by the world to combat the issue of climate change. Even though the contributions from the countries were decided voluntarily, and as per many experts’ opinion that even if all the countries are successful in achieving their intended targets, the global temperature rise is still likely to be more than 2^{o} C; it is the first time that so many countries have at least agreed upon to tackle the burning issue of climate change. India, by virtue of its large share of population and hence the carbon emissions, plays a vital role in the global arena. It is expected of the major countries to review their NDCs from time to time. The study aims to explore and analyze the options India has to make further improvements in the NDC. While designing the scenarios, it is ensured that the country’s economic growth is not hindered.

3. Methodology

The scenarios are a mix of qualitative assumptions made and corresponding quantitative calculations. The quantitative part of the study is based on NITI Aayog’s India Energy Security Scenarios (IESS) 2047 tool Version 2. IESS tool is not exactly an economic model with mathematical relations and formulae integrated into it. The study has various input options for the user in terms of ‘efforts’ made in a particular sector (demand or supply sectors), and the pathways are then generated. Some exogenous inputs such as growth rate are required for generating the scenarios using the tool.

There are four levels of efforts, starting from level 1 which signifies least effort in the particular sector, to level 4 which signifies the most aggressive or ‘heroic’ effort made in the sector. Scenarios have been generated by choosing different levels in accordance with the qualitative assumptions. For example, the Business-As-Usual (BAU) Scenario considers level 1 for the transport sector and level 2 for other demand sectors such as buildings, industry and agriculture. While on the supply side, all the supply alternatives such as coal, oil, gas, renewables are chosen at level 2, which signifies the determined effort to generate the BAU scenario. In the Low-Carbon scenario (LC), level 4 has been assumed for all the demand sectors, which signify heroic efforts in the energy efficiency or demand-side interventions in all the demand sectors.

4. Scenarios/ Pathways

Two scenarios, namely Business-As-Usual (BAU) scenario and Low-Carbon (LC) scenario, have been presented in the study. The **Business-As-Usual (BAU) scenario** is as the name suggests, a projection of current trends and practices to 2047 and serves as the reference scenario for comparison. Coal and oil remain to be the dominant sources for primary energy in 2047, according to the scenario. The share of renewables in installed capacity increases from 4% in 2012 to 45% in 2047. However, the share of electricity in the total final energy consumption is low. The assumptions made for demand and supply levels have already been covered in the earlier section.

Low-Carbon (LC) Scenario aims to determine a low-carbon growth pathway for India. Two major components of the Kaya identity viz. energy intensity (E/GDP) and carbon intensity(CO_2/E) are the focus areas for this scenario. Reduction in both these quantities shall lead to low-carbon growth of the economy. Reduction in energy intensity is mainly achieved through adopting energy-efficient technologies in various sectors. For example, using energy-efficient appliances in households and commercial buildings. Similarly, to reduce the carbon intensity, alternative technologies need to be adopted such as electric vehicles instead of ICE-based vehicles. Increasing the penetration of renewables in electricity generation is a supply-side intervention to achieve low-carbon growth. Thus, in the LC scenario, the installed capacity share of renewables increases from 4% in 2012 to 64% in 2047.

5. Infrastructural changes in the Indian power sector

Supply-side interventions in the LC scenario are focused upon changing the landscape of electricity generation and transmission sector. High penetration of renewables in the electricity generation mix is envisaged to reduce CO_2 emissions. Introduction of super-thermal technology in upcoming coal-based plants increases their efficiency and lowers the carbon intensity. Some other supply-side measures are discussed in the study. Reduction in T&D losses in the grid shall also help in reducing the carbon intensity. The study suggests the introduction of smart grids infrastructure as well as upgrading the transmission technologies such as using superconducting materials to minimize losses in the system. As a result of these infrastructural changes, LC scenario predicts the T&D losses to reduce to 7% by 2047 from 22.7% in 2012.

With the introduction of a high amount of renewables in the grid, balancing capacity will have to be provided to tackle the intermittency and variability of the generation. Pumped hydro can be used as a seasonal storage support while batteries and gas turbines would be required for catering to daily ramping requirements. All these infrastructural changes incur a high capital cost. The economic study of these measures shows that the average cost of electricity in 2047 shall be 5.3 Rs/unit for the BAU scenario and 5.9 Rs./unit in LC scenario.

6. Discussion and recommendation on relevant policies

The study discusses the policy interventions that shall be necessary for the implementation of the LC scenario practice in detail. It is understood that multiple government agencies need to work together in implementing the policy instruments. Some of the interventions are:

- Implementing Energy Efficiency in new buildings and retrofits in old buildings
- Providing tax benefits for expenditure on retrofitting and SPV installations
- Financial incentives for manufacturers of efficient appliances
- Differential taxation on buses and cars to promote public transport among citizens
- Incentivizing EVs through differential taxes and accelerated depreciation
- Shifting freight transport to railways
- Pricing of externalities on the industrial products
- Financial incentives for purchasing solar pumps for irrigation.
- Financial incentives for RE sources – subsidies, soft loans
- Upgradation of transmission and distribution networks
- The study also discusses the need for clarity and assurance in policy implementation. Policies need to be clear with all the stakeholders, and all the stakeholders shall be assured of the benefits they receive.

IX. Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings

Citation: Udetanshu, Pierpont B, Khurana S, Nelson D. Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings. 2019.

1. General information

The study 'Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings' is published by the organization Climate Policy Initiative (CPI), as a part of the Energy Transitions Commission (ETC) in February 2019. ETC is a collaboration of CPI, The Energy and Resources Institute (TERI) and National Renewable Energy Lab (NREL). The study presents only interim findings, and a detailed report is expected to be released soon. The central premise of the study is flexibility and low-carbon pathway in the Indian power sector.

