DISTRIBUTIONAL EFFECTS OF CLIMATE MITIGATION IN INDIA UNDER THE NET-ZERO PATHWAY

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Abstract

We analyze the distributional impacts of climate mitigation policies consistent with India's 2030 Nationally Determined Contribution and 2070 net-zero target, using a dynamic global computable general equilibrium model with heterogeneous households. Several policy levers are considered in this study, including carbon pricing, enhanced coal consumption tax (or coal cess), and fossil subsidies phaseout. These are further combined with five alternative revenue recycling options. Our results suggest the potential welfare costs of such mitigation policies are rather moderate and do not exceed 0.5% over 2023-2050 period, not accounting for health and environmental co-benefits and damages avoided by successfully limiting global temperature rise to well below 2°C. However, health co-benefits from lower air pollution can potentially outweigh the mitigation costs. Combining carbon pricing and fossil subsidy removal is more efficient than carbon pricing alone, generating progressive medium-term welfare gains due to reduced market distortions. Raising coal cess rates is the least efficient policy. Inequality and distributional impacts vary significantly based on the chosen revenue recycling approach. Equal transfer of tax revenue across households proves to be the most efficient and equitable, followed by labor tax subsidies, leading to a Gini index and S20/S80 ratio reduction of 0.01%-1.7% and 0.1%-7%, respectively. Recycling revenues to stimulate green energy investments yields the least favorable distributional impacts and worsens inequality. Trade-offs exist between reducing inequality and fostering investment-driven economic growth when choosing revenue recycling options.

Keywords: distributional impacts, net-zero pathway, climate mitigation, co-benefits, computable general equilibrium modeling

JEL Classifications: Q5, Q4, C68,

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1.1 Introduction

Climate change is a global challenge with far-reaching impacts on the environment, human well-being, and the economy (IPCC, 2022). Notably, the adverse economic implications of global warming due to greenhouse gas (GHG) accumulation have the potential to disproportionately affect tropical and subtropical regions like India, thereby intensifying global inequality (Diffenbaugh & Burke, 2019; Taconet et al., 2020). India is the third-largest global emitter of GHGs, accounting for 7% of emissions, and its role in combating climate change is crucial (UNEP, 2021). However, it is worth noting that India's per capita emissions are only a third of the world average (GoI, 2022). Moreover, despite being the world's most populous country with growing energy needs, India grapples with widespread energy poverty (UNEP, 2021). As such, India's climate targets should be set in a way that ensures continued economic and social development while making a fair contribution to global emission reductions.

The initial 2015 unconditional Nationally Determined Contribution (NDC) from India under the Paris Agreement was regarded as reasonably ambitious, aligning with the goal to restrict global warming under 2°C (CAT, 2019).[4] Dietz et al. (2021) suggest that India's economy would suffer a 3.6% loss in GDP relative to a baseline in 2070 from climate change—mainly from the impacts of rising temperatures but also from sea-level rise.[5] Moreover, within any individual nation, economically disadvantaged households are more susceptible to the repercussions of climate change (Skoufias et al., 2011; Hallegatte & Rozenberg, 2017). In response to these escalating climate threats, India stepped up its NDC commitment during the COP26 Glasgow summit, setting a more ambitious short-term target of a 45% reduction in emission intensity of GDP relative to 2005 levels by 2030 and a long-term target of achieving net-zero (NZ) emissions by 2070 (GoI, 2022).[6] Nevertheless, India faces a threefold challenge: reducing GHG emissions, fostering economic growth, and boosting socioeconomic development. Consequently, India's optimal mix

[4] The 2015 NDCs include reducing India's emission intensity of GDP by 33-35% and achieving a 40% non-fossil fuel share of its power generation capacity by 2030, both relative to 2005. Additionally, India plans to create a carbon sink via forest cover that can absorb 2-3 billion tons of CO2 equivalent by 2030. India also pledged to boost investments in sectors vulnerable to climate change by focusing on adaptive strategies (GoI, 2022).

[5] Moreover, variability in Indian monsoon poses a global threat and can increase the social cost of carbon by 1.3 % (Dietz et al. 2021).

[6] In the NDC update India has also set an ambitious goal to expand its non-fossil energy capacity to 500 GW by 2030, which would also mean that 50% of the country's cumulative electric power installed capacity will come from clean energy sources. This goal relies heavily on technology transfers and low-cost international financing, including contributions from the Green Climate Fund (GCF). As of 2022, India has made considerable progress towards this target, having already installed 172 GW capacity from non-fossil fuel-based energy resources.

to attain its mitigation goals is a subject of significant debate (Dubash, 2019; GoI, 2022; TERI, 2023).

Climate mitigation through economy-wide carbon pricing is theoretically considered the most cost-effective approach to reducing GHG emissions (Coase, 1960; Nordhaus, 1992; Stavins, 2008).[7] However, India currently lacks an explicit market-based carbon pricing mechanism due to political economy challenges, public apprehensions about the regressive impacts of such policies, competitiveness concerns for trade-exposed sectors, and administrative barriers (Jenkins, 2019; Chandra, 2021). While earlier studies suggest that carbon pricing may adversely affect India's economic growth (Fisher-Vanden et al., 1997; Pradhan et al., 2017; Singh, 2017), there is a limited understanding of the trade-offs across alternative mitigation instruments. Moreover, carbon pricing faces other challenges, particularly regarding its distributional impacts on households, which is often regressive (Ohlendorf et al., 2018). It is important to note that the effects of climate-mitigation policies, including explicit and implicit carbon pricing, alter the relative costs of goods and services, impacting households, particularly the low-income groups who often face the highest vulnerability (Grainger & Kolstad, 2010; Cronin et al., 2019; Goulder et al., 2019). For example, carbon pricing may elevate consumer costs for energy commodities like electricity and oil products. This could result in regressive effects due to the larger proportion of these products in lower-income households' budgets (Böhringer et al., 2019; Böhringer et al., 2022). The inequality and distributional consequences of climate policies in India have not been properly explored yet. Addressing these gaps is crucial for ensuring equitable and fair distributional impacts of climate mitigation measures in a diverse country like India (Steckel, 2021). This gap extends to the identification of optimal revenue recycling strategies that can effectively buffer low-income households from the adverse impacts of climate action. Research shows that proper compensatory measures can be implemented to mitigate the adverse distributional consequences of climate mitigation (Haug et al., 2018; Chepeliev et al., 2021). An inclusive analysis of climate mitigation strategies should cover not only the impacts of transition on sectoral indicators and macroeconomic aggregates but also address the question of how the costs and benefits of climate action are

[7] This theory is based on the principle that if the cost of reducing GHG emissions is equal to the benefits of mitigating the environmental impacts, the resulting level of emissions will be optimal. Under certain assumptions, a carbon tax and a cap-and-trade scheme are expected to lead to similar outcomes (Weitzman, 1974; Aldy & Stavins, 2012; Goulder & Schein, 2013).

distributed throughout the economy and society. Such comprehensive assessment can provide valuable insights for decision-makers in the context of designing equitable and inclusive climate mitigation policies.

Our study addresses these research gaps by examining the welfare, inequality, and distributional consequences of three policy simulation experiments and five alternative revenue recycling strategies, consistent with India's latest NDCs for 2030 and the NZ target for 2070, hereafter referred to as the "NDC-NZ" pathway.[8] Specifically, we investigate the impacts of (1) uniform carbon pricing; (2) enhancing the existing Clean Energy Cess (CEC or coal cess), a domestic carbon pricing policy that internalizes the negative externalities of coal consumption, in combination with carbon pricing; and (3) phasing out existing fossil subsidies in combination with carbon pricing. The revenue recycling approaches include both direct lumpsum transfers and indirect strategies such as factor and green energy subsidies. Additionally, we emphasize that macroeconomic costs from climate mitigation should not be the sole consideration for policymakers as it excludes the potential health and environmental co-benefits from climate mitigation (Köberle et al., 2021). Thus, we also evaluate if health co-benefits from reduced mortality due to lower air pollution outweigh the cost of climate mitigation.

Our study offers valuable insights to researchers and policymakers on the potential of mitigation policy mixes to combat emissions consistent with the NDC-NZ pathway, promote sustainable growth, and alleviate income inequality in India. To achieve our objective, first, we develop a database with heterogenous Indian households by reconciling the underlying social accounting matrix (SAM) for the year 2014 with household survey data. Second, we modify a recursively dynamic global multi-region Computable General Equilibrium (CGE) model with a disaggregated energy sector to incorporate multiple households. Third, we develop a no-mitigation baseline scenario and the NDC-NZ mitigation scenario that considers the latest short-term unconditional NDC targets for India and the rest of the world for 2030 and long-term NZ mitigation targets in India, with a continuation of mitigation policies for the rest of the world. Finally, we conduct different policy simulation experiments for India.

In a preview of our results, we find that India's goal of reaching NZ emissions by 2070 will entail a small economic cost, excluding the associated health and environmental co-benefits.

[8] In practice, we run the dynamic model until 2050, but the linearly declining emission trajectory starting 2031 assumes that India will attain NZ emissions by 2070.

However, health co-benefits only from lower pollution have the potential to offset the mitigation costs. Combining carbon pricing with fossil subsidy removal emerges as more efficient than increasing coal cess rates and provides short-term welfare gains. The inequality and distributional impacts of these climate policies differ significantly based on the revenue-recycling strategies employed. While direct lumpsum per-capita revenue transfers emerge as the most equitable option, they may cause the most substantial decline in GDP by decreasing savings and investments. Reducing labor taxes as a revenue recycling strategy presents moderate adverse effects on GDP and favorable effects on income inequality and distribution. In contrast, revenues allocated towards promoting green energy investments could exacerbate income inequality and distribution, despite having minimal impacts on GDP. Consequently, our findings reveal a trade-off between reducing inequality and encouraging investment-driven growth.

The rest of the paper is structured as follows: Section 2.2 overviews the policy background and our contributions. Section 2.3 details the data and methodology used. Section 2.4 presents the scenario framework. Results from the simulation experiments and co-benefit analysis are discussed in Section 2.5. Finally, Section 2.6 concludes the paper and highlights the policy implications.

1.2 Policy Background, antecedents and contributions

Climate inaction could cost India a staggering 35-47 trillion USD over the next 50 years, with the worst impacts felt in the health and agricultural sectors (CEEW, 2015; Deloitte India, 2021; Dietz et al., 2021). Climate threats, such as the increasing frequency of floods and heatwaves, and depleting groundwater, pose significant risks to India’s well-being and economic growth, and can exacerbate income inequality by disproportionality affecting the poorest households (Skoufias et al., 2011; Hallegatte & Rozenberg, 2017; Diffenbaugh & Burke, 2019). Flood damages alone have cost India exceeding 0.5% of its GDP in recent years (Krishnan et al., 2020; IMF, 2020; World Bank, 2021). As such, the Indian government has enhanced its initial NDCs under the Paris Agreement to attain NZ emissions by 2070. India’s latest NDC aims to (1) reduce emission intensity of GDP by 45% by 2030 compared to 2005 levels, (2) ensure 50% of total installed electric power capacity comes from non-fossil fuel energy sources, and (3) promote demand side nudges for a healthy, low-consumption, and sustainable lifestyle among its citizens

(GoI, 2022).[9] India's emission intensity reduction for 2030 is tied to economic growth and may not be as aggressive since global energy efficiency use is improving at a modest rate of 1.3-2% per year (IEA, 2022). However, this is an ambitious target given India's low emissions per capita and low historical contribution to emissions compared with other major economies (IPCC, 2022).

The Energy Conversation (Amendment) Bill 2022 enables the creation of the first EU-style domestic market for carbon trading in India, focusing on large consumers, which can help minimize the country's energy consumption and incentivize the shift towards clean technologies (GoI, 2021).[10] While many studies show that climate mitigation via economy-wide carbon pricing in India can have adverse impacts on economic growth and income distribution (Fisher-Vanden et al., 1997; Ojha, 2009; Pal et al., 2015), a recent study shows how carbon revenues are recycled could determine if mitigation policies can ameliorate adverse distributional consequences of climate mitigation in India (Ojha et al., 2020). India currently does not have uniform explicit carbon pricing in place, likely due to existing political economy hurdles (Jenkins, 2019; Chandra, 2021). Nevertheless, India has implicit carbon pricing mechanisms, including the Performance Achieve Trade (PAT), the Clean Energy Cess (or Coal cess), the Renewable Purchase Obligations (RPO), and the Internal Carbon Pricing (ICP). However, due to their limited emissions and sectoral coverage, these approaches are limited in their ability to incentivize fuel-switching to cleaner energy sources.[11]

On the other hand, the coal cess is a direct pricing mechanism that taxes domestic and imported coal consumption and internalizes the cost of carbon emissions, encouraging industries to transition to cleaner energy sources. However, it only applies to coal and does not include other fossil fuels. This lack of coverage reduces its effectiveness in incentivizing a comprehensive

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[9] In more detail, India has set an ambitious goal to expand its non-fossil energy capacity to 500 GW by 2030, which would also mean that 50% of the country's cumulative electric power installed capacity will come from clean energy sources. This goal relies heavily on technology transfers and low-cost international financing, including contributions from the Green Climate Fund (GCF). As of 2022, India has made considerable progress towards this target, having already installed 172 GW capacity from non-fossil fuel-based energy resources.

[10] Plans for initial phases of regulating these markets lack clarity regarding the designated regulatory authority and the potential voluntary carbon credit buyers. The government, however, aims to boost the demand for carbon credits during this phase, focusing on designated consumers, state-appointed agencies, power distribution companies, and airlines, but other sectors are also under consideration.

[11] While both PAT and RPO schemes have successfully incentivized energy efficiency and renewable energy use, they have limitations in addressing the full cost of carbon emissions. PAT mandates a decrease in "specific" energy consumption in energy intensive industries in India (Upadhyaya, 2010) and targets emission intensity instead of total emissions. RPO in India mandates all electricity distribution companies to purchase or produce 21% of their requirements from renewable energy with 10.5% from solar by 2022.

switch to cleaner energy sources. Therefore, evolving to a direct carbon tax linked to declared carbon emission targets could be the next logical step in India's carbon tax policy evolution, and the Energy Conversation (Amendment) Bill 2022 is a step in that direction.

The coal cess was increased from Rs. 50 per tonne in 2010 to Rs. 200 per tonne in 2015 and standing at Rs. 400 per tonne since 2016 (Garg et al., 2017). These high taxes on coal have led India to claim implicit carbon tax rates at approximately USD 4 per ton of CO_2, higher than the international average carbon tax rates of USD 2-3 per ton, indicating its commitment to reducing carbon emissions (IMF, 2021). However, revenue recycling from coal cess to fund the National Clean Energy Fund (NCEF) was heavily reliant on administrative and political bottlenecks and often remained underutilized (IISD, 2017). Thus, the coal cess was replaced by the goods and services (GST) Compensation Cess in 2017, intended to offset the revenue losses of states transitioning to the new indirect tax system. We may not expect this type of indirect carbon tax to induce efficient fuel-switching towards cleaner energy sources, but Pradhan (2022) shows there is potential for coal cess to induce switching to more clean energy use. Thus, our study explores the effects of boosting the coal cess rates in combination with implementing explicit carbon pricing. This experiment will contribute to assessing the future potential of explicit carbon pricing in India.

