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Article

An Assessment of Near-to-Mid-Term Economic Impacts and Energy Transitions under "2 °C" and "1.5 °C" Scenarios for India

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Abstract: The goal of limiting global temperature rise to "well below" 2 °C has been reaffirmed in the Paris Agreement on climate change at the 21st Conference of the Parties (COP21). Almost all countries submitted their decarbonization targets in their Intended Nationally Determined Contributions (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) and India did as well. India's nationally determined contribution (NDC) aims to reduce greenhouse gas (GHG) emissions intensity of national GDP in 2030 by 33–35% compared to 2005. This paper analyzes how India's NDC commitments compare with emission trajectories consistent with well below 2 °C and 1.5 °C global temperature stabilization goals. A top-down computable general equilibrium model is used for the analysis. Our analysis shows that there are significant emission gaps between NDC and global climate stabilization targets in 2030. The energy system requires significant changes, mostly relying on renewable energy and carbon capture and storage (CCS) technology. The mitigation costs would increase if India delays its abatement efforts and is locked into NDC pathways till 2030. India's GHG emissions would peak 10 years earlier under 1.5 °C global temperature stabilization compared to the 2 °C goal. The results imply that India would need financial and technological support from developed countries to achieve emissions reductions aligned with the global long-term goal.

Keywords: NDC; computable general equilibrium model; 1.5 °C target; India

1. Introduction

The Paris Agreement was a milestone in the United Nations climate negotiations. It sets out a new policy architecture broadening the scope of participation and providing flexibility to individual countries to set their own emission targets. The goal of limiting the global average temperature rise has been ratcheted down to "well below 2 °C" in the agreement, along with an enhanced ambition of limiting the rise to 1.5 °C above the pre-industrial levels [1]. Prior to the Paris Climate Conference (COP21), most of the countries submitted their Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat. India, the world's third-largest emitter, also submitted its INDCs and ratified the Paris

Agreement on climate change which is later known as nationally determined contributions (NDCs). Most of the countries have specified their NDCs in terms of emission reduction targets without any conditionality to international support. Contrary to these countries, India has put forward its intended target conditional on various factors like climate finance, international cooperation, economic and technological development [2]. India has framed its reduction target in terms of reduction in emissions intensity of GDP (Gross Domestic Product) to arrest the emission growth without hampering economic development. India has made a voluntary commitment to reduce its emission intensity of GDP by 33–35% by 2030 compared to the 2005 level. Besides the decarbonization target, the Indian government has enumerated various mitigation and adaptation strategies in its NDC. The Indian government has come out with a roadmap of mitigation actions in its NDC that can attract private investments into low-carbon activities. Considering these new climate policy developments at the global and national level, it is vital to understand how well India's NDCs are aligned with the global stabilization targets in the short and midterm.

Several studies have investigated the long-term emission reduction trajectories for India aligned with the 2 °C goal [3–9]. Few studies have assessed the mitigation cost in terms of GDP loss or abatement cost for India to achieve an emission reduction target in line with a 2 °C target [3,6,7]. Some studies have assessed economic implications of NDC commitments at the global scale and few estimates have also been presented for India in this study [9–12]. Mathur and Shrivastava [13] have identified several challenges such as access to low-carbon technology at affordable costs and lack of financial resources that India would be facing in achieving its NDC targets, but the assessment has not been done to estimate the long-term implications of India's NDC target. However, long-term assessment of enhanced efforts that India shall need to achieve the emissions reduction in line with the global 1.5 °C target is lacking. Dhar et al. [14] focus on the structural transformation required in the transport sector under "below 2 °C" scenarios. Vishwanathan et al. [15] assess the technological transformation required to achieve emission reduction aligned with global stabilization targets using bottom-up technological detailed model. Spencer et al. [16] investigate the socio-economic implications of early coal phase-out in coal-dependent countries under the 1.5 °C scenario. This paper aims to bridge this gap. We address three research questions.: First, what is the gap between the emissions target communicated by India in its NDC and that is required to transit to the global low-carbon pathway pegged to below the global 2 °C target aspired to in the Paris Agreement? Second, what would be the implications on India's economy and energy system if India aligns its emissions to the emission reduction target consistent with global 1.5 °C stabilization ambition? Third, what would be the long-term implications post-2030 if India's emissions pathway is locked-in to a NDC pathway in the short run? We carry out scenarios assessment using a top-down computable general equilibrium model—AIM/CGE (Asia-Pacific Integrated Model/Computable General Equilibrium) model [17,18]—to address these questions. The time frame of the assessment spans from 2005 to 2050.

The structure of the remaining paper is as follows. First, we describe the model used and the scenarios analyzed in this study. Then we present the results of the scenario assessment. Finally, we discuss the findings and conclude with the scope for future research, and limitation of the study.

2. Materials and Methods

2.1. AIM/CGE Model

The AIM/CGE model has been widely used for assessing global climate change mitigation and adaptation policies [19–22]. It is a one-year-step recursive-dynamic general equilibrium model, extended from the "Standard CGE model" [23], in which industry is classified into 42 sectors. Details of the model structure and mathematical formulas are described in Fujimori, Masui and Kainuma [18]. The AIM/CGE global model covers all regions of the world. The model is also developed separately for India which was applied in previous studies [24,25]. In the AIM/CGE model, the production sectors are assumed to maximize profits under multi nested constant elasticity substitution (CES) functions and each input price. Energy transformation sectors input energy and value-added are fixed coefficients of output. They are treated in this manner to deal with energy conversion efficiency appropriately in the energy transformation sectors. Power generation values from several energy sources are combined with a logit function [26]. This functional form was used to ensure energy balance because the CES function does not guarantee an energy balance. Household expenditures on each commodity are described by a linear expenditure system function. The parameters adopted in the linear expenditure system function are recursively updated in accordance with income elasticity assumptions. The saving ratio is endogenously determined to balance saving and investment, and capital formation for each good is determined by a fixed coefficient. The Armington assumption is used for trade (CES and constant elasticity of transformation function is used), and the current account is assumed to be balanced. For appropriate assessment of bioenergy and land use competition, agricultural sectors are also highly disaggregated [27]. The national version of AIM/CGE is also developed for other countries such as Indonesia and Vietnam for assessing economic implication of nationally determined contributions communicated to UNFCCC [28,29].

2.2. Scenarios Description

Three mitigation scenarios are developed to compare the national NDC policy scenario with global targets. All the scenarios are summarized in Table 1.

Table 1. Scenario description.

Scenarios	Climate Target	Control Strategy
NDC	Emission reduction target communicated by national government	Emission constraint
NDC_2D	Same reduction target as nationally determined contributions (NDC) till 2030 and then 2-degree pathway	Cumulative emissions are same as calculated using convergence and contraction approach
2_deg	Target aligned with global 2 degree	Carbon tax
1.5_deg	Target aligned with 1.5 degree	Carbon tax

The population projection similar to the medium variant scenario of the UN World Population Prospects is used [30]. The GDP projection for India is in line with the NDC document till 2030 and thereafter GDP follows an S-curve. The average GDP growth rate between 2005 and 2030 is expected to be around 8.1%, which would decline to 7.7% over the next two decades. Population and GDP are treated as main parameters driving the total energy demand consumption in each end-use sector with moderate energy efficiency improvement. The same underlying socio-economic assumptions related to population and GDP are considered across all the scenarios. As India has already ratified the Paris Agreement and submitted its NDCs, we are taking NDC scenario as the starting point in this study instead of the business-as-usual scenario, which is commonly used by energy system modelling studies. In this study, NDC scenario is taken as a benchmark scenario to understand to what extent technological changes from the NDC scenario are required in the energy sector to achieve stringent mitigation targets and implications of enhancing mitigation efforts on the economy.

