

Working Title: ENERGY SYSTEM TRANSFORMATION TO MEET NDC, 2 °C and WELL BELOW 2°C TARGETS FOR INDIA

Short Title: ENERGY SYSTEM TRANSFORMATION FOR INDIA

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SUPPLEMENTARY INFORMATION

Section 2: Scenario Architecture

2.2.1 Business as Usual (BAU) scenario

National policies implemented (NPi)¹ scenario has been considered the BAU scenario of this study. It assumes the continuation of current energy, sectoral and climate policies representing the business as usual (BAU) dynamics of the country. It takes into account the on-going mitigation and adaptation strategies encompassing the broad framework laid down by the National Environmental Policy (2006), and National Action Plan on Climate Change (2008). The scenario also adopts short and medium term policy interventions related to energy, technology and services in every major sector (NAPCC 2008; Vishwanathan et al. 2017).

2.2.2 Nationally determined contributions (NDC)

The INDC^{13,2} takes into account India's contributions to mitigate emissions in response to Conference of Parties (COP) decisions held at Warsaw (COP 19) and Lima (COP 20) for the period of 2021 to 2030 in every major sector. The scenario has an overall emission intensity to GDP reduction target by 33-35 per cent from 2005 level during 2005-2030 and requires 40% of electricity generation capacity to be based from non-fossil fuels by 2030 (INDC 2015; BUR 2015; Vishwanathan et al. 2017).

2.2.3 2 °C scenarios (2 °C_early action, 2 °C_late action)

The 2 °C deep decarbonization scenarios includes the policies and programs that will not only support sustainable development but also attempt to meet the long-term carbon budget constraints likely for India. In this study, we have analyzed four scenarios which are NPi2020_high (NPi2020H, 2 °C_early action_high), NPi2020_low (NPi2020L, 2 °C_early action_low), INDC2030_high (INDC2030H, 2 °C_late action_high), and INDC2030_low (INDC2030L, 2 °C_late action_low) as presented in McCollum et al. 2018. These are estimated to be in the range of 128-136 Gt - CO₂ during 2011-2050 (Shukla et al. 2015; Tavoni et al. 2014). In these scenarios, the budget constraint is not anticipated in inter-temporal optimization models until 2020 (NPi2020_high/low¹³) and 2030 (INDC2030_high/low¹³) respectively. After these years, the budget is fully anticipated via an explicit bound on cumulative emissions by ratcheting up BAU and NDC policy measures. NPi2020 scenarios also assumes to early investments that support technology transitions during 2020-30, while INDC2030 scenarios corresponds to investments made after 2030. NPi2020_high and INDC2030_high represent the same upper bound of 2 °C scenario carbon budget while NPi2020_low and INDC2030_low represent the same lower bound of 2 °C scenario carbon budget allocated to India by global models in the CDLINKS project. We have selected to present 2°C_early action (high and low) budget for discussion.

2.2.4 Well below 2 °C scenario (NPi2020_verylow¹³)

The well below 2 °C deep decarbonization scenario represents an alternate future that will be in the same direction but more aggressive than the 2 °C stabilization scenario for CO₂ mitigation, requiring below 115 Gt CO₂ for below 2 °C global target which are based on UNFCCC's Common but Differentiated Responsibilities and Respective Capabilities (CBDR–RC) paradigm for effort sharing (Kriegler et al. 2018; Dhar et al. 2017). It corresponds to early investments during the period of 2020-2030 to get a cumulative carbon budget of less than 115 Gt-CO₂.

¹ The scenario name submitted to CD-LINKS database

² INDC is now NDC scenario.

³ The scenario is named as NPi2020_verylow as the budget constraint is anticipated after 2020 and considerable mitigation takes places before 2030.