Phasing out fossil fuel subsidies is another significant policy instrument that is under consideration by the Indian government and is explored in this study. Despite increasing subsidies to clean energy, fossil subsidies in India remain four times higher in 2022 (IISD, 2022). India's fossil consumption subsidies amount to about 2% of its GDP (IEA, 2021). However, despite its vast population, India only accounts for 6% of global primary energy consumption and faces acute energy poverty (IEA, 2021). Thus, the government provides both direct and indirect subsidies to support industries and households most vulnerable to energy poverty and make energy more affordable.

Among various subsidy policies, the Pradhan Mantri Ujjwala Yojana and Direct Benefit Transfer for liquified petroleum gas (LPG) stand out as highly effective in incentivizing impoverished households to transition from traditional, environmentally harmful fuels like firewood, dung cakes, and crop residues to LPG (Mittal et al., 2017). Anand et al. 2013 show that fossil fuel subsidies in India have historically been poorly targeted, with the richest 10% of households receiving seven times the subsidy benefits compared to the poorest 10%. Findings by Lahoti et al. 2012 indicate that LPG use in India is correlated with urbanization and income levels, meaning that the burden of LPG subsidy reform is less likely to fall on low-income groups. On the other hand, kerosene subsidies are distributed more evenly across low-middle-income rural households, primarily through India's public distribution system (PDS). However, research presents evidence of significant leakage in the form of black-market transactions, accounting for up to 45% of PDS kerosene (Gupta, 2014).

While subsidy reforms are expected to generate significant fiscal savings, they may also increase fuel prices, particularly for kerosene and LPG, affecting all income groups by reducing real household incomes (Acharya & Sadath, 2017). Moreover, these reforms may have an inflationary effect on essential commodities like food due to increased transportation costs (IEA, 2015). It is worth noting that fuel price hikes in India have sparked political unrest in the past decade (Chandra, 2021). However, well-designed reforms accompanied by proper revenue recycling measures can help protect low-income households and generate substantial net fiscal savings (Anand et al., 2013). A recent study shows that the public in India has more-positive attitudes towards subsidy removal if optimal use of the saved fiscal revenues is specified (Harring et al., 2023). Thus, when assessing climate mitigation strategies, it is essential to consider their distributional impacts, in addition to their effectiveness in reducing emissions. Such analysis will enable the design of more targeted interventions and identify the households and sectors most and least affected. These critical aspects are the focus of our investigation in this study.[12]

Our paper makes several significant contributions to the literature on climate mitigation studies in India (see

[12] The other notable polices in India include PAT, ROC and ICP important local emission cap mechanisms employed by the government and private business in India to promote energy efficiency and renewable energy generation, but data and time constraint did not allow us to explore them in the current study.

Table 1). First, our study is the first to examine and compare the distributional impacts of various climate mitigation strategies on multiple Indian households using a global and dynamic CGE modeling framework consistent with India's NDC-NZ pathway. Few studies that have examined the distributional impact of carbon pricing on multiple Indian households offer mixed results—some found adverse distributional effects from carbon pricing (Ojha, 2009; Pal et al., 2015); others found that recycling the carbon tax as lumpsum transfers have some poverty-alleviating effects (Steckel et al., 2021; Soergel et al., 2021). However, most of these studies explore uniform carbon pricing as the only mitigation policy and focus only on direct revenue transfer mechanisms. Ojha et al. (2022) find that recycling revenue to promote green energy worsens income distribution.[13] However, they use a single-country CGE model calibrated using a 2008 SAM with limited granularity along model dimensions, including the number of households. Our analysis utilizes a more recent and detailed SAM with households disaggregated into ten rural and ten urban income deciles and more granularity in sectors and factors of production. Thus, we significantly contribute to the field of CGE modeling and provide a foundation for future research to include more granularity along other socio-demographic dimensions. Second, none of these discussed studies on India account for health co-benefits from reduced mortality and morbidity; thus, they overestimate the net mitigation cost generated from the mitigation policies (Markandya et al., 2018). We link the CGE model with an atmospheric source-receptor model to compare the mitigation costs with associated health co-benefits from reduced air pollution. Third, previous studies have not considered the role of (1) enhancing implicit carbon pricing policies, like the coal cess, or (2) phasing out fossil subsidies when studying the distributional impacts of carbon pricing in India. The only existing paper studying the role of coal cess in India's renewable energy transition is by Pradhan et al. (2022), and they focus on aggregate macroeconomic impacts. Therefore, our paper adds to the literature by comparing the distributional impacts of climate mitigation via the benchmark uniform carbon pricing and by complementing it with existing policy instruments in India. Additionally, we compare five direct and indirect tax revenue recycling methods that provide a comprehensive comparison of the distributional impacts and will aid policymakers in developing an optimal revenue recycling strategy. Fourth, policymakers in India need to factor in trade effects due to mitigation efforts from the rest of the world while designing or evaluating mitigation policies in India (Weitzel et al., 2015; Pradhan et al., 2017). The global

[13] Ojha et al (2020) only considers revenue recycling similar to the default multiplicative tax shifter used in this study.

CGE model used in this study also accounts for existing mitigation efforts in the rest of the world which is not possible in single-country CGE models. Finally, there needs to be more consideration of the long-term economic impact of climate change in India, including impacts on future economic growth, labor productivity, and investment. The long-term economic impacts of climate change are critical for understanding the sustainability of the economy and for designing effective response measures. We analyze the impacts of NDC-NZ mitigation in India using a recursively dynamic global CGE model with 2050 as the final simulation year.

Table 1. Summary of most relevant climate mitigation modeling studies on India

Economic impacts of climate mitigation policies	**Distributional impacts of climate mitigation policies**
Fisher-Vanden et al. (1997): A single-region CGE model of India reveals lower mitigation costs with globally tradable emission permits, based on historical levels and equitable per capita emissions allowances, compared to independent regional carbon taxes.	Ojha (2009) and Pal et al (2015): Single-region CGE models of India show that domestic uniform carbon taxes significantly impact the poorest households. Nevertheless, this negative distributional impact can be minimized by recycling the carbon tax revenue to specifically benefit poor households.
Shukla et al. (2008): A global CGE model compares a benchmark uniform carbon tax with a carbon tax combined with alternative sustainable development assumptions for transitioning to a low carbon future in India.	Ojha et al. (2019): A single-region CGE model of India demonstrates that redistributing uniform carbon tax revenue to households as lump-sum transfers, based on baseline shares, can alleviate poverty. However, using this revenue to promote green energy exacerbates income distribution issues.
Weitzel et al (2015): Soft linking of global and local CGE models studies the impact of a uniform carbon tax on India and China within an international climate regime, highlighting the importance of factoring in trade and international price fluctuation effects due to global mitigation.	Steckel et al (2021): A statistical incidence analysis on multiple Asian households uncovers regressive distributional impacts of uniform carbon pricing in India under the Paris Agreement targets, unless the carbon price is applied solely to liquid fuels, particularly in transportation sectors. Fully recycling revenues to households results in a positive budget change for the poorest household quintiles.
Singh et al. (2019): A single-region CGE model of India reveals that achieving India's Paris Agreement targets via a pure Renewable Portfolio Standard (RPS) is 10 times costlier than using benchmark uniform carbon pricing.	Soergel et al. (2021): Using an Integrated Assessment Modeling (IAM) framework, this study analyzes the global poverty impacts of national uniform carbon pricing under the Paris Agreement targets. Their findings suggest that when revenues are domestically redistributed on an equal per-capita basis, it results in poverty reduction, income inequality reduction in India, and a small net decline in global poverty.

1.3 Data and methods

Our analysis relies on a global recursive dynamic CGE model calibrated to a multi-region input-output database, where each region is represented by a single household. To capture the heterogeneity in Indian households, we disaggregate the single representative household into multiple households following van Ruijven et al. (2015). Specifically, we break down the single representative Indian household into ten rural and ten urban income deciles, thereby modifying the CGE model and SAM to represent separate households on the consumption and income sides. With the enhanced data and modeling framework, we first develop a business-as-usual (BAU) scenario till 2050 based on continuing historical trends in energy sectors, and projected macroeconomic and demographic changes. Using the BAU scenario as a reference case, we then assess the potential effects of different mitigation policies on the Indian economy and households. Additionally, we estimate the associated health co-benefits that arise from reduced air pollution from climate mitigation.

1.3.1 CGE framework

We employ a global recursive dynamic CGE model named ENVISAGE, specifically designed for environmental and climate change analysis (van der Mensbrugghe, 2019). The latest version of ENVISAGE is calibrated using the GTAP-Power database version 10, along with an added air pollution database for the reference year 2014 (Aguiar et al., 2019; Chepeliev, 2020). We aggregate this database into 11 regions, including India, 35 sectors, and five factors of production for this study (see Appendix A Table A1, A2, A3).[14]

ENVISAGE is based on the concept of a circular flow of the economy. The firms purchase factors of production as inputs to supply or produce goods and services. Households purchase or demand goods and services produced by firms, and they earn factor income from the firms. The model incorporates five different production factors– skilled labor, unskilled labor, capital, land, and natural resources. Demand equals supply at equilibrium prices for all factors, goods, and services markets. Households receive income from the factor payments after taxes, and all net taxes on purchases of goods and services go to the government. The firms use nested constant elasticity of substitution (CES) production functions to minimize costs while allowing for substitutability across all factors of

[14] The disaggregated GTAP 10 database has 141 regions and 65 sectors.

production. Production has an old and a new vintage, with a lower possibility of substitution linked to the old capital. ENVISAGE incorporates multiple utility functions, but we use the constant-differences-in-elasticities (CDE) utility function to determine household demand for this study. ENVISAGE employs the Armington specification to model trade, where demand for goods and services are differentiated by their region of origin. Market equilibrium involves two conditions: (1) domestic production equals domestic demand for domestically produced goods; (2) bilateral trade must balance.

ENVISAGE includes the main GHGs, such as carbon dioxide, methane, nitrous oxides, and fluorinated gases, along with nine additional emissions, including particulate matter (PM 2.5 and PM 10), ammonia, and black carbon. Commodity consumption, factor use, and processed base emissions such as methane from land generate the emissions. The model incorporates various carbon control regimes, such as an exogenous carbon tax or flexible emission caps. Dynamics involve labor supply growing at an exogenously determined rate, aggregate capital supply evolving according to the standard stock/flow motion equation, and technological change. Finally, ENVISAGE has a disaggregated energy sector where the electricity sector is disaggregated into 11 different generation technologies along with electricity transmission and distribution. Default model closure assumes that government expenditure and savings are fixed, and the direct household tax shifter is endogenous. With multiple households, we assume the shifter moves multiplicatively and uniformly across households. Investment is savings-driven, wages are endogenous with full employment assumption, and foreign savings are fixed.

1.3.2 Incorporating multiple households in the CGE framework

We disaggregate the representative Indian household in the GTAP10 database into ten rural and urban income deciles by utilizing the India Human Development Survey II (IHDS) 2011-2012 (Aguiar et al., 2019; Chepeliev, 2020; NCAER, 2012). The GTAP 10 Database is developed by the Center for Global Trade Analysis Project, providing a comprehensive representation of the world economy. This extensive dataset includes data on bilateral trade patterns, production, consumption, and intermediate use of commodities and services, allowing for sophisticated simulations that can illustrate the impacts of various policy changes on economies (Aguiar et al., 2019). The GTAP 10 Database, the latest version with the base year 2014, covers 141 regions, 65 sectors/commodities, and 8 factors of production. The IHDS is a nationally representative longitudinal survey that covers households from all states and union territories of India. The survey was conducted in two waves, the first in 2004-05 and the second in 2011-12, with a sample size of approximately 42,152 households for the second wave. Although conducted in 2011-2012, we expect household budget shares to remain relatively consistent between the survey year and our model base year of 2014. The IHDS is one of the largest and most comprehensive surveys in India, collecting data on both household consumption and income for the same households in the same year. This aspect makes it easier to incorporate into a CGE model without imposing additional assumptions, making IHDS a more robust dataset for conducting distributional analysis in the context of CGE modeling compared to other alternative data sources.[15] We complement our analysis with additional data sources to ensure consistency between the GTAP 10 and IHDS database (see details in Appendix B Section B1).

After obtaining the household expenditure budget and income shares for the rural and urban household deciles from the survey data, we use a bi-proportional Row and Column Adjustment (RAS) method to disaggregate the GTAP 10 SAM for a representative Indian household into ten rural and urban household income deciles. This method involves adjusting the SAM matrix's rows and columns to match predetermined income and expenditure shares based on prior information from household surveys or other sources. Since our SAM balancing task was not complex, we found the RAS method to be sufficient as it offers several advantages, including simplicity, speed, and transparency. The RAS method ensures consistency between the SAM and household survey data and requires minimal assumptions about the data while being computationally efficient.

Specifically, to ensure consistency between the survey data and the SAM, we adjust each household's expenditure shares from the survey while keeping total expenditure on each commodity constant in the SAM. Similarly, for each sector in the SAM, we adjust factor income shares while keeping the total value of each factor income constant.[16] Through careful adjustment, we ensure that the sector and commodity-specific expenditure and income totals remain unchanged in the GTAP database. This helps ensure that the total income and expenditures of the

[15] At the time of creating the household split for our research, we explored two alternative data sources: (1) the National Sample Survey Office (NSSO) and (2) the Center for Monitoring Indian Economy (CMIE) Database. The NSSO had extensive expenditure information in its household consumer expenditure survey (72nd round, 2014-15), but its information on household income was limited. Although the labor force and employment surveys had some information on income, the NSSO is cross-sectional, leading to inconsistencies between household expenditure and income data for the same year. Therefore, incorporating this information into the CGE model would require a lot more assumptions. On the other hand, the CMIE database, while extensive, is proprietary and not freely available to researchers outside India.

[16] The shares to split natural resource income across household deciles is assumed to be same land income shares obtained from the survey.

representative household remain unchanged and expenditure equals income across all household deciles. This approach ensures that our modeling results accurately reflect the consumption and income patterns of rural and urban households in India (see details in Appendix B Section B2).

After disaggregating the SAM into different household groups, we adjust the ENVISAGE model to accommodate multiple households. The disaggregated SAM is used to calibrate the model, which involves adjusting the equations and parameters to account for the different household groups. Specifically, we modify the production function, demand function, and market clearing conditions to reflect the different preferences and consumption patterns of the different households. The calibrated model is then solved to generate equilibrium prices, quantities, and incomes for each household group. By incorporating multiple households, CGE models can provide a more comprehensive and nuanced analysis of the impacts of economic policies on different income groups and can help policymakers design more equitable and inclusive policies.

1.3.3 Air pollution co-benefits estimation

We link the ENVISAGE model, which captures changes in air pollutant emissions, and the TM5-FASST global atmospheric source-receptor model (van Dingenen et al., 2018). This model link allows us to estimate the impact of changes in air pollutant emissions on six specific diseases identified in the TM5-FASST model: ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), stroke, lung cancer (LC), lower respiratory airway infections (LRIs), and diabetes mellitus type 2 (DMT2). By doing so, we can estimate the mortality rates associated with each of these diseases and aggregate the estimates across all air pollutants. This enables us to assess the health co-benefits of climate mitigation policies in India. To monetize the health co-benefits arising from improved air quality, we use the value of a statistical life (VSL) approach discussed in Markandya et al. (2018). Specifically, we utilize a “unit value transfer approach” that adjusts the VSL estimates of OECD countries to India, taking into account differences in GDP per capita and projected growth rates.[17] This approach allows us to quantify the economic value associated with the health improvements resulting from reduced air pollution.

