ASSESSING THE IMPLICATIONS OF A GLOBAL NET-ZERO TRANSITION FOR DEVELOPING ASIA

INSIGHTS FROM INTEGRATED ASSESSMENT MODELING

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ABSTRACT

This paper uses a global integrated assessment model to assess how developing Asia, the world's fastest-growing source of carbon emissions, could transition to low-carbon growth. It finds that national net-zero pledges do not have a high chance of keeping peak warming below 2°C. Under an efficient approach to achieve the Paris Agreement goals, the power sector would almost fully decarbonize by mid-century, and emissions from land use would strongly fall. Although the climate has a lagged response to emissions reductions, climate benefits outweigh costs by a factor of 3, with gains concentrated in the lowest-income subregions of Asia. Air quality would also improve, saving about 0.35 million lives in the region by 2050. Including these co-benefits raises the benefit–cost ratio for Asia under ambitious decarbonization to 5. Energy-related employment also rises during the transition. However, appropriate policies are needed to address potential effects on disadvantaged groups.

Keywords*:* climate change, greenhouse gas, mitigation, energy, land use, net-zero, NDCs

JEL codes*:* C61, D58, Q52, Q53, Q54

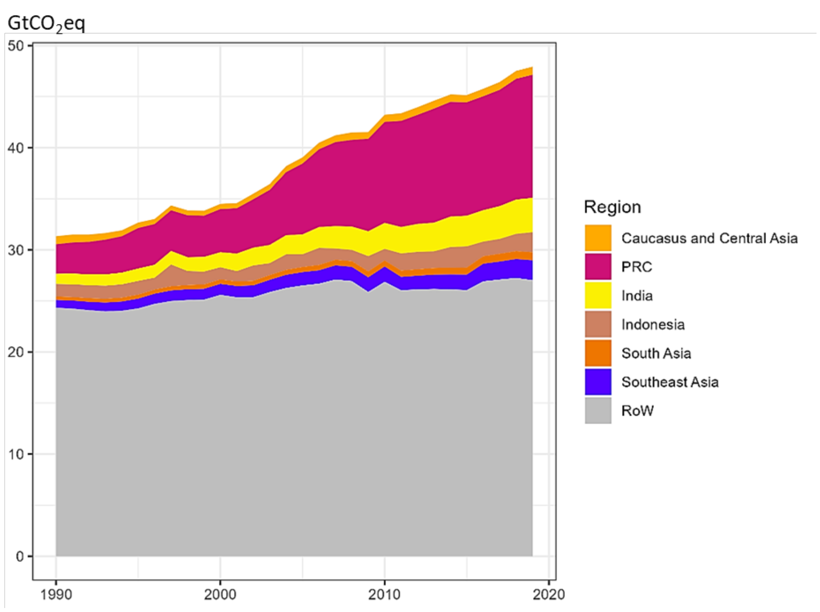
This paper presents much of the modelling that underpins *Asia in the Global Transition to Net Zero: Asian Development Outlook 2023 Thematic Report* and was initially prepared as a draft background paper prior to that report.

1. Introduction

Developing Asia is vulnerable to climate change. The geography of the region exposes much of the population to climate-related risks, while coping ability is impeded by limited socioeconomic development in many economies. According to the 2021 Climate Risk Index, 6 out of the 10 economies most affected by weather-related loss events such as floods, storms, landslides, and heatwaves during 2000–2019 were in developing Asia.

At the same time, the region is increasingly a contributor to climate change, with its share of global greenhouse gas (GHG) emissions increasing from 26% in 2000 to 44% in 2019. The People's Republic of China (PRC), Southeast Asia (particularly Indonesia), and India all experienced substantial growth in emissions, while South and Central Asia experienced only modest increases (Figure 1). Yet, per capita emissions from the region remain lower than the global average to date.

Figure 1: Greenhouse Gas Emissions, 1990–2020

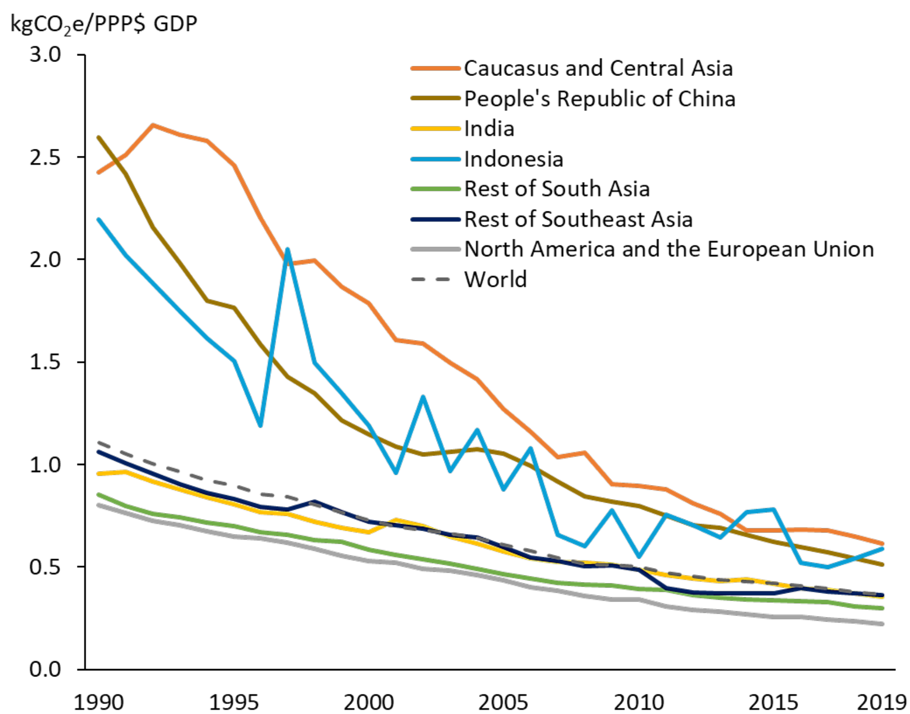


$GtCO_2eq$ = billion tons of carbon dioxide equivalent; PRC = People's Republic of China, RoW= rest of the world.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' calculations from World Resources Institute. Climate Watch (accessed February 2023).

Energy accounts for close to 75% of GHG emissions from the region, with electricity generation a major contributor. Agriculture, land use, and forestry are also important sources of emissions in the region, especially in Southeast Asia and the Pacific. Carbon intensity in developing Asia is 41% higher than the global average, so that each unit of economic activity is associated with higher emissions. Intensity fell rapidly in the 1990s and early 2000s in the PRC and Caucasus and Central Asia but has remained stable since 2010 (Figure 2).

Asia's future growth has important implications for climate change. In 2017, about one billion people in the region were still living on less than $3.20 a day in purchasing power parity (PPP) terms, implying much potential for future income increases. Meanwhile, an estimated 940 million people in the region experience frequent power interruptions, and about 350 million do not have adequate power supply (IEA 2020), so that energy needs will continue to increase.

Figure 2: Carbon Intensity in Developing Asia and the World, 1990–2019



GDP = gross domestic product, $kgCO_2e$ = kilogram per carbon dioxide equivalent, PPP = purchasing power parity.
Note: Emissions from land use change and forestry, which can be positive or negative, are included.
Source: Authors' calculations from World Resources Institute. Climate Watch (accessed February 2023).

Policymakers in economies around the world, including in developing Asia, have recognized the need to limit global warming. The Paris Agreement, agreed upon by 196 parties, seeks to limit global warming to well below 2 degrees Celsius (°C) and pursue efforts to 1.5°C compared to pre-industrial levels. Under the agreement, parties submit nationally determined contributions (NDCs) to reduce future GHGs and increase adaptation to climate change. NDCs were initially submitted in 2015, covering until 2030, but they are insufficient to achieve Paris Agreement goals (UNFCCC 2022).

At the same time, an expanding number of economies have pledged to achieve carbon neutrality, or net-zero emissions, by specific target years. As of late 2022, 140 economies globally had announced or were considering targets for net-zero emissions. Of this number, 19 developing Asian economies, accounting for approximately 80% of the region's 2019 total GHG emissions, have put forward net-zero pledges. Yet, only a few are written into law, and only a few governments in the region have developed long-term strategies under the Paris Agreement.[1]

Article 6 of the Paris Agreement contains a provision for linking national commitments through internationally transferred mitigation outcomes (ITMOs). However, there is lack of clarity on the potential of ITMOs to improve the economic efficiency of the Agreement. While the Paris Agreement also creates provisions for a "sustainable development mechanism" as a global emissions offset market, details are yet to be resolved.

Against this background, this paper analyzes what pursuing different climate policies would mean for developing Asia. Section 2 details the methodology, including the modeled scenarios, while the rest of the paper examines the transformations required in energy and land use and their socioeconomic implications.

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[1] Global net zero emissions are achieved when anthropogenic emissions of GHGs in the atmosphere are balanced by anthropogenic removals over a specific period (IPCC 2018). National net zero pledges seek to achieve a balance of emissions and removals at the national level.

2. Methodology

2.1 Scenario Design

This paper examines the implications of climate policies on developing Asia based on five core scenarios (Table 1). These scenarios represent some of the key policy choices confronting policymakers. All five scenarios follow the “middle of the road” shared socioeconomic pathway (SSP2) agreed on by the international modeling community for population and economic growth (Riahi et al. 2017).

- **Current policies** include the enacted energy and climate policies in all economies until 2020. A complete list of policies is detailed in the Appendix. No further strengthening of policies is assumed in this scenario. This scenario serves as the reference against which all scenarios are compared. Where NDCs and more specific sector policies diverge, this scenario reflects sector policies rather than NDCs. This is similar to how the 6th Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) defines current policies (IPCC 2022a).
- **NDC effort** assumes the implementation of unconditional NDCs until 2030.[2] There is gradual strengthening of NDC efforts afterwards, with the implicit carbon price in each region assumed to grow at the social discount rate, which is approximately 3% (Aldy et al., 2017). The scenario includes energy constraints, such as the PRC’s solar and wind capacity targets and Europe’s 55% emissions-reduction target for 2030. When energy constraints are not specified or are not implementable, targets for emissions are met using a cost-optimal strategy imposed by the scenario’s regional carbon tax

[2] Pledges that countries would undertake if international support were provided or other conditions are met. This paper considers pledges submitted to the United Nations Framework Convention on Climate Change (UNFCCC) portal until 22 June 2022.

extrapolation. The Appendix provides more details on the interpretation and implementation of NDCs.

- **Uncoordinated net-zero** implements unconditional NDCs until 2030 followed by national net-zero pledges for economies with such pledges. It represents an uncoordinated effort of parties using the "pledge and review" framework of the Paris Agreement. Economies pledge emission reductions voluntarily, without considering if such pledges are sufficient to achieve Paris Agreement goals. For economies without net-zero pledges, this follows the NDC effort scenario.[3] The Appendix provides more details on net-zero pledges included in the paper.

The final two modeled scenarios can be considered as more optimal alternatives to the current bottom-up approach of the Paris Agreement. Under these scenarios, global climate policy is more coordinated than has been the case so far. Both scenarios are implemented under a carbon budget of 1,150 billion tons of carbon dioxide ($GtCO_2$).[4] After exhausting the budget, emissions need to stay close to zero to keep peak warming well below 2°C, or an average peak warming of 1.7°C. This is unlike older studies that relied on optimistic assumptions about negative emissions technology being able to draw down excess GHG concentrations in the late 21st century to compensate for an overshoot of the carbon budget (Drouet et al. 2021, Riahi et al. 2021).

A global carbon market allocates emission allowances among economies via a "contraction and convergence" framework that transitions from grandfathered emission shares to

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[3] In this paper, net zero refers only to net zero of CO_2 emissions, and this is a standard approach in the literature (e.g., Meinshausen et al., 2009; and Millar et al. 2017). Only national net zero pledges that were tagged "achieved," "documented," and "declared" in the UNFCCC's long-term strategies website and the World Resources Institute Net-Zero Tracker and confirmed by documents and online national and international media were considered. Information on the pledges were analyzed and confirmed by documents and online national and international news. Whenever information from ENOVATE (2022) could not be confirmed through other documents or information sources, the pledge was tagged as "proposed" and was not considered. This was the case for several countries that appeared in ENOVATE (2022) as "proposed/in discussion" and were only mentioned at the 2019 United Nations Climate Change Conference (COP25).

[4] The total carbon budget is expressed relative to 2020.

equal per-capita allowances by 2050 (Meyer 2000). Emissions respond to a global carbon price that triggers optimal abatement for the globe to stay within the global carbon budget. Economies that emit more than their allowances compensate economies that emit less than their allowances based on the carbon price.

Table 1: Climate Policy Scenarios

Scenario	NDCs until 2030	2030 to Net-Zero Year	International Carbon Trade	Carbon Emissions 2020–2100
Current policies	Not reflected	Current policies	No	3,270 $GtCO_2$ (endogenous)
NDC effort	Unconditional	NDCs extrapolated	No	2,650 $GtCO_2$ (endogenous)
Uncoordinated net-zero	Unconditional	Net-zero pledges	No	1,420 $GtCO_2$ (endogenous)
Global net-zero	Unconditional	Fast transition	Yes	1,150 $GtCO_2$
Accelerated global net-zero	Beyond NDCs	Fast transition	Yes	1,150 $GtCO_2$

$GtCO_2$ = billion tons of carbon dioxide, NDC = nationally determined contribution.
Source: Authors.

These additional scenarios include the following:

- **Global net-zero** assumes unconditional NDCs until 2030 and a coordinated global effort thereafter, to stay within a carbon budget.
- **Accelerated global net-zero** follows the previous (global net-zero) scenario, except that global efforts are accelerated from 2023, rather than after 2030.

2.2 Model Implementation

The paper uses the World Induced Technical Change Hybrid (WITCH) model to explore mitigation pathways under the five scenarios. Currently being developed at the RFF-CMCC European Institute on Economics and the Environment (EIEE), WITCH is a dynamic optimization model of the world economy specifically designed to assess climate policies (Bosetti et al. 2006, Emmerling et al. 2016). The model covers energy system transition, land-use change, and climate and economic variables in a comprehensive integrated assessment model (IAM).

IAMs have been widely used to develop and evaluate socioeconomic and environmental pathways, and more recently, Paris-compatible emissions pathways (Rogelj et al. 2018, Weyant 2017). In IPCC's AR6 report, over 1,200 scenarios developed and implemented in IAMs (over 100 in the WITCH model) have been used prominently to assess costs; benefits; economic, environmental, and energy-related implications of different climate targets; and other variations in key assumptions.[5]

WITCH includes electricity generation from fossil fuels (natural gas combined cycle, fuel oil, pulverized coal, and integrated gasification combined cycle coal power plants) and non-fossil sources (onshore and offshore wind turbines, solar photovoltaic panels, concentrated solar photovoltaics, hydroelectric, biomass, nuclear, and two carbon-free backstop technologies representing technological options that are still quite far from commercialization, for long-term scenarios). Carbon capture and storage (CCS) can be added to coal, gas, and biomass. Grid integration is modeled considering flexibility constraints that trace to generation type, capacity constraints, and grid storage and capital. Beyond electricity, the use of coal, oil, and traditional biomass are incorporated both generally and specifically for transport (including by international aviation, shipping, and road).