FIGURES

Section 3: Results

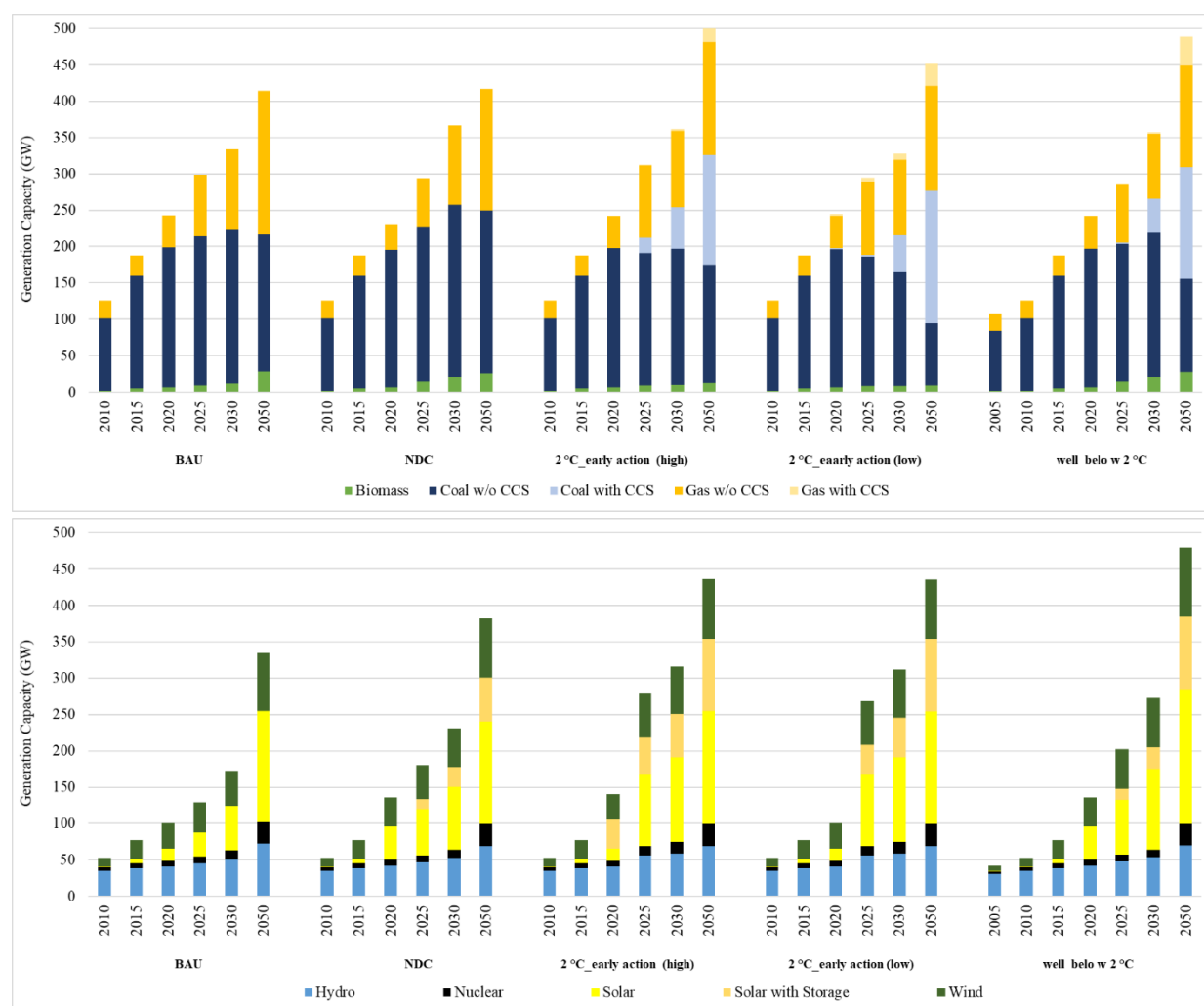
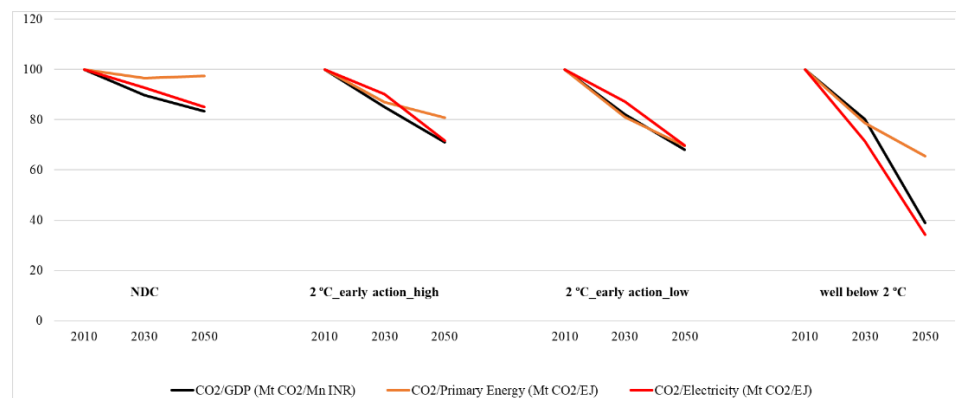