2. Thematic background

India in the NDC submitted at COP 21 has committed upon having a 40% share of renewables in the installed capacity by 2030. The study argues that it can be achieved with even lower costs than that of the current trajectory. It is technically feasible with options such as flexibility in generation, flexibility in consumer demand, and availability of storage options. However, the implementation of these mechanisms together is a challenging task. Four types of flexibility requirements have been defined in the study: Reserve power, ramping requirement, daily balancing and seasonal balancing. All these requirements can be catered by three options viz. demand-side, storage and power plant. By taking combinations of these options to address the various needs, multiple scenarios have been generated and analyzed.

3. Methodology

The methodology has been described only briefly in this report. Details shall be included in the detailed report. All the scenarios generated are based upon the scenarios presented in the report 'Exploring Electricity Supply-mix Scenarios to 2030' published by TERI. The scenarios considered are - **Current trajectory** scenario, **Current Policies scenario** and **High Renewable Energy** scenario. These three scenarios demonstrate: a continuation of current trends, the achievement of currently stated policies by government and maximizing the share of renewables in the energy mix, respectively. For each scenario, different flexibility needs such as reserve supply, ramping, daily balancing and seasonal balancing are considered. Potential to supply the need and the costs are calculated for each alternative using three options viz. demand flexibility, storage flexibility and power plant flexibility. Then, cost supply curves are created and the options to be exercised in each scenario are determined. Apart from the country-level analysis, four states with distinct energy needs and sources are examined separately.

4. Scenarios/ Pathways

There are four scenarios or 'portfolios' presented in the study. **Powerplant driven portfolio** assumes that the flexibility needs are entirely fulfilled by thermal and hydropower plants. This portfolio has also been referred to as **Thermal portfolio.** The required flexibility is achieved through increasing or decreasing the generation and load shedding. However, there are certain limits for thermal power plants such as minimum generation capacity, ramp-up time, start-up time which have to be considered while looking for flexibility options.

Similarly, hydropower plants with large reservoirs can provide flexibility, with seasonal availability of water being a constraint. Costs of providing flexibility have been considered while designing the portfolio.

Demand-Side Portfolio assumes that the flexibilities required in the system all come from demand-side interventions such as demand response and real-time pricing. Real-time pricing option is limited as of now in India and only applies to industrial customers. The portfolio takes four options into consideration - EV charging, space cooling, agricultural pumping and industrial loads, and calculates flexibility potential in terms of the factors mentioned earlier. Demand-side options are relatively less developed but can be amongst the low-cost options to provide the required amount of flexibility.

Storage Portfolio focuses on providing flexibility requirements such as reserve capacity through battery storage or pumped hydro storage. All kinds of flexibility requirements can ideally be fulfilled through storage options if they are inexpensive enough. In general, batteries is one of the costlier options. Still, considering the recent decline in prices of Li-ion batteries in the market, they can be a good investment for the future, especially when some of the coal capacity is expected to retire.

The last portfolio presented in this study is the Integrated flexibility portfolio or **Balanced Portfolio**, which is a combination of all the three portfolios described earlier. It has been developed by creating a combined cost supply curve for all the flexibility options.

5. Infrastructural changes in the Indian power sector

To implement the mentioned portfolios, various types of modifications in the power sector are required. For exercising demand-side options, measurement and communication is an essential part. Smart metering infrastructure has to be in place for 2-way communication between a consumer and the grid. Equipment which can automatically be controlled through electronic signals is also required for better implementation of DR schemes. Thermal portfolio discusses the change in operating practices required for thermal and hydropower plants to provide flexibility, such as continuous operation at lower than maximum capacity so that output can be increased if needed. In the energy storage portfolio, the role of batteries as an option to provide all kinds of flexibilities has been discussed. The study proposes that battery storage option if exercised on a large scale appropriately can cater to daily balancing & seasonal balancing requirements. Moreover, if batteries are placed strategically at critical locations, they can help in easing out transmission constraints by providing local support.

6. Discussion on relevant policy recommendations

Policy interventions have been discussed for the operationalization of each portfolio. Some of the key policies mentioned are:

- Continued push for completion of feeder separation in agriculture
- Time-of-day pricing for residential and commercial consumers
- Sharing of DR linked savings between DISCOM and participants
- Promoting markets which allow electricity price arbitrage
- Incentivization of storage systems, either as a standalone system or with solar PV systems
- Adjustment and restructuring of thermal power plant contracts – providing financial compensation for plant owners to have more flexibility in generation.

X. India Energy Security Scenario (IESS) 2047

Citation: Aayog N. India Energy Security Scenarios 2014 Version 2.0 2015.

1. General background information about the study

India Energy Security Scenario 2047, is an open source web tool launched by NITI Ayog in 2015. The UK Department for Energy and Climate Change (DECC) is the initiative partner with NITI Aayog in this project. Objective of IESS tool is to explore the various potential future energy scenarios for India. It considers diverse energy supply sources including renewables sources such as solar, wind, biomass, hydro, non-renewables such as coal, oil, gas and nuclear energy along with diverse energy demand sectors such as transport, industry, agriculture, cooking and lightning appliances for projecting the given future energy scenarios leading to 2047. This model allows user to explore the impact of a given scenario on outcomes such as, Energy security, costs, Carbon dioxide emissions, and land-use, import dependence etc.

2. Thematic background

Governments of the various countries are inducting its Intended Nationally Determined Contributions (INDCs) of COP21 in Paris into practicality through climate sensitive policy measures. Such measures will help in containing and mitigating the impacts of climate change on ecology. India also has setup an ambitious target of increasing the proportion of the clean energy to 175 GW in its total energy mix by 2022. IESS tool is intended to engage various stakeholders such as governments, parliamentarians, consultants, researchers to develop more secure and sustainable energy future for India and suggest current policy interventions to put India on a trajectory of becoming energy self-sufficient while ensuring climate responsibility.