[17] The VSL values used in this study for OECD countries range from 1.8 million USD per capita to 4.5 million USD per capita, as measured for the reference year of 2005, following Holland et al. (2014).

1.4 Scenario Framework

1.4.1 Baseline Scenario

We have calibrated the baseline BAU scenario between 2014 and 2050, assuming no significant mitigation efforts from India and the majority of other countries worldwide. However, we do incorporate mitigation measures for countries that presently have carbon pricing policies in place, such as the EU, China, and our aggregated high-income regions, compared to their unconditional NDCs. The carbon price trajectories applied to these regions are provided in Appendix C Table C1. These carbon prices are only applied to specific energy-intensive (EIT) sectors, including paper and wood, chemicals, metals, non-metallic minerals, petroleum, and electricity generation (from fossil and renewable). The macroeconomic and demographic assumptions are based on SSP2 from the shared socioeconomic pathways (SSP) database. SSP2 is a middle road pathway where trends broadly follow historical patterns, with medium socioeconomic challenges for mitigation and adaptation (Carbon Brief, 2018; Dellink et al., 2017). [18]

We impose additional energy-specific assumptions to our baseline scenario, and we discuss these assumptions in Appendix C Table C2. In summary, these assumptions include the declining cost of renewable power generation over time, targeting an increase in the share of renewable energy in the power bundle, growth in autonomous energy efficiency, and an Armington twist to increase the import-to-domestic-demand ratio. For India specifically, we impose assumptions to increase the growth in nuclear power and decrease the growth in oil power generation. This adjustment for India is necessary to align its growth in power generation sources with historical and government-projected trends (CEA, 2020). These assumptions helped us closely align the cumulative world carbon budget in ENVISAGE BAU at 1114 Gt with that of the TIAM's (Times Integrated Assessment Model) BAU between 2019 and 2050 (Labriet & Loulou, 2008). We were also able to closely align the world emission growths between ENVISAGE and TIAM in the BAU scenario (see Appendix C Figure C1, C2).[19]

[18] Climate scientists, economists and modelers have developed 5 different pathways to determine scenarios for how demographics and economics might change in the next century. These 5 pathways are together known as the Shared Socioeconomic Pathways (SSPs). Recent studies however suggest the need to update these pathways (O' Niell et al., 2020).

[19] TIAM-World is a versatile global energy system model based on the TIMES approach. It aims to optimize energy sector costs across various fuels, technologies, and policies, analyzing the energy system's response to different

In the context of India, several key observations in the baseline helped shape the design of our mitigation scenario in the next section. India was able to achieve its latest NDC emissions intensity of GDP target of 45% reduction relative to 2005 by 2030, without any additional mitigation measures, simply with the trend growths in emissions. In the BAU scenario, India achieves a 46.8% reduction in emission intensity of GDP by 2030 compared to its 2005 levels (see Appendix C Figure C3). This reduction is primarily attributed to a decline in energy intensity and fuel switching, as shown in the Kaya decomposition analysis in **Error! Reference source not found.**. The analysis reveals that around 35% of the GHG emission intensity decline is due to a reduction in energy intensity, while the remaining 10% is from fuel switching.

GDP per capita growth is identified as the primary driver of emissions in India, while a decrease in the energy intensity of GDP plays a crucial role in emission reduction. Despite an increase in energy demand between 2023-2050, there is significant growth in renewable energy, which accounts for approximately 24% of the energy supply mix by 2050. However, fossil fuels, particularly coal, still dominate the energy mix in 2050 (see Appendix C Figure C4). Structural changes in output, such as the rise in relatively low EIT services and the decline in relatively high EIT heavy manufacturing, contribute to the long-term decline in energy and emission intensity in India in the BAU (see Appendix C Figure C4). Finally, in the medium term (2030), population growth has a more significant positive impact on emissions compared to the decline in emission intensity, but this trend reverses in the long term (2050) when declining emission intensity becomes a prominent driver of emission growth.

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incentives and constraints. The model identifies least-cost investment pathways and operations that meet externally projected energy demands. It features a flexible, modular framework for customizing energy commodity flows and modifying technologies. The model is calibrated to the IEA's 2019 balances and covers air pollutants, regional and sectoral coverage, and user-defined time periods.

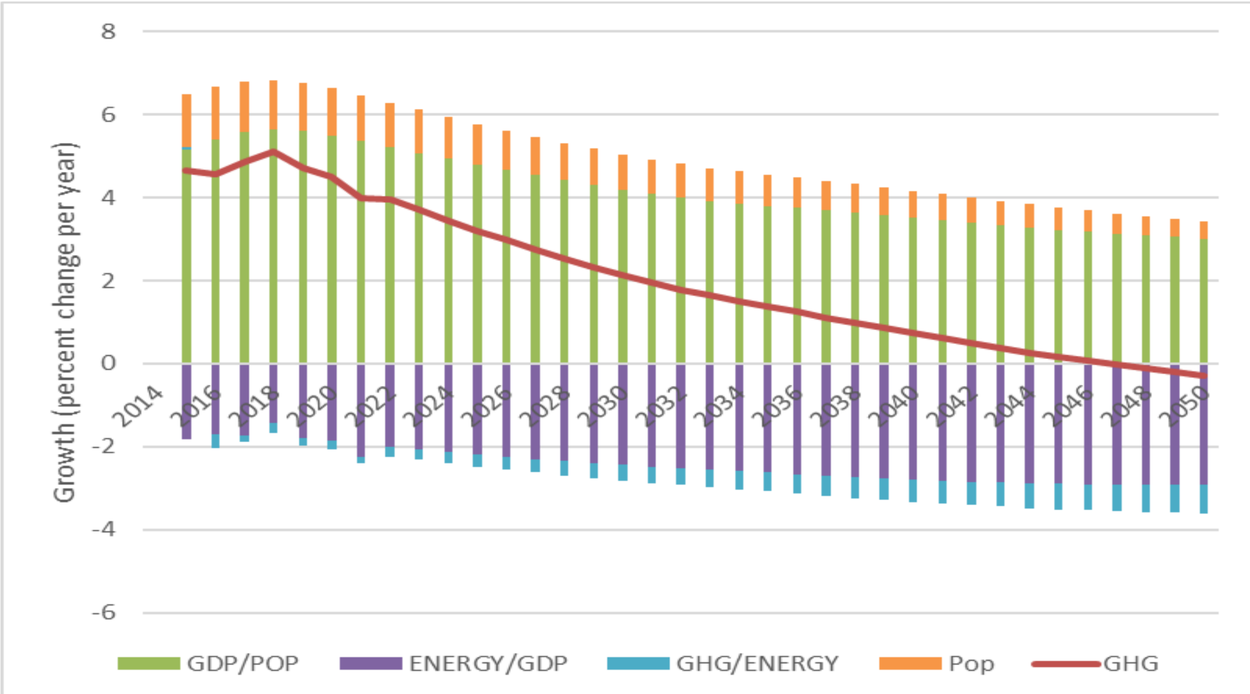

Figure 1. Kaya decomposition for India's GHG growth trajectory in BAU Scenario

Notes. Horizontal axis shows years and vertical axis shows annual percentage change. India's annual growth in GHG emission is show by the blue line. We also see India's annual growth in per capita GDP (green bar), energy intensity of GDP (purple bar), emission intensity of energy (blue bar), population in (orange bar).

1.4.2 Mitigation Scenario

In the mitigation scenario, we have set two different emission reduction targets India will achieve in 2030 and 2050 relative to the BAU. First, we ensure that all regions, including India, achieve at least their unconditional NDC emission reduction targets by 2030. Second, specifically for India, we ensure that it follows an emission trajectory between 2031 and 2050, enabling it to reach its NZ emissions goal by 2070. A caveat is that since India already meets its unconditional NDC target in the BAU scenario, we use a rough back-of-the-envelope estimation approach to set a mitigation target for India by 2030. First, we impose the implicit carbon pricing mitigation policy that currently is in place in India, the coal cess, on the BAU scenario. We apply historical cess rates up to 2020 and projected cess rates starting 2021 as described in Pradhan et al. (2022) (see Appendix C Table C4). This exercise helps us obtain an emission reduction trajectory for India until 2030. Thus, the final mitigation strategy for India reduces emissions similar to what existing policies in India would achieve by 2030 and a continuation of policies beyond 2030 (Pradhan et al., 2022). Between 2031 and 2050, we assume a linearly accelerating emission reduction trajectory aligned with the Indian government's plans to achieve NZ emissions by 2070. We refer to our mitigation scenario for India as the NDC Net-Zero (NDC-NZ) pathway.[20] For regions other than India, the unconditional Paris Agreement NDC emission reduction targets for 2030 are obtained following the EM36 scenario protocols by Kitous et al. (2016). Between 2031 and 2050, we assume a constant 3 percent and 5 percent growth in carbon prices per year for developed and developing economies, respectively (see Appendix C Table C5). The carbon budget for the NDC-NZ scenario is consistent with achieving at least the 2^{o} C warming goal, as the word budget in ENVISAGE falls below the respective carbon budgets from the TIAM and CAT (Climate Action Tracker). This scenario effectively reduces India's emissions to 1.8 GtCO2e by 2050, demonstrating that the mitigation efforts align with the global goal to limit temperature increase and prevent the most severe consequences of climate change (see Appendix C Figure C5).

It should be noted here that we target CO_2 emissions reduction in the model, as we do not have abatement options for non-CO_2 GHG emissions in the current version. **Error! Reference source not found.** below shows India's CO_2 annual emission growth trajectory in NDC-NZ and BAU scenarios (indexed at 2023=1), where we observe about a 6% and 52% reduction in emissions under NDC-NZ relative to BAU in 2030 and 2050, respectively. Non-CO_2 emissions account for about 20-25% of total emissions in India (Word Bank, 2019). As such, to achieve NZ by 2070, we assume that technological advancements in carbon capture and storage and other demand-side mitigation efforts are sufficient to mitigate the remaining emissions (IPCC, 2022).

[20] Given the considerable uncertainty surrounding the emission trajectory that the Indian government will adopt to achieve net-zero emissions by 2070, our study uses a linearly accelerating rate for mitigating emissions beyond 2030. This approach is consistent with India's net-zero target, provides a straightforward yet reasonable approximation and allows for comparison with other climate models. It offers a practical starting point for analysis, considering the challenges of predicting policy measures and technological advancements in the coming decades.

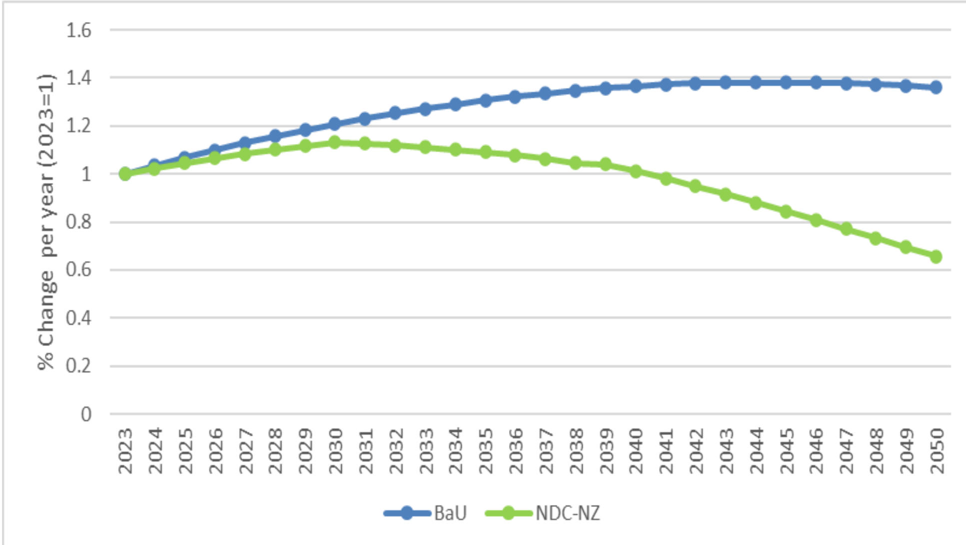

Figure 2. BAU versus NDC-NZ CO_2 emission growth trajectories for India (2023=1)

Notes. Horizontal axis shows year and vertical axis shows annual percentage change. We see India's growth trajectories for CO_2 emission between 2030 and 2050 (indexed wrt 2023 levels = 1) for BAU (in blue) and NDC-NZ (in green).

1.4.3 Policy choices

Error! Reference source not found. provides an overview of the policy mixes (PC1-PC3) with default revenue recycling in Panel A and the alternative revenue recycling strategies (PC4-PC8) in Panel B that are considered in this study to help India achieve its NDC-NZ mitigation pathway. The policy mixes CP, CPCESS, and CPSUB are analyzed with the default tax revenue recycling closure, while the five alternative revenue recycling options— RADD, REQL, RFAC, RLAB, and RGNRG—are explored for the most efficient policy mix.

Policy mixes

In the first policy simulation CP, NDC-NZ mitigation is achieved by implementing a uniform carbon pricing on all agents, with the carbon price adjusting endogenously to meet the emission reduction trajectory. The second experiment CPCESS combines uniform carbon pricing with a coal cess, adding a moderate 15% annual increase in coal consumption taxes from 2031, which mitigates part of the emissions, while the rest is addressed by carbon pricing.[21] In the third experiment CPSUB, a combination of gradual fossil subsidy removal and carbon pricing is used. Specifically, fossil subsidies are phased out between 2023-2029, beyond which carbon pricing is applied to achieve NDC-NZ mitigation. In CP, CPCESS, and CPSUB, all revenue is recycled to households using our default method, adjusting taxes paid by households with a uniform multiplicative shifter to provide lumpsum direct transfers to households.

Revenue recycling strategies

Here we explain the five alternative revenue recycling options under policy mix CPSUB. Specifically, RADD and REQL involve direct transfers to households, similar to the default revenue recycling method. RADD uses a uniform additive tax shifter, while REQL involves per capita equal lumpsum transfers. The indirect revenue recycling options include—RFAC, which subsidizes factor use taxes; RLAB, which subsidizes labor use taxes; and RGNRG, which subsidizes investments in the renewable energy sectors to promote green energy. The reason for testing alternative revenue recycling options with policy mix CPSUB is that the combination of carbon pricing and fossil subsidy removal proved to be the most efficient policy among the policy mixes (see details in Results Section 2.5).[22]

The various household-based revenue recycling schemes are summarized in Equation (1), where *YD* is disposable after-tax income for household h in year *t*, *Y* is pre-tax income, τ^0 is the original tax rate per household and α and μ, respectively 0 and 1 in the base year, are the additive and multiplicative tax shifters. *CRev* is total carbon revenue generated from mitigation and *Pop* is the population of household group h. The default closure adjusts the μ parameter to maintain the fiscal target. If carbon revenues rise, μ will fall uniformly across all households. If the initial tax rate is zero, households see no benefit in the revenue recycling. The first alternative is to adjust α, which is an additive shifter—all households would benefit from the same downward shift in the shifter. In this case a zero-tax rate household would see a net positive transfer. The second alternative is a uniform lumpsum rebate to households based on the level of the per capita carbon

[21] Since 2016, the coal cess has remained fairly constant. Therefore, we assume a moderate annual growth rate of 15% following the approach used by Pradhan et al. (2022).
[22] In PC1-PC8 the other regions achieve their exogenous mitigation pathways using an endogenously determined carbon pricing over all sectors, with revenues recycled to households.

revenue. Note that in this case, the μ shifter may still see some minor adjustment to maintain the overall fiscal target.

$$YD_{ht} = (\alpha_t + \mu_t * \tau_{ht}^0)Y_{ht} + \frac{CRev_t}{\sum_h Pop_{ht}} Pop_{ht} \qquad (1)$$

It's worth noting that the case of equal per capita revenue transfer is in fact a progressive revenue recycling strategy as the value of a dollar transferred to poor households is greater than its value to rich households as the marginal utility of income or wealth is diminishing (Easterlin, 2005; Laylard et al., 2008; Lawsky, 2010).