WITCH is linked to the Global Biosphere Management Model to include emissions from forestry, land-use change, and agriculture, and to the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) to translate emissions into global temperature changes. The model features endogenous representation of research and development (R&D) and diffusion and innovation processes, allowing it to reflect how R&D investments in energy efficiency and carbon-free technologies integrate with currently available mitigation options. While the model

[5] See Pindyck (2017), Keppo et al., (2021), and Stern et al. (2022) for a discussion of these assumptions, criticisms, as well as recent model developments in WITCH such as published in Bosetti et al. (2013), Drouet et al. (2021), Emmerling et al. (2020), and Krey et al. (2018).

typically covers 17 world regions, the version for this paper separates Caucasus and Central Asia from the transition economies to model results for 18 regions (Table 2).[6]

Table 2: Regional Aggregation Used for Modeling

	Regions and Economies
1	People's Republic of China
2	India
3	Indonesia
4	**Caucasus and Central Asia:** Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyz Republic, Mongolia, Tajikistan, Turkmenistan, and Uzbekistan
5	**Rest of Southeast Asia:** Brunei Darussalam, Cambodia, Lao People's Democratic Republic, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Viet Nam
6	**Rest of South Asia:** Afghanistan, Bangladesh, Bhutan, Maldives, Nepal, Pakistan, and Sri Lanka
7	**Oceania:** Pacific island economies, Australia, New Zealand, and Papua New Guinea
8	Canada
9	Hong Kong, China; Japan; Macau, China; Republic of Korea; and Taipei,China
10	South Africa
11	Brazil
12	Mexico
13	Rest of Latin America and Caribbean (excluding Brazil and Mexico)
14	Middle East and North Africa
15	Europe
16	Rest of Sub-Saharan Africa (excluding South Africa)
17	Transition Economies: Belarus, Moldova, Russian Federation, Türkiye, and Ukraine
18	United States

Note: Effective 1 February 2021, ADB placed a temporary hold on sovereign project disbursements and new contracts in Myanmar. ADB placed on hold its regular assistance in Afghanistan effective 15 August 2021.
Source: Authors.

3. Emissions Pathways

Global emissions trajectories and the resultant mean warming by the end of the century are summarized in Figure 3. Under the current policies scenario, cumulative global GHG emissions will reach 3,270 $GtCO_2$ by 2100, leading to mean warming of 3.0°C (Figure 3[a]). Developing Asia will contribute to about 44% of annual GHG emissions until mid-century. Under the NDC effort scenario, global emissions will taper to 2,650 $GtCO_2$ by 2100, which is still not enough mitigation to achieve Paris Agreement goals, with mean warming of 2.4°C. Including national net-zero

[6] WITCH. https://www.witchmodel.org/.

pledges generates a more dramatic reduction of emissions under the uncoordinated net-zero scenario, with only 209 GtCO_2e remaining by 2100. This budget is in line with previous findings, including those of Meinshausen et al. (2022) and Birol (2021).

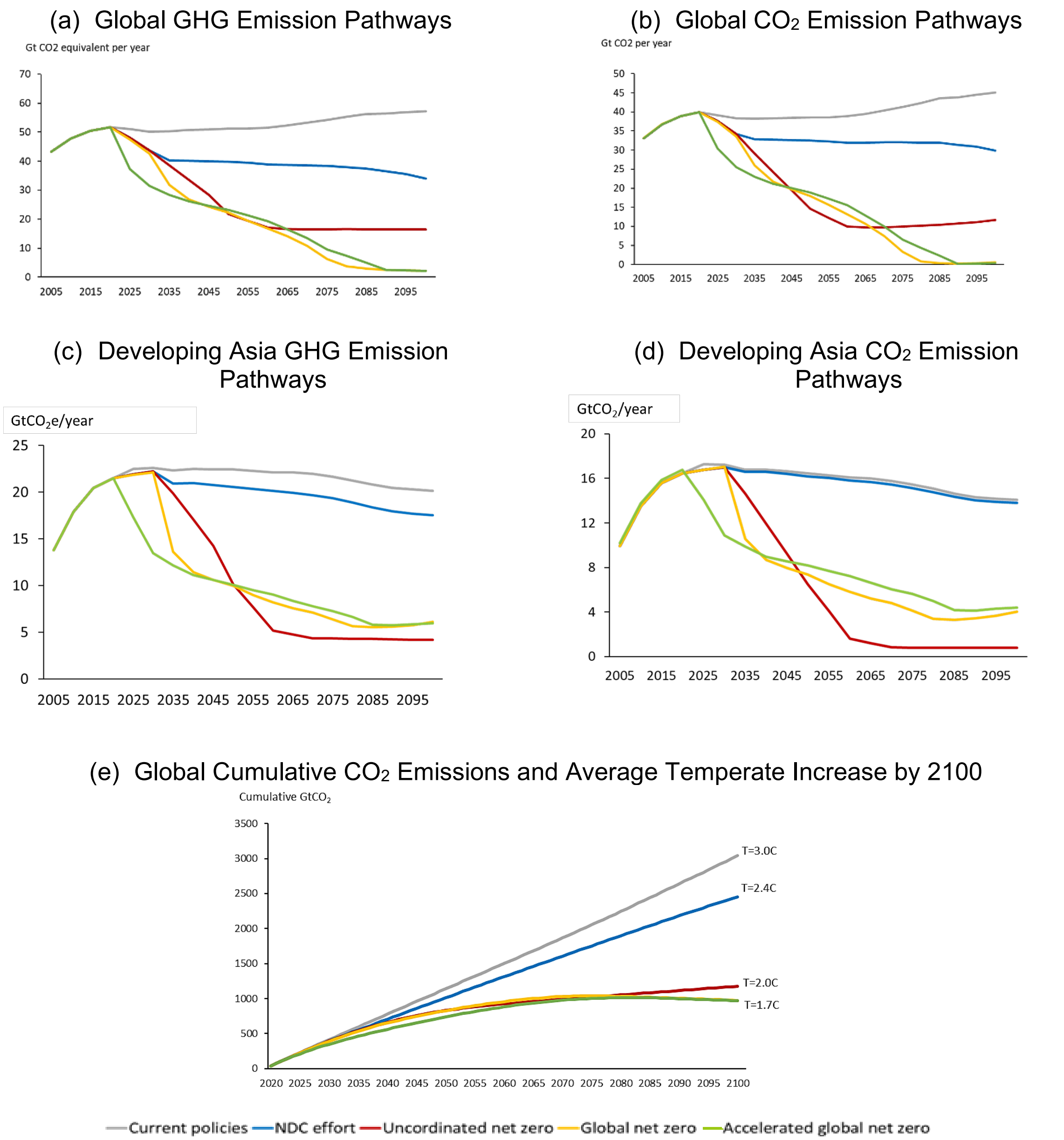
However, the uncoordinated net-zero scenario does not fully achieve Paris Agreement goals, as there is only 50% probability of staying within the 2°C target.[7] This implies that the current NDCs and net-zero pledges do not yet fully achieve Paris Agreement goals, highlighting the need to raise global ambitions and cooperation. Nevertheless, the national voluntary net-zero pledges, if implemented, represent a major step towards an optimal emission pathway.

The Paris Agreement's long-term goal of limiting global warming to well below 2°C is only achieved under the global net-zero and accelerated global net-zero scenarios implemented under stringent carbon budgets. These two scenarios are designed to avoid overshooting of temperatures, which not only reduces the risk of triggering climate tipping points but also significantly lowers the risk of climate change damage (Drouet et al. 2021).

Overall, to meet the Paris Agreement target, the world would achieve net-zero CO_2 emissions by 2075 in the global net-zero scenario and by 2085 under the accelerated global net-zero scenario (Figure 3[b]). The delay in climate action under the global net-zero scenario means that emissions need to fall to net-zero faster to stay within the carbon budget, while early action under accelerated global net-zero scenario allows for a smoother transition.

[7] Well below 2°C is interpreted as a higher-than-67% probability of staying below a 2°C peak temperature increase. This is based on climate category C3 of the IPCC AR6 Working Group III report (IPCC 2022b). The peak temperature is reached in 2080 in the net zero scenarios.

Figure 3: GHG and CO_2 Emission Pathways under the Modeled Scenarios, 2005–2100



CO_2 = carbon dioxide, GHG = greenhouse gas, $GtCO_2$ = billion tons of carbon dioxide, $GtCO_2e$/year = billion tons of carbon dioxide equivalent per year, NDC = nationally determined contribution, T = temperature in 2100.

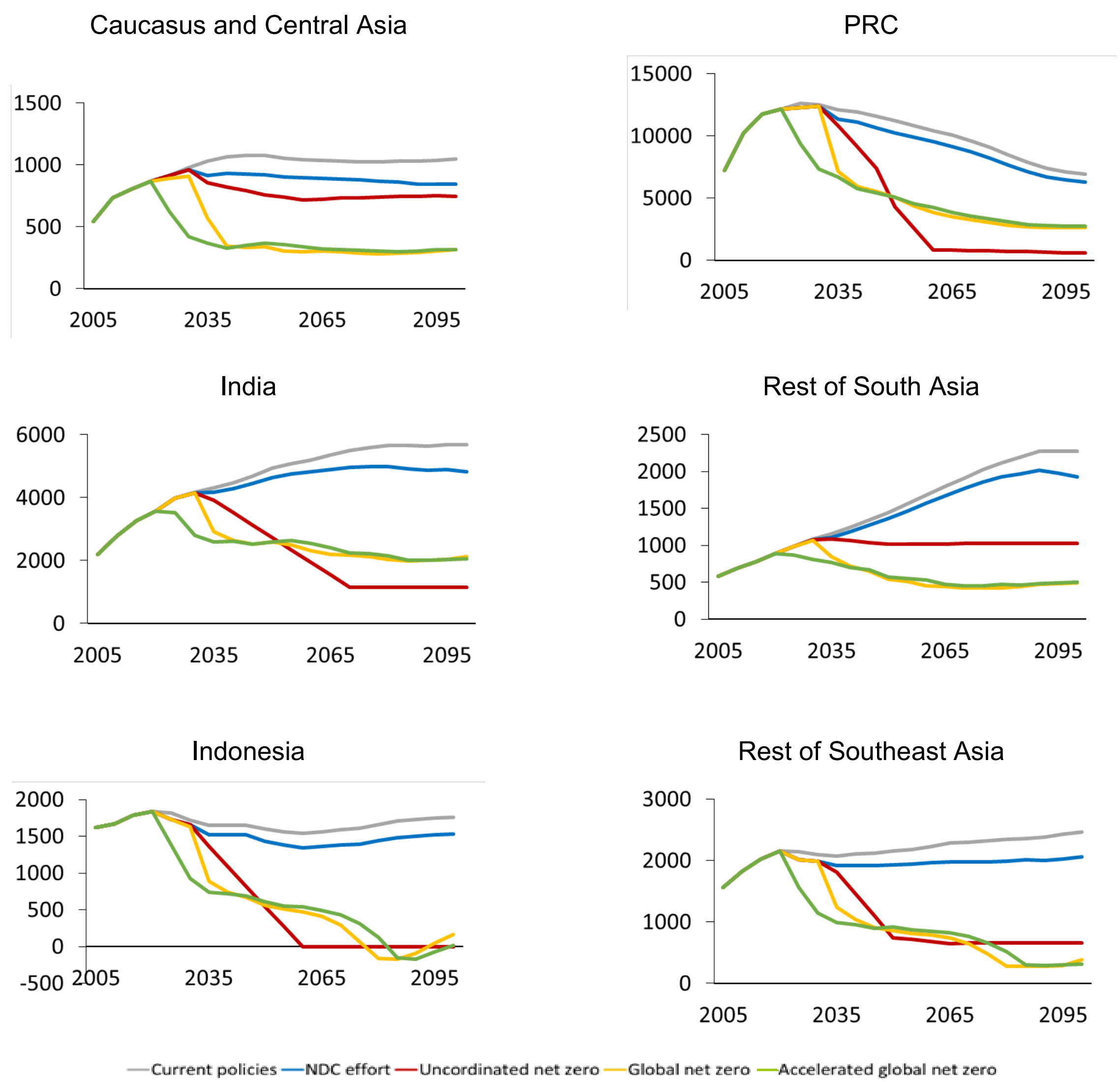
Notes: International shipping and aviation emissions are not included in the global CO_2 emission pathways. All temperatures calculated with MAGICC v6 model.

Source: Authors' estimates.

GHG and carbon dioxide (CO_2) emission pathways of developing Asia are shown in Figure 3(c) and 3(d), respectively. Notably, both CO_2 and all GHG emissions continue to be positive for the region by the end of the century. This implies that, globally, negative emission technologies may be deployed in regions with high potential for storage or afforestation. The uncoordinated net-zero scenario (red line), where economies independently follow through on their pledges, shows a less stringent mitigation pattern until mid-century, after which the net-zero pledges of large economies in the region would lead to a fast phaseout of CO_2 emissions. In the short run, however, the modeled pathway remains significantly below the trajectories for the accelerated and even global net-zero scenarios (green and yellow lines, respectively).

Figure 4: GHG Emission Pathways for Subregions of Developing Asia under the Modeled Scenarios

($MtCO_2e$/year)



$MtCO_2e$/year = million tons of carbon dioxide equivalent per year, NDC = nationally determined contribution, PRC = People's Republic of China.

Source: Authors' estimates.

Figure 4 summarizes the GHG emission pathways of key economies and subregions of developing Asia. The charts reveal a likely strong increase in emissions in most of the region under the current policies scenario, particularly in South Asia. Over the longer term, the PRC would undergo decarbonization, even under the current policies scenario. Under the uncoordinated net-zero scenario, economies with net-zero pledges such as the PRC, India, and Indonesia will require drastic reductions in emissions compared to the more optimal global net-zero scenarios, where global carbon markets lead to a more efficient allocation of mitigation.

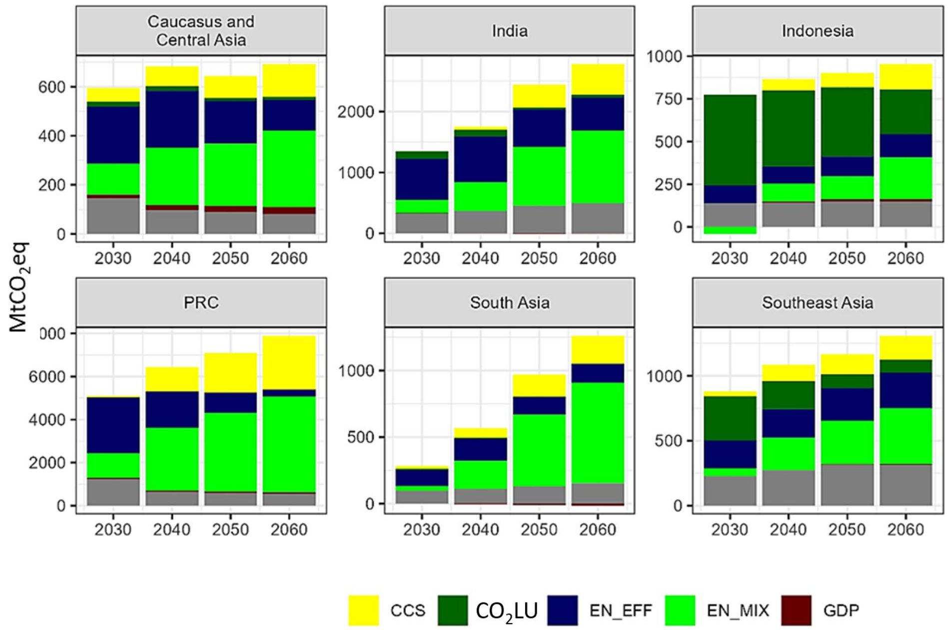
4. Transformation of Key Mitigation Sectors

This analysis decomposes mitigation efforts in developing Asia into contributions from energy efficiency, change in energy mix, non-CO_2 abatement related to land use and agriculture, and carbon capture and storage (CCS) using the kaya identity and Logarithmic-Mean Divisia Index (LMDI) decomposition (Ang and Liu 2001, 2007).[8]

Figure 5 shows this decomposition for the accelerated global net-zero scenario for key economies and subregions in selected years. Energy efficiency improvements dominate mitigation in the years prior to 2040, except in Indonesia and the rest of Southeast Asia where non-CO_2 abatement from agriculture and land use serves as an important source of mitigation. In the longer run, transition of energy to cleaner sources will be the key source of mitigation in most of the region, accounting for 45% of mitigation in 2050. CCS is important after 2050. For example, in 2060, CCS will account for about a third of mitigation in the PRC under the accelerated global net-zero scenario.