2.2.1. NDC Scenario

NDC scenario represents the current national climate policy scenario. It considers broad commitments announced by the government in its Copenhagen pledge and NDC document. NDC scenario represents the situation where the government would make necessary efforts to achieve India's Copenhagen pledge, i.e., 25% emission intensity reduction by 2020 and NDC commitment, i.e., 35% reduction by 2030 compared to its 2005 level and will follow the same emission reduction growth rate after 2030. The scenario narrative is driven by the political aspects of the Paris Agreement, a scenario whereby the government has committed to a reduced emission intensity by 2030, and introduced several policies to promote the renewable energy penetration in the energy system. The scenario focuses on the implementation of supply-side mitigation strategies stated in

India's NDC document such as augmentation of the renewable and nuclear-based electricity generation capacity in order to achieve the share of non-fossil-based power capacity to 40% by 2030 (details in Table 2). In addition to the implementation of decarbonization strategies in the electricity sector, it assumes that policies initiatives will be taken to increase the forest and tree cover to create a carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent (CO_2 eq) by 2030.

Table 2. Non-fossil-fuel-based capacity addition target.

Category (Power Capacity)	Capacity Targets
Wind	60 GW by 2022
Solar	100 GW by 2022
Biomass	10 GW by 2022
Small hydro	5 GW by 2022
Nuclear	63 GW by 2032

2.2.2. Mitigation Scenarios

In the mitigation scenarios, we are using either harmonized global carbon tax as an economic instrument or emission cap to achieve required emission reductions pegged with global stabilization targets, as well as sociocultural transformation that influences energy consumption. We are using AIM/CGE model to assess the least cost options to achieve these mitigation targets and compare the energy system transformation in mitigation scenarios with the national NDC scenario.

(a) 2_deg scenario: 2_deg scenario represents the global climate regime focusing on achieving the emission reduction target consistent with the global target of holding the global temperature rise below 2 °C (i.e., a likely (>66%) chance of limiting warming below 2 °C). Uniform global carbon price aligned with respective stabilization target estimated from the global AIM/CGE model is exogenously introduced in the AIM/CGE national (India) model to represent this regime [31].

(b) 1.5_deg scenario: 1.5_deg scenario represents the global climate regime focusing on achieving the emission reduction target consistent with limiting the temperature rise to 1.5 °C compared to pre-industrial level, i.e., (>50%) chance of limiting warming to 1.5°C. The global carbon tax consistent with the global emission trajectory is imposed in this scenario to increase the penetration of low-carbon energy sources in the energy system.

(c) NDC_2D: NDC_2D scenario represents the regime where India follows the national emission intensity reduction target till 2030 and then increases the emission reduction rate to keep the cumulative carbon budget the same as the emission budget that would be given to India using an equal per capita emission allocation approach (2020–2075). The scenario storyline assumes a technology-focused market-based approach that includes a technology-focused policy push till 2030 and thereafter a carbon market to limit the emissions. We have estimated the emissions for each country using the contraction and convergence (C&C) approach to each country. C&C approach is applied considering 2035 as convergence year, and all nations converge at equal per capita emissions in the convergence year starting from their current level [32]. Emission pathways aligned with the two climate stabilization targets for India are calculated using Equation (1). The global emission trajectories aligning with above-mentioned targets to calculate the equal per capita emissions for future years are taken from the study done by Rogelj et al. [33]. The cumulative GHG emission budget for India from 2020 to 2075 is estimated to be around 185 billion tonnes of CO_2 eq emissions.

$$S_y = \frac{S_0(y_c - y) + P_c\,(y - y_0)}{y_c - y_0} \tag{1}$$

where y_0 and y_c represent the starting year and convergence year, respectively, S_y is the share of the country's emission in the total global emissions in the year y and S_0 is the share of the country's emission in the total emission in the start year y_0.

3. Results

3.1. Emission Gap

It is evident from Figure 1 that the emissions gap exists between the NDC and global stabilization targets. The emission pathways in 2_deg and 1.5_deg scenarios indicate the optimal market response to the global carbon tax at the national level. The reduction rate in the NDC scenario is not fast enough to achieve the emission reduction level required in the international climate regime targeting to limit the warming below 2 °C compared to pre-industrial levels in the long term. The results show that even if the reduction target pledged in NDC is attained by 2030, the emission gap of 18 billion tons of CO_2 eq would exist in the next ten-year period (2020–2030) between NDC and India's emission pathway attained by imposing a global carbon tax aligned with a 2 °C stabilization target. The emission gap of 135 billion tons CO_2 eq would exist in the long term (2020–2050) if India continues to decarbonize at the current annual emission reduction rate after 2030. The results show that the faster emission reduction rate is required after 2030 in NDC_2D scenario if the India emissions pathway is locked in NDC pathway until the year 2030 to remain under the total carbon budget. This highlights the importance of considering longer-time planning horizon for national climate policies and aligning short- and medium-term emission reduction targets. The decoupling between GHG emission and GDP is more significant in 2_deg scenario in the year 2030 compared to what is committed by the government in NDC scenario. In the 2_deg scenario, the GHG intensity of GDP would reduce to 67% in 2030 and 93% in 2050 compared to the 2005 level. Emission intensity would further reduce to 81% in 2030 and 96% in 2050 in 1.5_deg scenario (see Figure S1). This indicates that the short-term emission intensity reduction goal set by India in its NDC needs to rise to align with Paris Agreement goals.

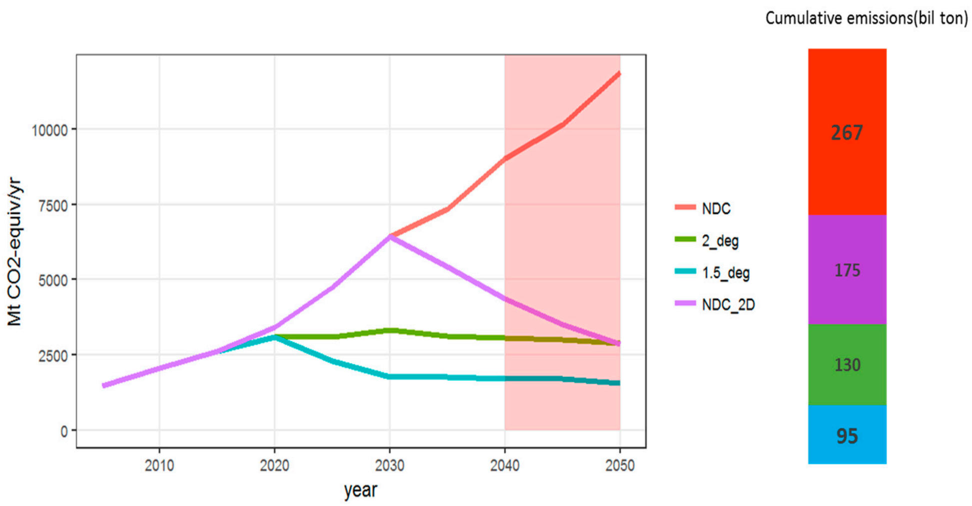


Figure 1. Annual greenhouse gas (GHG) emissions and cumulative GHG from 2005 to 2050 (billion tons CO_2 eq) across different scenarios.