Fig. S1: Generation Capacity in Power Sector (fossil fuels and renewables)

Figures S1 (fossil fuels and renewables) gives a picture of the capacity mix by fuel source from 2015 to 2050. Coal remains a major source of energy, however there is increase in energy efficiency through retrofitting of EE coal technologies; at least super critical coal combustion technology for all new power plants, and phasing out of relatively inefficient plants older than 30 years under NDC scenario and even those older than 20 years in deep CO₂ mitigation scenarios, and introduction of CCS. CCS will become a critical technology to mitigate emissions as coal continues to remain the dominant fuel especially in deep decarbonization mitigation futures.



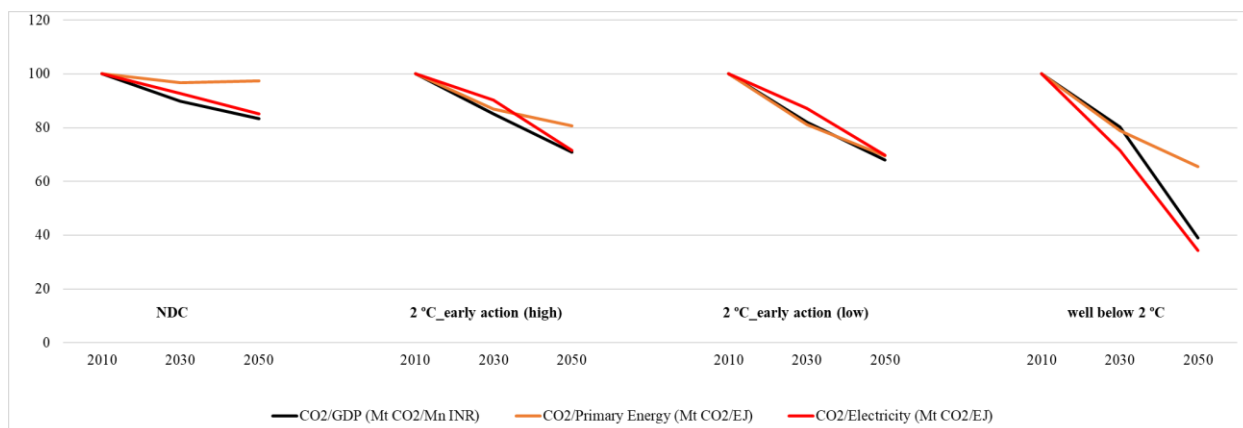


Fig. S2: Decoupling – Energy systems

Figure S2 illustrates decarbonization index through decrease in carbon intensity of GDP, primary energy demand, and electricity consumption compared to 2015 data.