3. Methodology:

Assessment of various energy sources it's growth potential was assessed on the timeline till 2047. IESS tool is based on Bottom – Up model. Aggregated data was compared with the energy demand from all the sectors of the economy along with their possible future growth rates. This energy demand and supply data was used to project the various energy security pathways leading to 2047. IESS 2047 is a calculator tool that allow us to vary the contribution of the particular energy source into whole energy mix of the country with respect it the aggregate energy demand of that particular time period. Demand and supply numbers projected in every scenario has considered various energy efficiency measures and technology interventions along with increasing indigenization of resources production in country.

4. Scenarios / pathways presented:

IESS 2047 allows user to explore number of energy security scenarios with permutation and combination of various energy sources by varying its contribution in the total energy mix. These scenarios assume GDP of the country will grow from 84.25 trillion INR in 2012 to 1031.67 trillion INR in 2047 and over the same timeline urbanization will experience a growth from 30 % to 51 %. Some of the important energy security scenarios are described below:

a) Determined Efforts Scenario: This scenario generates exact amount of electricity demanded from the various sectors of the economy from 2012 to 2047. Over the same timeline annual electricity demand was expected to grow from 876 TWh to 5518 TWh. In this scenario the share of renewable energy in electricity generation increases to 22 % of the 3833 TWh of total electricity generation in 2047. Coal power stations produces 1963 TWh of energy in 2047.
b) Heroic Efforts Scenario: In this scenario, all the energy sources are harnessed to their highest of the potential. Total electricity generated in this scenario is 9253 TWh in 2047. Share of the renewable energy in total electrictity generation increases to 39 % in 2047. Coal power stations produce 3704 TWh of the total electricity in 2047 in this scenario.
c) Maximum Renewable Energy Scenario: In this scenario, all the renewable energy sources are explored to their highest potential to meet the total energy demand. Only the remaining part of the energy demand which was unmet through renewables is met through nonrenewable energy sources. This scenario projects 4957 TWh of total electricity generation in 2047 out of which 2428 TWh is generated through renewable energy sources and 1572 TWh is generated through Coal power stations.
d) Maximum Energy Security Scenario: In this scenario, heroic efforts are made in demand side of the energy sector. All the sectors that need energy are assumed to operate at their full capacity and then energy supply side distribution is analyzed. Total electricity generation through this scenario is 4280 TWh. 40 % of this electricity generation is obtained from renewable energy sources in 2047. Coal power stations produce 1963 TWh of electricity in 2047.

5. Infrastructure changes within Indian Power system:

Most of the infrastructure changes in this study are related to storage capacity and as balancing support to tackle the intermittency of the renewable energy sources. Infrastructure changes in all the above four scenarios are mentioned below:

a. Determined Effort Scenario:

This scenario do not generate any excess electricity. So, there is not electricity export potential though this scenario. 22 % of the electricity is generated through renewable sources. Renewable energy need alternate standby support or storage medium to meet the electricity generation demand when renewable sources are not producing the electricity. In this case, 55 MW of gas based capacity is required for balancing the intermittency of the renewable energy sources. This is expected to cost 1 trillion INR to the economy.

b. Heroic Effort Scenario:

This scenario generates 5972 TWh of excess electricity which is available for the export. So, the grid infrastructure necessary for the exporting of the electricity generated need to be created. 39 % of the electricity in this scenario is generated through renewable energy sector. 140 MW of additional gas power is capacity is required to cover up the intermittency of the renewable energy sector. This is expected to cost 2 trillion INR to the economy.

c. **Maximum Renewable Energy Scenario:**
This scenario generates 570 TWh of excess electricity which is available for the export. So, the grid infrastructure necessary for the exporting of the electricity generated need to be created. 140 MW of gas power capacity is required to balance the intermittency offered by the renewable energy sources which generates 49 % share of the total electricity produced in the 2049. This is expected to cost 2 trillion INR to the economy.

d. **Maximum Energy Security Scenario:**
This scenario generates 315 TWh of excess electricity which is available for the export. So, the grid infrastructure necessary for the exporting of the electricity generated need to be created. 140 MW of gas power capacity is required to balance the intermittency offered by the renewable energy sources which generates 40 % share of the total electricity produced in the 2049. This is expected to cost 2 trillion INR to the economy.

XI. The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India

Citation: Gulagi A, Bogdanov D, Breyer C. The role of storage technologies in energy transition pathways towards achieving a fully sustainable energy system for India. J Energy Storage 2017;17:525–39.

1. General background information about the study:

India has agreed zero emission based energy system by 2050 in COP 21. India's success in this direction will be a great milestone in a direction to restrict the global rise in the temperature to 2^{o}C. Government has initiated various initiatives in order to increase the share of the renewable energy in India's total energy mix. Being a tropical country India has abundant solar energy potential. Government has kept a target to achieve 100 GW of the solar energy by 2022 and 250 GW by 2030. These renewable energy sources have inherent property of intermittency. This creates a possibility of India becoming one of the largest market for Energy storage technologies. This model comprehensively covers the hourly demand of energy needs of power, desalination and non-energetic industrial gas sectors in integrated hourly based model.

2. Thematic background

100 % renewable energy for the electricity and other energy demands has a major obstacle posed by the intermittency of the renewable energy sources such as Solar, Wind, and Biomass etc. Problem of intermittent energy sources can be tackled by deployment of cost effective energy storage systems such as, batteries, pumped hydro storage (PHS), adiabatic compressed energy storage, thermal energy storage and power to gas technologies. These storage technologies are considered for the modelling of optimum storage infrastructure required for 100 % renewable energy scenarios. Results of the study show that 100 % renewable energy is achievable in 2050 with levelised cost of the electricity falling from current level of 52 €/MWhe to 46 €//MWhe in 2050. In this work, 100 % renewable energy transition pathway based on hourly resolved model is simulated till 2050. This is the first such study where full hourly resolution is simulated for Indian scenario.