In the case of the stringent 1.5 °C goal, the emission gap between NDC and 1.5_deg scenario is substantial (≅26 billion tons in 1.5_deg) in the short term. This indicates that India's short-term mitigation target as envisioned in India's NDC is inadequate to achieve the reduction required to transit to low-carbon pathways pegged with a stringent 1.5 °C stabilization goal. In the global carbon tax regime, the cumulative emissions from 2020 and 2050 in the 1.5_deg scenario are 36% lower compared to the 2_deg scenario. The modelling results show that peaking of emissions would occur ten years earlier in the 1.5_deg scenario compared to the 2_deg scenario if the global tax is imposed from the year 2020. India's GHG emission would peak in the year 2020 to achieve the emission reduction target in line with the 1.5 °C goal. This indicates that there is no room for developing countries to delay the mitigation actions in the 1.5_deg scenario due to a smaller national emission budget in 1.5_deg compared to the 2_deg scenario. In the 1.5_deg scenario, the rate of emission reduction is higher after 2020 due to the high global carbon price.

3.2. Carbon Price

The shadow carbon prices in 2_deg and 1.5_deg scenarios are obtained from the global AIM/CGE model by putting the exogenous emission constraint aligning with global climate stabilization targets. The carbon price represents the marginal mitigation cost in global stabilization scenarios which imply that emissions reductions occur in a cost-effective manner. The carbon price from the global AIM/CGE model is inputted as emission tax in the AIM/CGE India model exogenously assuming equal marginal mitigation cost across nations. The emission tax increases the price of fossil fuels that encourages energy savings and utilization of renewable energy. The carbon price increases from $74 per tCO_2 in 2030 to $187 per tCO_2 in 2050 in the 2_deg scenario [31]. Figure 2 indicates that economic implication of delaying the emission reduction efforts in the NDC_2D scenario is quite significant. The amount of abatement and speed of abatement need to be higher after 2030 due to delayed mitigation actions in the NDC_2D scenario. The shadow carbon price is obtained as a complementary variable when the exogenous emission constraint is implemented in the NDC_2D scenario. The carbon price is around $551 in 2050 in the NDC_2D scenario to increase the emission reduction rate after 2030 if India is pegged to NDC pathways till 2030. In the 1.5_deg scenario, the global carbon price increases from $328 per tCO_2 in 2030 to $860 per tCO_2 in 2050 that accelerates the emission reduction efforts. The modelling assessment results indicate that early investment in low-carbon activities would help to gradually reduce the emission reduction in a cost-effective manner comparing 2_deg and NDC_2D scenarios.

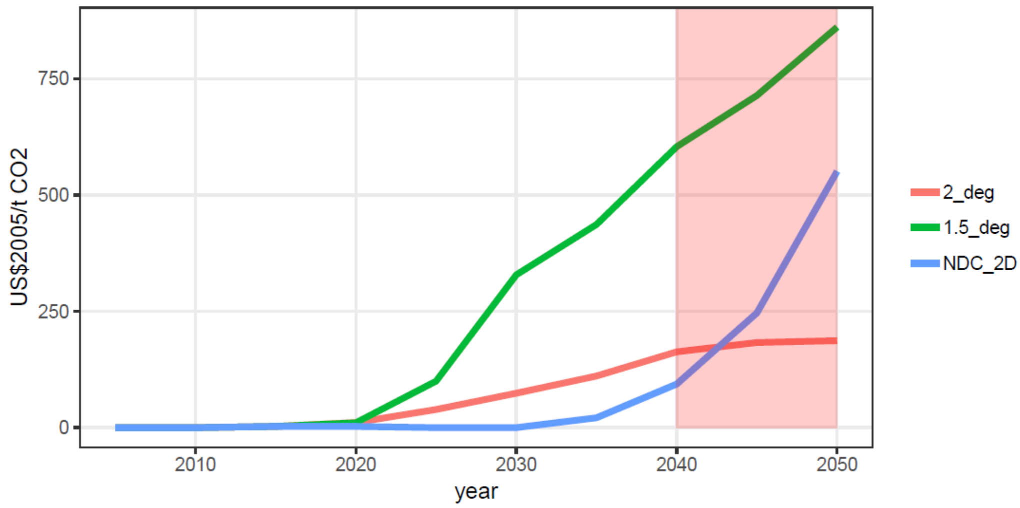


Figure 2. Carbon price in different mitigation scenarios.

3.3. Energy System Transformation in Below 2 °C Scenario

3.3.1. Primary Energy

Figure 3 represents primary energy supply mix for different scenarios for three milestone years (2010, 2030, and 2050). The total primary energy supply would increase from 26 exajoule (EJ) in 2010 to 77 EJ in 2030 to 157 EJ in the NDC scenario in 2050. A major shift in the primary energy mix is not witnessed in the NDC scenario, and the share of fossil fuels is high during the entire assessment period. The contribution of non-fossils to primary energy supply is around 12% in NDC in 2030 due to the government push for non-fossil-based electricity generation.

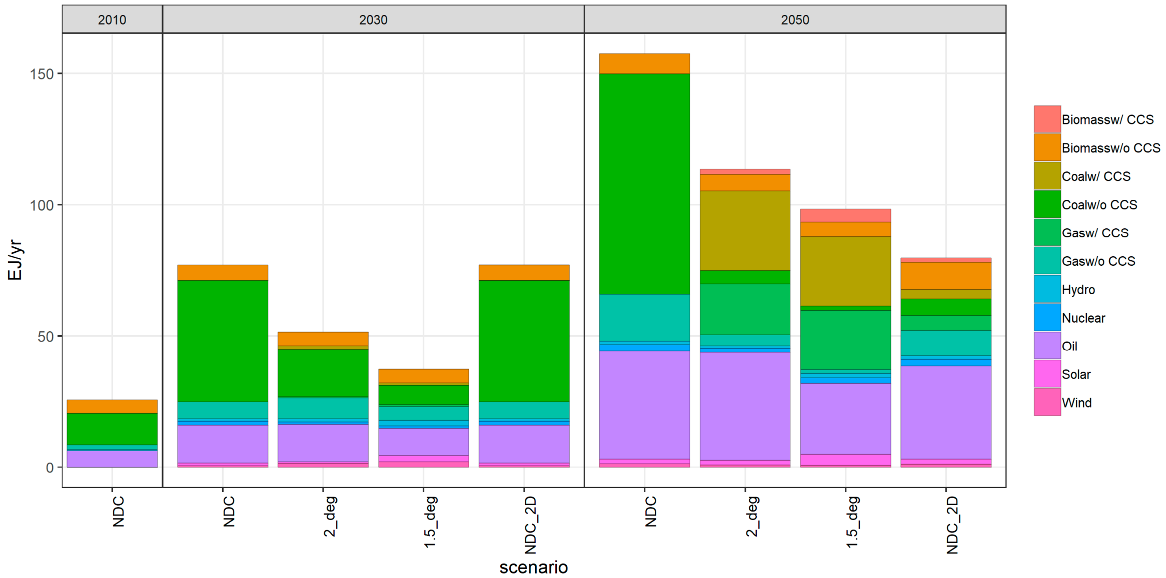


Figure 3. Primary energy mix in different scenarios.