Table 2. Summary of simulation scenarios for India

Scenario/Policy	Acronym	Description
Baseline	BAU	Business-as-usual scenario with no policy efforts
Policy Choices (PC) that achieve NDC-NZ (Nationally Determined Contributions-Net Zero) Pathway: India achieves its unconditional NDC targets by 2030. After 2030, India follows a linearly accelerating trajectory, to mitigate emissions between 2031 and 2050, that aligns with India's NZ emissions goal by 2070.		
Panel A. Policy Mixes with default revenue recycling to attain NDC-NZ		
PC1	CP	This is our initial reference case. NDC-NZ is achieved using uniform carbon pricing; default recycling of revenues to households via uniform multiplicative shifter of tax schedule
PC2	CPCESS	NDC-NZ is achieved using a combination of uniform carbon pricing and increased coal cess rates; default recycling of revenues to households via uniform multiplicative shifter of tax schedule
PC3	CPSUB	NDC-NZ is achieved using a combination of uniform carbon pricing and fossil subsidy elimination, default recycling of revenues to households via uniform multiplicative shifter of tax schedule. [23]
Panel B. Alternate Revenue Recycling Options (with PC3) to attain NDC-NZ		

[23] Fossil subsidy is used to target emissions reduction till it exhausts over 6 years between 2023-2029, beyond this point carbon pricing is introduced endogenously to avoid any interaction effects starting 2030. This helps avoid any interactions between the two polices to attain NDC-NZ.

PC4	RADD	Revenue recycled to household via a uniform additive shifter (AT) of tax schedule
PC5	REQL	Revenue recycled to household via an equal (EQL) lumpsum transfer on a per-capita basis
PC6	RFAC	Revenue recycled indirectly to reduce factor (FAC) taxes
PC7	RLAB	Revenue recycled indirectly to reduce labor (LAB) taxes
PC8	RGNRG	Revenue recycled indirectly to subsidize investments in renewable or green energy (GNRG) sectors

Note. All the other regions achieve their exogenous mitigation pathways using endogenously determined carbon pricing, with revenues recycled to households.

1.5 Results

Carbon pricing applied in India across the different policy choices to achieve the NDC-NZ mitigation increases from 7.5 USD/tCO_2 in 2030 to 159 USD/tCO_2 in 2050 on average (see Appendix D Figure D 1 D1). In the utilized modeling framework, carbon pricing serves as a universal tool representing the overall mitigation effort required to achieve the emission reduction target.[24] In terms of fiscal impacts, the implementation of carbon pricing generates substantial revenues. The carbon tax collection is estimated to be around 297-298 billion USD in 2050, approximately 1.1% of India's GDP. These revenue streams can be directed towards various purposes, such as funding social programs, climate mitigation initiatives, infrastructure investments, or other government priorities. The distribution of these carbon tax revenues has implications for fiscal indicators (see Appendix D Table D4).

[24] In the real world, governments might employ a mix of policies, such as subsidy and/or tax reforms, promoting specific production and consumption technologies, enforcing emission or energy efficiency standards, and implementing specific sectoral/technological regulations. The selection of a particular mix of instruments could alter the overall impact of the mitigation policies on the country's economy compared to the findings presented in this section. Nonetheless, the overall level of effort and the general economy-wide consequences of the transition are anticipated to align with the mitigation scenarios implemented.

1.5.1 Efficiency Impacts

The change in aggregate discounted welfare (DW) metric relative to the BAU scenario serves as our basis to identify the most efficient policy mix for India to attain the NDC-NZ mitigation. The DW metric is calculated as follows:

$$DWs = \sum_{t=2023}^{2050} W(t) * (1+r)^{-(t-2023)} \qquad (2)$$

In Equation (2), the discount factor r $\epsilon(0,0.1)$ and W(t) represents the equivalent variation (EV) measure for the year *t*.[25] The sum runs from the initial year (2023) to the final year (2050) of the mitigation efforts modeled. The DW metric takes into account the welfare for each year, discounted by a factor that depends on the discount rate, and aggregates them to estimate the overall welfare impact of the policy being examined on Indian households. We assume a default discount rate of 2%. While there is considerable uncertainty and debate on the choice of social welfare discount rate in the climate literature ranging from 1.4% (Stern, 2007) to 4.3% (Nordhaus, 2007; Meldelsohn, 2008), a 2% rate in the medium future (over 26-27 years) has received most consensus in the climate research community (Nesje et al., 2022; Polasky & Dampha, 2021). A higher DW metric signifies greater efficiency in achieving the desired pathway while maximizing welfare.

Error! Reference source not found. Panel A illustrates the impact on discounted welfare (DW) metrics, specifically from household expenditures under various policy mixes relative to the BAU scenario between 2023-2050. The most effective policy mix is combining fossil subsidy removal with carbon pricing (CPSUB). CPSUB results in a 0.04 percentage points less decline in welfare compared to the reference policy with carbon pricing only (CP). Additionally, analyzing this welfare effect over time under CPSUB reveals net welfare gains in the short-term due to efficient resource allocation (see Appendix D Figure D 2 D2). On isolating the welfare effect between 2023-2050 from only fossil subsidy removal under CPSUB, we see small but positive welfare effects relative to BAU. These findings align with global studies that highlight the positive

[25] Equivalent Variation (EV) is a metric that quantifies the change in well-being or welfare experienced by an individual or community as a result of changes in economic conditions such as prices or income. Essentially, EV reflects how much additional income is required to maintain the same level of welfare as before the change.

social welfare effects of energy subsidy reforms, which reduce market distortions (Groot & Oostveen, 2019).

On the other hand, augmenting the coal cess in combination with carbon pricing (CPCESS) proves to be the least efficient, resulting in a welfare decline of 0.03 percentage points greater than CP. CPCESS disproportionately affects sectors and consumers heavily reliant on coal for their energy needs. Transitioning to clean energy is a gradual process, and the heavy reliance on coal in India's energy mix necessitates a location-specific phased transition (Tongia & Gross, 2019). Thus, it is plausible that the welfare decline under CPCESS is more substantial. These results highlight the complexities associated with transitioning away from coal and the need for a carefully managed and gradual transition by the Indian government (Tongia et al., 2020).[26]

Error! Reference source not found. Panel B presents the change in the DW metrics for different revenue recycling alternatives relative to the BAU scenario between 2030-2050. We find that direct household per capita lumpsum transfers (REQL) emerge as the most efficient strategy for households, resulting in a 0.04 percentage points less decline in DW than the default multiplicative revenue recycling closure under CPSUB. A recent study in Brazil finds that per capita lumpsum revenue transfer benefits low-income households and stimulates overall consumption (Graffa et al., 2021) and may explain the favorable DW under REQL. We also verify this in the next section.

Recycling revenue to reduce labor taxes (RLAB) also results in a lesser DW decline of 0.01 percentage points compared to the default mode of revenue transfer under CPSUB. It is essential to note that we are using a full employment closure in this analysis. Under the alternative labor market closure, where involuntary unemployment exists, RLAB may have a more favorable impact on household welfare than REQL, particularly for labor-dependent households. This is because the labor tax subsidy can reduce labor costs for businesses, stimulating labor demand, increasing employment levels, and boosting overall output. Equal lumpsum transfers do not directly target employment and may primarily affect household consumption, leading to increased demand for goods and services, consequently higher output and a less significant indirect effect on employment (Graffa et al., 2021). Nevertheless, both REQL and RLAB have the potential to enhance household welfare outcomes in India.

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[26] The government of India currently plans to ramp up coal production (via coal mine expansions) by one billion ton in 2023-2024 and peak by 2026 (GOI, 2022), which has faced some criticisms (Tongia, 2022).

The DW changes for the other revenue recycling options do not show significant variations compared to the default case. So far, findings indicate that all emission mitigation strategies will result in a small to moderate welfare cost. However, the impact on household welfare will vary depending on the chosen revenue recycling strategy. To understand better the mechanisms driving the welfare effects across different revenue recycling strategies, we study other aggregate macroeconomic indicators in the next section.

Table 3. Aggregate Discounted Welfare (DW) between 2023-2050, % change wrt BAU

	Panel A. Policy mixes				
	PC1 (CP)		PC2 (CPCESS)		PC3 (CPSUB)
DW	-0.19		-0.22		-0.15
	Panel B. Alternate revenue recycling				
	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
DW	-0.14	-0.11	-0.15	-0.14	-0.15

Notes. Table shows DW=discounted welfare from household expenditure. Calculations shown with r= 2%.

1.5.2 Overview of other macroeconomic indicators, sectoral and fiscal effects

Appendix D Table D1 presents the percentage changes in macroeconomic measures relative to the BAU scenario in 2050 for different policy mixes (Panel A) and alternate revenue recycling options (Panel B). When comparing the policy mixes, the relative GDP declines are similar to the welfare declines. CPSUB is again the most efficient policy for the economy, and CPCESS is the least efficient. However, when comparing the revenue recycling options, two key observations emerge. Firstly, the two recycling options with the most favorable household welfare impacts—REQL and RLAB—exhibit worse GDP impacts compared to recycling through green energy subsidies RGNRG, which shows the least GDP decline.

Decomposing the GDP impacts, we see that under REQL, household demand is stimulated, and consumption decline is minimized (at around 1%, the smallest decrease among all policies), despite the rise in energy costs, whereas investments fall by approximately 4.5%. While investment declines at a similar magnitude across all other scenarios due to the rise in investment costs, in the case of REQL, there is an additional decline in investments due to higher-income households reducing their savings. Direct transfers that are more targeted towards low-income households may discourage savings and investments among high-income households (Ojha et al., 2021). However, the relatively smaller GDP decline under RGNRG is a result of the enhanced capital investment in the green energy sector; it stimulates production, economic growth, and innovation, particularly in the renewable sectors (see Appendix E

Table E 2 E2). These results highlight a policy choice trade-off between attaining efficiency with respect to bolstering household consumption versus attaining investment-driven economic growth.

Furthermore, in all policies examined, there is a consistent trend of rising export prices in India in comparison to import prices. Additionally, aggregate production experiences a decline of 3.6-4% in 2050 relative to BAU. This decline is primarily driven by the manufacturing sector. The higher carbon prices in India contribute to increased production costs relative to other countries, resulting in higher prices for Indian exports compared to imports. As a result, the competitiveness of Indian exports in the global market diminishes, leading to declines in sectoral output. The declines in sectoral nominal export values are presented in Appendix D Table D2. The higher average carbon prices in India are the outcome of implementing more stringent NDC-NZ mitigation measures, setting it apart from the rest of the world that only achieves their NDCs and maintains lower carbon prices. Average carbon prices for India and the rest of the world are shown in Appendix C Table C5.

The sectoral impacts of the various policy scenarios compared to the baseline in 2050 reveal significant challenges for traditional fossil-dependent energy sectors, such as coal power, gas power, and coal, with declines in output ranging from 32% to 92%. In contrast, renewable energy sectors, including solar, wind, and hydropower, experience substantial growth in output, with increases between 30% and 40%. Moderate negative impacts are observed in EIT sectors such as metal, non-metallic minerals, oil extraction, and oil, with declines between 5% and 15%. Sectors like services and livestock face smaller negative impacts, while a few sectors, such as forestry and agriculture, see small positive impacts across the scenarios. While there are small variances in impacts on sectoral output across the policy mix scenarios, they show a general shift from traditional energy sectors to renewable energy sectors by 2050 (Appendix E Table E1). Additionally, as expected, India experiences a significant shift away from fossil power generation sources from 68% in baseline to approximately 8% in 2050 across all policy mitigation scenarios (Appendix E Table E2).

1.5.3 Inequality Impacts

Error! Reference source not found. shows the change on the Gini Coefficient and S80 by S20 ratio for the different policy mixes (Panel A) and revenue recycling options (Panel B) relative to the BAU scenario in our final simulation year 2050.[27] Comparing the policy mixes (**Error! Reference source not found.** Panel A), we find that a combination of subsidy removal with carbon pricing (CPSUB) leads to the least adverse inequality impacts, while boosting coal cess with carbon pricing (CPCESS) results in worse inequality impacts. Comparing the revenue recycling options (**Error! Reference source not found.** Panel B), we find that equal per capita revenue transfer (REQL) and transfers to lower labor use taxes (RLAB) are the only two notable revenue recycling strategies that show a substantial reduction in income inequality compared to the default revenue recycling case CPSUB. These strategies directly address income disparities and support lower-income households. Specifically, the Gini Index and S80/S20 ratio decrease by 1.8 and 7.5 percentage points for REQL, and 0.07 and 0.14 percentage points for RLAB, respectively, compared to the default case. In contrast, RGNRG worsens inequality and results in a 0.15 and 0.36 percentage point increase in the Gini Index and S80/S20 ratio, respectively, compared to the default case.

For REQL, the equal per capita revenue transfer ensures that every individual receives the same amount, which benefits lower-income households more, as it represents a larger share of their income. REQL addresses income disparities and narrows income gap between the rich and the poor, resulting in a decrease in the Gini Index and S80/S20 ratio. This finding particularly aligns with Soergel et al (2021), who find similar inequality effects from per capita carbon tax revenue recycling in India under a 1.5°C. mitigation target.

On the other hand, RLAB reduces labor use taxes, making labor less expensive for firms. This leads to increased labor demand and higher wages as employment is fixed. As lower-income households are generally more reliant on labor income, this policy can contribute to a more equitable income distribution by raising wages for this segment of the population. In contrast, RGNREG, which focuses on promoting investments in green energy, does not directly target income inequality. The subsidies for green energy sectors might primarily benefit capital owners and businesses in those specific industries, leading to a more unequal income distribution.

Results so far collectively suggest that while all emission mitigation strategies may result in a slight welfare loss (as seen in **Error! Reference source not found.**), the impact on income

[27] The Gini coefficient index is a measure of income inequality ranging from 0 (perfect equality) to 1 (perfect inequality). The S80 by S20 ratio compares the income of the top 20% (S80) to the bottom 20% (S20) of a population. Both indicators show higher values for greater income inequality.

inequality measures can vary significantly based on the revenue recycling strategy (as seen in **Error! Reference source not found.**). In the next section, we study the underlying welfare distributional impacts to better understand inequality impacts.

Table 4. Inequality Measures, % changes w.r.t BAU in 2050

	Panel A. Policy mixes			**Panel B. Alternate revenue recycling**				
	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUB)	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
Gini Index	0.08	0.09	0.06	0.07	-1.79	0.10	-0.01	0.21
S80/S20	0.09	0.12	0.05	0.19	-7.40	0.17	-0.09	0.41

Notes. Table shows Gini coefficient which is a measure of income inequality ranging from 0 (perfect equality) to 1 (perfect inequality). The S80 by S20 ratio compares the income of the top 20% (S80) to the bottom 20% (S20) of a population. Both indicators show higher values for greater income inequality.