[8] The Kaya identity was proposed in 1989 as a method to decompose emission changes into four drivers: population, gross domestic product (GDP) per capita, energy intensity of GDP, and carbon intensity or energy. Meanwhile, the additive LMDI provided a way to identify these drivers so that the total effect equals the sum of the individual contributions.

Figure 5: Decomposition of Mitigation Sources under the Accelerated Global Net-Zero Scenario



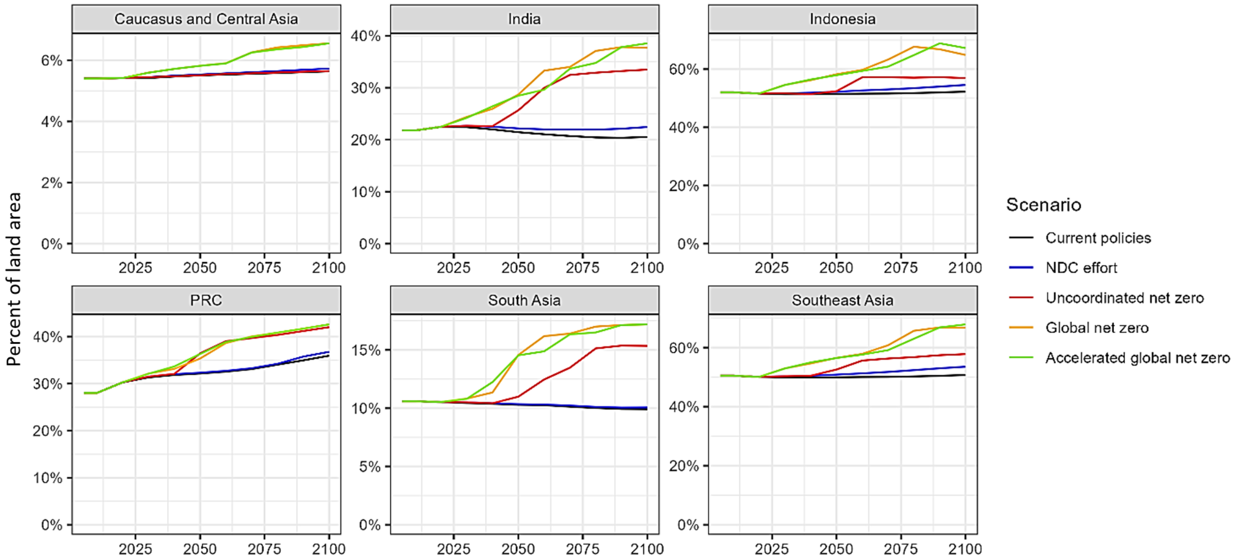
CCS = carbon capture and storage, CO_2LU: carbon dioxide from land use, GDP = gross domestic product, EN_EFF = energy efficiency, EN_MIX: energy mix, MtCO_2e = million tons of carbon dioxide equivalent, PRC = People's Republic of China.

Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.

Source: Authors' estimates.

Land use. There is great potential to reduce emissions from land use in much of developing Asia. However, the current policies and NDC effort scenarios will add little additional forest cover in the region (black and blue lines, respectively, in Figure 6). This is partly because it is difficult to translate pledged NDCs on land use to economy-level values. Forest cover tends to increase in the most stringent scenarios (accelerated and global net-zero cases represented by green and yellow lines). Under the accelerated global net-zero scenario, forest cover in the region will increase by 95 million hectares, reaching 30% of land cover versus 26% under the current policies scenario. Under the accelerated global net-zero scenario, about 36 million hectares of land currently used to grow food crops will be primarily diverted to grow bioenergy crops by 2050. By 2070, about 5% of land area in the region will be used to grow bioenergy crops.

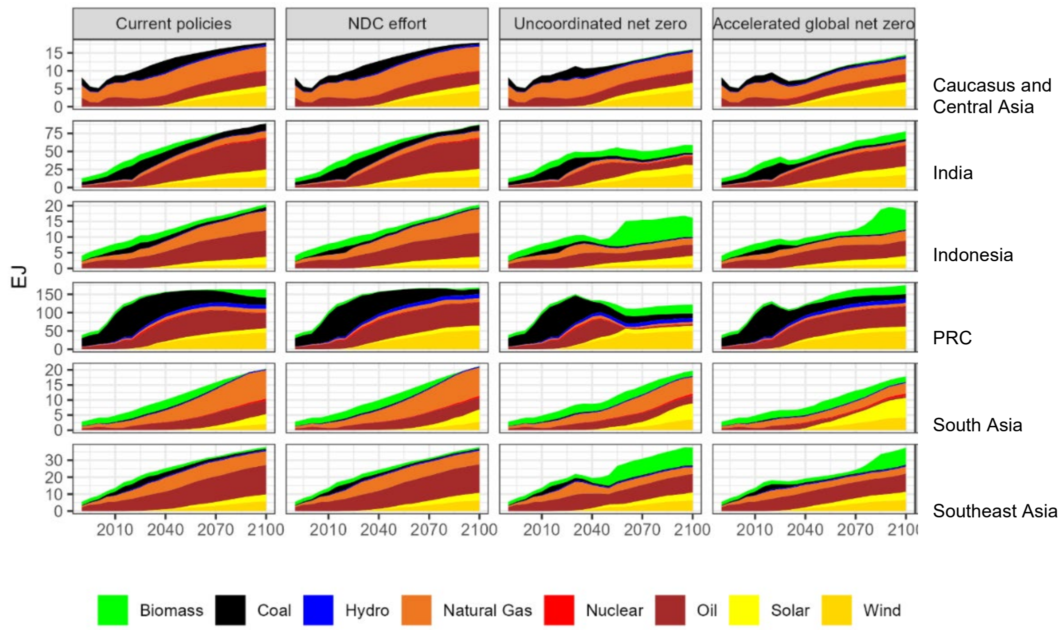
Figure 6: Total Forest Cover as Share of Total Land Area under Modeled Scenarios



NDC = nationally determined contribution, PRC = People's Republic of China.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

Energy Transition. As mentioned earlier, the energy sector is the largest source of emissions in the region and will be the main source of mitigation in the medium to long run. Figure 7 depicts the primary energy mix in key economies and subregions of developing Asia across the modeled scenarios. Energy demand in the region will increase by 50% by 2070 under the current policies scenario, while it will grow more slowly under the accelerated global net-zero scenario. This is partly due to higher energy efficiency and partly due to lower thermal losses in the latter scenario, as more energy is generated from non-fossil fuel sources. Under the current policies scenario, the share of coal in primary energy in the region will decrease from about 50% in 2020 to less than 25% by 2050. Under the accelerated global net-zero scenario, this will further decrease to 13%, while renewable sources of energy such as solar, wind, hydro, and biomass will provide about 25% of primary energy in the region by 2050.

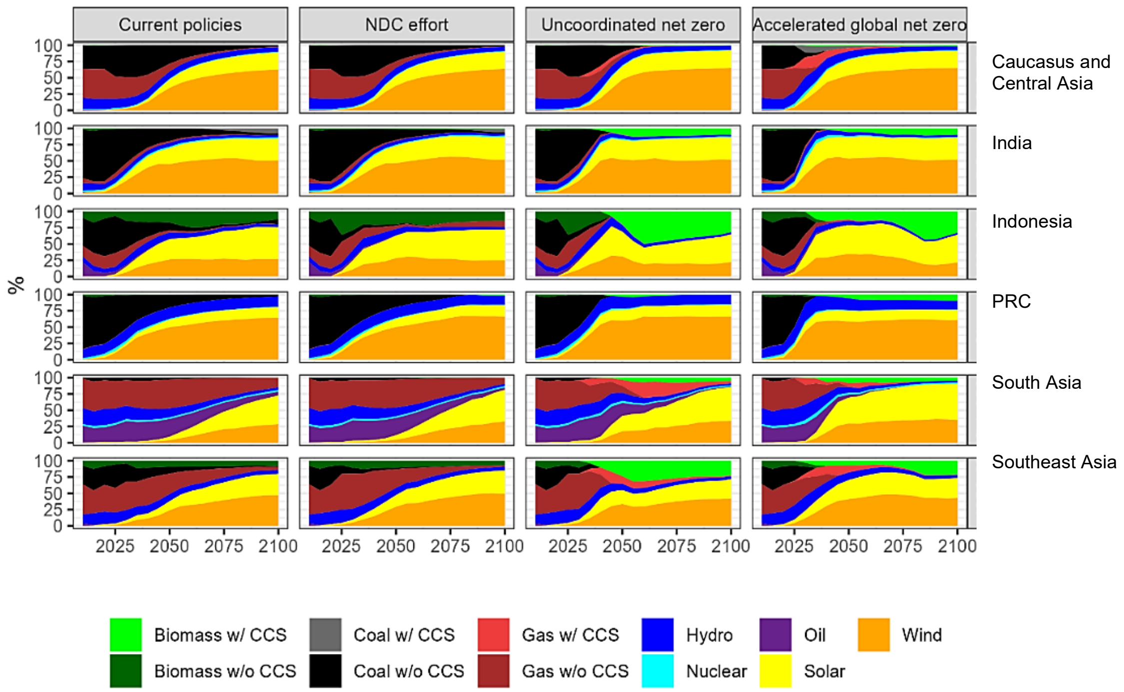
Figure 7: Primary Energy Mix in Developing Asia



EJ = exajoules, NDC = nationally determined contribution, PRC = People's Republic of China.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

The transition to clean energy is more dramatic within the electricity sector. The share of coal in electricity generation will decrease even under the current policies scenario to only 17% by 2050, while under the net-zero scenarios, coal will be practically phased out from the region's power sector. Figure 8 shows that large-scale renewable energy deployment will dominate in most regions, with solar and wind power contributing to about 75% of the region's electricity supply by 2040. CCS can provide an economical option for economies and regions that rely heavily on fossil fuels (such as coal and natural gas). Bioenergy with CCS (BECCS) and biomass will potentially account for a large share of the energy generated in Indonesia and other Southeast Asian economies, while hydropower will play an important role in South Asia and the PRC.

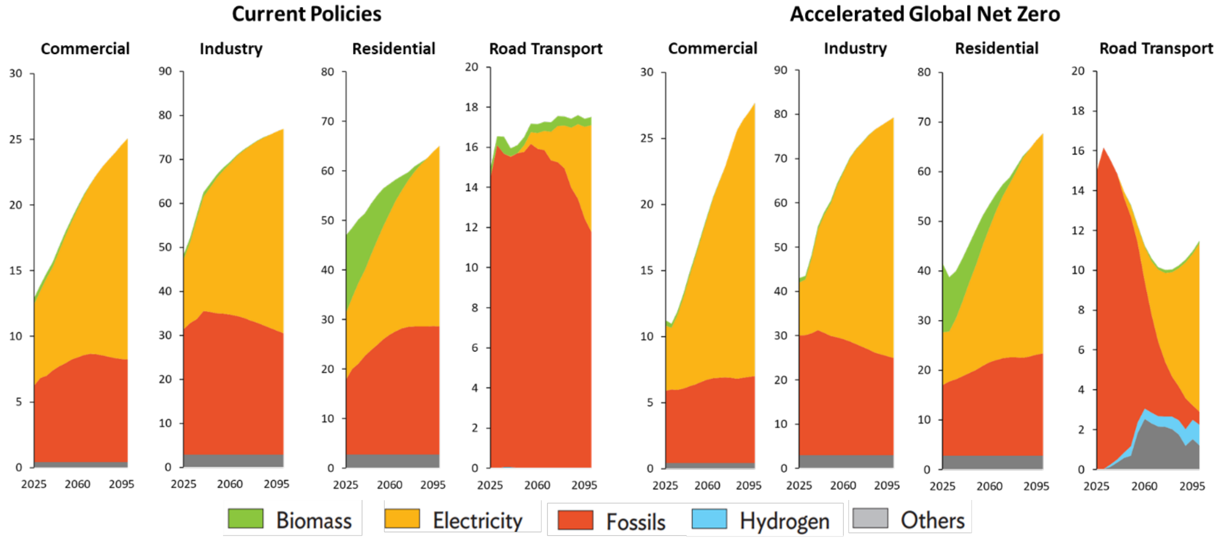
Figure 8: Electricity Mix in Developing Asia



CCS = carbon capture and storage, NDC = nationally determined contribution, PRC = People's Republic of China.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

Electrification of end services is another key transformation that will contribute to a decline in GHG emissions. Figure 9 shows the final energy carrier shares in different sectors under the current policies and accelerated global net-zero scenarios. Under the accelerated global net-zero scenario, the transport sector will see the highest electrification level by the end of the century, with almost a full shift to electric vehicles. In the residential sector, traditional biomass will be phased out, while the share of electricity will slowly increase. In industry, the share of electricity will increase from around one-third of final energy today to two-thirds by the end of the century in the accelerated global net-zero scenario.

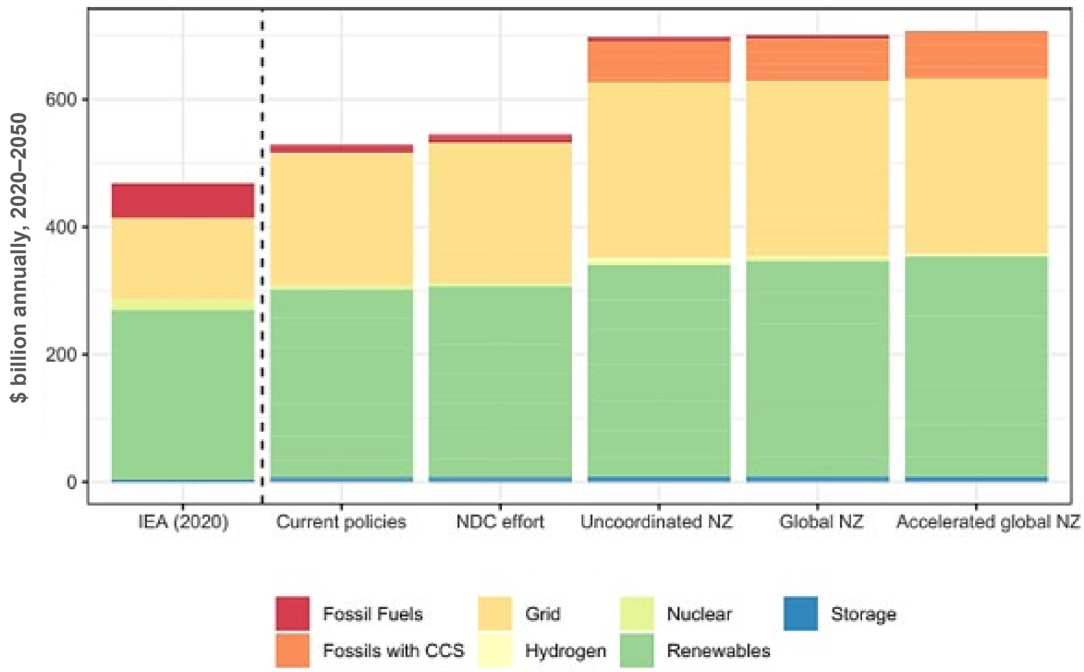
Figure 9: Final Energy Carrier Shares in Developing Asia
(Exajoules)



Source: Authors' estimates.