3. Methodology:

Transition of the India's power system as zero emission system from 2030 to 2050 with five year time steps was modelled with LUT (Lappeenranta University of Technology) energy system model tool. This model is along with the constraints considered is explained by Bogdanov and Breyer (1). LUT model is a linear optimization model with constrains applied to the future renewable energy generation capacity and market demand. Objective of this optimization function is to minimize the total annual cost of energy system. This cost includes cost of capacity installation, energy generation and energy ramping costs. LUT linear optimization function is applied to five year steps over a timeline of 2030 to 2050. It was assumed that there will be no new installation of the nuclear, coal or oil power plant for achieving the transition toward sustainable energy future. However installation of the gas power plant was allowed as gas power plant is considered as one of the most energy efficient electricity production technology.

4. Scenarios / pathways presented:

Study considered the two scenarios of zero carbon emission by 2050. These scenarios are Current scenario and Integrated scenario. Aggregated demand of the energy from Power, desalination and industrial gas sector was satisfied through the energy mix consisting only of renewable energy choices. This study mainly focuses on balancing the intermittency of the renewable energy sources such as wind and solar energy by providing appropriate mix of energy storage technologies. Major difference between two scenarios presented in this study, Power scenario and Integrated scenario is, integrated scenario, in addition to the power sector also consider the energy consumption by desalination and non-energetic industrial gas sectors. Additional energy demand created in the integrated sector is assumed to be satisfied by the solar PV electricity production. In 2050, 25 % extra solar PV energy and 19 % more energy storage system is necessary in integrated scenario than the power scenario. As compared to Solar PV, wind energy share increases gradually in both the scenarios. These scenarios assume the levelized cost of the electricity (LCOE) will be reduced by 26 % from current level by 2050. LCOE in both the cases first increases till 2025 and then further decreases to 2050. This happen due to increasing cost of generation and carbon emission till 2025. Increase of the renewable energy technologies after 2025 will have significant Impact on the reduction of LCOE in both the scenarios.

5. Infrastructure changes within Indian Power system:

Role of the energy storage system increases with increase in the share of renewable energy system in the total electricity generation. Till 2025, PHS is considered as most effective energy storage system. However, with decreasing the cost of the solar power, influence of battery systems in storage sector is expected to increase. As per the Power and Integrated scenarios, there is a need of installation of 2596 TWh and 3145 TWh battery capacity respectively in both the energy transition scenarios. In the Monsoon season, less amount of the solar energy is produced from solar PV sector, so batteries are less charged. So, to such monsoonal problem, there is a need of gas storage. This gas can be used in the monsoon season to produce the electricity by combined cycle gas turbine (CCGT). CCGT power can be ramped up quickly in night time and for the days of the lower solar radiations.Transmission grid also plays important role in balancing the electricity demand in the different regions of the country and reduces the need of the storage technology. The net electricity exchange in the monsoon months is expected to reach to 698 TWh in 2050 (11.2 % of the total electricity demand). So, in order to meet such regional electricity demand grid integration and stability measures are needed to be incorporated while developing the infrastructure for future energy scenarios.

6. Discussion and recommendation of relevant policies:

This is the first such study that shows the possible scenarios for the transition of the India's energy sector towards zero emission – 100 % renewable energy system. Study shows that 100 % renewable energy by 2050 is technically feasible and economically viable for India. Proposed energy system will have the major share of the Solar PV along with batteries supplying energy during night and early hours of the morning. LCOE for power and integrated scenarios are expected to be 52 €/MWhe to 46 €//MWhe respectively in 2050. These values can be further decreased with government policy initiatives, schemes or subsidies for the promotion of the renewable energy sources. Report also shows that fully renewable energy along with storage technology is cheaper than the current cost of electricity. Storage plays important role in achieving 100 % renewable energy scenario. Till

2025, gas will dominate the storage sector, but after 2025 with increase in the share of solar PV sector batteries will influence the storage sector. Increase in the deployment of the Solar PV is only possible when there will be significant decrease in the cost of the Solar panels and the electric storage batteries. In the monsoon month’s gas storage is discharged to produce the electricity. So, even after 2025, importance of the gas storage cannot be neglected. India’s commitment to the INDC, establishment of the International Solar Alliance shows the will power of the government in accelerating the journey of India toward zero emission energy economy.

XII. Exploring Electricity Supply-Mix Scenarios to 2030

Citation: Pachouri R, Spencer T, Renjith G. Exploring Electricity Supply-Mix Scenarios to 2030. 2019.

1. General background information about the study:

The objective of this study is to present the integrated electricity capacity scenarios for 2030. Three scenarios presented in this study have different combinations of coal and renewable energy capacities. This study was performed by The Energy Research Institute (TERI) as a part of the Energy Transmission Commission India Project led by the National Renewable Energy Laboratory.

2. Thematic background:

The theme behind developing different scenarios, namely Current Policy Scenario, Current Trajectory Scenario and High Renewable Energy Scenario, is to study the issue of flexibility needs, associated costs, and challenges that may arise in Renewable Energy Grid Integration by 2030. This study can work as a reference for the initial analysis of various grid stability issues by readers, commentators and researchers working in electricity market analysis.

3. Methodology:

This study is based on the scenario-based approach where cost optimization was neither the constraint nor was the objective. Modeling of the power dispatch and hourly operation is done using PLEXO model. All the scenarios are prepared using CAGR of 6 % till 2030 to 2040 TWh excluding Aggregation and Transmission losses.

4. Scenarios/pathways presented:

The objective behind the following scenarios is to examine technical, financial and market aspects of the power system transition through various pathways.