1.5.4 Distributional Impacts

Appendix D

Table D 3 D3 presents the changes in welfare by household deciles in 2050 relative to the BAU scenario. The findings in this section reinforce the conclusions drawn from previous sections, which examined the impact of different policy mixes and revenue recycling options on welfare and inequality. Specifically, combining fossil subsidy removal and carbon pricing in CPSUB demonstrates progressive distributional impacts. The wealthiest urban and rural household deciles experience the most significant decline in welfare. Existing research indicates that fossil subsidies in India have been poorly targeted, with significant leakage (Anand et al., 2013; Lahoti et al., 2012; Gupta, 2014). Consequently, it is plausible that the burden of subsidy removal falls more on urban and higher-income households, who consume more energy on average. This trend becomes even more evident when isolating the welfare effect that is solely the removal of these subsidies.

The aggregate household welfare impacts stem from the distributional mechanisms employed in each revenue recycling approach, that is, how the revenues are recycled and how the benefits are distributed among income groups. REQL emerges as the most progressive strategy, directly transferring revenues equally to all individuals. This benefits the poorest deciles U0 (+3%) and R0 (+11%) relative to the baseline, providing them with a higher relative income, improving their welfare, thus reducing income inequality. In comparison, RLAB displays moderate progressive welfare effects on lower-income deciles by reducing labor costs for firms. This potentially leads to increased labor demand, higher wages, and improved incomes for the poorest who rely more on labor income, resulting in the smallest adverse welfare impact on U0 (-0.6%) and R0 (-0.5%) relative to the baseline. Strategies such as CPSUB (with default multiplicative tax shifter) and RADD (with additive tax shifter) show less progressive impacts, as they do not specifically target lower-income households, though as expected for the poorest deciles, U0 and R0, the additive shifter show less worse welfare outcomes than the multiplicative shifter.

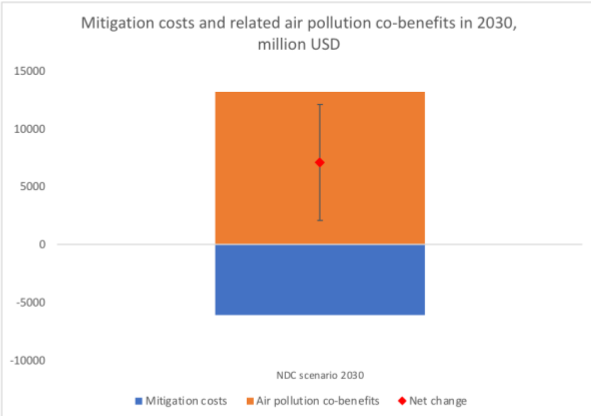
Furthermore, the distributional effects from RFAC (factor income subsidies) and RGNRG (green energy investments) rely on the distribution of factor income sources and green energy investment benefits, respectively. RFAC recycles revenues to reduce taxes on factor incomes (e.g., labor, capital, land), leading to mixed welfare changes for different deciles depending on the distribution of factor income sources among households. RGNRG involves reducing capital use taxes in the green energy sector to finance green energy investments. RGNRG is not as progressive compared as REQL or RLAB because subsidies to capital use increases demand and price of capital investments.[28] As such, it primarily benefits higher income households who rely more on capital income; thus, income inequality also worsens.

1.5.5 Air Pollution Co-benefits

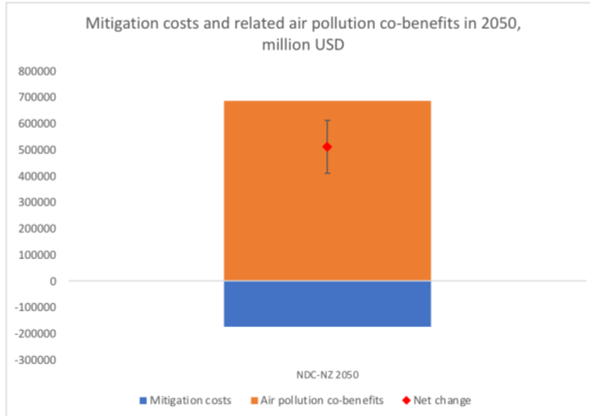
In this section, we illustrate the degree to which health co-benefits of achieving the NDC-NZ target could compensate for the associated mitigation costs.[29] As depicted in **Error! Reference source not found.**, the monetized health co-benefits, derived solely from the reduction in premature deaths attributable to lower pollution concentrations, have the potential to fully offset these mitigation costs. This is the case even without accounting for other health and environmental co-benefits or damage costs stemming from temperature increases and sea-level rise.

We note a significant reduction in premature mortality-related deaths, with an estimated average decline of approximately 0.5 million relative to the baseline in 2050, with the biggest driver being the decline in COPD both in short- and long-term (see Appendix D Figure D3). Monetizing these health co-benefits leads to an effective offsetting of both short-term costs from NDC mitigation (Panel a) and long-term costs from NZ mitigation (Panel b), regardless of the applied Value of Statistical Life (VSL). While our study does not estimate the cumulative co-benefits and mitigation costs over the entire mitigation period, related research suggests that the total discounted cumulative co-benefits from 2020 to 2050 will outweigh the mitigation costs for India by 3-5 times if the global mitigation efforts are aligned with achieving the Paris Agreement targets (Markandya, et al., 2018; Sampedro et al., 2020). Moreover, other health and environmental co-benefits or damages avoided from mitigation that are not accounted for in this study would further amplify the net positive welfare impact derived from the mitigation efforts.

[28] This is due to a stronger demand effect as it takes time to expand capital production (Ojha et al., 2019)
[29] These mitigation costs reflect total annual welfare decline in India. We take the welfare cost from our reference simulation experiment PC1 (or CP).



Panel a



Panel b

Figure 3. Mitigation costs and related air pollution co-benefits in 2030 and 2050, in million USD

Notes. Figure compares the monetized health co-benefits (orange) from reduced premature mortality due to lower pollution and NDC-NZ scenario mitigation the costs (blue) in 2030 (Panel A) and 2050 (Panel B). Red dots represent net change (costs minus benefits). The error bars show the co-benefits range with high and low VSL values, respectively. The mitigation costs reflect total annual welfare decline in India.

It is important to highlight a common concern regarding studies that employ VSL estimates—these estimates are dependent on GDP and thus assign higher value to human life in developed countries compared to those in developing countries, introducing an ethical dilemma. Additionally, the monetized co-benefits of mitigation are likely greater in densely urban areas in India compared to rural regions, due to higher pollution concentration per capita in urban areas. For instance, studies have shown that New Delhi, the capital of India, suffers the highest per capita economic loss due to air pollution (Pandey et al., 2021). However, rural India face unique developmental challenges that could compound their health risks from indoor and outdoor pollution (Ravishankara et al., 2020; Chakraborty & Basu, 2021). Thus, the distribution of adverse pollution impacts on health will also vary based on an individual's socio-economic status. Such spatial heterogeneity, if considered, could further augment the health co-benefits for some groups while reduce it for other groups.

1.6 Discussion and policy implications

This study provides new evidence on the welfare, inequality, and distributional impacts of two policy levers in India: boosting coal cess rates and phasing out fossil subsidies, compared to market-based instruments like a uniform carbon tax. Additionally, it explores five alternative direct and indirect revenue recycling options relative to the default tax shifter to achieve India's NZ emissions goal by 2070. To conduct the policy experiments, first, we develop a database with heterogeneous Indian households by reconciling the underlying SAM for the year 2014 with household survey data. Second, we modify a global and recursively dynamic multi-region CGE model with a disaggregated energy sector to incorporate multiple households. Finally, we developed a baseline and a mitigation scenario aligned with India's current and future policy objectives.

Our results have four key implications for policymakers in India. First, our analysis shows that pursuing emission mitigation in alignment with the government's target of achieving NZ emissions by 2070 would entail a moderate economic cost. However, the decline in aggregate welfare relative to the baseline scenario between 2023 to 2050 would not exceed 0.5%, while the long-term GDP decline in 2050 would not exceed 2%. While it is essential to consider these aggregate mitigation costs, it is equally crucial to acknowledge that they do not capture the distributional consequences, health and environmental co-benefits of climate mitigation efforts, and the damages avoided from climate inaction. Previous studies have emphasized the need to consider these factors in comprehensive policy assessments. (Dubash et al., 2012; Markandya et al., 2018; Deitz et al., 2021; Köberle et al., 2021; Stahlke, 2023). In line with this, our analysis highlights the potential health co-benefits that can result from reduced pollution. We find that the health co-benefits alone, arising from reduced premature mortality due to lower air pollution, have the potential to offset the climate mitigation costs in India.

Second, combining carbon pricing with fossil subsidy removal reduces market distortions, minimizes aggregate welfare losses, and proves to be a more efficient policy lever than carbon pricing or a coal cess boost, which is the least efficient policy lever. Furthermore, fossil subsidy removal results in the most favorable income equality and distributional impacts. Although solely removing fossil subsidies cannot help India achieve its long-term mitigation goals, it can provide short-term welfare gains. This result is plausible because fossil subsidies in India disproportionately benefit wealthier households (Anand et al., 2013).

Third, climate mitigation policies' distributional impacts and income inequality consequences significantly vary with the specific revenue recycling strategies implemented. This finding aligns with previous studies that find climate mitigation via carbon pricing results in progressive distributional impact only when targeted revenue recycling compensatory mechanisms are designed (Ojha, 2009; Pal et al., 2015; Ojha et al., 2020). Distributing tax revenues equally to households results in the most efficient and equitable outcome and the least decline in consumption. Research has shown that people in India generally have more positive attitudes toward climate mitigation policy levers, including subsidy removals, when the optimal use of the saved fiscal revenues is clearly specified (Harring et al., 2023). Consequently, a per-capita direct lumpsum revenue transfer could hold greater political appeal and public acceptance in India. Although successful cases like Alaska's Permanent Fund Dividend (PFD) and Norway's Government Pension Fund Global (Norway GPFG) illustrate the feasibility of per capita direct transfer policies, India's larger and more diverse population and its distinct economic structure necessitate a careful examination of such policies within the Indian context (Baena et al., 2013; Qiao & Shan, 2023). However, this recycling option results in lower aggregate welfare and GDP due to reduced investments, as disposable income and savings decline for wealthier households.

Fourth, similar to the per capita lumpsum revenue recycling option, a trade-off exists between reducing inequality and promoting investment-driven economic growth under other revenue recycling options. For instance, subsidies promoting investments in green energy sectors can exacerbate income inequality while showing the least adverse aggregate welfare and GDP impacts. Capital owners and businesses in specific industries will primarily benefit from green energy subsidies, leading to a less equitable income distribution. Moreover, the green energy sector may have higher initial costs and may not improve factor income as much as other sectors (Ojha et al., 2020). In contrast, recycling revenues to reduce labor taxes could bump labor compensation and promote equitable income distribution, albeit to a lesser extent than equal lumpsum transfers, but come at a smaller economic cost.[30]

It is essential to highlight some caveats of our results here that can be explored in future work. First, the magnitude of the impact of labor revenue recycling depends on the unemployment structure in the economy, and our analysis uses a full employment model closure. Under less-than-full-employment conditions, labor tax subsidies could potentially have a better impact on welfare than equal lumpsum transfers, as they directly target employment and can increase labor demand, output, and household incomes. In contrast, equal lumpsum transfers only indirectly affect

[30] It is possible that under a less than full-employment closure labor tax recycling could have the potential to yield a triple dividend (emission abatement, improved equality and economic growth) in India and can be explore as future work.

employment through increased household consumption. Nevertheless, both revenue recycling options–labor tax subsidies and targeted direct equal lumpsum transfers— can potentially improve India's welfare, inequality, and distributional outcomes.

Second, our modeling framework does not account for the damages avoided from temperature or sea-level rise, heat-stress-related human and agricultural productivity loss, or the benefits from energy diversification, sustainable development, and biodiversity conservation (Kapshe et al., 2013; Dhar & Shukla, 2015; Mittal et al., 2015; Dhar et al., 2017; Dietz et al., 2021; Venugopal et al., 2021; Tibrewal & Venkataraman, 2021). Our findings align with other studies that show mitigation policies fail to deliver a double dividend—abating emissions and promoting economic growth (Pal et al., 2015; Ojha, 2009). However, we can expect the net economic gains from mitigation efforts to be large and positive when considering these additional benefits of climate mitigation.

Third, the real-world future welfare impacts from mitigation policies will depend on various factors, such as the size of the transfers or subsidies, how well the transfers are monitored to avoid leakage, the structure of the economy, and the degree of mitigation effort from the rest of the world. Therefore, it is essential to consider the specific context and the model's underlying assumptions when comparing the welfare impacts of these strategies.

In conclusion, addressing climate change in India requires a balanced approach that considers emissions reduction, income equality, and long-term economic growth and development. A comprehensive, multi-faceted approach that takes into account a range of policy measures and trade-offs is essential to effectively combat climate change while promoting sustainable economic growth and mitigating income inequality in India. Policymakers should prioritize policy mixes and methods for recycling revenue based on their goals. However, to ensure equitable results, policymakers must consider the distributional consequences of mitigation policies. It is also important to continuously monitor and evaluate the impacts of these policies to ensure that they remain effective and relevant in India's evolving economic and social landscape. By adopting these recommendations, policymakers can navigate the complexities and trade-offs while actively addressing climate change in India.

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APPENDIX A: MODEL DIMENSIONS

Table A 1. Modeled regions

No.	Modeled Regions	Description
1	USA	United States
2	EUR	Western Europe
3	IND	India
4	CHN	China
5	ECA	East Europe and Central Asia
6	MNA	Middle East and North Africa
7	LAC	Latin America and Caribbean
8	SSA	Sub Saharan Africa
9	XEA	Rest of East Asia and Pacific
10	XSA	Rest of South Asia
11	XHY	Other High Income Countries

Table A 2. Modeled sectors

No.	Sectors	Description
1	RIC	Rice
2	WHT	Wheat
3	CRP	Other crops
4	LVS	Livestock
5	FRS	Forestry
6	COA	Coal
7	OIL	Oil
8	GAS	Gas
9	OXT	Minerals nec
10	PRX	Other Processed Food
11	PRM	Meat Processed Food
12	PRD	Dairy Processed Food
13	B_T	Beverages and tobacco
14	PPP	Paper products
15	TWP	Textile and wearing apparals
16	XMN	Other manufacturing
17	P_C	Petroleum and coal products
18	CME	chemicals and pharmaceuticals
19	NMM	Non-metallic minerals
20	MET	Metals
21	NFM	Non-ferros metals
22	ETD	Electricity transmission
23	CLP	Coal-fired power
24	OLP	Oil-fired power
25	GSP	Gas-fired power
26	NUC	Nuclear power
27	HYD	Hydro power
28	SOL	Solar power
29	WND	Wind power
30	XEL	Other power
31	OTP	Land Transport
32	WTP	Water Transport
33	ATP	Air Transport
34	CNS	Construction

35	SRV	Services

Table A 3. Modeled factors of production

No.	Modeled Factors	Description
1	nsk	Unskilled labor
2	skl	Skilled labor
3	cap	Capital
4	lnd	Land
5	nrs	Natural resource

APPENDIX B. ADDITIONAL DATA REQUIREMENTS AND METHOD DETAILS

B1. Additional data requirements

IHDS is a multistage, stratified sampling design selects each household, and the data covers a wide range of characteristics, including household demographics, education, health, employment, and consumption patterns. IHDS has income and expenditure information for the same households. Additionally, IHDS includes data on household assets, such as land, livestock, and durable goods. The IHDS is one of the largest and most comprehensive surveys in India, collecting data on both household consumption and income for the same households in the same year. However, IHDS did not distinguish between household consumption of domestic and traded goods, nor did it have information on dwellings (rents including self-imputed rents by owners). In the GTAP10 database, the traded commodities and dwellings comprise a significant sectoral share of approximately 9.1% and 8.9%, respectively. As such, we complement the IHDS data with additional sources of information to enhance the accuracy of our analysis. Firstly, we utilize the national input-output tables (IOTs) published by the Asian Development Bank (ADB) to calculate the trade and transportation cost shares for each sector (ADB, 2014). Second, we impute rents using the state-level average rents for all households in the IHDS data. Additionally, we categorize the households as skilled and unskilled based on the average number of years of educational attainment from the survey.[31] We also incorporate the information on savings across different household types published by the International Food Policy Research Institute (IFPRI) to refine the representation of households' behavior and savings patterns (Pal et al., 2020). These additional data sources provide us with a more comprehensive picture of the Indian economy.