The transformation of the energy sector will require rapid scaling up and reallocation of investment to cleaner sources of energy. Figure 10 shows that investments in power supply in developing Asia will need to increase from around $529 billion annually under the current policies scenario to $707 billion under the accelerated global net-zero scenario. These are mostly needed to scale up renewable energy supply and facilitate the integration of intermittent power from renewables, the latter through the development of grid networks and storage. Overall, the investments account for about 2.2% of gross domestic product (GDP) in the region, with slightly higher shares of 2.6 to 2.7% in the Caucasus and Central Asia.

Figure 10: Average Annual Investment in Power Supply in Developing Asia



CCS = carbon capture and storage, NDC = nationally determined contribution, NZ = net-zero.

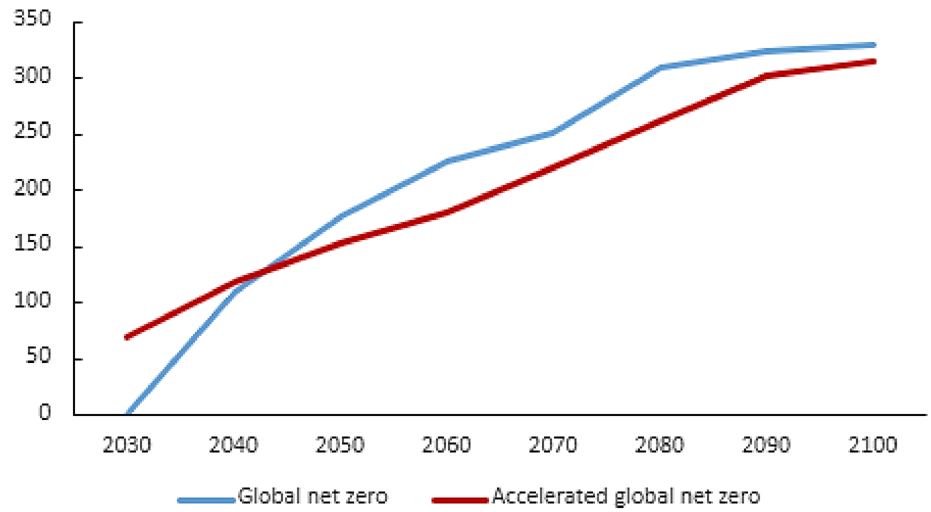
Note: Renewables include solar, wind, hydro, and biomass. International Energy Agency (IEA) data has been downscaled using weights and aggregated to the reported region definitions.

Sources: International Energy Agency. 2020. World Energy Outlook 2020: Access to Electricity Database; Authors' estimates.

5. Economic Costs of Low-Carbon Policies

The imposition of carbon prices is the policy that triggers decarbonization within the WITCH model. These prices are modeled to increase over time. The NDC effort scenario requires little carbon pricing modification since the emissions pathways do not differ strongly from current policies, while the uncoordinated net-zero scenario features carbon prices that vary strongly among regions. Under the accelerated net-zero scenario, global carbon prices rise to $70 per ton of CO_2 equivalent (tCO_2e) in 2030 and $153 per tCO_2e in 2050 (Figure 11). Carbon prices are initially higher in the accelerated global net-zero scenario than in the global net-zero scenario, but the accelerated scenario faces lower prices by 2040 as early mitigation proves to be more cost effective than delayed action.

Figure 11: Global Carbon Prices under the Modeled Global Net-Zero Scenarios
($ per tCO_2e)



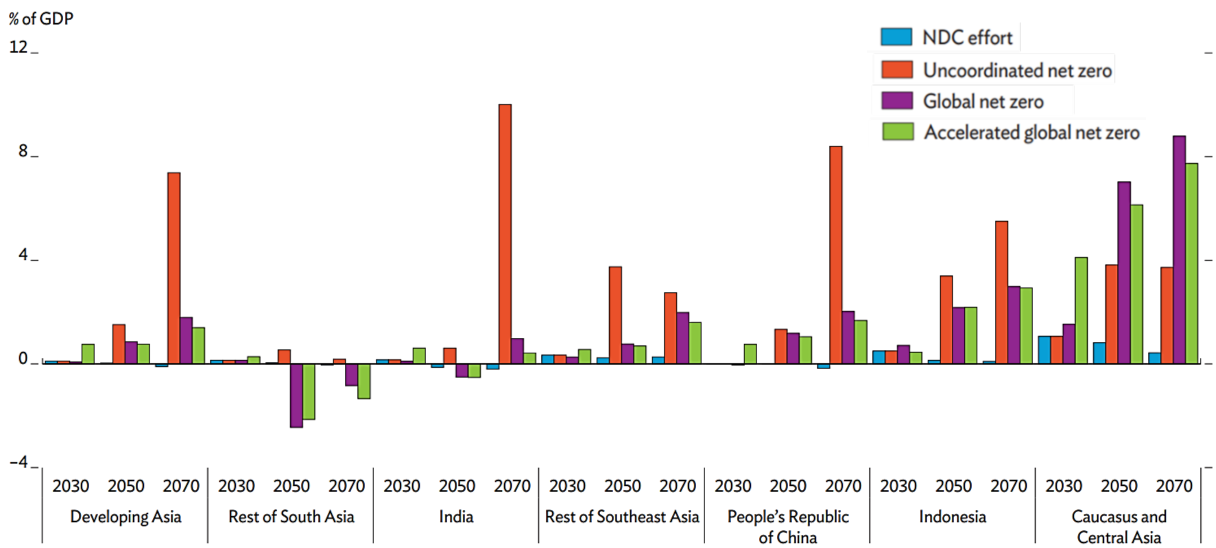
tCO_2e = ton of carbon dioxide equivalent.
Source: Authors' estimates.

Policy costs follow similar patterns to carbon prices. These costs are very low under the NDC scenario due to the modest changes from current policies. Net-zero pledges implemented in an uncoordinated manner have higher costs for economies with more ambitious net-zero pledges. Global net-zero scenarios have much lower costs overall in comparison.

Among subregions of developing Asia, policy costs are larger in more carbon-intensive economies such as in the Caucasus and Central Asia, Indonesia, and the PRC, while they are generally lower in poorer and less carbon-intensive economies.

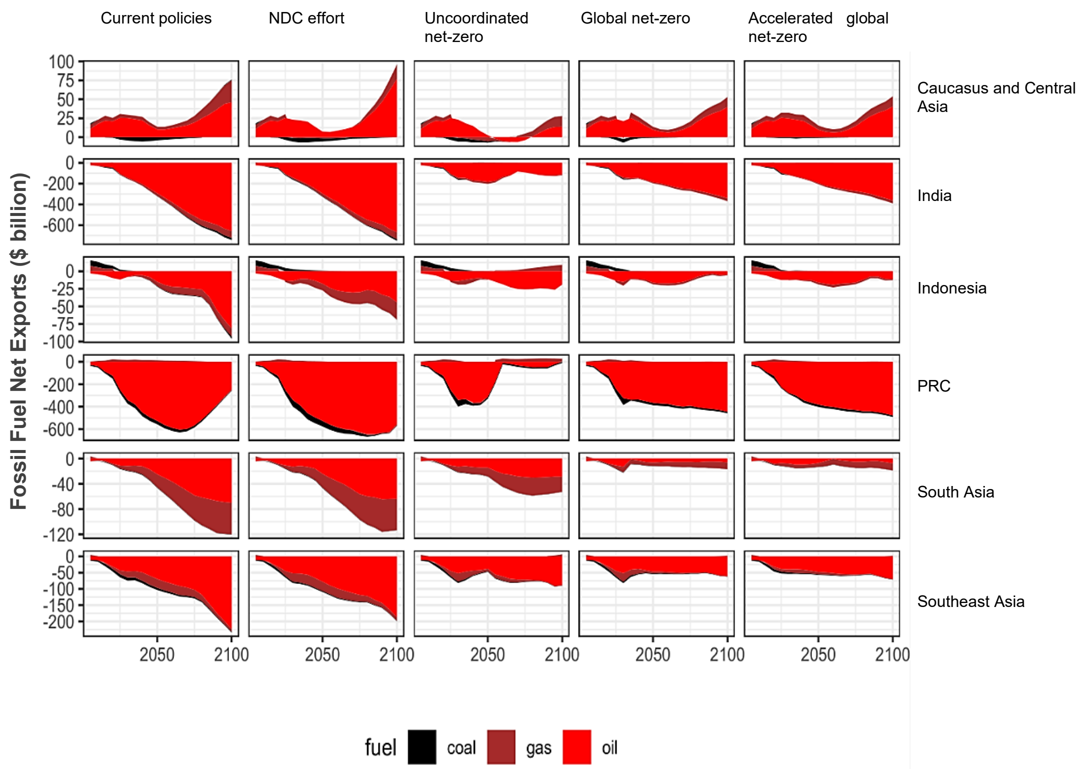
Central Asia stands out as having the highest policy costs in the region, primarily due to its heavy economic dependence on fossil fuels (Figure 12). Around one-third of the policy costs in this subregion traces to a reduction in export revenues from fossil fuels (such as coal, natural gas, and oil), which in turn traces to reduced prices and exported quantities. For other subregions, however, the lower import costs of fossil fuels help to mitigate the output losses due to the economic and energy transition. The decline in fossil fuel prices under net-zero scenarios stem from large changes in the net export of these resources (Figure 13), which are mainly due to a reduction in demand under decarbonization policies.

Figure 12: Policy Costs for the Modeled Scenarios in Developing Asia, Excluding Benefits and Relative to Current Policies, 2030, 2050, and 2070



GDP = gross domestic product, NDC = nationally determined contribution.
Source: Authors' estimates.

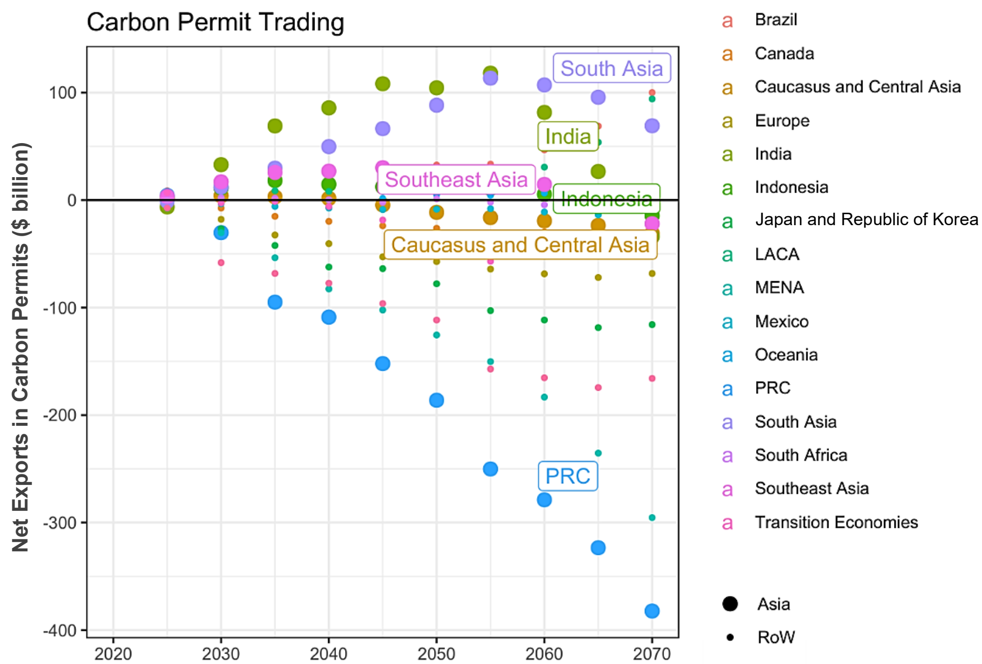
Figure 13: Fossil Fuel Trade in Developing Asia under the Modeled Scenarios



NDC = nationally determined contributions, PRC = People's Republic of China.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

Figure 14 shows the expected flows from the trade of carbon permits in developing Asia in the accelerated global net-zero scenario. South Asia, especially India, stands out as the largest exporter of carbon permits overall. The PRC, meanwhile, is expected to become a substantial importer of these permits, with import value estimated to reach $400 billion by 2050, when emissions rights would be allocated on an equal per-capita basis across economies.

Figure 14: Trade Balance of GHG Offsets under the Accelerated Global Net-Zero Scenario



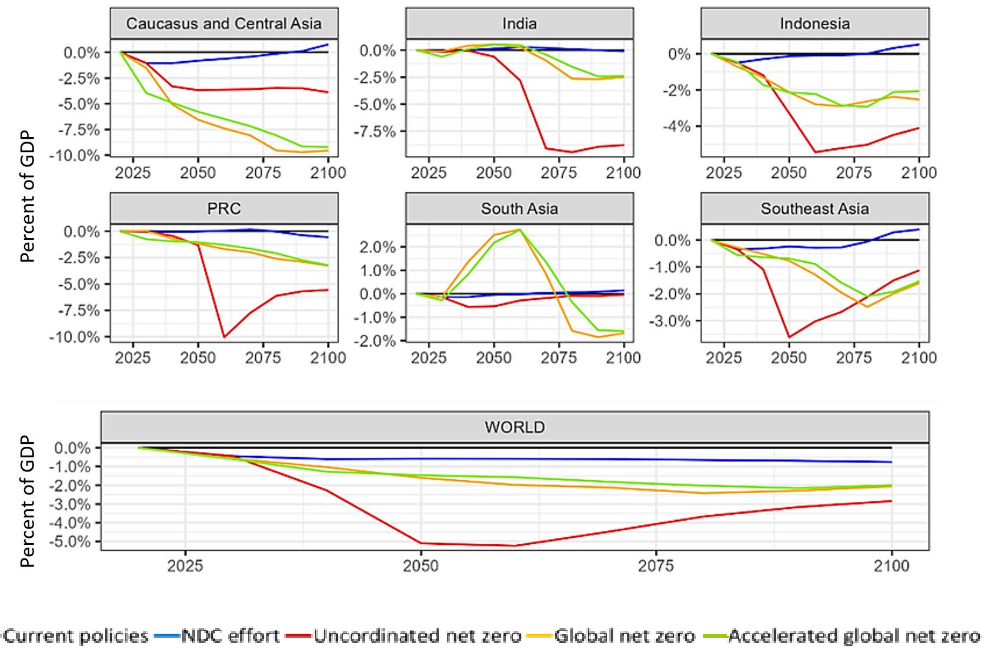
GHG = greenhouse gas, LACA = Latin America and Caribbean, MENA= Middle East and North Africa, OECD = Organisation for Economic Co-operation and Development, PRC = People's Republic of China.

Notes: Positive value means exports, and negative value means imports. South Asia and Southeast Asia excludes India and Indonesia, respectively.

Source: Authors' estimates.

Net-zero pledges lead to a discontinuous progression of effort and costs. NDCs impose limited emissions reduction and costs until 2030, but efforts will have to rapidly accelerate after this period to meet net-zero targets. This creates a large spike in policy costs. The accelerated global net-zero case, on the other hand, exhibits much higher immediate costs, though this is balanced by lower GDP losses after 2050 (Figure 15).