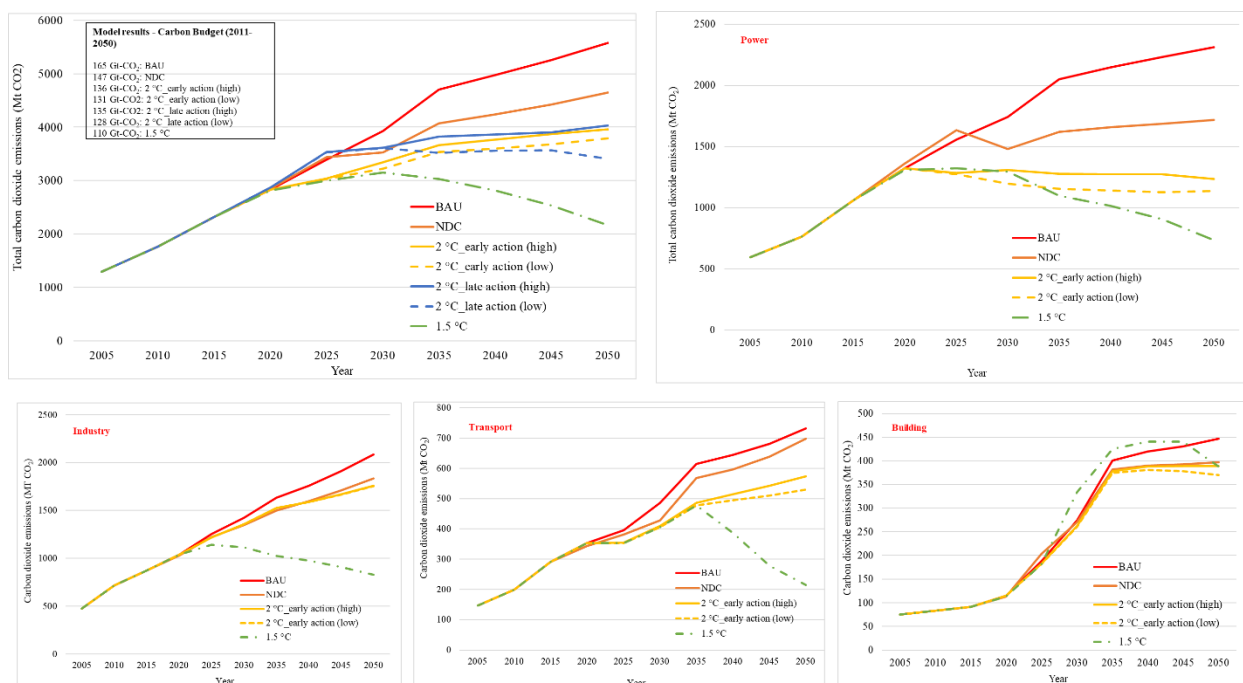


Fig. S3: Total carbon dioxide emissions at national (all scenarios) and major end-use sectors under selected scenarios for the paper (2005-2050)

Figure S3 presents the trend in total carbon dioxide emissions from energy supply (power sector) and demand (enduse sectors including industry, building, and transport) sectors. The carbon budgets during 2011-2050 have been estimated to be 165 Gt-CO₂ under BAU scenario, 147 Gt-CO₂ (NDC), around 128-136 Gt--CO₂ for 2 °C early and late actions depending on early and late investments during 2020-2030 and 110 Gt-CO₂ for well below 2 °C scenarios. The decrease in energy demand during 2011-2050 by implementing policies in NDC has been estimated to be 112 EJ, which corresponds to about 18 Gt- -CO₂ reductions. Energy efficiency enhancements followed by renewables across supply and demand sectors are the main contributors for this reduction. The key measures that contribute to decrease in carbon budgets over the scenarios include energy efficiency enhancements across energy supply and enduse sectors, increased renewable energy, demand reduction and lifestyle changes, and CCS in power and industry sectors. It can be inferred that energy efficiency and renewable play an essential role in the NDC scenario, while demand reduction and CCS play a critical role in low carbon scenarios. The decrease due efficiency is 10 Gt-CO₂ from BAU to NDC scenario, 1-2 Gt-CO₂ for INDC to 2 °C deep decarbonization scenarios, and 4 Gt-CO₂ for NDC to well below 2 °C transition. Shift to cleaner and renewable energy in power sector accounts for increased share in alternate futures, correspond to -

CO₂ reductions of 7 Gt-CO₂ from BAU to NDC, 3-5 Gt-CO₂ for INDC to 2 °C deep decarbonization scenarios, and 6 Gt-CO₂ for INDC to well below 2 °C transition. Introduction of CCS accounts for 4-8 Gt-CO₂ reductions from NDC to 2 °C deep decarbonization scenarios, and 23 Gt-CO₂ from NDC to well below 2 °C scenario.

Figure S4 shows the variants of 2°C scenarios for electricity generation by fuel.