[31]Average years of educational attainment as a proxy for skill is a better approach than using occupation in the Indian context because of occupational mobility and informality in the labor market, and educational attainment is a more objective and measurable indicator of skill. Skilled workers in India typically have higher levels of educational attainment and work as professionals, while unskilled workers are those who work in production or informal sectors and have lower levels of educational attainment (NITI Ayog, 2015).

We obtained information on India's aggregate value of fossil subsidies on coal, electricity, gas, and oil from the International Energy Agency (IEA). Energy subsidies for households were derived using imputed prices in a household survey. For example, only poor households with ration cards can purchase kerosene at subsidized prices from government fair-price stores; we assumed zero subsidies for households not purchasing from these stores and calculated subsidies for those that did, resulting in heterogenous subsidy rates for kerosene. There is more variance among urban households, as many cannot access ration stores, while rural households show less variation. Electricity subsidy rates among households are fairly constant and thus are proportional to the quantity consumed. As such, household energy subsidies appear to be regressive in their implementation, likely because poor households in India consume less energy (see Appendix Figure A2). For intermediate and industry usage, we obtained agent-specific subsidy rates from the International Institute for Sustainable Development (IISD) report. This allowed us to introduce heterogeneity in the subsidy rates across agents and sectors. We ensure that the aggregate subsidy values introduced align with those of the IEA (see Appendix Figure A3).[32]

B2. Household shares

Understanding the household income and expenditure shares is crucial when evaluating the impacts of different mitigation strategies, as they may affect different households and sectors differently. For instance, mitigation through carbon pricing results in increased prices for energy intensive goods, and it may disproportionately affect households that spend a larger share of their budget on these goods. Likewise, if mitigation efforts result in decreased demand for agricultural goods, it may disproportionately affect rural households that rely on agriculture as their primary source of income and for subsistence consumption.

To illustrate the household shares, Figure A1 shows the distribution of factor income shares across different household types. Table B 1shows the commodity expenditure shares. Overall, we observe that capital income and skilled labor income rise, while non-skilled labor income declines,

[32] The average value of total fossil consumption subsidies in India is estimated to be around $26.4 billion USD, accounting for approximately 2% of the country's GDP during this period (IEA, 2021). A report by the International Institute for Sustainable Development (IISD) indicates that about 70% of these subsidies were directed towards households, with the remaining 30% allocated to industries. However, it should be noted that discrepancies exist in the availability of fossil subsidies data in India, and these studies rely on different methodologies and assumptions to obtain the estimates.

as household income rises. When comparing rural and urban households, we also observe that land income is mostly concentrated among rural households, whereas urban households earn more skilled income. These income side shares can be explained by the structure of the Indian economy, which has a large informal sector with many low-skilled workers. As household income rises, households tend to invest more in capital assets such as land or businesses, generating capital income. As education and skills levels increase, households tend to earn more skilled income. Agriculture is the primary source of income for many rural households in India, which explains the concentration of land income among rural households. Urban households, on the other hand, are more likely to earn skilled income due to more job opportunities in urban areas.

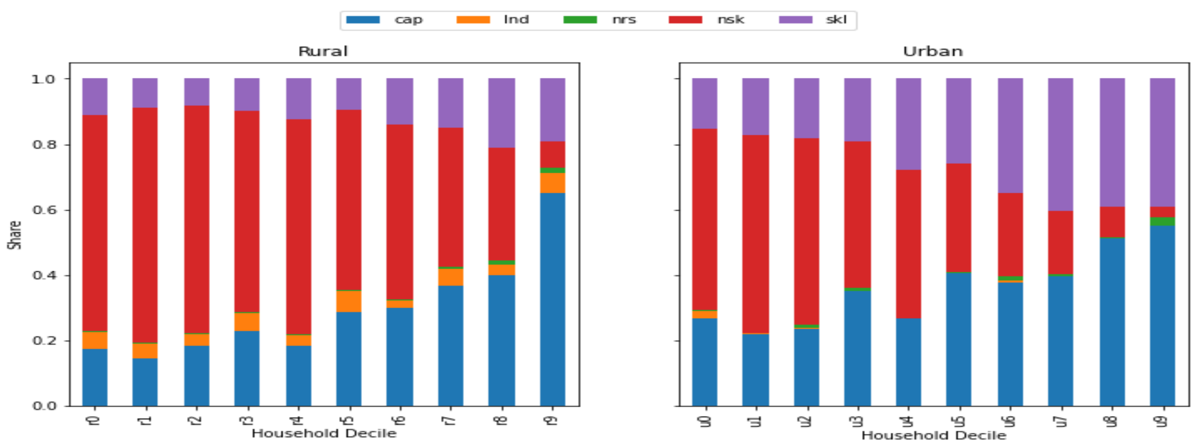


Figure B 1. Share of factor income by rural and urban household deciles

Notes. Horizontal axis shows rural (left) and urban (right) household deciles. Vertical axis shows share income by factor sources: capital (cap), lnd (land), natural resource(nrs), non-skilled labor (nsk) and skilled labor (skl).

On the expenditure side, we observe that households with higher income deciles spend less on food (staples and others) and more on power, services, and other energy intensive manufacturing goods. This can be attributed to the fact that these goods are often associated with higher living standards and a better quality of life, which is seen as a marker of social status and upward mobility in India. The higher expenditure on food among rural households can be explained by the fact that agriculture is their primary source of income, these household are poorer, and they rely on their own production for their food needs. Urban households, on the other hand, tend to spend more on services such as education, healthcare, and entertainment, which are more readily available in urban areas.

Table B 1. Share of expenditure on commodities by household deciles, %

Household	food-staple	food-other	electricity & energy	chemicals & metals	transport	other manufacturing	services	education	total
R0	27.53	27.65	6.33	5.21	7.06	9.86	12.88	3.47	100
R1	27.11	25.33	6.38	5.29	7.94	9.82	14.29	3.84	100
R2	25.11	25.13	6.40	5.73	9.06	10.19	14.11	4.26	100
R3	25.14	24.86	6.92	6.03	7.56	10.44	14.32	4.73	100
R4	22.90	24.09	6.80	6.51	9.03	10.19	15.89	4.58	100
R5	22.22	25.10	6.75	5.77	10.21	10.34	15.45	4.15	100
R6	20.55	23.39	6.89	7.04	11.07	10.41	16.20	4.46	100
R7	18.65	21.52	7.02	8.37	10.30	11.06	18.64	4.44	100
R8	15.66	20.10	7.68	9.48	11.95	11.53	18.74	4.85	100
R9	12.31	16.90	8.76	10.82	11.60	11.87	21.21	6.52	100
U1	19.75	21.62	9.82	5.15	8.31	10.11	18.32	6.93	100
U2	19.75	20.82	10.10	5.85	8.43	10.32	18.48	6.26	100
U3	18.39	20.42	9.71	7.08	8.87	10.00	19.55	5.99	100
U4	17.85	19.88	9.84	9.23	9.05	10.20	17.70	6.25	100
U5	17.23	20.06	10.18	7.38	9.66	10.38	18.48	6.63	100
U6	16.33	17.69	11.16	6.89	10.16	11.04	19.48	7.24	100
U7	15.01	17.21	10.42	7.57	9.86	10.37	21.65	7.91	100
U8	13.80	16.19	10.79	9.11	9.49	11.84	20.84	7.95	100
U9	10.33	12.74	10.78	12.53	8.81	11.09	25.39	8.33	100
Average	19.35	21.12	8.62	7.32	9.39	10.56	17.90	5.75	100

Notes. We have aggregated the GTAP commodity sectors into 8 categories to facilitate better illustrations (see Appendix E).

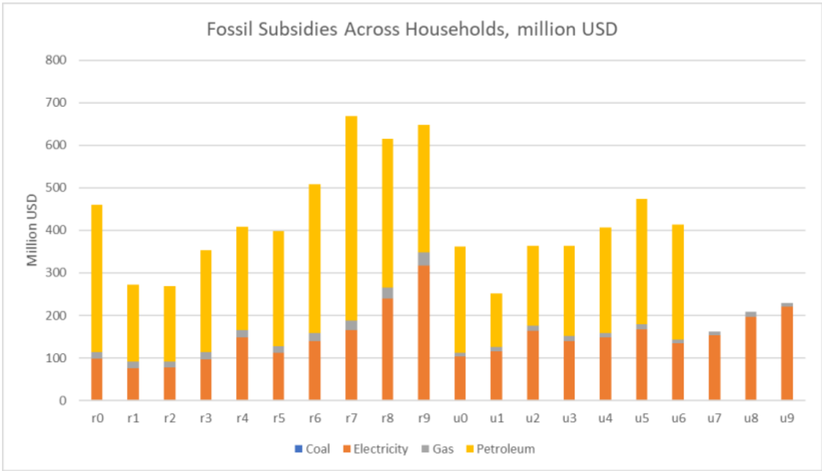


Figure B 2. Value of energy subsidies across household deciles, Million USD

Notes. Horizontal axis of the graph represents rural and urban household deciles, while the vertical axis represents the value of subsidies for coal (blue), electricity (orange), liquefied petroleum gas (LPG) or gas (grey), and petroleum (yellow), primarily kerosene.

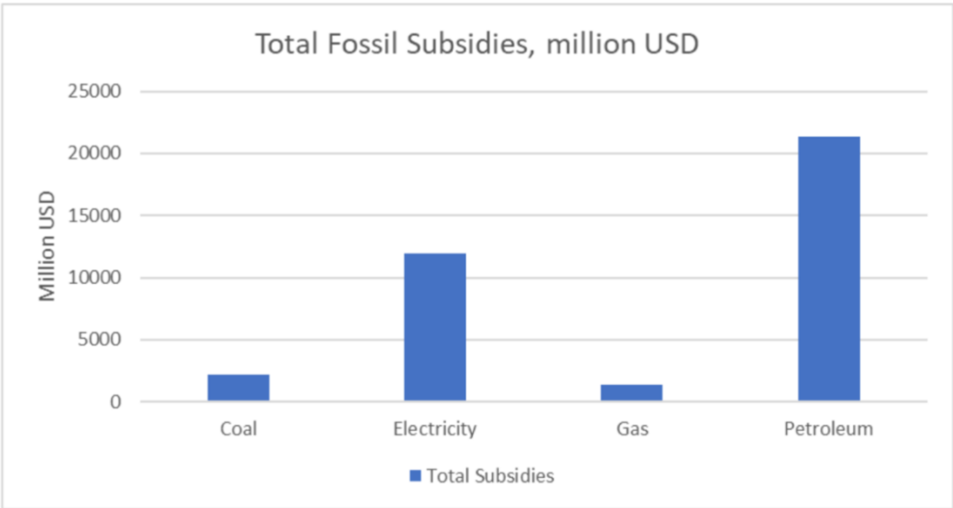


Figure B 3. Value of total fossil subsidies by fossil commodity, Million USD

Notes. The graph shows the average value of fossil fuel consumption subsidies in India between 2019-2021, with the horizontal axis representing different fossil fuel commodities.

APPENDIX C. BASELINE AND MITIGATION DETAILS

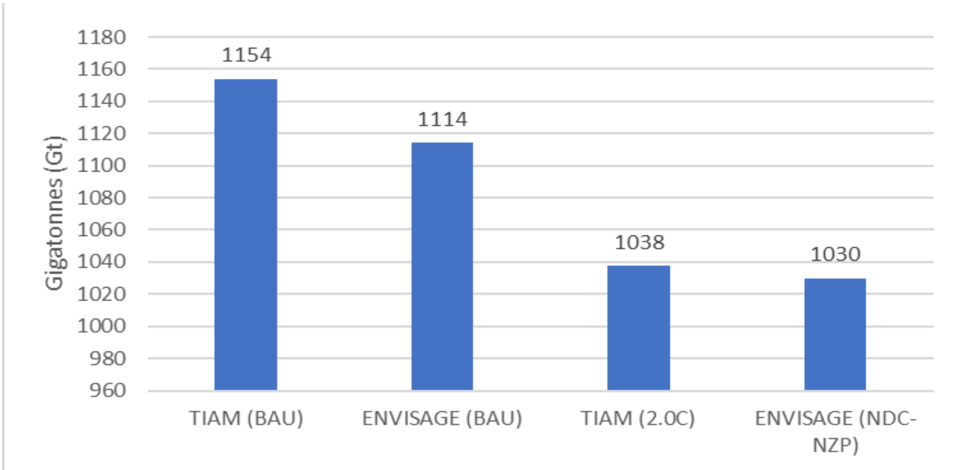


Figure C 1. Comparison of world cumulative carbon budget 2019-2050, Gt

Notes. Horizontal axis is showing the model (scenario) and vertical axis shows the carbon budget in gigatons between 2019-2050. ENVISAGE world carbon budget for baseline (BAU) and mitigation (NDC-NZ Pathway) appear to be under the TIAM model baseline (BAU) and 2º C mitigation (2.0C) values.

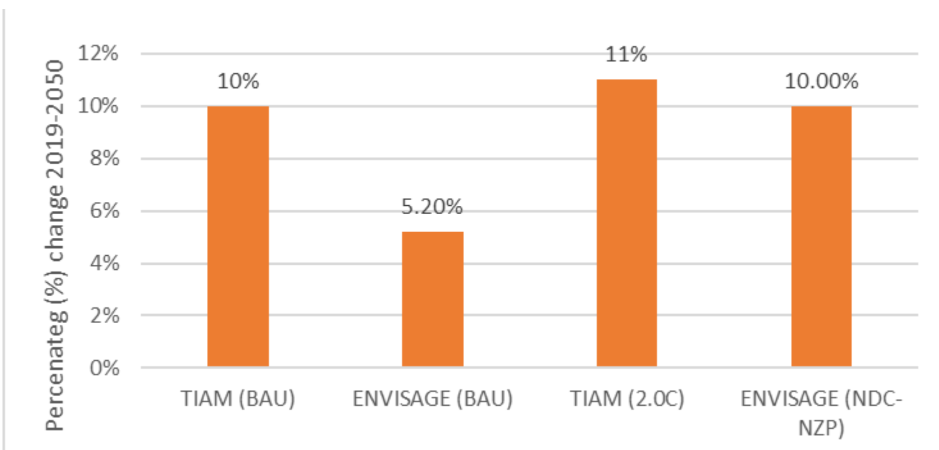


Figure C 2. Comparison of world emission growth 2019-2050, %

Notes. Horizontal is showing the model (scenario) and vertical axis shows the % change in emissions between 2019-2050. ENVISAGE world emission growth in baseline (BAU) and mitigation (NDC-NZ Pathway) appear to be under the TIAM model baseline (BAU) and 2º C mitigation (2.0C) growths.