- **Current Policy Scenario –** 175 GW RE by 2022 and further RE capacity additions as per the National Electricity Plans developed for the years after 2022. Expected Coal Capacity Generation in 2030 be 238.1 GW with 54 % of the total electricity generation and the Renewable energy capacity be 355 GW with a 30 % share in total electricity generation.
- **Current Trajectory Scenario –** This scenario follows the existing trajectory of new electricity capacity addition by incorporating current commercial and on-ground realities. Less deployment of coal power plants until 2022 has been considered due to current financial strain. Also, deployment of renewable energy targets is also expected to be missed by a significant margin due to challenges faced in rooftop and on-ground solar installations. In this scenario, coal-fired capacity addition is greater than that mentioned in the Current Policy Scenario. Expected Coal Capacity Generation In 2030 be 262.2 GW with a 61 % share in the total electricity generation and the renewable energy capacity be 289 GW with a 24 % share in total electricity generation.
- **High Renewable Energy Scenario –** This Scenario considers maximum deployment of the renewable energy capacity by 2030. There will not be any new deployment of the coal-fired power plant in the country beyond the plants that are

under construction. So, this scenario has a minimum coal capacity by 2030. Expected coal capacity generation in 2030 be 191.7 GW with a 50 % share in total electricity generation and 421 GW renewable energy capacity with a 34 % share in the total electricity generation.

5. Infrastructure changes within the Indian Power system:

- Additional storage or ramping capacity needs to be installed to increase the system flexibility issues.
- Pumped storage plants, gas-powered electricity plants are some of the ways suggested to increases the system flexibility in the electricity sector.

6. Discussion and recommendation of relevant policies:

- It is possible to meet the electricity growth demand to 2030 with renewable energy and the addition of coal capacity, as mentioned in the National Electricity Plan.
- With High Renewable Energy Scenario and without the addition of new coal power capacity beyond the current pipeline, it will be difficult to meet the electricity demand without increasing the Power Load Factor of the existing coal power plant to the unfeasible levels.
- With the emergence of renewable energy as a feasible option for electricity generation, the development of new coal power plants has shifted to the downside.
- Annualized capital investment in all three scenarios is broadly the same and it is in the order of 1.65-1.75 trillion R/year. According to the study, this amount is a sizeable but not infeasible financing challenge.
- All three scenarios have similar flexibility challenges but vary in the degree. With the increase in the deployment of renewable energy sources, flexibility challenges due to intermittency also increase. Flexibility challenges necessitate the additional system flexibility in the form of gas power plants, and Pumped storage plants are needed to satisfy the immediate ramping requirements.
- On a per-unit basis, renewable energy is cheaper than grid electricity. However, grid integration costs are higher and that puts the major challenge in large scale renewable energy penetration.
- Further decrease in the cost of renewable energy and storage technologies, renewable energy power systems will be highly cost-effective.

XIII. The Energy Report- India, 100% Renewable Energy by 2050

Citation: The Energy and Resource Institute TERI. The Energy Report – India: 100% Renewable Energy by 2050. New Delhi: 2013.

1. General background information about the study:

Climate change is the biggest threat to humanity. WWF International had published a report "The Energy Report : 100 % renewable energy by 2050" showing the energy transition pathway that can satisfy the energy needs with clean and economically viable approach. On same lines, WWF – India in partnership with TERI had undertaken an exercise to study the renewable energy pathway for India's energy future. This report intends to assess the feasibility of the 100 % renewable energy by 2050 at national level.

2. Thematic background:

India has a significant problem of energy access at ground level. 300 million people in India do not have access to the electricity. Renewable energy sources provide opportunity for providing access of clean electricity at decentralized level. Increasing urbanization should have incorporated the use of renewable energy use for its electricity needs. This study also intends to visualize the implications and challenges associated with transition towards 100 % renewable energy scenario. Report expects every stakeholder in the energy chain should strive for "Renewables as the new normal."

3. Methodology:

- Bottom-up integrated modeling of energy demands and potential of all alternate energy technologies and energy sources.
- Factors such as increase in demand due to increase in electricity access, improvement in energy efficiency technology across power sector are incorporated while projecting both the scenarios for future timelines.
- TERI developed MARKAL (MARKetALlocation) modeling framework to perform this energy transition assessment.
- "MARKAL interconnects the conversion and consumption of energy." Minimizing the cost of transition, identifying cost effective pathways for reducing emissions were the objectives and capacity potentials of all energy sources were constraints of this optimization modeling framework.

MARKAL framework is shown in following figure:

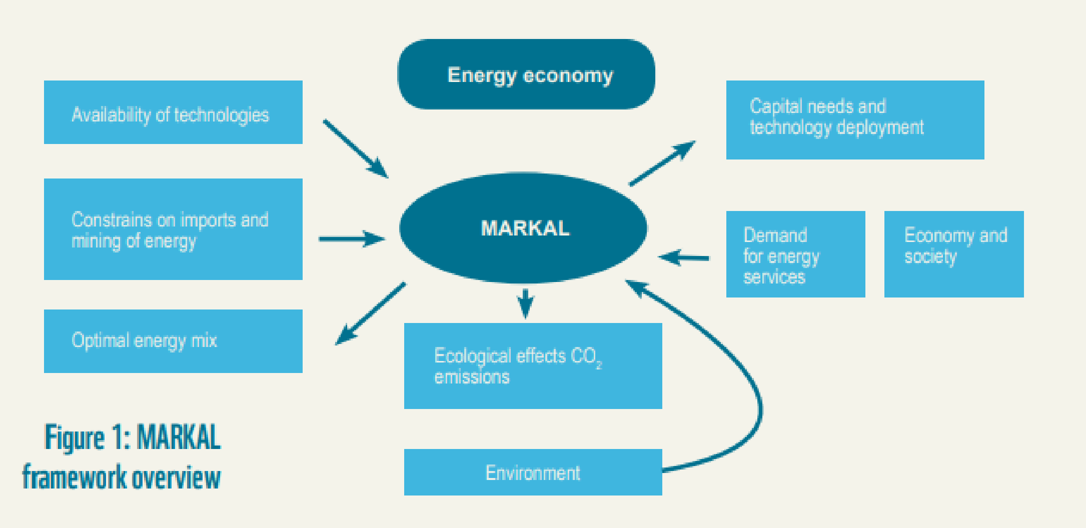


Figure 1: MARKAL framework overview

4. **Scenarios/pathways presented:**

There are two scenarios developed in this study, Reference Energy Scenario (RES) and Renewable Energy Scenario (REN).