Figure 15: Policy Costs Over Time for the Modeled Scenarios

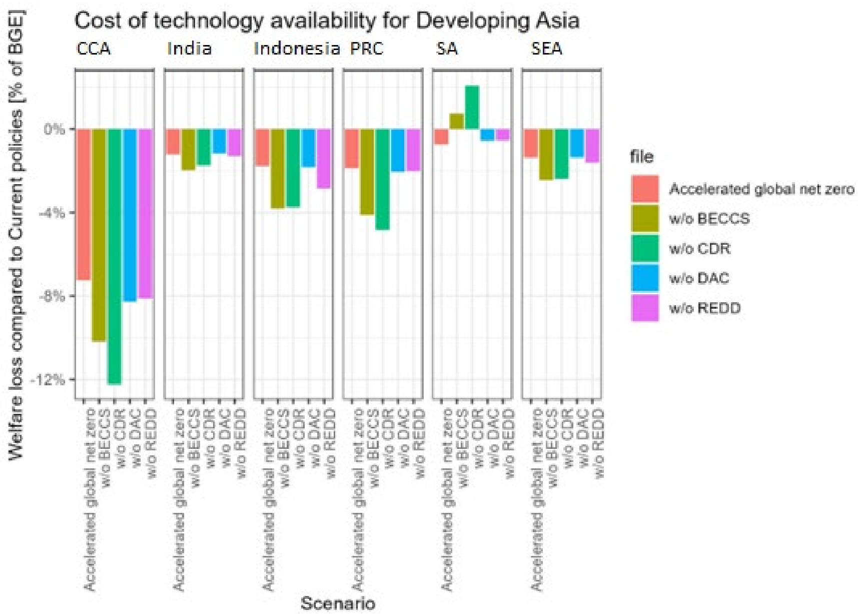


GDP = gross domestic product, NDC = nationally determined contributions, PRC = People's Republic of China.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

Different assumptions about the availability of advanced technologies lead to different costs of the accelerated global net-zero pathways, although costs remain at feasible levels even without these technologies (Figure 16). BECCS turns out to be an important determinant of mitigation costs, as it allows negative emissions from energy generation. Notably, the unavailability of BECCS increases policy costs by about 1 to 2 percentage points, while direct air capture (DAC) appears to play a less important role, given the energy and heat requirements, relatively low storage potential in the region, and high investment costs.

Without the option of mitigation through reduced emissions from deforestation and forest degradation (REDD), the costs increase in most regions. In areas with relatively cost-efficient REDD potential such as Indonesia, where peatland protection and restoration provide an important potential carbon-emission sink (Humpenöder et al. 2020), this mitigation strategy allows lower contribution of the economy to the global emissions target, thus bringing down policy costs.

Figure 16: Policy Cost of the Accelerated Global Net-Zero Scenario without Carbon Dioxide Removal Technologies



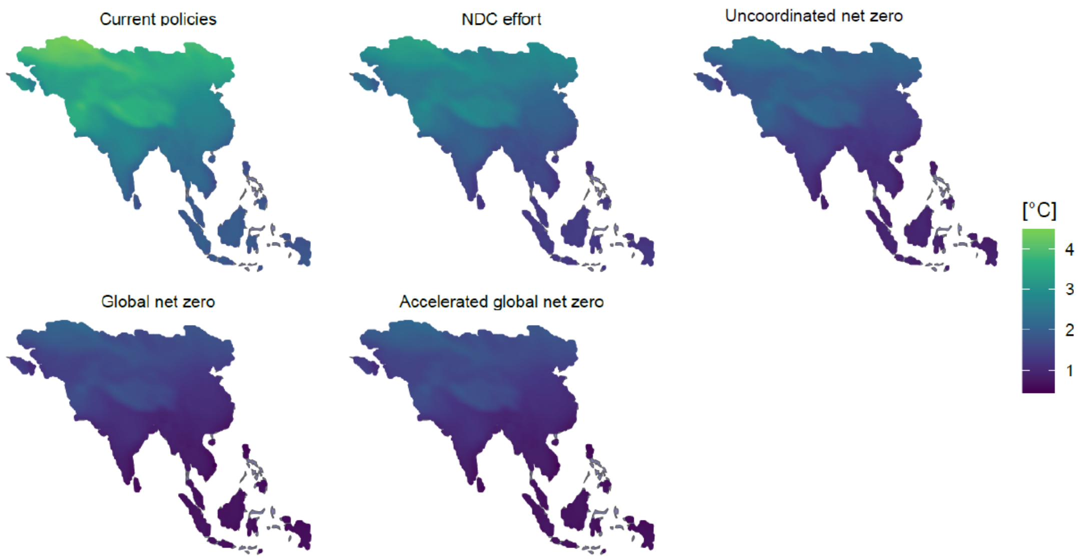
BECSS = biomass with carbon capture and storage, BGE = balanced growth equivalent, a measure of welfare, CCA = Caucasus and Central Asia, CCS = carbon capture and storage, DAC = direct air capture, GDP = gross domestic product, PRC = People's Republic of China, REDD = reduced emissions from deforestation and forest degradation, SA = rest of South Asia,
SEA = rest of Southeast Asia.

Source: Authors' estimates.

6. Climate Benefits of Low-Carbon Policies

The climate scenarios have distinct implications for global warming, and consequently, for temperature changes and losses from climate change in Asia. Figure 17 illustrates the peak temperatures projected for individual economies within the 21st century under the different scenarios. It is important to note that the accelerated global net-zero scenario consistently yields the lowest maximum temperatures, emphasizing the need for swift and collaborative climate action to mitigate the most severe consequences of climate change across the region.

Figure 17: Maximum Temperature Change Over the 21st Century Compared to Average Historical Temperature



NDC = nationally determined contribution.
Note: The map shows Asian Development Bank developing member economies.
Source: Authors' estimates.

The difference between temperature changes in the scenarios allows calculation of the net benefits of climate action, measured as the difference between the damages avoided compared to the current policies reference scenario and the mitigation costs associated with the policy scenario. Although there is substantial disagreement in the literature regarding the magnitude of economic impacts resulting from climate change, there is a consensus that these impacts escalate with increasing temperatures.

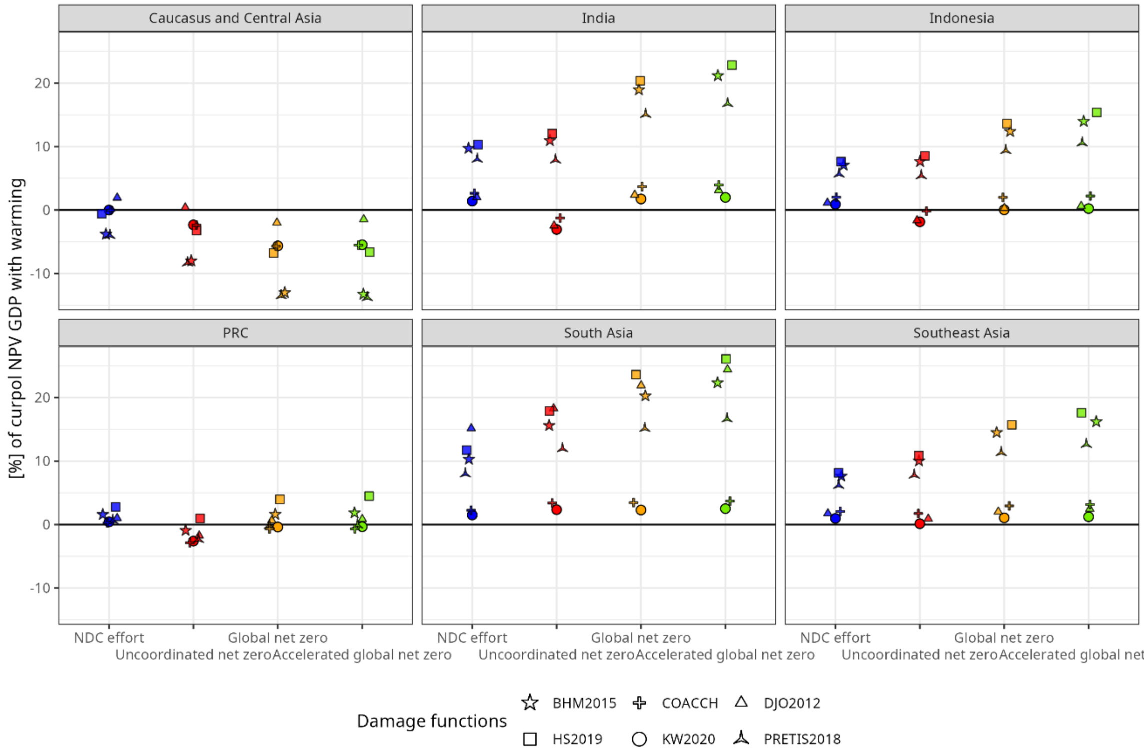
The implications of a range of estimates are first considered. The analysis incorporates various econometric estimates from the literature (O'Neill et al. 2022, IPCC 2022a and Drouet et al. [2022]), which vary in terms of dataset usage and specifications (e.g., differentiation between poor and rich economies and inclusion of year-lags). It is important to mention, however, that these estimates do not account for non-market damages and catastrophic or extreme events, and primarily include persistent damages with limited adaptation measures.

Five functions are econometric: (i) growth functions of linear temperature with persistent damage (Dell, Jones, and Olken 2012); (ii) growth damage functions of quadratic temperature with persistent damage (Burke, Hsiang, and Miguel 2015); (iii) specification refinements to Burke, Hsiang, and Miguel (2015) in Henseler and Schumacher (2019); (iv) inclusion of within-year temperature variation in the Burke, Hsiang, and Miguel (2015) model genre (Pretis et al. 2018); and (v) a growth-based function of regional temperature and annual temperature variation (Kalkuhl and Wenz 2020).

Recent literature has pointed out limitations and issues in these econometric estimates. For example, use of economic growth rate as dependent variable leads to higher damage estimates than use of economic activity level, but the former indicator may tend to be unstable and sensitive to specification (Newell, Prest, and Sexton 2021). Econometric methods all proxy weather variations for climate change in a manner that extrapolates from shocks that cannot be easily predicted to longer-term trends. In view of these limitations, damage functions from an exercise that embed sectoral impacts in computable general equilibrium models are also applied (van der Wijst et al. 2023).

The net present value (NPV) of net costs/benefits in 2020 are calculated using a 3% discount rate across various scenarios, as presented in Figure 18. Most Asian regions experience benefits from climate action, with some estimates showing substantial gains. In India and South Asia, net benefits may exceed 20% of the NPV of GDP under the current policies scenario with warming. As these regions face significant impacts from climate change, the relative benefits are notably high. Indonesia and Southeast Asia observe net benefits of up to 15%.

Figure 18: Sum of Policy Costs and Climate Benefits in Developing Asia under the Modeled Scenarios



BHM2015 = Burke, Hsiang, and Miguel 2015; COACCH = Co-designing the Assessment of Climate Change costs summarized in van der Wijst et al. 2023; DJO2012 = Dell, Jones, and Olken 2012; HS2019 = Henseler and Schumacher 2019; KW2020 = Kalkuhl and Wenz 2020; PRC = People's Republic of China; PRETIS2018 = Pretis et al. 2018.

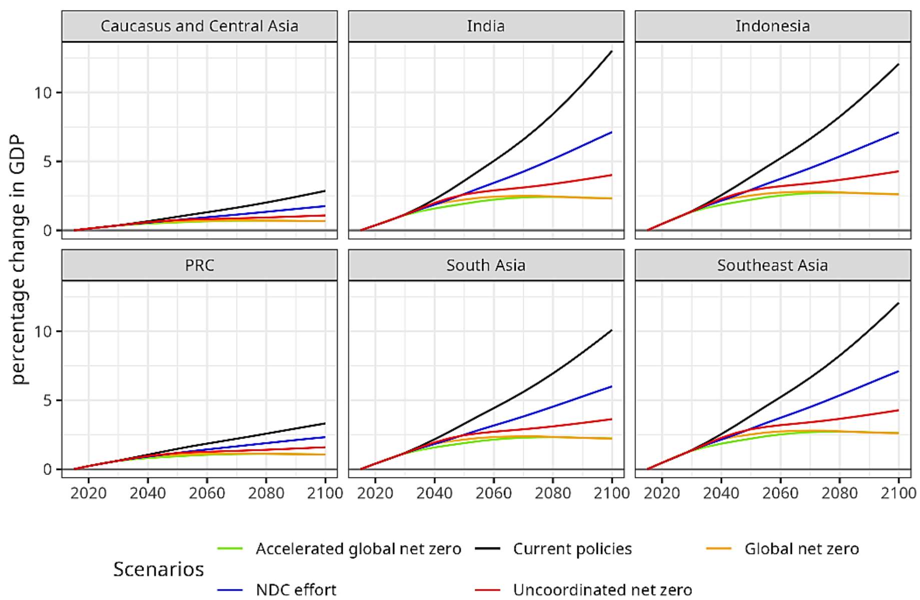
Notes: Results for Caucasus and Central Asia are based on climate damage functions that often consider the region as part of "transition economies" that are dominated by larger eastern European economies and may not represent effects for the region appropriately. They should be interpreted with caution and are omitted from further analysis. South Asia and Southeast Asia exclude India and Indonesia, respectively.

Source: Authors' estimates.

Across the various scenarios, certain trends emerge irrespective of the estimates used. The NDC effort scenario yields low net benefits compared to the current policies scenario for all regions, while the net-zero scenarios show a more diverse range of responses across regions. In the global net-zero scenarios, net benefits from climate action are observed, but in the uncoordinated net-zero scenario, three regions (India, Indonesia, and the PRC) experience net costs, while South Asia and Southeast Asia report net benefits. This highlights the importance of coordinated climate action. Early action, as illustrated in the accelerated net-zero scenario, increases net benefits compared to slower action under the global net-zero scenario.

Climate impacts are calculated using parameters produced from the recent Co-designing the Assessment of Climate Change Change costs (COACCH) project, as illustrated in Figure 19. This is considered a preferred source of damage functions, as the project based losses on simultaneous consideration of modeled sectoral losses in an economywide framework, rather than root damages in unstable econometric specifications that typically proxy weather for climate. Results are also largely consistent with the meta-study on climate damage functions by Howard and Sterner (2017).

Figure 19: Total Gross Damages due to Climate Change under the COACCH Specification



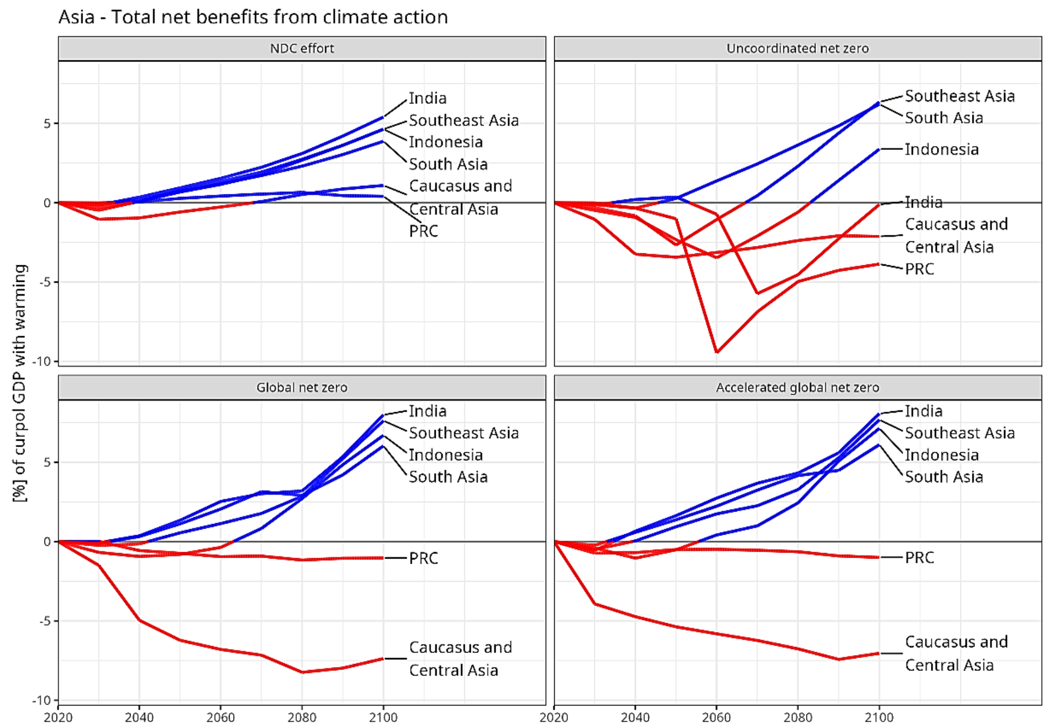
COACCH = Co-designing the Assessment of Climate Change costs summarized in van der Wijst et al. 2023; GDP = gross domestic product; NDC = nationally determined contribution; PRC = People's Republic of China.