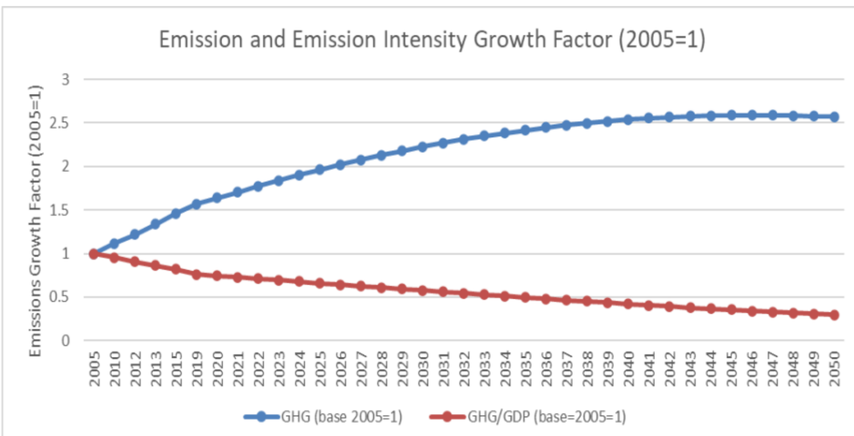


Figure C 3. Emission and emission intensity growth trajectories for India in BAU Scenario

Notes. Horizontal axis shows year and vertical axis shows annual percentage change. We see India's growth trajectories for emission and emission intensity between 2005 and 2050 (indexed wrt 2005 levels = 1). The blue line shows GHG emissions growth, and the red line shows emission intensity of GDP growth in India.

Table C 1. Carbon Price Trajectories used in BAU, 2014 USD / ton of CO2.

Year\region	EU	China	Rest of high-income countries
2021	33.6	7.5	33.6
2022	37.3	8.6	37.3
2023	40.9	9.5	40.9
2024	44.6	10.5	44.6
2025	48.2	11.6	48.2
2026	51.9	12.9	51.9
2027	55.5	14.3	55.5
2028	59.2	15.8	59.2
2029	62.8	17.5	62.8
2030	66.4	19.3	66.4
2031	68.4	19.9	68.4
2032	70.5	20.5	70.5
2033	72.6	21.1	72.6
2034	74.8	21.8	74.8
2035	77	22.4	77
2036	79.3	23.1	79.3
2037	81.7	23.8	81.7
2038	84.2	24.5	84.2
2039	86.7	25.2	86.7
2040	89.3	26	89.3
2041	92	26.7	92
2042	94.7	27.6	94.7
2043	97.6	28.4	97.6
2044	100.5	29.2	100.5
2045	103.5	30.1	103.5
2046	106.6	31	106.6
2047	109.8	31.9	109.8
2048	113.1	32.9	113.1
2049	116.5	33.9	116.5
2050	120	34.9	120

Notes. We closely follow Chepeliev et al (2023) to make implement the baseline carbon prices. These prices are only imposed on the energy intensive sectors.

Table C 2. Assumption in the baseline/BAU scenario

No.	Assumption	Details
1	Declining cost of renewables over time	The costs of renewable energy sources are decreasing over time. A hyperbolic specification is used to model this cost reduction, which has a cost asymptote. We calibrated the cost curve using three parameters: the asymptote relative to current costs, a targeted reduction, and the year when the target is achieved. For wind and solar energy, we assume that the cost asymptote is 60% of current price, decreasing by 30% between 2014-2050. For other renewables, we assume that the cost asymptote is 70% of current price, and the costs decline is by 20% between 2014-2050.
2	Non-Price Preference related 'twists' relative to other commodities, keeping the aggregate costs same	We set a goal for the proportion of renewable electricity in the total electricity demand, implementing the adjustment with the assumption that prices remain unchanged relative to the base year. Table B2a below reports the shares assumed. Due to the decreasing costs and advancements in other power activities, the actual shares will likely be higher. In countries with no renewable energy share in the benchmark year of 2014, renewables are not considered new technology.
		We assume that by 2050, the share of electricity consumption (in total energy consumption) will double for all modeled sectors other than transportation. For air transport, we assume a times increase in electricity consumption, while road and water transport are expected to see a fourfold increase. For households, we expect electrification rates to triple. Finally, we assume that all other sectors have capped the share of electricity in total energy use at 95%.
3	Armington Twist	An Armington twist was applied in 2014 to account for a higher preference for import demand. This adjustment is essential since the import-to-domestic-demand ratio was initially low in the baseline. We assume a 25% increase in import share in 2014, accompanied by a modest annual growth rate of 5%.
4	Phantom tax (India only)	We employ revenue-neutral phantom taxes to control preferences in the power bundle. We restrict changes to oil power and increase nuclear power preference by 5% annually.
5	Energy efficiency improvements	We model the energy efficiency improvements using the autonomous energy efficiency improvement parameter (AEEI). The country specific AEEIs range between 1.5 and 3.0, and they are differentiated by countries, energy commodities, and agents. We see AEEIs to equal 0 for transformation activities and fossil fuel-based power generation. For heavy metals, minerals and chemical sectors which are energy intensive, we assume AEEIs to equal 1 and 1.5 for high-income and developing countries, respectively. In developing

	nations with rapid GDP growth rates, AEEIs are assumed to be larger, while in advanced economies, they are assumed to be lower. The average AEEIs fall between about 1.0 and 2.0 percent when the varied AEEI assumptions among nations, energy commodities, and agents are taken into account.

Note. We closely follow Chepeliev et al (2022) to make our baseline assumptions, particularly (1) and (5); and van der Mensbrugghe (2019) for assumption (2).

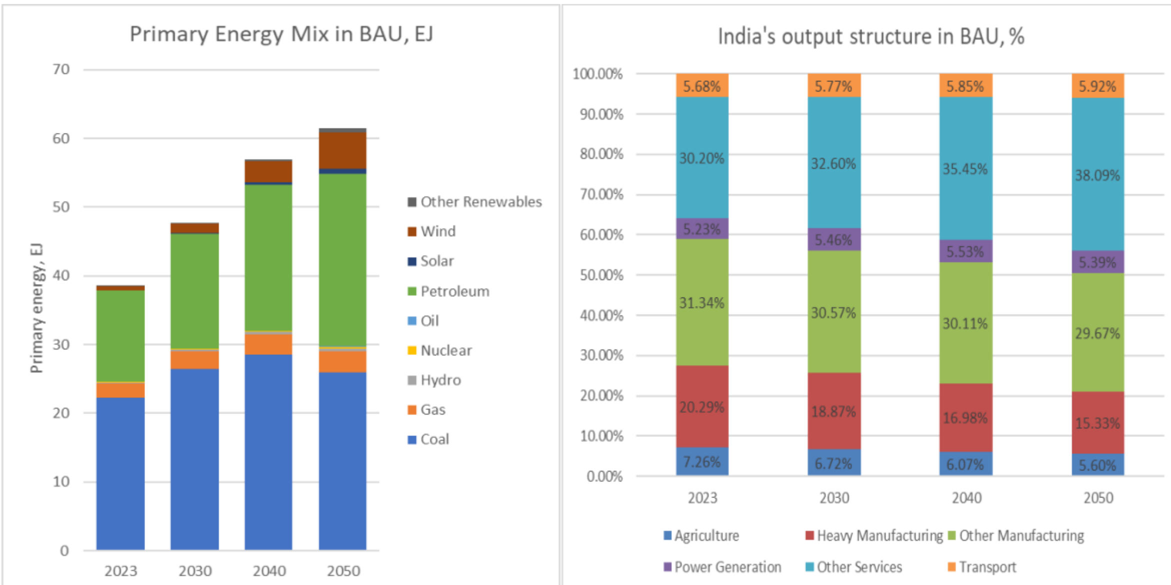
Table C 3. Share on renewables in power generation under baseline scenario by target year 2050, %

Region	Targeted share
United States (USA)	40
European Union (EUR)	45
India (IND)	25
China (CHN)	35
Rest of East Europe (ECA)	25
Middle East and North Africa (MNA)	20
Latin America and Caribbean (LAC)	25
Sub-Saharan Africa (SSA)	25
Rest of East Asia (XEA)	25
Rest of South Asia (XSA)	25
Rest of high income countries (XHY)	40

Table C 4. Historical evolution of coal cess rates in India

Year	Coal cess rate (INR per tonne)	Coal cess rate (USD per tonne)
2010	50	1.11
2014	100	1.64
2015	200	3.08
2016	400	5.97

*Notes. *USD conversion rates based on the average annual exchange rate for each year was used to convert these values to USD per tonne. The coal cess rate has remained fairly constant since 2016, as there has been no announcement of any changes so far.*



Panel (a) Panel (b)

Figure C 4. Energy Mix and output structure in BAU

Notes. Panel a shows primary energy mix in extra joules under BAU scenario. Panel b shows share of sectoral output in total output in percentage under BAU scenario. Horizontal axis shows years.

Table C 5. Average carbon price in USD $/tCO2 for select years

Year	IND	ROW Average (excluding IND)
2023	1.42	10.13
2030	7.56	24.89
2040	33.86	35.07
2050	159.66	49.77

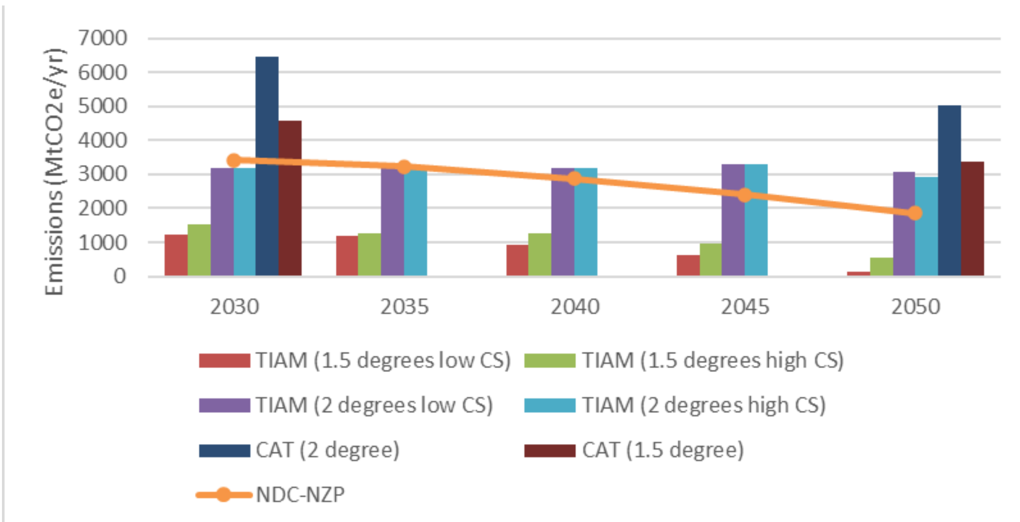


Figure C 5. Comparing India's NDC-NZ Pathway with other emission trajectories, MtCO2eq

Notes: Horizontal axis displays years in 5-year intervals, and the vertical axis shows emissions. The line represents emissions in our NDC-NZ mitigation scenario. The bars depict expected emission levels from various sources for comparison with our mitigation trajectory: (1) TIAM 1.5 Low CS: Mitigation from the TIAM model under the SSP2 scenario with low carbon storage, consistent with NZ emissions in India by 2070 and limiting global temperature rise to 1.5°C. (2) TIAM 1.5 High CS: Same as (1), but with high carbon storage. (3) TIAM 2 Low CS: Same as (1), but consistent with a 2°C temperature rise. (4) TIAM 2 High CS: Same as (2), but consistent with a 2°C temperature rise. (5) CAT 2° C (upper limit): Mitigation consistent with India's unconditional NDC goal, placing India in the fair share range to limit global temperature rise to 2°C (lower limit= 3389). (6) CAT 1.5° C (upper limit): A more stringent goal aligned with the 1.5°C target of the Paris Agreement (lower limit = 469Gt). (The models have different assumptions for emission trajectories but despite that NDC-NZ fall under the 2°C emission levels).

APPENDIX D. ADDITIONAL RESULTS

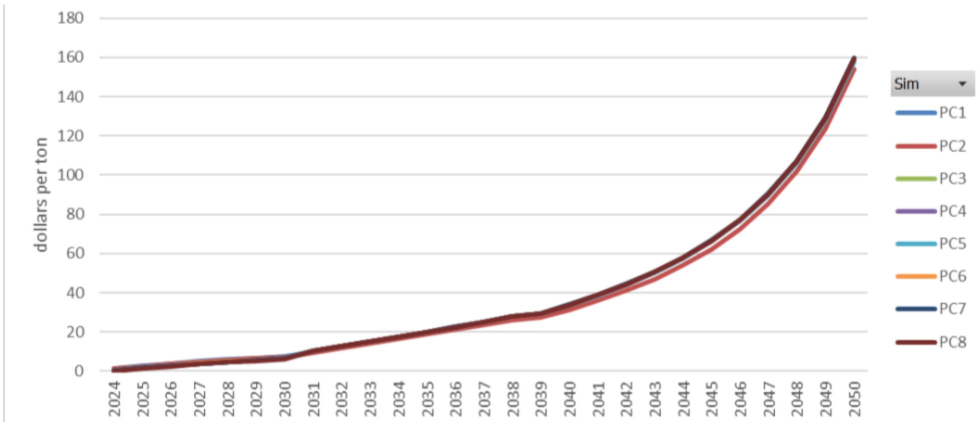


Figure D 1. Annual carbon price in USD \$/tCO2 between 2023-2050

Notes. Horizontal axis shows year and vertical axis shows the carbon price in US dollars per ton of CO2e emission. The legend shows PC1-PC8 policy simulations.

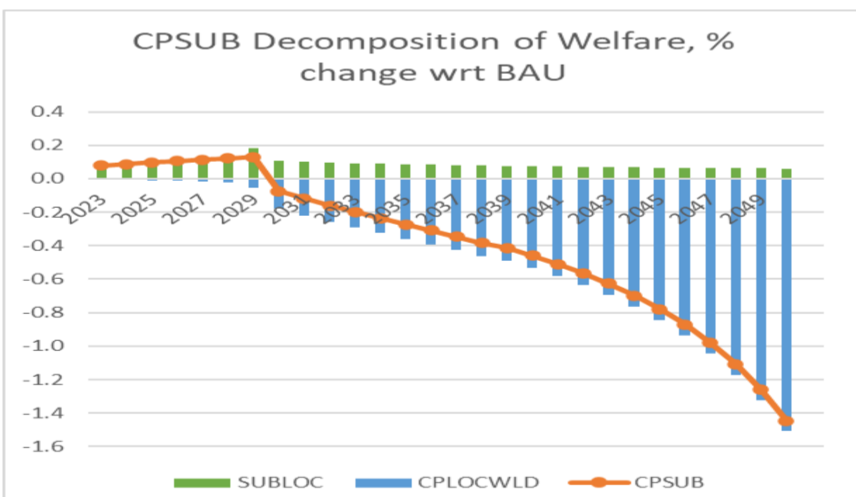


Figure D 2. Decomposition of welfare change from CPSUB, % change wrt BAU

Notes. Horizontal axis shows year and vertical axis shows % change in welfare (EV) relative to BAU. The net welfare change under policy mix CPSUB (orange line) is the sum of the change in welfare from (1) only by fossil subsidy phase-out or SUBLOC (green bars) between 2023-2029; and (2) carbon pricing in India and the rest of the world or CPLOCWLD (blue bars).