Reference Energy Scenario (REF): This scenario considers current trends, policies, and projects them in a future timeline. REF includes all forms of energy sources such as fossil based, nuclear and renewable.

Renewable Energy Scenario (REN): In this scenario, fossil based, nuclear energy capacity sources are faced out and replaced by renewable energy sources. No new fossil or nuclear power capacity based capacity addition. Solar, wind and hydro be the main sources of the electricity generation and second generation biofuels for meeting the demand of transport sector. There is significant emphasis on increasing the energy efficiency across the energy system.

5. **Infrastructure changes within the Indian Power system:**
   - Infrastructure and technological developments for improving the energy efficiency are necessary in all the aspects of power sector. It can save 59 % of energy by 2051.
   - Before the ending of lifetime, fossil based power plants and technology need to be phased out.
   - Large scale production of biofuels for fueling the transportation sector.
   - Establishment of Solar thermal technology based plants for electricity generation and industrial process heating applications of temperature need upto 700 degree Celsius.
   - Large scale development of energy storage technologies need to be deployed to tackle the intermittency offered by renewable energy sources.
   - Immediate development of grid integration and load management system.

6. **Discussion and recommendation of relevant policies:**
   - Sustainable, renewable energy based economy can be theoretically achieved. Here, 90 % of country's primary energy needs are fulfilled through renewable

energy sources. But still, remaining 10 % need to be fulfilled through fossil based energy sources.

- Need to undertake significant changes in daily lifestyle, technology and policy initiatives for implementing near 100 % renewable energy scenario by 2050.
- Efforts needed toward making alternative technology commerciable available and also viable.
- Apart from popular renewable technologies such as Solar PV, wind and hydro power, equal emphasis needed on renewable energy choices such as solar thermal, geo thermal, tidal and waste to energy.
- End uses where fossil fuels based energy is a preferred choice (ex. LPG for cooking), behavioral changes are must for increasing the acceptance towards renewable energy powered alternatives.
- Import dependency of coal and oil is predicted in both these sector. In REF scenario, domestic production of coal and oil will not meet the pace of demand. In REN scenario, it is assumed that domestic production of coal and gas is completely stopped.
- Energy efficiency will play an important role in making renewable energy technology commercially viable.

XIV. Expert group on 'low carbon strategies for inclusive growth' (LCSIG)

Citation: Planning Commission G of I. The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth. New Delhi: 2014.

1. General background information about the study:

"There is near consensus among the scientific community that ongoing global warming is an anthropogenic phenomenon, a result of carbon intensive activities since the industrial revolution" (Page 1, Executive summary). Although India have been one of the least carbon emitter in the world, but still it is highly vulnerable to the adverse impacts of the climate change. In December 2009, India announced a goal of reducing emission intensity of its GDP by 20 to 25 %, over 2005 levels by 2020. In this regards, "Low Carbon Strategy for Inclusive Growth" expert group was setup by the Planning commission to suggest the low carbon transition pathways for inclusive growth of the country. This report presents low carbon pathways along with their macro-economic and welfare implications on economy.

2. Thematic background

Energy is the critical constraint in the development of the economy of a country. Rational policy that accounts the total domestic energy resources, reduce import dependence, ensure energy security and restrict the carbon emission to least possible level was considered imperative. This report envisages the possibility of holistic low carbon economic growth of the country.

3. Methodology:

Expert group developed a model that incorporates inter-sectoral implications of carbon emission reduction along with sustaining economic growth. Multi-sectoral, dynamic optimization model used in this study is named as "Low Carbon Growth" model. This model is the combination of bottom-up and top-down approaches. Bottom up, because it includes many available energy technology options and top down, because it includes the whole macro economy. This model optimizes the cost involved in various options of energy mix, their emissions and the costs involved. This model was solved using GAMS program. Output of this model is presented in the form of two scenarios: Baseline Inclusive Growth Strategy (BIG) and Low Carbon Inclusive Growth Strategy (LCIG).

4. Scenarios / pathways presented:

This study developed two strategies, Baseline Inclusive Growth Strategy (BIG) and Low Carbon Inclusive Growth Strategy (LCIG).

Baseline Inclusive Growth strategy (BIG):

- This strategy generates average growth rate of 7 % between 2007 and 2030.
- This strategy generates 3.6 tons per capita carbon emissions in a year 2030.
- This scenario incorporates inclusive growth policies as mentioned in Twelfth Five Year Plan.

Low Carbon Inclusive Growth (LCIG):

- This strategy generates marginally lower growth rate of 6.9 % between 2007 and 2030.
- This strategy generates 2.6 tons per capita emissions in year 2030, which are significantly less than BIG strategy.
- LCIG strategy need significant additional investment of 1.5 % of the GDP for deploying low carbon emission technologies for commercial use.

- Energy efficiency in households, industries, buildings, transport have significant roles in achieving low carbon inclusive growth.
- Low carbon growth model also have effect on reducing the import dependency of fossil fuels.
- Expert group is of opinion that although low carbon growth strategy have low economic growth but still it's worth pursuing.