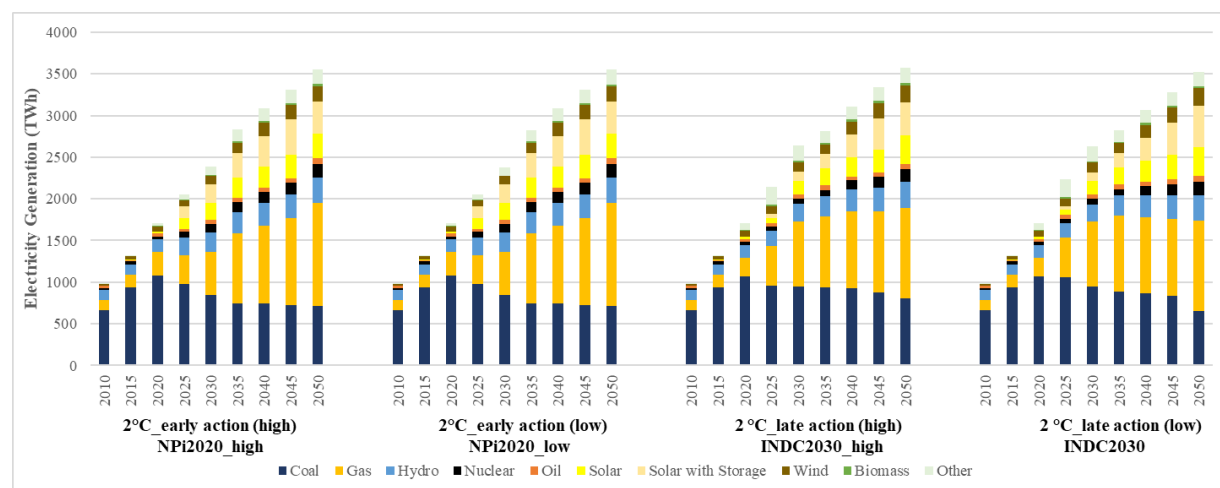


Fig. S4: Electricity generation by fuel in all 2°C scenarios

TABLES

Table S1: Submitted national scenarios list

		Long-term CO2 cumulative budget (2011-2050)			
		None	High	Low	Very Low
Short-term Policy dimension	No Policy (counterfactual)	(NoPol)			
	National Policies implemented (NPi)	(NPi) BAU 165 Bt-CO ₂	(NPi2020_high) 2 °C_early action (high) scenario 136 Bt-CO ₂	(NPi2020_low) 2 °C_early action (low) scenario 131 Bt-CO ₂	(NPi2020_verylow) well below 2 °C scenario 110 Bt-CO ₂
	National Policies implemented and planned (NPip)	(NPip)			
	Intended Nationally Determined Contributions (INDC)	(INDC) NDC 147 Bt-CO ₂	(INDC2030_high) 2 °C_ late action (high) scenario 135 Bt-CO ₂	(INDC2030_low) 2 °C_ late action (low) scenario 128 Bt-CO ₂	

Source: CD-LINKS database scenarios (in brackets).

Note: The scenarios highlighted in yellow are used in this study. We analyze the higher and lower bound of the four scenarios which are NPi2020_high (2 °C_early action) and INDC2030_low (2 °C_late action).

Table S2: Detailed explanation of policy database submitted to CD-LINKS

Policy status	SECTOR	POLICY/MEASURE	Target
BAU	Energy supply	National action plan on climate change (2008): Renewable target (electricity)	15% renewables (electricity) by 2020
		National action plan on climate change (2008): Solar Mission	20 GW solar by 2022
		12th five-year-plan: Renewable Capacity Target	Add 30,000 MW of renewable energy capacity during 2012-2017
		Accelerated depreciation tax benefit	Renewables - tax relief
		National Electricity Plan	Universalizing access to electricity and promoting renewable sources of energy
BAU	Industry	Renewable Portfolio Standard (PAT scheme)	It is expected to save 6.6 million toe (4.8% energy reduction in the industries covered, representing around 60% of primary energy consumption). The Perform, Achieve and trade (PAT) will help reduce emissions by 26 million tonnes of carbon dioxide equivalent (Co2e) by 2015. It is expected to save 6.6 million tonnes of oil equivalent (Toe) over its first cycle (2012-2015).
Intended Nationally Determined Contributions (INDC, now NDC)			
NDC	Economy-wide	INDC target (general)	Reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level.
NDC	Energy supply	Renewable target (conditional INDC)	40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
		Integrated Energy Policy	• The phase-out of capital subsidies by the end of the 10th Plan linked to creation of renewable grid power capacity • Requiring power regulators to seek alternative incentive structures that encourage utilities to integrate wind, small hydro, cogeneration and so on into their systems, and the linking of all such incentives to energy generated as opposed to capacity created • Requiring power regulators to mandate feed-in laws for renewable energy, where appropriate, as provided under the Electricity Act 2003. The policy also made a range of more specific recommendations in relation to particular renewable energy sources, including mini hydro, wind and wood gasification power