The total primary energy reduces significantly in all mitigation scenarios compared to the NDC scenario in 2050 (see Table 3). The change in the primary energy compared to the NDC scenario is high in the 2_deg scenario in the short term. The reduction in the primary energy in the 2_deg scenario is 33% in 2030 owing to demand reduction and efficiency improvement. In the long term, the total primary energy would increase from 51 EJ in 2030 to 112 EJ in the 2_deg scenario in 2050. This corresponds to an energy reduction by 29% compared to the NDC scenario in the year 2050. In the NDC_2D, the primary energy would decline nearly by half in the year 2050 compared to the NDC scenario. The reduction in coal demand largely contributes to the decline in total primary energy in NDC_2D in the year 2050.

Table 3. Changes in the total primary energy demand in different scenarios compared to the NDC.

Scenario Name	2030	2040	2050
2_deg	−33%	−39%	−29%
1.5_deg	−52%	−53%	−38%
NDC_2D	0%	−36%	−49%

The total primary energy supply in the 1.5_deg scenario is lower compared to the 2_deg scenario in 2050. The total energy supply would decline by 13% in 1.5_deg compared to the 2_deg scenario in 2050. In the 1.5_deg scenario, renewables like solar PV and hydro gain significant share in the energy mix by 2050 compared to the 2_deg scenario. The share of renewable (excluding biomass) in primary energy mix increases to 9% of total primary energy in the 1.5_deg scenario compared to the 2_deg scenario in 2050. The share of biomass rises to 11% in 1.5_deg compared to 7% in the 2_deg scenario in 2050. High carbon prices in mitigation scenarios increase the energy prices that resulted in energy demand reduction in mitigation scenarios. The energy intensity of GDP reduces to 82% and 84% in the 2_deg and 1.5_deg scenarios, respectively, in 2050 due to efficiency improvement and reduction in energy demand (See Figure S1).

3.3.2. Carbon Sequestration

Carbon capture and storage(CCS) technologies are expected to be deployed on a large scale to achieve the deep cuts required in the 2 °C and 1.5 °C scenarios. In mitigation scenarios, the rollout of CCS technologies in the power sector is greater, followed by the industry sector. The estimated storage potential of CO_2 for India ranges from 45 gigatonnes (Gt) to 572 Gt [34,35]. Figure 4 represents the cumulative carbon sequestered during the period (2030–2050) in different scenarios. In the 1.5 °C scenario, the total cumulative CO_2 sequestered is lower than the 2 °C scenarios due to the lower share of fossil fuels, high penetration of renewable energy sources and energy savings in energy demand. Penetration of CCS technology in power, industry and biomass sector results in 23.1 Gt and 32.8 Gt of negative CO_2 emissions in the 1.5_deg and 2_deg scenarios, respectively. In the case of NDC_2D, the penetration of CCS technologies would be slow compared to other mitigation scenarios. The cumulative negative emissions in the NDC_2D scenario would be around 4 Gt through CCS technologies in different sectors.

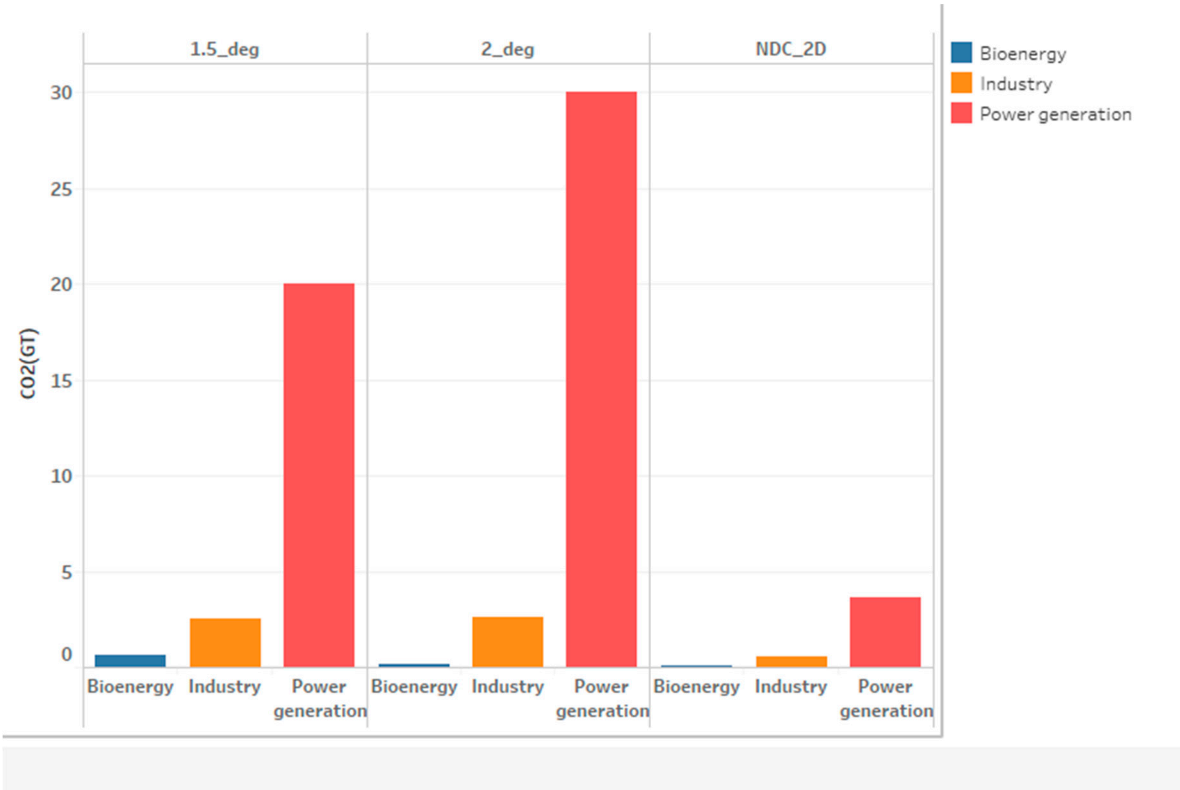


Figure 4. Cumulative Carbon Sequestered by CCS (Gt of CO_2).