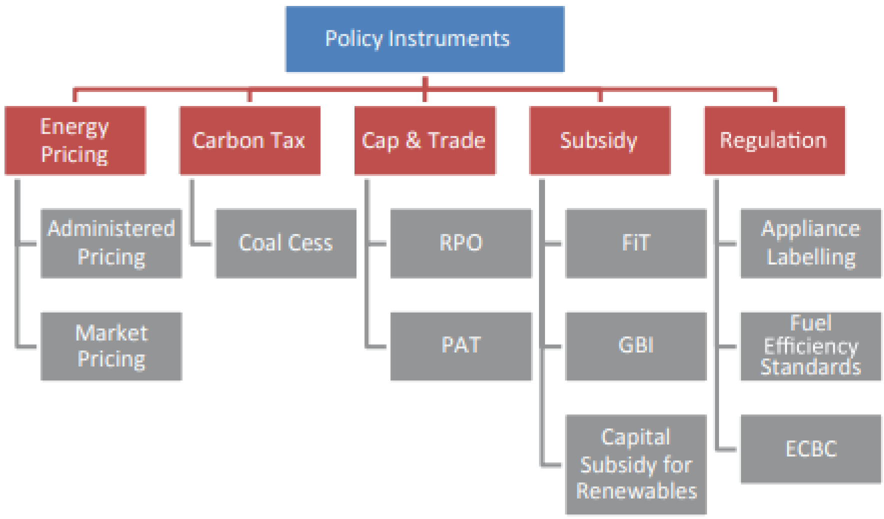
5. Infrastructure changes within Indian Power system:

Solar and Wind energy delivery varies with respect to time so, they are non- dispatchable. Smart grids with improved storage, enhanced flexibility for baseload application are necessary for smooth operation of the grid.

6. Discussion and recommendation of relevant policies:

- LCIG strategy will help in reducing carbon intensity of the economy by 25 % over 2005 levels by 2030.
- Expert group suggested two policy measures: Reducing energy requirement by promoting energy efficiency; and other suggested measure is, increasing the proportion of low carbon renewable energy sources in total energy mix.
- Expert group suggested some policy instruments that can help in approaching towards policy measures. Policy instruments are: Energy pricing, Carbon tax, Cap & trade, Subsidy and regulation.

Figure 10.1: Types of Policy Instruments



- Administering energy pricing in the form of levying cess on fossil fuels and providing subsidy on low carbon fuels so that the pricing gap between low carbon energy sources and fossil fuel based energy sources.
- Incorporating energy efficiency in building architecture so as to reduce its energy demand.
- Implementation of Perform – Achieve _ Trade (PAT) in industries so that emission intensity of the economy can be reduced.
- Feed-in-tariff policy so as to ensure the payback to the investors in renewable energy sectors. Providing generation based incentives for low carbon energy generation and strict implementation of Renewable Purchase Obligations (RPO).

- Improve the efficiency of the coal power plants by deploying advanced technologies such as Ultra-Super Critical technology. Reduce emissions from coal-fired power plants by incorporating policy for carbon sequestration.
- Research and development for developing indigenous technology in low carbon energy generation sector.
- Implementation of low carbon growth strategy is inter-disciplinary task. So, coordinated approach is necessary to pursue growth, inclusion and sustainability.

XV. India energy outlook

Citation: International Energy Agency IEA. WEO-2015 Special Report: India Energy Outlook. 2015.

1. General background information about the study

Energy will remain at the center of India's economic growth targets. Being one of the most populated countries, India will play an important role in influencing the global economy. So, it was imperative to analyze India's energy sector to a greater depth. World Energy Outlook – 2015 special report is dedicated to cover India's present and future energy sector with an emphasis on assessing India's clean energy transition strategy.

2. Thematic background

Per capita demand In India's energy sector is 40 % below the world average. Trends Expanding economy and population will put India a major driving force in the global energy market. Population, economic growth, urbanization, new infrastructure developments, and government policy interventions in the energy sector are the parameters for assessing India's future energy mix scenarios. India's climate pledge at Paris Climate Summit (COP 21) has already state India's targets towards expanding the use of renewable energy sources in its energy mix. This report does not prescribe any initiatives, but it analyzes India's energy choices, and it's interaction with its economy and also on the overall global energy sector.

3. Methodology:

India Energy Outlook uses World Energy Model for predicting India's future energy mix scenario. This model covers energy supply, energy demand, and energy transformation into account in its energy scenario assessments. The central scenario in this report is the "New Energy Scenario." It takes into account the present policy regulations and declared policy goals towards the expansion of renewables in the total energy mix. The objective of the scenario is to provide electricity access. World Energy Model has considered real-life constraints such as regulatory, financial, and administrative barriers.

[Note: Details about the World Energy Model not mentioned in this report. World Energy Model discussed in World Energy Outlook 2015 report.]

4. Scenarios/pathways presented:

The report presents two future energy scenarios, namely "New Policy Scenario" and " India Vision Case."

(a) New Policy Scenario:

It assumes that the Indian economy will grow at a rate of 5.5 % till 2020, then at 6.3 % till 2030 and at 6.5 % till 2040. The effect of "Make in India" is expected to increase the contribution of the manufacturing sector in the growth of overall GDP. Population dynamics in the form of growing urbanization is also the driver of the energy economy. Urbanization expected to increase to 45 % till 2040. New Policies Scenario allots preference for solar energy and efforts towards improving energy efficiency. It assumes the continuation of the levy on coal to support the National Clean Energy Fund. This scenario also considered the mandatory use of Supercritical technology for new coal power plants and emphasis on reducing transmission and distribution loss to the target of 15 %.

New policies scenario accommodated the practical barriers that may arise in the implementation of the existing regulations and policies that are meant for achieving future targets. So, in the New Policies Scenario case, it takes a longer duration of time to achieve the present targets committed by India.

(b) Indian Vision Case:

Indian Vision Case scenario has two important pillars or assumptions. One pillar is a universal and uninterrupted supply of electricity to all the customers. The second pillar is about the increase in the share of the manufacturing sector in the country's GDP to 25 % of GDP. This scenario assumes accelerated investment in the power sector of the country than that in the New Policies Scenario. All the targets envisioned by the Indian policy makers are expected to achieve in the Indian Vision case scenario unlike in the New Policies Scenario, where targets not met in the intended time duration. Specific push to the two pillars (Increasing share of renewables and share of the manufacturing in the total GDP of the country) will increase the energy consumption to 15 % more than the predicted in the New Policies Scenario.