Policy status	SECTOR	POLICY/MEASURE	Target
		Clean energy cess rules	INDC: India imposed a cess on coal in 2010 @ INR 50 (USD 0.8) per tonne of coal. Recently it has been quadrupled to INR 200 (USD 3.2) per tonne of coal. The coal cess translates into a carbon tax equivalent, using the emission factor for coal, of around USD 2 per tonne.
		Fiscal instruments for renewable energy	Renewable Energy Certificates (REC); regulatory regime of Renewable Purchase Obligation (RPO); Feed-in Tariffs
		National smart grid mission (NSGM)	Efficient transmission and distribution network
		National Missions for Enhanced Energy Efficiency (NMEEE)	It seeks to upscale the efforts to unlock the market for energy efficiency and help achieve total avoided capacity addition of 19,598 MW and fuel savings of around 23 million tonnes per year at its full implementation stage. The programmes under this mission have resulted in an avoided generation capacity addition of about 10,000 MW between 2005 and 2012 with government targeting to save 10% of current energy consumption by the year 2018-19.
NDC	Industry	PAT continuation	While the PAT scheme does not explicitly target carbon and emission reductions, reduced energy intensity will have direct impact on India's national emissions. With a relatively carbon intensive fuel mix, we estimate that each metric tonne of oil equivalent (mtoe) is equivalent to 3.5-4.0 tonnes CO₂e. Up to 6.6million mtoe is expected to be saved by the scheme over the first 3-year cycle, with further savings expected in further cycles out to 2020. INDC: <i>The scheme is to be widened and deepened to include additional sectors like railways, electricity distribution and refineries in the next cycle and would cover more than half the commercial energy consumed in India. Limitation: These latest changes have not be added in the current scenarios.</i>
NDC	Transport	Rail transport	Policies to increase production of energy efficient 3 phase locomotives and switchover to 100% of these locos from 2016-17 onwards.
		National Policy on Biofuels	Executive. Indicative target of 20% blending of biofuels, by 2017, both for bio-diesel and bio-ethanol. Since October 2007, 5% blending of ethanol with petrol has been mandatory, increasing to 10% from October 2008.
		Electric cars subsidies until 2016	In 2013, the National Electric Mobility Mission Plan (NEMMP) 2020 was launched to promote adoption of hybrid and electric vehicles in the country. In the Union Budget 2015-16, INR 75

Policy status	SECTOR	POLICY/MEASURE	Target
			crore (USD 12.5 million) was earmarked for manufacturing and adoption of electric vehicles under the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) scheme
		Fuel efficiency (light-duty vehicles)	130 gCO₂/km in 2016 and 113 gCO₂/km in 2021 for new cars (<i>The standards will keep 50 million tons of CO₂ out of the atmosphere in 2030 alone. The fuel efficiency standard will be based on the average weight of the fleet that manufacturers sell in a given year - transportpolicy.net</i>). Cumulative reduction of 22.97 million tonnes of fuel consumption (approximately 66.4 million tCO₂) by 2025. The MoP notified average fuel consumption standards for passenger cars in January 2014 which are expected to come into effect from April 2017 and are anticipated to result in a cumulative reduction of 22.97 million tonnes of fuel consumption (approximately 66.4 million tCO₂) by 2025.
NDC	Agriculture	National Policy for Farmers	Sustainable development of Agriculture
NDC	Economy-wide	Zero effect, zero defect (ZED) & Make in India Campaign	To enhance energy& resource efficiency, pollution control, use of renewable energy, waste management etc.
Other polices	Energy supply	Nuclear power	Efforts are being made to achieve 63 GW installed capacity by the year 2032, if supply of fuel is ensured.
Non-climate policies			
NDC	Cities	Smart Cities Mission	100 smart cities are planned with the objective to develop new generation cities, which will provide core infrastructure and a decent quality of life to its citizens by building a clean and sustainable environment. Smart solutions like recycling and reuse of waste, use of renewables, protection of sensitive natural environment will be incorporated to make these cities climate resilient.
	Cities	National Heritage City Development and Augmentation Yojana (HRIDAY):	Launched to bring together urban planning, economic growth and heritage conservation in an inclusive manner
	Cities	Atal Mission for Rejuvenation and Urban Transformation (AMRUT)	For 500 cities with focus on ensuring basic infrastructure services such as water supply, sewerage, storm water drains, transport and development of green spaces and parks by adopting climate resilient and energy efficient policies and regulations.