3.3.3. Electricity Mix

Continuous efforts by the government to provide reliable power supply to each household and full electrification of railway tracks along with rising income would drive the substantial increase in electricity demand in future years. The total electricity generation increases from 3.8 EJ in 2010 to 46 EJ in 2050 in the NDC scenario to satisfy the growing electricity demand. In mitigation scenarios, the generation of electricity grows at a slower rate compared to the NDC scenario due to higher electricity prices (Figure S2). The total electricity generation would decline by 46% and 40% in 2_deg and 1.5_deg compared to the NDC scenario in 2050. The contribution of non-fossil in the 1.5_deg scenario drops from 69% in 2030 to 33% in 2050 due to the high penetration of CCS technology with fossil fuels.

The electricity generation reduces significantly by 62% in the NDC_2D scenario compared to the NDC scenario in 2050. It can be seen from Figure 5 that non-fossil fuels contribute nearly half of the electricity generation in 2050 in NDC_2D scenarios to achieve the required emission reductions, as CCS technology would penetrate at the slow pace in the India market compared to other mitigation scenarios where the carbon tax is imposed from 2020.

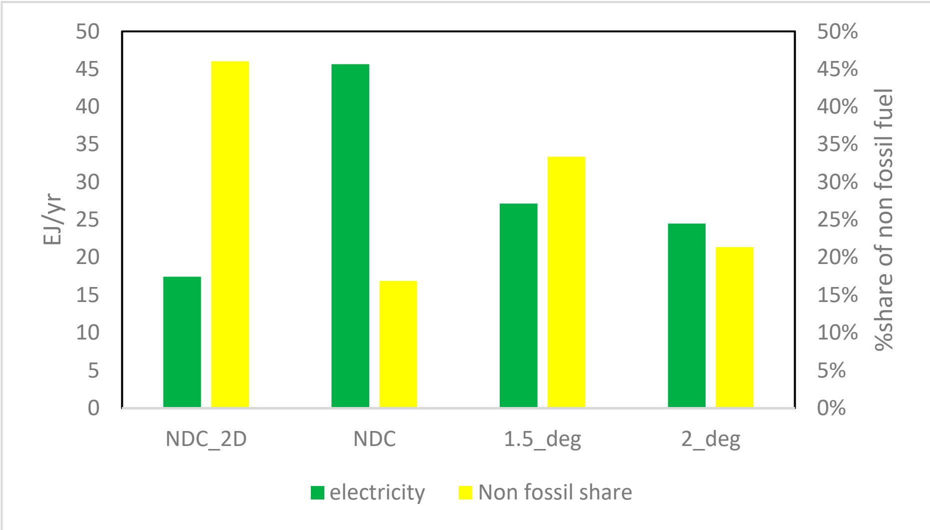


Figure 5. Total electricity generation and share of non-fossil fuel (%) in different scenarios in 2050.

The electricity generation capacity is expected to increase in all scenarios to meet the growing electricity demand. Government incentives such as feed-in tariffs, regulatory purchase obligations, and accelerated depreciation to achieve the ambitious target set in India's NDC would lead to a rapid increase in installed renewable-based power capacity in NDC scenario. The total electricity generation capacity in the NDC scenario increases from 210 GW in 2010 to 1002 GW and 2567 GW in 2030 and 2050, respectively (Figure 6). Renewable-based power capacity increases from 47 GW in 2010 to 500 GW in 2050 in the NDC scenario.

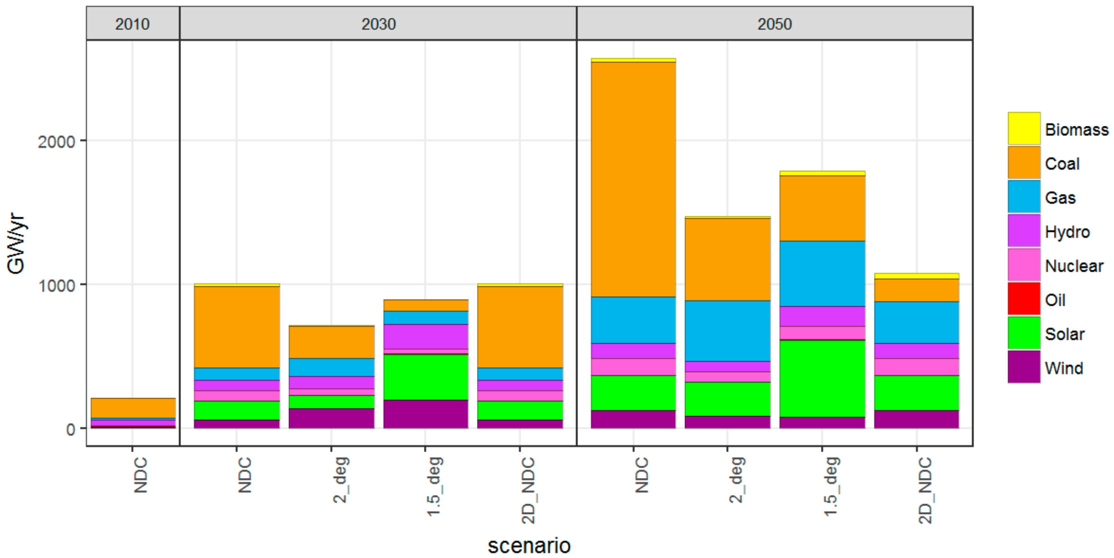


Figure 6. Electricity generation capacity in different scenarios.

The electricity generation capacity reaches 1400 GW and 1711 GW in the 2_deg and 1.5_deg scenarios, respectively, in 2050 (Figure 6). Even though the total installed capacity decreases in mitigation scenarios, the ratio of installed electricity capacity to electricity generation is higher in 2_deg and 1.5_deg scenarios compared to the NDC scenario in 2050 due to higher penetration of renewable energy. The total electricity generation capacity is higher in the 1.5_deg scenario than 2_deg due to the greater share of renewables in the electricity mix. The electricity generation capacity in 1.5_deg scenario gets doubled compared to 2_deg in 2050. Augmentation in installed solar capacity contributes primarily to an increase in the installed capacity in 1.5_deg in comparison to the 2_deg scenario. The solar installed capacity increases from 1 GW in 2007 to 500 GW, respectively, in 2050 in the 1.5_deg scenario. Other renewable sources like wind and hydro also contribute to the increase in the renewable share in the electricity mix in the 1.5_deg scenario.

3.3.4. Final Energy

The final energy demand increases from 4.6 times between the period 2010 and 2050 in the NDC scenario. The share of electricity in final energy increases from 16% in 2010 to 42% in 2050. In the 2_deg scenario, the final energy demand would decline by 25% in the year 2050 compared to the NDC scenario due to efficiency improvement and reduction in energy demand (Figure 7). The final energy demand would reduce further by 37% and 38% in the 1.5_deg scenario and NDC_2D respectively compared to the NDC scenario. Driven by economic growth, the energy demand in the industry would increase in the coming decades in India and industry would remain the largest consumer of energy. In the NDC scenario, the industrial energy demand increases fivefold between 2010 and 2050.