Table D 1. Macroeconomic Measures, % changes w.r.t BAU in 2050

	Panel A. Policy mixes			Panel B. Alternate revenue recycling				
	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUB)	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
GDP	-1.94%	-1.97%	-1.97%	-1.98%	-2.14%	-1.97%	-1.97%	-1.96%
C	-0.98%	-1.02%	-1.04%	-1.04%	-1.00%	-1.04%	-1.04%	-1.05%
I	-3.84%	-3.91%	-3.83%	-3.87%	-4.54%	-3.86%	-3.85%	-3.85%
PEXP	0.58%	0.56%	0.57%	0.57%	0.63%	0.57%	0.57%	0.56%
PIMP	-0.60%	-0.55%	-0.60%	-0.60%	-0.64%	-0.60%	-0.60%	-0.61%
EVT	-1.44%	-1.49%	-1.43%	-1.43%	-1.59%	-1.44%	-1.43%	-1.44%
TOT	1.18%	1.11%	1.18%	1.18%	1.27%	1.18%	1.18%	1.18%
Output	-3.80%	-3.91%	-3.78%	-3.79%	-4.02%	-3.78%	-3.79%	-3.61%
DWA	-0.481	-0.516	-0.432	-0.432	-0.490	-0.432	-0.432	-0.430

Notes. The export and import indices reflect the compound changes, due to changes in values of the export and import bundles relative to the baseline, similar to the fisher's index.[33] *DWA= discounted welfare from aggregate expenditure. Calculations shown with r= 2%.*

Table D 2. Nominal exports, changes w.r.t BAU in billion USD

Scenario	Agriculture	Manufacturing	Other	Services	Total
PC1 (CP)	0.930	-86.764	-0.316	2.624	-83.525
PC2(CPCESS)	0.988	-84.346	-0.336	3.823	-79.871
PC3(CPSUB)	0.922	-86.613	-0.316	2.658	-83.349
PC4 (RADD)	0.933	-86.816	-0.317	2.618	-83.581
PC5(REQL)	0.850	-90.237	-0.330	1.749	-87.968
PC6(RFAC)	0.952	-86.356	-0.310	2.742	-82.971
PC7(RLAB)	0.926	-86.676	-0.317	2.649	-83.417
PC8(RGNRG)	0.986	-85.603	-0.302	2.452	-82.467

[33] For example, PEXP index in simulation w.r.t. to baseline is given by the formula $\left(\frac{PXIND_{sim}}{PXIND_{bau}}\right) = \left(\sqrt{\frac{\sum_{i,s} PX_{i,s}^{sim} QX_{i,s}^{bau}}{\sum_{i,s} PX_{i,s}^{bau} QX_{i,s}^{bau}} * \frac{\sum_{i,s} PX_{i,s}^{sim} QX_{i,s}^{sim}}{\sum_{i,s} PX_{i,s}^{bau} QX_{i,s}^{sim}}}\right) * 100,$ and PIMP in simulation w.r.t. baseline is calculated similarly. Whereas % change in TOT in simulation w.r.t baseline is simply $\left(\frac{PXIND_{sim}}{PXIND_{bau}} * \frac{PMIND_{bau}}{PMIND_{sim}} - 1\right) * 100.$

Table D 3. Changes in welfare (EV) by household deciles, % changes w.r.t BAU in 2050

	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUB)	Subsidy removal effect only (SUBLOC)	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
			CPSUB vs SUBLOC						
U0	-0.66%	-0.73%	-0.61%	0.12%	-0.57%	3.11%	-0.74%	-0.60%	-0.71%
U1	1.02%	0.88%	1.07%	0.14%	0.47%	2.03%	0.02%	0.25%	0.08%
U2	0.69%	0.57%	0.74%	0.13%	0.26%	1.31%	0.10%	0.32%	0.17%
U3	0.45%	0.35%	0.50%	0.12%	0.10%	0.53%	0.17%	0.46%	-0.13%
U4	0.90%	0.78%	0.95%	0.13%	0.44%	0.59%	0.49%	0.72%	0.60%
U5	0.11%	0.03%	0.15%	0.10%	-0.11%	-0.20%	0.16%	0.25%	0.24%
U6	0.39%	0.29%	0.43%	0.10%	-0.05%	-0.48%	0.53%	0.66%	0.64%
U7	-0.27%	-0.33%	-0.24%	0.08%	-0.38%	-1.03%	1.35%	1.50%	1.46%
U8	-0.23%	-0.30%	-0.20%	0.08%	-0.44%	-1.64%	-0.25%	-0.21%	-0.14%
U9	-3.36%	-3.32%	-3.37%	0.02%	-2.62%	-3.11%	-0.40%	-0.40%	-0.31%
R0	-0.85%	-0.89%	-0.81%	0.10%	-0.44%	11.55%	-0.71%	-0.53%	-0.75%
R1	0.15%	0.06%	0.20%	0.11%	0.08%	8.09%	0.63%	0.88%	0.50%
R2	0.26%	0.16%	0.31%	0.11%	0.11%	5.52%	0.38%	0.59%	0.26%
R3	0.29%	0.16%	0.35%	0.08%	-0.16%	3.43%	0.20%	0.34%	0.07%
R4	0.71%	0.61%	0.75%	0.11%	0.46%	3.10%	0.56%	0.80%	0.51%
R5	0.28%	0.21%	0.31%	0.07%	0.12%	1.32%	-0.05%	0.01%	-0.19%
R6	0.79%	0.70%	0.83%	0.09%	0.42%	0.32%	0.16%	0.28%	0.11%
R7	1.76%	1.66%	1.80%	0.09%	1.15%	-0.04%	-0.34%	-0.33%	-0.44%
R8	-0.30%	-0.33%	-0.27%	0.07%	-0.17%	-1.20%	-0.36%	-0.34%	-0.37%

R9	-0.33%	-0.38%	-0.31%	0.06%	-0.44%	-2.31%	-2.80%	-3.07%	-2.93%

Table D 4. Taxes as a share of GDP, % 2050

Tax Share %/Scenario	BAU	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUM), PC4 (RADD) or PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
	Baseline	Direct Household Lumpsum Transfers			Factor Subsidies		Green Energy Subsidies
Net Carbon Tax / GDP	0	1.08	1.05	1.09	1.09	1.09	1.08
Net Direct Tax /GDP	3.41	2.41	2.42	2.40	2.64	2.63	2.64
Net Factor Tax /GDP	0	0	0	0	-0.23	-0.23	-0.23
Net Production Tax/GDP	0	0	0.01	0	0	0	0

Notes. Total value of carbon revenue collected by the government across scenarios is between 287-298 billion USD in 2050. Direct transfers of revenues to households lead to a reduction of approximately 1% in net direct taxes as a percentage of GDP, providing relief from the carbon tax burden and potentially stimulating consumer spending. This approach may enhance political acceptability. On the other hand, if revenues are used to subsidize factors of production like labor or capital, we observe a decrease of around 0.23% in factor taxes as a percentage of GDP and a decline of approximately 0.77% in direct taxes as a share of GDP compared to the baseline scenario (see Appendix C, Table C1). These findings highlight the impact of revenue distribution choices on fiscal indicators and underscore the trade-offs and considerations involved in selecting revenue allocation strategies within the context of carbon pricing.

Table D 5. Changes in wage, % changes w.r.t BAU in 2050

	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUB)	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
Unskilled	-5.53%	-5.73%	-5.47%	-5.51%	-6.16%	-4.90%	-4.31%	-4.67%
Skilled	-1.99%	-2.16%	-1.92%	-1.95%	-2.45%	-1.33%	-0.71%	-0.89%

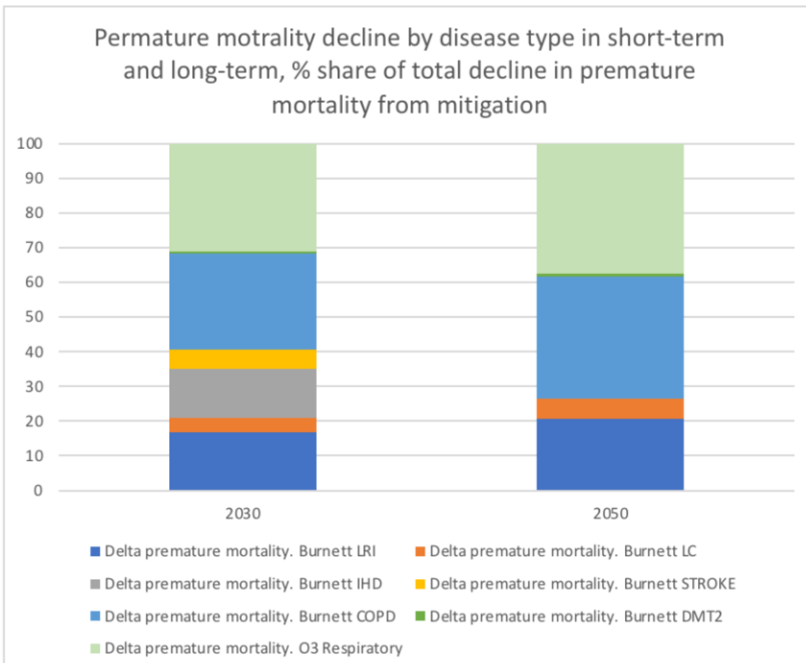


Figure D 3. Premature mortality declines by disease type, % of total premature mortality

Notes. Horizontal axis shows years and vertical axis shows the reduced premature mortality due to lower pollution in 2030 (left) and 2050 (right) under the NDC-NZ scenario mitigation from the six different kind of diseases and O3 related respiratory diseases in TM5-FAAST model.

APPENDIX E. SECTORAL IMPACTS DETAILS

Table E 1. Sectoral impacts, % changes w.r.t BAU in 2050

Sectors	PC1 (CP)	PC2 (CPCESS)	PC3 (CPSUB)	PC4 (RADD)	PC5 (REQL)	PC6 (RFAC)	PC7 (RLAB)	PC8 (RGNRG)
HYD-a	40.16%	40.02%	40.28%	40.21%	39.25%	40.23%	40.25%	41.94%
WND-a	39.82%	39.77%	39.84%	39.82%	39.53%	39.83%	39.83%	40.14%
SOL-a	39.40%	39.25%	39.52%	39.45%	38.46%	39.48%	39.49%	39.94%
XEL-a	30.11%	30.27%	30.12%	30.10%	30.00%	30.11%	30.11%	30.05%
ETD-a	6.56%	6.56%	6.58%	6.56%	6.34%	6.57%	6.58%	6.68%
WTP-a	5.26%	5.46%	5.26%	5.26%	5.24%	5.27%	5.26%	5.23%
FRS-a	1.74%	1.67%	1.76%	1.72%	1.51%	1.77%	1.74%	1.73%
ATP-a	1.61%	1.77%	1.64%	1.62%	1.44%	1.64%	1.63%	1.64%
WHT-a	1.02%	1.05%	1.03%	1.01%	1.06%	1.03%	1.02%	1.06%
PRX-a	0.65%	0.67%	0.67%	0.64%	0.71%	0.65%	0.66%	0.66%
crp-a	0.31%	0.33%	0.32%	0.31%	0.29%	0.33%	0.32%	0.35%
RIC-a	0.30%	0.30%	0.32%	0.28%	0.40%	0.29%	0.31%	0.28%
TWP-a	0.26%	0.37%	0.28%	0.25%	0.18%	0.27%	0.27%	0.27%
PRM-a	0.25%	0.28%	0.29%	0.23%	0.26%	0.25%	0.27%	0.22%
NUC-a	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
OLP-a	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B_T-a	0.01%	-0.01%	0.03%	-0.02%	0.17%	-0.01%	0.01%	-0.03%
PRD-a	-0.19%	-0.23%	-0.17%	-0.22%	-0.03%	-0.21%	-0.18%	-0.23%
lvs-a	-0.33%	-0.36%	-0.31%	-0.27%	-0.42%	-0.28%	-0.30%	-0.27%
SRV-a	-0.56%	-0.58%	-0.54%	-0.54%	-0.63%	-0.54%	-0.54%	-0.55%
PPP-a	-1.28%	-1.22%	-1.26%	-1.27%	-1.42%	-1.25%	-1.26%	-1.22%
OTP-a	-3.23%	-3.18%	-3.21%	-3.23%	-3.34%	-3.22%	-3.22%	-3.20%
CNS-a	-3.98%	-4.02%	-3.97%	-4.00%	-4.54%	-4.00%	-3.99%	-3.99%
CME-a	-5.53%	-5.36%	-5.49%	-5.51%	-5.90%	-5.48%	-5.50%	-5.40%
NFM-a	-5.71%	-5.56%	-5.68%	-5.71%	-6.23%	-5.68%	-5.70%	-5.57%
XMN-a	-5.84%	-5.80%	-5.82%	-5.84%	-6.34%	-5.83%	-5.83%	-5.78%
OIL-a	-7.43%	-7.13%	-7.53%	-7.54%	-8.07%	-7.00%	-7.53%	-6.63%
P_C-a	-6.90%	-6.83%	-6.89%	-6.88%	-7.08%	-6.86%	-6.89%	-6.85%
OXT-a	-7.92%	-7.82%	-7.90%	-7.93%	-8.33%	-7.86%	-7.92%	-7.75%
NMM-a	-8.42%	-8.45%	-8.42%	-8.45%	-8.90%	-8.44%	-8.43%	-8.41%

MET-a	-14.55%	-14.52%	-14.53%	-14.56%	-14.98%	-14.55%	-14.55%	-14.46%
GAS-a	-33.17%	-32.39%	-33.13%	-33.17%	-33.65%	-33.05%	-33.14%	-33.08%
GSP-a	-61.55%	-60.32%	-61.55%	-61.58%	-61.41%	-61.55%	-61.56%	-61.92%
COA-a	-81.85%	-88.93%	-81.85%	-81.85%	-81.82%	-81.83%	-81.85%	-81.80%
CLP-a	-91.97%	-92.13%	-91.98%	-91.98%	-91.81%	-91.99%	-91.98%	-92.03%

Table E 2. Share of power generation by source in 2050, %

Scenarios\ Source	Fossil	Nuclear	Renewable
BAU	28.67%	3.27%	68.06%
PC1 (CP)	7.72%	3.12%	84.16%
PC2(CPCESS)	7.77%	3.12%	89.11%
PC3(CPSUB)	7.71%	3.12%	89.17%
PC4 (RADD)	7.71%	3.12%	89.17%
PC5(REQL)	7.77%	3.13%	89.11%
PC6(RFAC)	7.71%	3.12%	89.17%
PC7(RLAB)	7.71%	3.12%	89.17%
PC8(RGNRG)	7.47%	3.10%	89.43%