Policy status	SECTOR	POLICY/MEASURE	Target
NDC (adaptation Policies)	Agriculture	National mission on sustainable agriculture (NMSA)	Enhancing food security and protection of resources such as land, water, biodiversity and genetics.
	Agriculture	National initiative on climate resilient agriculture (NICRA)	Its four main modules include Natural Resource Management, improving crop production, livestock and fisheries and institutional interventions.
	Agriculture	National Agroforestry Policy (NAP)	encouraging and expanding tree plantation in complementarity and integrated manner with crops and livestock

Source: NAPCC 2008, INDC 2015

Table S3: Sectoral policies, policy instruments and model drivers.

Sector	Policy	Policy Instruments/mechanism	Model driver
Electricity	Increase non-fossil capacity to 175 GW	Solar: 100 GW, Wind: 60 GW, Small hydro: 15 GW, Biomass: 25 GW by 2030	Electricity demand is inter-looped in the model. So, the model estimates sector-wise end use demands and selects the set of power technologies based on the costs and capacity constraints. In the current study, constraints were added in hydro and nuclear power based on literature.
	National Solar Mission (NSM)	Regulation: Solar Target - 100 GW by 2030	Improvement of device cost range
	National Mission on Enhanced Energy Efficiency (NMEEE)	Market Instrument: Perform, Achieve and Trade (PAT)	Improvement of device parameter range
	National Mission for clean coal technologies	Phase out of conventional coal power, addition of fuel-efficient generation options (PC, IGCC, SC and USCC)	Improvement of device parameter range
	National Smart Grid Mission		Reduction of transmission and distribution losses parameters
	Improve AT&C losses by 6-8%		Autonomous energy efficiency improvement (AEEI) in power, industry, building, transport and agriculture systems
Industry	National Mission on Enhanced Energy Efficiency (NMEEE)	Market Instrument: Perform, Achieve and Trade (PAT). PAT cycles I, II and III enhanced. Recycling of material, waste heat recovery	Improvement of device parameter ranges
Transport	National Urban Transport Policy, National Mission on Sustainable Habitat Mission, National Electric Mobility Mission Plan	Passenger: Ethanol blending- 5%, Increase in electric vehicles (EV), increase in public transport	Adjustment of modal demands, Adjustment of allowable service share by EV
		Freight: Service share increase in transport demand from 36 to 45% through	Adjustment of freight modal demand,

	(NEMMP) 2020 National biofuel policy	dedicated freight corridor (DFC) by 2050, improve vehicle efficiency	Adjustment of allowable service share by rail
Residential and Commercial Sectors	NSM, NMEEE, NSHM	Energy-efficient residential and commercial through Energy Conservation Building Code (ECBC); Standards and Labelling (S&L) Programme	Improvement of device parameter ranges
Agriculture	NSM, NMEEE	Shift to solar pumps, increased use of EE diesel pumps	Improvement of device parameter ranges

^a Source : Gupta et al. (2019), Vishwanathan et al. (2018a)

Table S4: Total investments between 2015-2030 in all sectors (Trillion USD)

	Power sector	Other sectors	Total
NDC	2.37	3.83	6.20
2 °C_early action (High)	4.04	3.84	7.88
2 °C_early action (Low)	3.69	3.82	7.51
2 °C_late action (High)	2.99	3.81	6.80
2 °C_late action (Low)	3.15	3.81	6.96
well below 2 °C	3.22	3.81	7.03