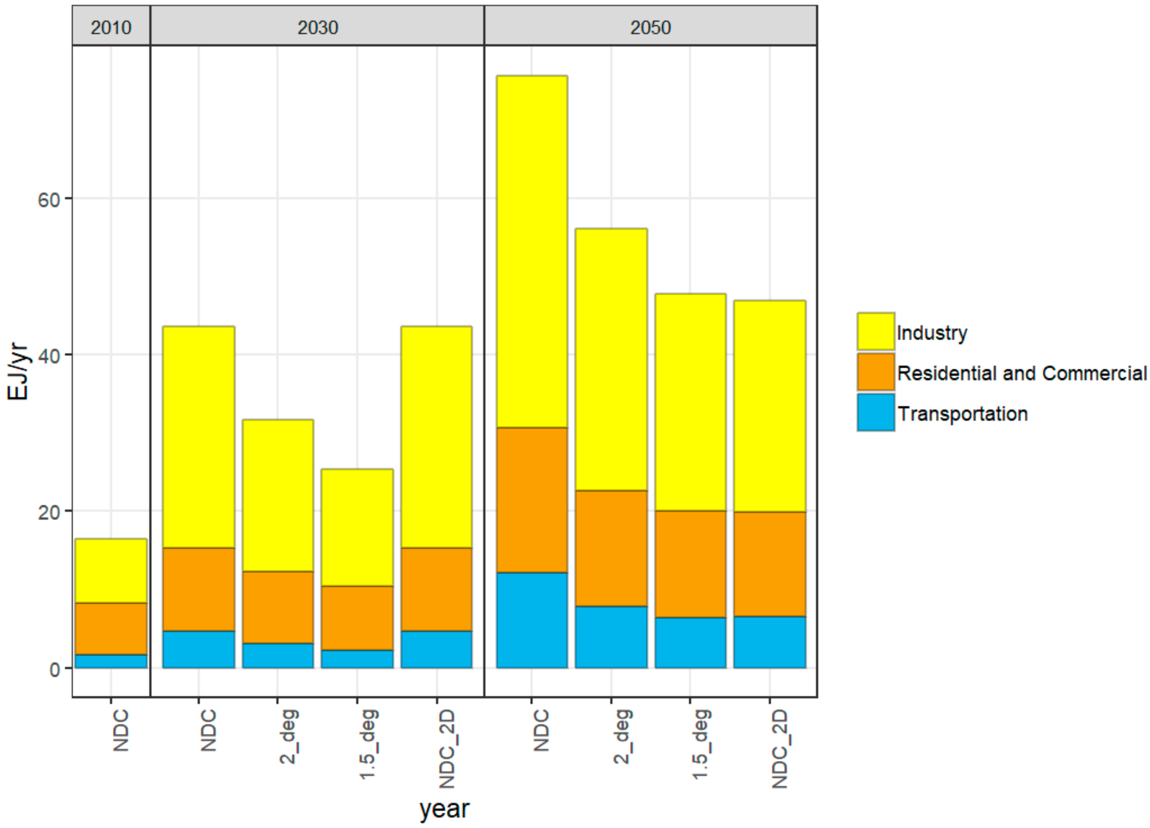


Figure 7. Final energy demand in different scenarios.

The share of cleaner fuels such as biofuels, electricity and hydrogen would increase in the transport sector in the mitigation scenarios (Figure 8). The strong government interventions such as a national electric mobility program and integrated bioenergy mission would help to transit towards cleaner fuels, i.e., electricity and biofuel in the NDC scenario in the long term. The transport energy demand increases from 1.7 EJ in 2010 to 12 EJ in 2050 in the NDC scenario. The final energy demand in the transportation sector reduces by 47% in the 1.5_deg scenario in 2050 compared to NDC scenario. In the transport sector, 18% and 24% energy demand would be met by electricity in the 2_deg and 1.5_deg scenarios. Decarbonisation of the electricity sector along with electrification of transport in 1.5 °C would help to reduce overall carbon emission and local air pollution (Figure S3).

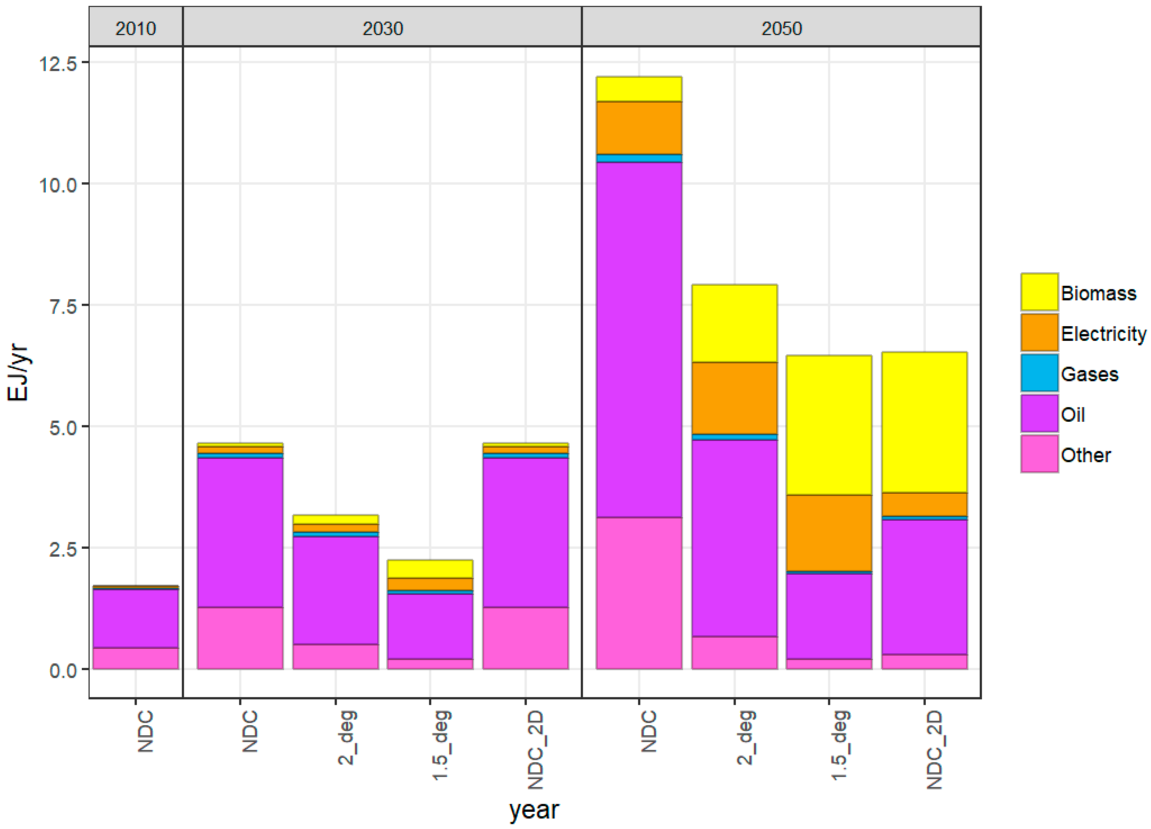


Figure 8. Transport mix in different scenario.