Notes: South Asia and Southeast Asia excludes India and Indonesia, respectively. More information on COACCH project can be found in van der Wijst et al. 2023. "New Damage Curves and Multimodel Analysis Suggest Lower Optimal Temperature." *Nature Climate Change.* 13. 434–441. The percentage change in GDP is relative to the reference scenario without climate change.

Source: Authors' estimates.

Under the COACCH damage function, there is an increase in net benefits from the present until the end of the century for most regions across all scenarios (Figure 20). Notably, substantial net benefits are not expected before 2050, as mitigation costs tend to outweigh avoided damages during this period. In fact, under the net-zero scenario, net costs are expected to persist until mid-century. In the latter half of the century, once the zero-emission target has been achieved, avoided damages dominate mitigation costs. This aligns with the existing literature that examines the costs and impacts associated with net-zero emissions pathways (Riahi et al., 2021).

Figure 20: Annual Net Policy Costs and Climate Benefits against the Current Policies Scenario



NDC = nationally determined contribution, PRC = People's Republic of China.

Note: Climate benefits are based on van der Wijst, K. et al. 2023. "New Damage Curves and Multimodel Analysis Suggest Lower Optimal Temperature." Nature Climate Change 13. 434–441. Net costs are highlighted in red, while net benefits are in blue. Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.

Source: Authors' estimates.

7. Co-benefits of Low-Carbon Policies

Decarbonization is known to yield co-benefits in terms of air pollution reduction (Rao et al. 2017). It is important therefore to consider not only the direct climate benefits of reducing fossil fuel consumption but also the potential improvements in air quality and public health. Exposure to air pollution is a major health concern worldwide. According to the Global Burden of Disease (GBD) study in 2019, one in nine deaths globally can be attributed to fine particulate matter (PM2.5) and ozone (O_3) air pollution. Among these deaths, 5.7% are due to O_3, with the rest linked to PM2.5.

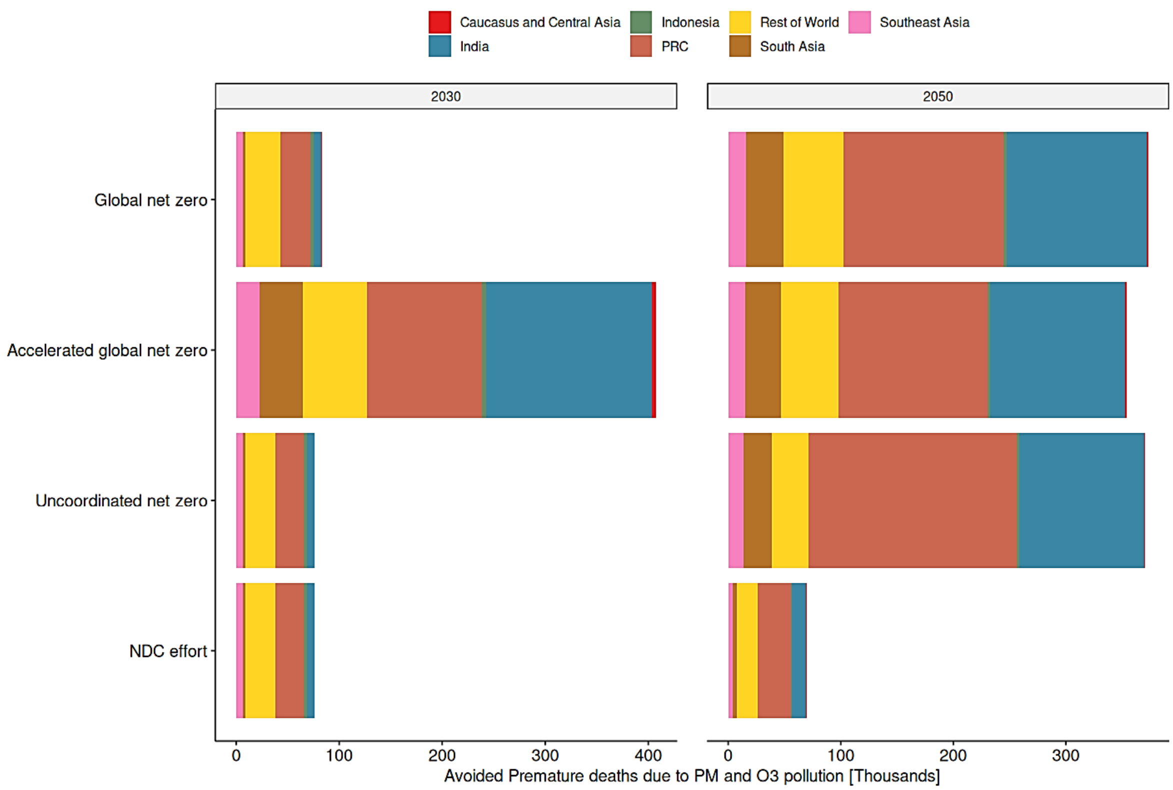
To assess the impact of air pollution on human mortality, the FASST(R) model is employed (Reis et al. 2018). The FASST(R) model (Van Dingenen et al. 2018) is a global source-receptor model that estimates concentrations of the most harmful pollutants (ozone and PM2.5) based on precursor emissions. Using O_3 and PM2.5 concentrations, the model applies mortality and crop impact functions as described in Van Dingenen et al. (2018). Although these estimates may be considered conservative, as newer GBD estimates report higher mortality effects, FASST(R) model results fall within the lower bound of the range in the literature, when considering other studies (Reis et al., 2022). The model considers emissions of primary pollutants (i.e., nitrogen oxides [NOx], sulfur dioxide [SO_2], volatile organic compounds [VOCs], organic carbon [OC], ammonia [NH_3], and black carbon [BC]) and calculates PM2.5 and O_3 concentrations. BC and OC constitute the primary component of PM2.5, while NOx, SO_2, VOCs, and NH_3 react in the atmosphere to form secondary PM2.5. Additionally, NOx, VOC, and, to a lesser extent, carbon monoxide (CO) and methane (CH_4), react in the atmosphere to produce O_3.

The analysis inputs air pollutant emissions data from the WITCH model into the FASST(R) model. These include NOx, SO_2, VOCs, NH_3, CH_4, CO, OC, and BC. FASST(R) subsequently calculates pollutant concentrations and their impacts on premature mortality and crop yields.

Figure 21 shows that in all scenarios, the regions of developing Asia—primarily, India and the PRC—experience the largest air quality benefits of decarbonization. Clearly, global net-zero scenarios not only reduce climate risks but also decrease mortality associated with air pollution throughout developing Asia.

A crucial insight from this analysis is that delayed climate policies lead to higher near-term premature deaths, as shown by the difference between the accelerated global net-zero scenarios and NDC-based ones in 2030. This finding underscores the need to increase ambitions in climate policies not only post-2030 but also leading up to 2030 (IPCC 2018). By prioritizing timely and effective climate action, policymakers can address both climate change and health objectives.

Figure 21: Avoided Annual Premature Deaths due to Outdoor Particulate Matter 2.5 and Ozone under the Modeled Scenarios



NDC = nationally determined contribution, O_3 = ozone, PRC = People's Republic of China.

Notes: Avoided mortality is calculated against the current policy scenario. South Asia and Southeast Asia excludes India and Indonesia, respectively.

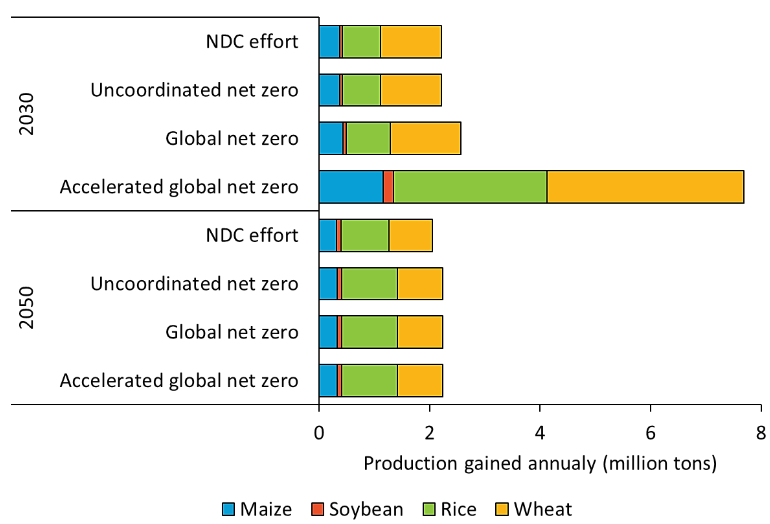
Source: Authors' estimates.

The analysis further reveals that all scenarios result in avoidance of crop losses. Figure 22 indicates that, in terms of volume, wheat and rice are the crops most likely to benefit from reduced air pollution. Meanwhile, cost-optimal policies implemented globally and early, as in the accelerated global net-zero case, are likely to deliver the highest co-benefits.

In the PRC, accelerated global net-zero policies may prevent production losses of more than 1 million metric tons (MT) of rice and over 2.4 million MT of wheat by 2030. Meanwhile, in India, rice production could yield over 1.2 million MT more in the same year under these ambitious policies.

Air quality co-benefits can be added to climate benefits to give a broader picture of how gains of climate action compare with its losses. Combining the total economic costs and benefits gives the overall losses and gains associated with the stringent net-zero scenarios. The primary components considered include total mitigation costs, the value of air-pollution-related premature deaths based on the value of a statistical life (VSL), and the estimated economic losses from global warming. A VSL of 160 times the gross national income for each economy, as suggested by Robinson et al. (2019), is used to translate mortality into economic values.

Figure 22: Avoided Annual Crop Loss from Ozone under the Modeled Scenarios (Relative to the Current Policies Scenario)

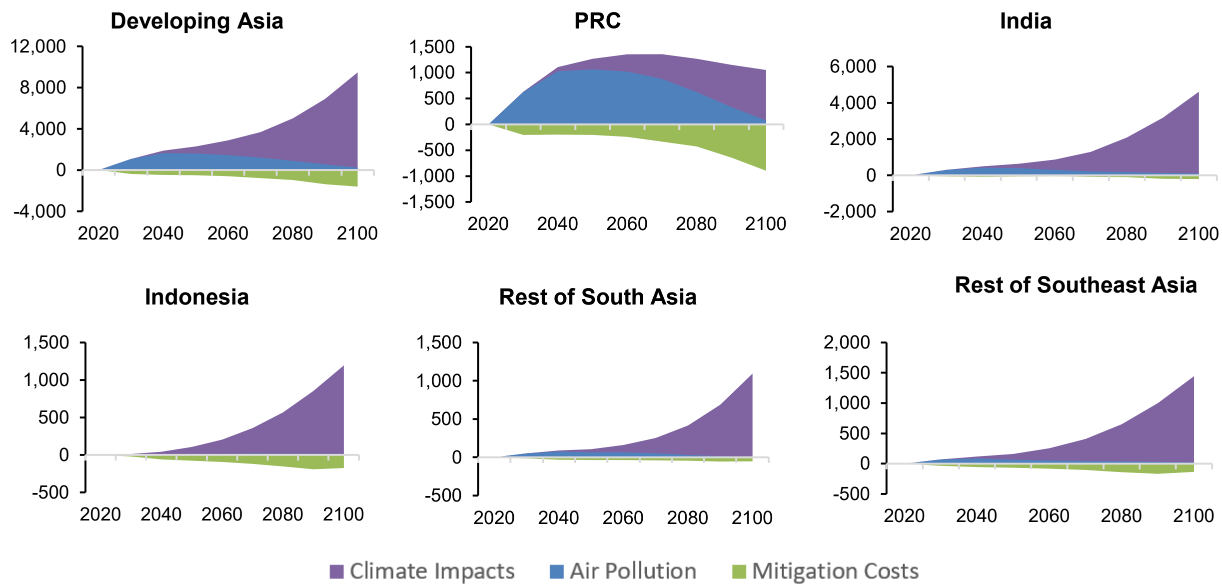


NDC = nationally determined contribution.
Source: Authors' estimates.

Figure 23 presents the total flow of benefits and costs for developing Asia and the world, including air pollution impacts. Air pollution damages are extrapolated beyond 2050 by taking the difference in primary PM2.5 emissions (BC and OC) between a stringent policy scenario and the current policies scenario. By 2050, mitigation costs in all regions will be outweighed by air pollution co-benefits—reaching up to 1,200 billion in the PRC and 400 billion in India—and climate impacts.

Collectively, the net present value of benefits (discounted at 3%) is five times costs for developing Asia, and all regions face benefits that are at least 3 times costs. The highest ratios of benefits to costs are in the lowest income economies/subregions of India, the rest of South Asia, and the rest of Southeast Asia.

Figure 23: Annual Net Policy Costs, Climate Benefits, and Air Quality Co-benefits in Developing Asia under the Accelerated Global Net-Zero Scenario, Relative to the Current Policies Scenario
(millions of $)



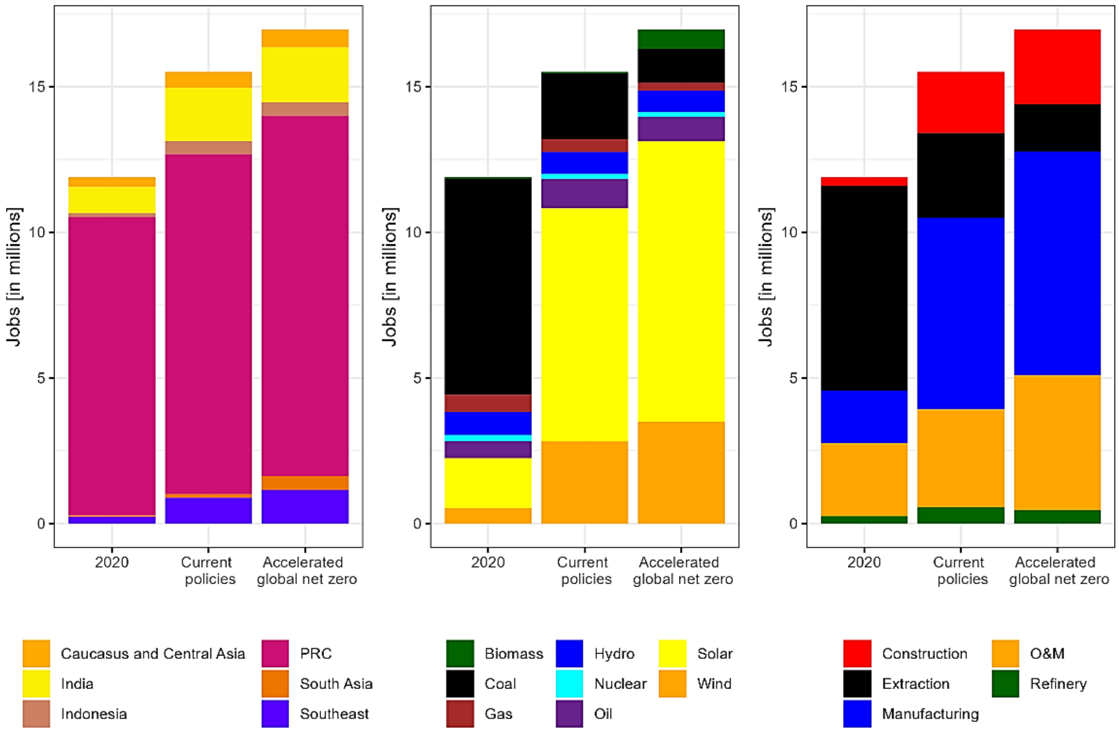
PRC = People's Republic of China
Source: Authors' estimates.