5. Infrastructure changes within the Indian Power system:

Both Scenarios have a common emphasis on increasing per capita energy consumption. Increasing energy consumption may also lead to the establishment of more energy-intensive industries. So, new infrastructure being setup must adhere to the principles of energy efficiency and environmental regulations. All the new coal fired power plants must use Supercritical technology. Domestic manufacturing of the equipment needed for the power plants will in reducing the cost of advanced power generation technology.

6. Discussion and recommendation of relevant policies:

Financial support to the Small and Medium Enterprises to improve energy efficiency. Strict implementation of the Perform, Achieve and Trade schemes in the industries to control the carbon emissions. Spreading awareness about the transition towards more energy-efficient technologies in domestic and industrial applications considered an important factor in achieving low carbon growth in both scenarios. Easy provisions of the knowledge transfer for undertaking energy-efficient measures and appropriate financing tools on a large scale are the immediate to improve the energy efficiency in the industrial sector. In the Indian context, decisions related to the power sector also taken at the state level. Foreign investment in the power sector has a statewide deployment disparity. The top six states have absorbed 70 % of the foreign investment from 2000 to 2015. But, the transmission and distribution of the produced power occur through the national grid. So, there is a need for competitive and cooperative federalism well-coordinated by the national institution such as NITI ayog. Such a coordinated approach of policy making will help in better channelizing the investment in the power sector and also the better implementations of the innovative policies towards low carbon growth in the energy sector.

XVI. Energy system transformation to meet NDC, 2 °C, and well below 2 °C targets for India

Citation: Vishwanathan SS, Garg A. Energy system transformation to meet NDC, 2° C, and well below 2° C targets for India. Clim Change 2020:1–15.

1. General Information

The article 'Energy system transformation to meet NDC, 2 °C, and well below 2 °C targets for India' was published in January 2020 edition of Springer's *Climatic Change* journal. Lead authors of this article are Saritha Vishwanathan and Amit Garg who are associated with Indian Institute of Management Ahmedabad and Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), Tsukuba, Japan. The research was funded under the European Union's Horizon 2020 research and innovation programme. The study focuses on energy system transition in India.

2. Thematic Background

Indian energy system must undergo a rapid transformation for meeting the commitments made in Paris agreement, as well as attaining the national sustainable development goals. Innovations in multiple aspects such as technology and policy are required simultaneously to bring about the required transformation. Policies made in recent years focus on decoupling the economic growth and use of fossil fuels as a major fuel source through various measures such as changing fuel mix, modal shift, behavioural change, enhancement in energy efficiency and conservation, etc. This study attempts to provide a quantitative assessment of the challenges faced by the Indian energy system. The study covers financial aspects such as investments required for deep decarbonization in India. The impacts of early and late actions on the energy system and associated investments have been analyzed, with the help of five scenarios.

3. Methodology

Authors have used Asia-Pacific Integrated Model (AIM), which is a bottom-up optimization model. The model 'captures the techno-economic perspective at the national level with sectoral granularity'.(p.4) The model used in the study has been developed considering more than 450 technologies and is set up for five sectors viz. energy supply, buildings, industry, agriculture, and transport. Electricity demand is inter-looped in a way such that model itself estimates the end demand for sectors and accordingly chooses power technologies based on various factors such as costs, capacity limits, efficiency, etc. Years 2000 to 2015 have been used for calibrating the model, and the results are obtained at a timestep of one year upto 2050.

4. Scenarios/ Pathways

Authors have estimated the carbon emission budget for India between 40 to 140 giga-tons of CO_2 between 2011 and 2050, based on the literature survey. Whereas, the business-as-usual (BAU) emissions for India are estimated to be in the range of 165-300 gigatons of CO_2. Thus, to reduce the carbon emissions, authors have proposed four alternative scenarios in this particular report. Thus, five scenarios have been discussed in this report.

Business-as-Usual (BAU) scenario assumes the continuation of the existing policies upto 2050 and therefore acts as a reference scenario. **NDC scenario** assumes implementation of policies submitted in India's INDC to UNFCCC. There are three variants of **2^{o}c scenario** - **i)**

Early action ii) high-budget iii) low-budget. These scenarios assume different variants of policy choices to meet the carbon budget of 110-136 Gt-CO_2 for 2^{o}c and well below 2^{o}c target.

5. **Infrastructural changes within the Indian power system**

The study discusses the impacts of late and early actions on changes that would take in the Indian power system. If early actions are taken, demand from solar will increase till 2030, leading to the rapid deployment of solar PV in the mix. Late actions lead to faster adoption of CCS after 2030, and more investment is required as a consequence. All the alternative scenarios propose retrofitting of coal plants, adopting supercritical technology, and timely phasing out of older plants.

With solar PV technology, authors suggest that land acquisition and grid integration might be challenging issues. Also, rooftop solar penetration is likely to be more difficult due to reducing the high-end customer base. Hence, solar PV needs to be integrated with value-added services and initiatives such as micro-grids, storage, and EV charging infrastructure. Authors propose that future electricity sector shall consist of load-responsive smart grids, low-cost storage and high-efficiency thermal plants operating as peaker plants.

6. **Discussion/ recommendations of relevant policies**

The study is mainly an attempt to quantitatively assess the challenges for India's transition towards a low-carbon energy system and economy. The study presents the results of different scenarios and impacts of action on investments. The study does not explicitly mention policy interventions that need to be put in place to tackle the challenges. However, the points mentioned below briefly come up in the discussion section:

1. Special policy support for deployment of CCS technology and its R&D in India is required
2. Policy analysis and measures to be taken for handling labour transitions and job losses that occur due to shifting the power mix from coal to renewables.
3. Electrification of end uses such as EVs, and building infrastructure to support the electrification.