3.4. GDP Loss

The difference in GDP between mitigation scenarios and the NDC scenario where India follows national policy regime is estimated for calculating mitigation cost. The modelling assessment results show that 3.2% GDP loss occurs in the 2_deg scenario compared to the NDC scenario. Our analysis shows that if India gets locked-in to the NDC emission pathway, then the mitigation cost in terms of GDP loss rises to 5.3% in 2050. The estimated economic loss in terms of GDP loss is quite significant in the 1.5_deg scenario due to high emission reduction required in the next few decades (Table 4). The economic losses go up to 6% of GDP in the year 2050 in the 1.5_deg scenario, 50% higher than in the 2_deg scenario. This indicates that targeting for emission reduction to transit towards emission trajectory pegged with the stringent 1.5degree goal would jeopardize India's economic development.

Table 4. GDP loss in different scenarios.

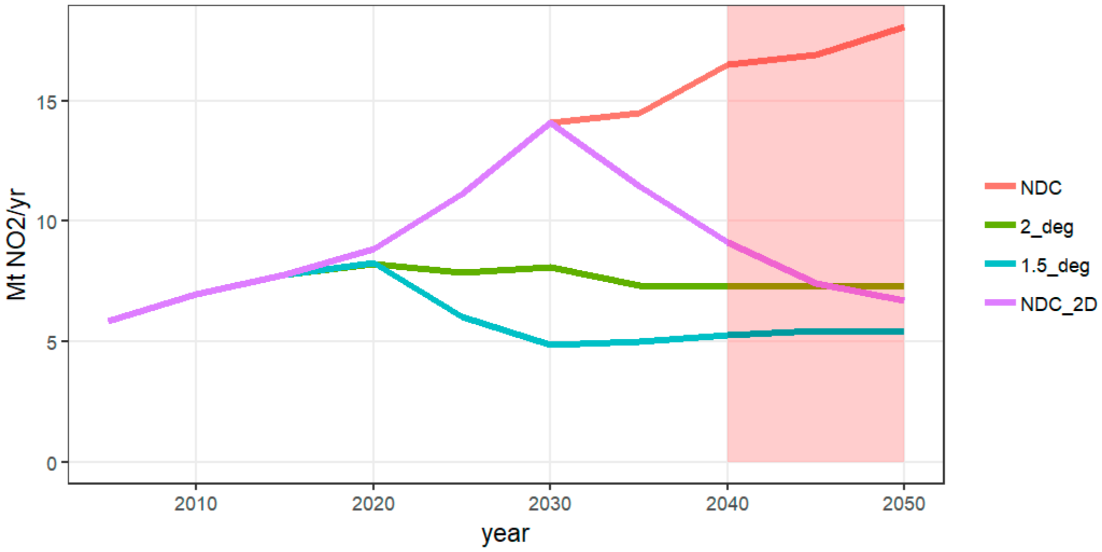
Scenario	2020	2035	2050
1.5_deg	0.7%	6.4%	5.8%
2_deg	0.7%	3%	3.2%
NDC_2D	-	0.6%	5.3%

3.5. Co-Benefits

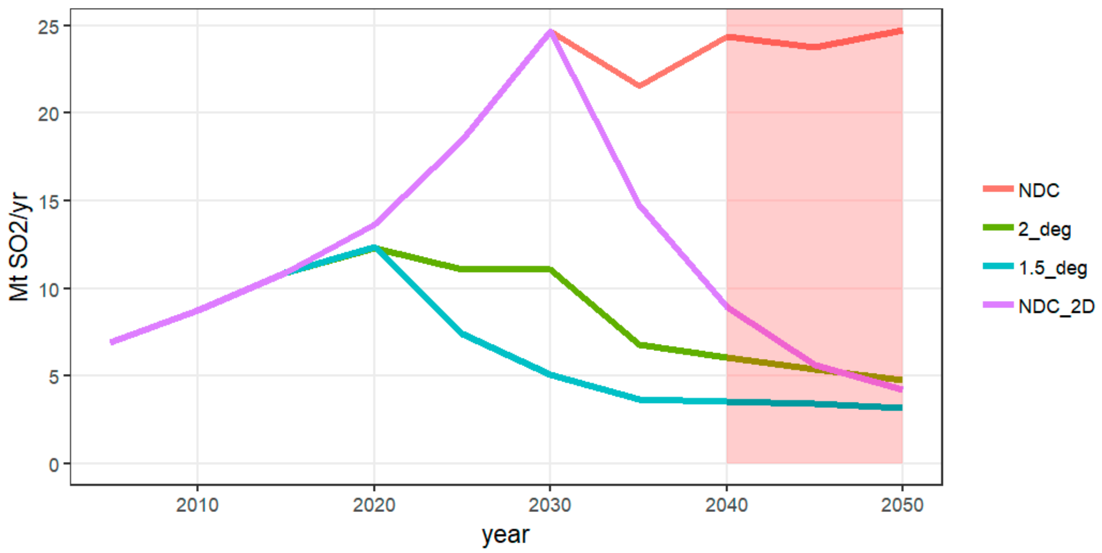
3.5.1. Air Pollutants Emissions

Several studies have shown that stringent climate policies could help to overcome national and local level challenges like air pollution and energy security [36–38]. Figure 9 represents the NO_x and SO_x emissions in different scenarios. It can be seen that the emission levels of air pollutants increase in the NDC scenario. NO_x emissions rise threefold from 7 million tonnes (Mt) NO_2/year in 2010 to

18 Mt NO_2/year in 2050. Significant reduction in the NO_x and SO_x emissions would happen in the mitigation scenarios where stringent climate policies are assumed. NO_x emissions decline 60% and 70% in the 2_deg and 1.5_deg scenarios, respectively, compared to the NDC scenario in the year 2050. Transport is the main contributor to NO_x emissions, followed by industry. The NO_x emissions from transportation reduce by half in the 1.5_deg compared to the NDC scenario in 2050 due to efficiency improvement and vehicle electrification. In the case of sulfur emissions, total emissions increase from 8.7 Mt SO_2/year to 24.7 Mt SO_2/year in the NDC scenario. The contribution of the supply sector such as coal-based power generation plants is significant in the NDC scenario. The sulfur emissions reduce significantly by 87% in the 1.5_deg scenario due to higher penetration of renewable energy in the power sector. This indicates that the penetration of renewables in the electricity sector along with electrification of end-use sectors driven by carbon tax also help to reduce the local air pollution.



(**a**)



(**b**)

Figure 9. (**a**) NO_x emissions (top) and (**b**) Sulfur emissions (bottom) in different scenarios.

3.5.2. Energy Security

At the national level, energy security is one of the major challenges of developing countries, and it encompasses various risks that could affect economic growth. The focus on energy security has increased in the last decade due to several political and socioeconomic reasons such as constrained supplies, high oil prices, terrorism threat, political instability in some exporting countries, geopolitical rivalries, and expected increase in the energy demand required to fuel the country's economic growth. There are several strategies such as diversification of energy sources, improving energy efficiency, competitive market suggested in the literature to reduce the risk to energy security [39]. In this study, we used the Shannon–Wiener index to compare different scenarios, which has been used in past research studies to capture fuel diversity or suppliers' diversity [40,41].

$$H = -\sum_{i} p_i ln p_i \tag{2}$$

where p_i is the share of the fuel, i in the fuel mix (the higher the value of H, more diversity exists in the fuel mix).