8. Equity Implications of Low-Carbon Policies

To understand the distributional implications of the net-zero scenarios via labor markets, an energy employment module based on economy-level data from Pai et al. (2021) is applied. The model estimates total direct employment in the energy sector of developing Asia at about 12.7 million full-time equivalent jobs in 2020 (Figure 24). This number is expected to increase to 15.5 million by 2050 under the NDC effort scenario, and even further to 17.3 million in the accelerated global net-zero scenario, an increase of over 36%. The PRC accounts for a large share of total employment, largely due to manufacturing of solar photovoltaic (PV) capacity, which is estimated to cover about 77% of the world market.

However, the increase also implies a large shift in the energy sector's workforce across job types, technologies, and regions. Compared to the outlook under current policies, about 1.4 million jobs in the coal sector may be lost in Asia under the accelerated global net-zero scenario, while 2.9 million jobs may eventually be created by mid-century, particularly in the manufacturing and installation of solar PVs and windmills (Figure 25).

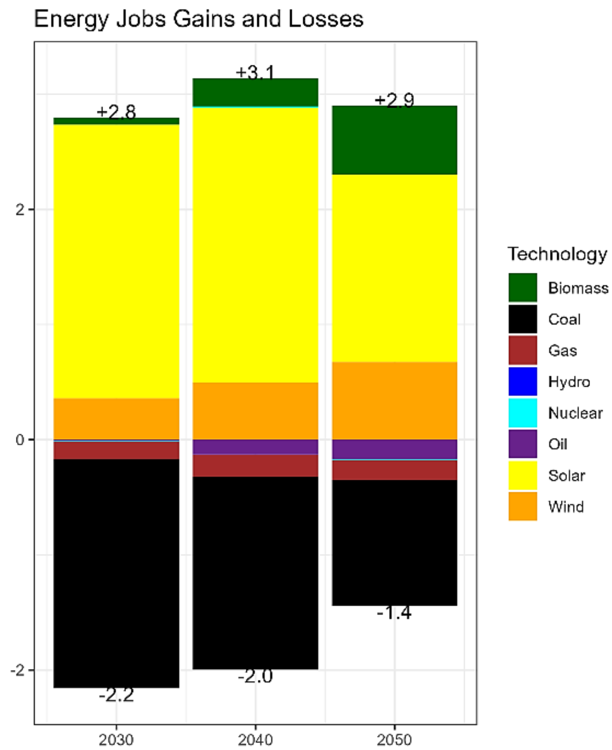
Figure 24: Total Direct Energy Sector Jobs in Developing Asia under the Modeled Scenarios, 2020 and 2050



PRC = People's Republic of China, O&M = operations and maintenance.
Note: South Asia and Southeast Asia excludes India and Indonesia, respectively.
Source: Authors' estimates.

Figure 25: Change in Full-time Direct Energy Sector Employment by Type of Energy between the Current Policies and Accelerated Global Net-Zero Scenario

(million full-time-equivalent jobs)



Source: Authors' estimates.

The analysis has focused so far on examining the regional and economy-level impacts of the different mitigation scenarios, in which the net effects of an efficient and ambitious approach to decarbonization are found as overwhelmingly positive. However, it is also crucial to consider within-economy impacts of carbon pricing and resulting energy and food price changes, as these may lead to winners and losers.

The food price index serves as an indicator of competition for land and resources as economic actors choose between forest, cropland for food production, and bioenergy production. It is decreasing in the current policies scenario but rises by 5% to 10% by the end of the century under the NDC effort scenario (Figure 26).[9] In the uncoordinated net-zero scenario, food prices

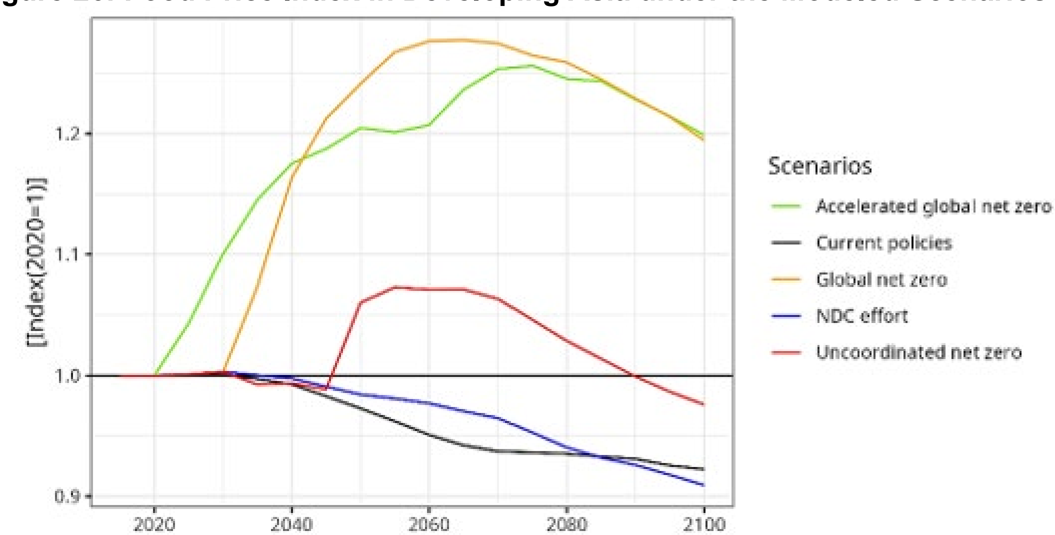
[9] Note that the impacts of climate change on agriculture are not reflected in the prices modeled.

initially rise to a maximum of 10% around mid-century, and then fall back to their previous level once net-zero targets are achieved. In the global net-zero scenarios, food prices may see a rapid increase of up to 20% to 25% by the end of the century.

Ambitious climate change mitigation policy also affects households via energy price signals (Figure 27). Household energy substitution from traditional biomass to other sources and shifts in electricity prices mean that energy use for cooking and heating becomes more costly. Transportation costs also initially increase to cover the costs of changes to infrastructure and vehicle electrification, even though those changes save expenditures in the longer term.

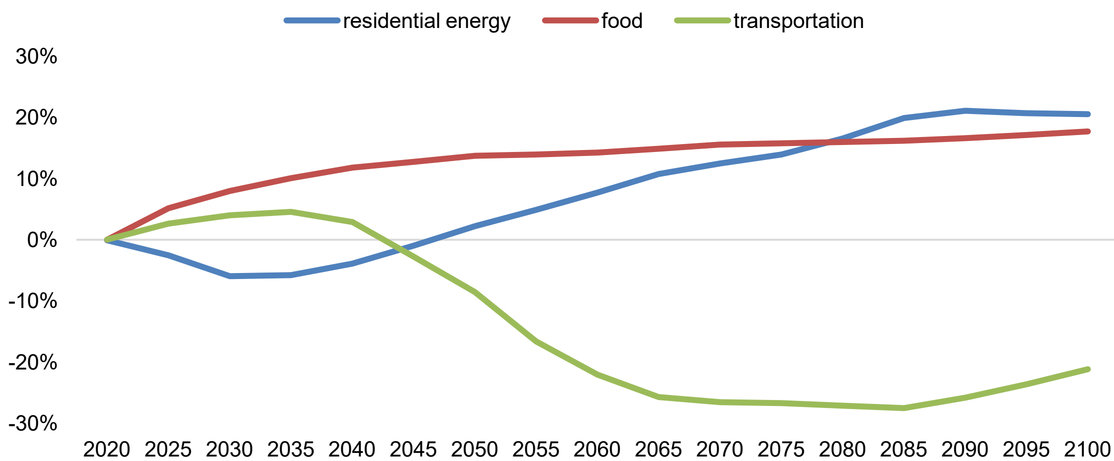
A range of studies suggests that carbon pricing may be regressive within economies, as it places a disproportionately higher burden on poorer households (e.g., Budolfson et al. 2021, Feindt et al. 2021, Hallegatte and Rozenberg 2017). Revenue recycling and redistribution schemes or climate dividends have thus been proposed as a solution to alleviate the regressive effect while at the same time ensuring policy support and acceptance.

Figure 26: Food Price Index in Developing Asia under the Modeled Scenarios



NDC = nationally determined contributions.
Source: Authors' estimates.

Figure 27: Change in Household Food, Energy, and Transportation Expenditures from the Current Policies to Accelerated Global Net-Zero Scenario



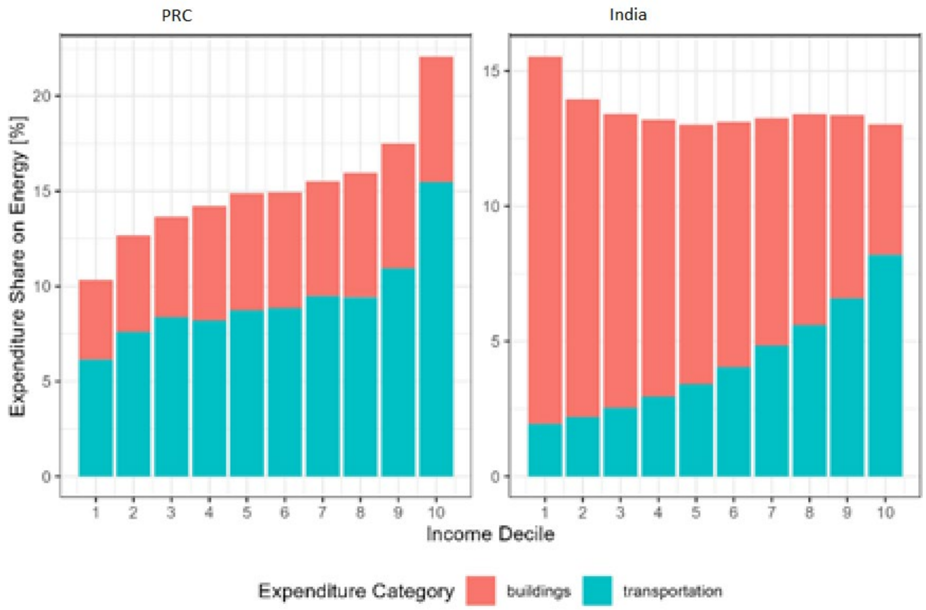
Source: Authors' estimates.

Based on household surveys from India and the PRC microeconomic models are calibrated and coupled to the WITCH model for the different scenarios. [10] This allows computation of the energy and food consumption of households at the decile level of the income distribution while incorporating energy prices and quantities provided by the WITCH model. This allows quantification of the distributional impacts compared to the current policies scenario, which serves as a baseline (Malerba and Emmerling 2022).

Based on this approach, the expenditures for residential energy consumption tend to be regressive in India, although energy expenditures are neutral in the PRC. Transportation energy expenditures, including gasoline, are typically progressive, however, as richer households spend more on transportation (Figure 28).

[10] Government of India, Ministry of Statistics & Programme Implementation. 2012. National Sample Survey 2011–2012 (68th round). Consumer Expenditure. http://microdata.gov.in/nada43/index.php/catalog/1; Government of the PRC. 2013. Chinese Household Income Project, 2013 wave (CHIP). CHIP Dataset Homepage. http://www.ciidbnu.org/chip/index.asp

Figure 28: Household Expenditure Shares for Energy for Housing and Transportation per Decile in India and the People's Republic of China, 2012–2013

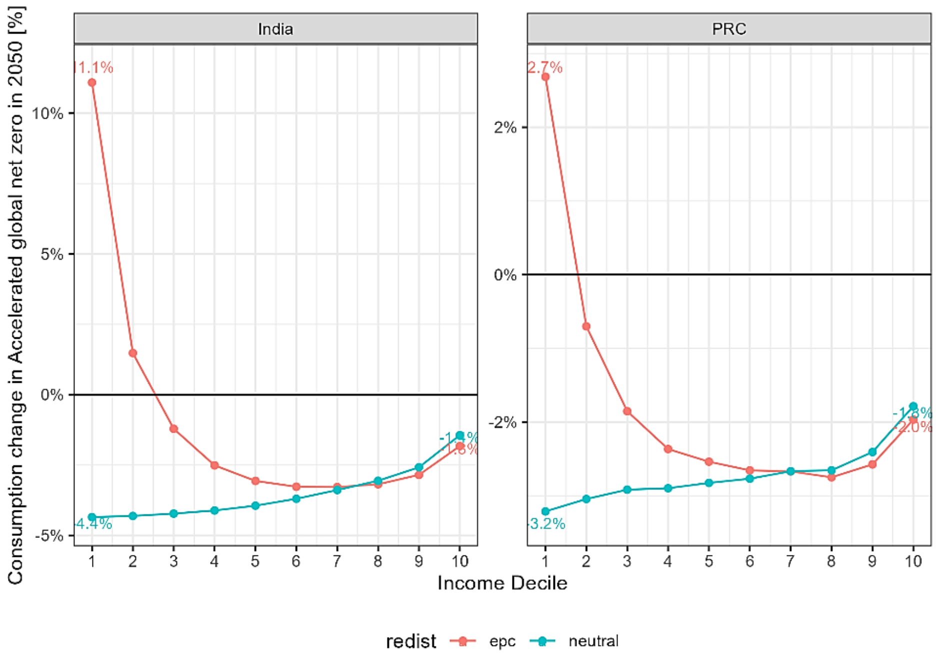


PRC = People's Republic of China.
Source: Authors' estimates.

Combining these results with the energy and food price patterns in the scenarios finds strong regressivity of ambitious climate policy in India. In contrast, the impact tends to be more evenly distributed across income deciles in the PRC (blue line in Figure 29).

Redistribution of carbon revenues can partly offset potentially inequitable outcomes. For example, a simple climate dividend in the form of an equal per-capita (EPC) transfer to households as in Budolfson et al. (2021) can be compared with the default scenario of using carbon revenues to reduce general taxation pressure. As the figure shows, this policy provides great potential to lead to a highly progressive climate-policy impact in both India and the PRC (red line in Figure 29). The lowest 2 to 4 deciles, in particular, may become better off than they would be in the current policy baseline scenario, implying a "poverty" dividend from climate policy and redistribution.

Figure 29: Total Impact of Alternative Redistribution of Carbon Pricing Revenues on Household Consumption under the Accelerated Global Net-Zero Scenario Compared to the Current Policies Scenario



epc = equal per capita transfers, PRC = People's Republic of China.
Source: Authors' estimates.

9. Conclusion

Decarbonization presents important challenges, but it also holds potentially large benefits for developing Asia. At the same time, the changes required are likely to be substantial, as the current and pledged policies of economies in the region still fall short of ambitions to meet the temperature-stabilization goals of the Paris Agreement.

The findings indicate that a continuation of current policies would lead to global warming of around 3°C on average by the end of the century, while NDC effort will bring this down to around 2.4°C. The uncoordinated net-zero scenario, in which each economy simply follows its pledge, also leads to temperature increases that do not meet the well below 2°C target. Only the global net-zero scenarios are, by design, compatible with the Paris Agreement.