The calculated value of H is estimated to be 1.62 in the 1.5_deg scenario in the year 2050 due to the diversification of primary fuel mix and the high share of renewables, which indicates that high penetration of renewables in the fuel mix improves the energy security along with carbon mitigation. The H index value in all mitigation scenarios is higher compared to the NDC scenario (1.27) in 2050 as coal and oil are dominating the primary fuel mix in NDC scenario. The index value is higher in the NDC_2D scenario (1.55) compared to the 2_deg scenario (1.45) as the share of fossil fuels is high in the primary energy mix due to the penetration of CCS technology in the 2_deg scenario in 2050.

4. Discussion

The results of scenario assessment show that India's goal of 35% emission intensity reduction between years 2005 to 2030 in NDC would be inferior compared to an optimal response from India in a global 'well-below 2 °C' climate stabilizations regime (see Figure 1). This result is in agreement with various studies [10,11,15] where India's NDC pathway is compared with emission pathways aligned to global 2 °C and 1.5 °C stabilization targets. The Paris Agreement is a dynamic instrument. The emissions 'gap' can be responded to by revisiting and enhancing emissions reduction targets in the second round of climate pledges in 2020. The paper shows that, in India's case, the closing of emissions gap between the global ambition for deep decarbonization and the national emissions pathway is feasible. The optimal portfolio of decarbonization national options however would need alignment with global policy regime that supports innovations, transfer of technologies and investments.

The NDCs communicated by India in 2015 demonstrated the recognition and desire of the nation to lower GHG emissions. In India's case, the elements of low-carbon transformation are on the ground such as competitive feed-in-tariff [42] for clean and renewable electricity sources, participation in the International Solar Alliance [43], renewable target obligation [44], roadmap for transport electrification [45], applying carbon price on fossil fuels [2], and support for investments in smart grid, green infrastructures, waste recycling, etc. However, these policies need to be enhanced to fill the emissions gap vis-à-vis India's optimal emissions mitigation response to stabilize climate at 'well-below 2 °C' global ambition.

The Paris Agreement along with the adoption of Sustainable Development Goals (SDGs) provides a platform for higher ambition for emissions mitigation together with the new direction of socio-economic development. In this study, we focused on the implications of achieving GHG emission reductions aligned with global climate goals which is one of the UN Sustainable Development Goals (Goal 13). The quantification of the interactions between other SDGs and SDG13 (climate action) would reveal multiple co-benefits at a national level [46] and how it can assist to mitigate emission from the developing countries at a lower economic cost. The architecture of 'Sustainable Development

Goals' [47], which is co-evolving with the Paris Agreement, provides an additional window of opportunity to gain co-benefits in developing countries [37,48–50]. Researchers have shown that the "social cost of carbon" is much lower if the carbon reduction takes place through the sustainability measures since institutional weaknesses inhibit competitive behavior in a developing economy [51]. To reduce the mitigation cost to developing countries, we also need to mainstream climate change into ongoing development policies.

India's stage of development and high growth momentum offers fortuitous opportunities to radically alter the emissions pathway through investments in low-carbon infrastructures, shaping low emissions urban forms, avoidance of unsustainable and high-carbon-emitting lifestyles and behaviors and gaining co-benefits from lowered air pollution. The timing of the mitigation actions plays a crucial role to achieve the ambitious goal of limiting the temperature rise of 'well below 2 °C'. We find that the economic loss till 2050 if India follows the NDC pathway till 2030 and then transits to optimal 2 °C pathway would be similar to the economic loss incurred to follow the 1.5_deg scenario (see Table 4). Evidently, the cost of delaying mitigation is very high and hence there is a need to ratchet upwards the ambition of the Paris Agreement in the near term. Our analysis shows that to align India's emissions pathways with the global ''2 °C" and "1.5 °C" scenarios will impose substantial GDP loss respectively of 3% and 5.8% in 2050 (see Table 4). This would be a significant barrier to ratcheting climate change actions in India. Even to achieve the NDC target in 2030, it has been estimated that India needs investments of around 2.5 trillion USD in the next 15 years [2]. The international cooperation towards a low-carbon world along the ideals of the Paris Agreement would require bridging the gap between ambition and reality by creating an efficient carbon market [52] as well as a just system for sharing of the mitigation burden. The historical contribution of developing countries to the climate change problem is small compared to developed countries. This is especially true for India in terms of per capita emissions.

It would be infeasible to achieve a "below 2 degree" target without mitigation efforts in India. Given the sizable economic losses to deep decarbonize the Indian economy, it would be fair to recognize and support India's legitimate development needs. Our results showed that measures such as increased share of renewables and early penetration of advanced technologies like carbon capture and storage would make it possible to achieve early emission reductions goals aligned with the global climate target (Figure 3). Enhanced financial flows, low-carbon technology transfer and joint scientific and industrial activities in developing countries are vital to engage developing countries in mitigation activities at the scale our study envisages in India.

To align with the ambitious 1.5 °C target, other than economic loss challenge, the assessment results show that significant structural changes are required to achieve emission reduction. On the supply side, renewable energy technologies in the short run together with CCS in the long run can play an important role in substantial decoupling of GHG emission from economic growth. Whereas supply-side mitigation interventions are feasible for short-term mitigation, they are insufficient for sustaining drive towards deep carbonization such as is needed in the 1.5 °C scenarios. To make 1.5 °C real, the sustained deep carbonization would require transformative changes in technologies and behaviors that promote low-carbon lifestyles. Our assessment shows that, coincidently, India is at a development stage when simultaneous gains from deep decarbonization and sustainable development are on offer side-by-side with the conventional development options.

5. Conclusions

The study assesses the implications of mitigation targets agreed in the global Paris Agreement on India's economy and energy system using a computable general equilibrium model. The main conclusions are as follows. First, the emission gap exists between the emission pathway aligned with the NDC target and global "well below 2 °C" target. Second, the penetration of low-carbon technologies like renewable energy and carbon capture and storage and energy savings would drive the transition required to achieve emission reduction goals aligned with global climate stabilization targets. Third, the abatement cost would increase significantly in 2050 if India is pegged with NDC emission pathway till 2030.

In this study, carbon tax revenues are redistributed directly to households through lump-sum transfers to provide compensation to vulnerable groups, but there are several recycling strategies proposed in the literature like reduction in distortionary taxes/labor taxes or financing the large-scale deployment of low-carbon technologies. It would be interesting to assess the implications of different recycling strategies on India's economy. In this study, damage cost avoided due to low-carbon transition is not taken into consideration. Further research would be worthwhile to estimate economic impacts of low-carbon transition considering co-benefits and damage cost avoided by emission reductions.

Supplementary Materials: The following are available online at http://www.mdpi.com/1996-1073/11/9/2213/s1. Figure S1: Key indicators in different scenarios, Figure S2: Electricity prices in difference scenarios, Figure S3: CO_2 emissions from power sector in different scenarios.

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