Coal, a major source of emissions, already sees no new capacity additions in developing Asia under existing policies. Moreover, it is phased out completely across the region by 2040 in the net-zero scenario, except in the non-electric sector (such as the heavy industry, cement, and steel industries). The power sector meanwhile will need to achieve full decarbonization as early as 2040 in the accelerated global net-zero scenario. This rapid pace will require a large change in energy system investments over the next two decades. Land-use emissions will likewise have to be radically curtailed, including through expanded area of forest, which may compete with food production.

In economic terms, an accelerated global net-zero transition may incur average costs of around 1% of GDP. Central Asia, the only major net exporter of fossil fuels in developing Asia, may suffer higher losses than elsewhere in the region. Losses however are found to be smallest in the subregions with the lowest incomes.

An accelerated transition to net-zero potentially offers numerous benefits and gains to compensate for the costs. First, the findings indicate that a projected loss of approximately 2 million jobs in the energy sector, specifically in coal mining, can be more than offset by the creation of 3 to 4 million jobs in manufacturing (primarily in the PRC) and installation of renewables (across developing Asia). Second, the reduction in air pollution resulting from the transition can help reduce premature deaths and crop losses, leading to about 0.4 million avoided deaths annually by 2050.

Finally, adverse climate impacts averted because of climate mitigation measures will be substantial, with India and the rest of South Asia most likely to escape the biggest damages relative to the baseline (current policies) scenario. Overall, these benefits more than outweigh the mitigation costs in almost all regions by 2030—and in Central Asia from 2040 onwards—eventually exceeding costs roughly by a factor of five to one in the whole of Asia by 2050.

At the same time, not everyone is necessarily a winner from climate policy. At the economy level, carbon pricing may prove to be regressive, and certain groups may experience adverse employment outcomes. Redistribution and reskilling schemes to help the affected are thus critically important, especially to mitigate adverse impacts on the poor, garner public support for climate policies, and ultimately ensure a just transition.

APPENDIX

Interpretation and Implementation of Current Policies, NDCs, and Net-Zero Pledges

Table A1 lists national policies implemented in the World Induced Technical Change Hybrid (WITCH) model under the current policies scenario. Policies are implemented as explicit constraints on a specific year, for example, the People's Republic of China (PRC) has a target of achieving 35% share of electricity from renewable energy and nuclear energy by 2030, which is implemented as an explicit constraint in the model starting in 2030. When policies cannot be represented explicitly as constraints, carbon taxes are imposed. For example, policies to achieve certain industry performance targets or targets on numbers of trees planted are imposed as carbon taxes.

Table A1: National Climate-Energy Policies

Implemented Policies	Sector	Starting Date	Economy	Target Value	Unit
Share biofuels in fuel oil	Transport	2030	ARG	0.12	
Renewables share	Electricity production	2023	ARG	0.18	
Renewables share	Electricity production	2025	ARG	0.20	
Implicit carbon tax in the energy sector in 2025			ARG	5.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			ARG	1.00	$/tCO_2$
Renewables share	Electricity production	2025	AUS	0.35	
Renewables share	Electricity production	2030	AUS	0.50	
Intensity change	Transport	2030	AUS	0.29	
Emissions	HFC	2030	AUS	0.02	GtCe/year
Implicit carbon tax in the energy sector in 2025			AUS	3.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			AUS	0.01	$/tCO_2$
Capacity target per technology	Wind	2029	BRA	0.04	TW
Capacity target per technology	Biomass	2029	BRA	0.02	TW
Capacity target per technology	Hydro	2029	BRA	0.11	TW
Renewables share	Electricity production	2024	BRA	0.16	
Renewables share	Electricity production	2029	BRA	0.81	
Renewables share	Primary energy supply	2029	BRA	0.48	

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Implemented Policies	Sector	Starting Date	Economy	Target Value	Unit
Renewables share	Transport	2023	BRA	0.15	
Implicit carbon tax in the energy sector in 2025			BRA	1.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			BRA	0.00	$/tCO_2$
Share biofuels in fuel oil	Transport	2015	CAN	0.05	
Emissions	HFC	2036	CAN	0.00	
Emissions	GHG (BAU)	2030	CAN	0.01	GtCe/year
Emissions	Ch4_2015	2025	CAN	0.40	
Implicit carbon tax in the energy sector in 2025			CAN	5.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			CAN	0.01	$/tCO_2$
Renewables + Nuclear share	Electricity production	2030	PRC	0.35	
Renewables + Nuclear share	Primary energy supply	2035	PRC	0.20	
Capacity target per technology	Nuclear	2025	PRC	0.07	
CO_2 Intensity change		2025	PRC	0.18	
Intensity change	Energy consumption	2025	PRC	0.14	
Renewables share	Transport	2020	PRC	0.01	
Implicit carbon tax in the land-use sector in 2025			PRC	0.01	$/tCO_2$
Emissions	GHG	2030	EUR	8.29	
Renewables + Nuclear share	Primary energy supply	2030	EUR	0.27	
primary energy consumption	Energy consumption	2030	EUR	14800.00	TWh
Share biofuels in fuel oil	Transport	2020	EUR	0.17	
Emissions change	F-gases	2030	EUR	0.66	GtCe/year
Renewables share	Energy consumption	2030	EUR	0.32	
Implicit carbon tax in the energy sector in 2025			EUR	25.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			EUR	3.00	$/tCO_2$
Share biofuels in fuel oil	Transport	2025	EUR	0.25	
Renewables + Nuclear share	Primary energy supply	2025	INO	0.23	
Capacity target per technology	Hydro	2028	INO	0.01	TW
Capacity target per technology	Wind	2028	INO	0.00	TW
Capacity target per technology	Solar	2028	INO	0.00	TW
Capacity target per technology	Solar	2035	INO	0.00	TW
Share biofuels in fuel oil	Transport	2025	INO	0.23	
Implicit carbon tax in the energy sector in 2025			INO	0.01	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			INO	0.01	$/tCO_2$

Continued on the next page

Implemented Policies	Sector	Starting Date	Economy	Target Value	Unit
Capacity target per technology	Solar	2022	IND	0.10	TW
Capacity target per technology	Solar	2022	IND	0.06	TW
Capacity target per technology	Solar	2022	IND	0.01	TW
Capacity target per technology	Hydro	2022	IND	0.01	TW
Renewables share	Electricity production	2022	IND	0.20	
Renewables share	Electricity production	2027	IND	0.24	
Implicit carbon tax in the energy sector in 2025			IND	3.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			IND	0.50	$/tCO_2$
Capacity target per technology	Wind	2030	JPN	0.01	TW
Intensity change	Energy consumption reduction	2020	JPN	0.06	
Intensity change	Energy consumption reduction	2030	JPN	0.16	
Renewables share	Electricity production	2030	JPN	0.36	
Implicit carbon tax in the energy sector in 2025			JPN	3.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			JPN	0.01	$/tCO_2$
Renewables + Nuclear share	Electricity production	2040	ROK	0.33	
Renewables share	Electricity production	2034	ROK	0.40	
Renewables + Nuclear share	Electricity production	2030	ROK	0.20	
Capacity target per technology	Wind offshore	2030	ROK	0.01	TW
Capacity target per technology	Wind onshore	2030	ROK	0.01	TW
Capacity target per technology	Hydro	2030	ROK	0.00	TW
Capacity target per technology	Biomass	2030	ROK	0.00	TW
Implicit carbon tax in the energy sector in 2025			ROK	3.33	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			ROK	0.01	$/tCO_2$
CH4 Emissions		2030	MEX	0.09	GtCe/year
Renewables share	Electricity production	2018	MEX	0.25	
Renewables share	Electricity production	2021	MEX	0.30	
Renewables share	Electricity production	2024	MEX	0.35	
Implicit carbon tax in the energy sector in 2025			MEX	3.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			MEX	3.00	$/tCO2
Renewables + Nuclear share	Primary energy supply	2030	RUS	0.13	
Implicit carbon tax in the energy sector in 2025			RUS	3.00	$/tCO2

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Implemented Policies	Sector	Starting Date	Economy	Target Value	Unit
Implicit carbon tax in the land-use sector in 2025			RUS	0.01	$/tCO2
Capacity target per technology	Solar	2040	SAU	0.04	TW
Capacity target per technology	Wind	2040	SAU	0.01	TW
Implicit carbon tax in the energy sector in 2025			SAU	0.10	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			SAU	0.01	$/tCO_2$
Renewables share	Final energy consumption	2037	THA	0.34	
Intensity change	Energy intensity reduction 2010	2036	THA	0.30	
Renewables share	Electricity production	2037	THA	0.21	
Capacity target per technology	Biomass	2037	THA	0.01	TW
Capacity target per technology	Hydro	2037	THA	0.00	TW
Capacity target per technology	Solar	2037	THA	0.02	TW
Capacity target per technology	Wind	2037	THA	0.00	TW
Share biofuels in fuel oil	Transport	2020	THA	0.10	
Implicit carbon tax in the energy sector in 2025			THA	1.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			THA	1.00	$/tCO_2$
Capacity target per technology	Hydro	2023	TUR	0.03	TW
Capacity target per technology	Wind	2023	TUR	0.01	TW
Capacity target per technology	Solar	2023	TUR	0.01	TW
Renewables share	Electricity production	2023	TUR	0.30	
Intensity change	Energy intensity reduction 2010	2023	TUR	0.20	
primary energy consumption change	Primary energy supply 2015	2023	TUR	0.14	PJ
Implicit carbon tax in the energy sector in 2025			TUR	0.01	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			TUR	0.01	$/tCO2
Share biofuels in fuel oil	Transport	2022	USA	0.21	
HFC Emissions		2030	USA	0.01	GtCe/year
Implicit carbon tax in the energy sector in 2025			USA	8.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			USA	1.00	$/tCO_2$
Capacity target per technology	Hydro	2030	ZAF	0.00	TW
Capacity target per technology	Wind	2035	ZAF	0.02	TW
Capacity target per technology	CSP	2030	ZAF	0.00	TW
Capacity target per technology	PV	2030	ZAF	0.01	TW

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Implemented Policies	Sector	Starting Date	Economy	Target Value	Unit
Capacity target per technology	Nuclear	2030	ZAF	0.00	TW
Share biofuels in fuel oil	Transport	2020	ZAF	0.05	
Implicit carbon tax in the energy sector in 2025			ZAF	5.00	$/tCO_2$
Implicit carbon tax in the land-use sector in 2025			ZAF	0.01	$/tCO_2$

$/tCO_2 = United States dollar per ton of carbon dioxide, GtCe/year =gigatons of carbon equivalent, ARG = Argentina, AUS= Australia, BAU = business-as-usual, BRA= Brazil, CAN= Canada, CH4 = methane, CO_2 = carbon dioxide, EUR = Europe, GHG = greenhouse gas, HFC = hydrofluorocarbons, IND= India, INO= Indonesia, JPN = Japan, MEX = Mexico, PRC = People's Republic of China, ROK= Republic of Korea, RUS = Russian Federation, SAU = Saudi Arabia, THA = Thailand, TUR = Türkiye, TW = terawatt, TWh = terawatt-hour, USA = United States, ZAF = South Africa.

Source: Authors.

Table A2 lists the interpretation of nationally determined contributions (NDCs) of developing Asian economies implemented in the WITCH model. It lists both unconditional and conditional targets in terms of fraction of emission reduction along with reduction in absolute emissions. Only NDCs that are implementable in the model are included. Absolute emissions are not given when economies are part of a macro region and did not provide a usable baseline scenario (BAU), and absolute emissions are calculated endogenously using WITCH downscaled BAU emissions. For India and the PRC, the targets are defined as intensity targets, therefore the numbers displayed in the table refer to the results of the NDC effort scenario.

Table A2: Nationally Determined Contributions of Developing Asian Economies

	Unconditional Reduction (fraction)	**Conditional Reduction** (fraction)	**Target Year**	**Unconditional Absolute Emissions** ($GtCO_2e$)	**Conditional Absolute Emissions** ($GtCO_2e$)
Afghanistan		0.14	2030	0.049	0.042
Armenia	0.40	0.40	2030	0.016	0.016
Azerbaijan	0.35	0.35	2030	0.045	0.045
Bangladesh	0.0673	0.1512	2030	0.158	0.143
Brunei Darussalam	0.20	0.20	2030		
Bhutan	1.00	1.00	2030		
China, People's Republic of			2030	12.3	12.3
Georgia	0.35	0.57	2030	0.029	0.019
Indonesia	0.3189	0.432	2030	1.95	1.63

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	Unconditional Reduction (fraction)	**Conditional Reduction** (fraction)	**Target Year**	**Unconditional Absolute Emissions** ($GtCO_2e$)	**Conditional Absolute Emissions** ($GtCO_2e$)
India			2030	4.16	4.16
Kazakhstan	0.15	0.25	2030	0.249	0.220
Kyrgyz Republic	0.16	0.44	2030	0.013	0.008
Cambodia	0.42	0.42	2030	0.090	0.090
Lao PDR	0.60	0.67	2025	0.042	0.034
Sri Lanka	0.07	0.23	2030		
Maldives	0.26	1.00	2030	0.002	0.000
Myanmar			2030		
Mongolia	0.23	0.27	2030	0.057	0.054
Malaysia	0.45	0.45	2030	0.759	0.759
Pakistan	0.15	0.50	2030	1.363	0.802
Philippines	0.03	0.72	2030	0.325	0.093
Singapore			2030	0.065	0.065
Thailand	0.20	0.25	2030	0.444	0.416
Turkmenistan			2030	0.136	0.136
Uzbekistan			2030	0.392	0.392
Viet Nam	0.09	0.27	2030	0.844	0.677

$GtCO_2e$= Billion of tons of carbon dioxide equivalent, Lao PDR = Lao People's Democratic Republic.

Notes: Effective 1 February 2021, ADB placed a temporary hold on sovereign project disbursements and new contracts in Myanmar. ADB placed on hold its regular assistance in Afghanistan effective 15 August 2021.

Source: Authors.

Table A3 lists national net-zero pledges of developing Asian economies. Reis and Tavoni (2023) has a complete list of global net-zero pledges implemented in the model.

Table A3: Net-Zero Pledges of Developing Asian Economies

ISO3	Target Year	Status	GHG Covered
Afghanistan	2050	Proposed	CO_2
Bhutan	2030	Achieved	CO_2
China, People's Republic of	2060	Document	CO_2
Indonesia	2060	Declared	GHG
India	2070	Declared	CO_2
Kazakhstan	2060	Declared	CO_2
Kyrgyz Republic	2050	Proposed	CO_2
Cambodia	2050	Document	GHG
Lao PDR	2050	Document	GHG
Sri Lanka	2050	Document	CO_2
Maldives	2050	Proposed	CO_2
Myanmar	2050	Proposed	CO_2
Malaysia	2050	Declared	CO_2
Nepal	2050	Document	GHG
Papua New Guinea	2050	Declared	GHG
Singapore	2050	Document	CO_2
Thailand	2065	Document	CO_2
Uzbekistan	2050	Proposed	CO_2
Viet Nam	2050	Declared	CO_2

CO_2 = carbon dioxide, GHG = greenhouse gases, Lao PDR = Lao People's Democratic Republic.

Note: Effective 1 February 2021, ADB placed a temporary hold on sovereign project disbursements and new contracts in Myanmar. ADB placed on hold its regular assistance in Afghanistan effective 15 August 2021.

Source: Authors.

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Assessing the Implications of a Global Net-Zero Transition for Developing Asia
Insights from Integrated Assessment Modeling

Global climate goals will not be attainable unless Asia's growth becomes much less carbon-intensive. This paper uses a global integrated assessment model to assess how developing Asia would develop in a world that meets Paris Agreement temperature goals. It finds that a profound transition is needed, with a rapidly decarbonized power sector and a dramatic drop in land-use emissions. Benefits are found to be far in excess of costs for Asia if an efficient set of decarbonization policies is deployed.

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