DECARBONIZATION PATHWAYS IN DEVELOPING ASIA

EVIDENCE FROM MODELING SCENARIOS

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ABSTRACT

Unless developing Asia decarbonizes its development, global warming is unlikely to stay below the internationally agreed limit of 2°C above preindustrial levels. Integrated assessment modeling offers insights into how a low carbon transition can be achieved. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change incorporated an ambitious model intercomparison effort that compiled thousands of model-scenario combinations to consider low carbon development pathways. This paper explores the evidence within that database to consider decarbonization pathways for developing Asia. Overall, a comparison of the major models finds strong consistency in the transformation of the energy sector required to achieve Paris Agreement goals. This includes a rapid decline in the share of coal—a mainstay of the power sector in developing Asia—and a substantial rise in renewable energy. The cost of the transition can be relatively low if mitigation efforts are efficient, as assumed in the models.

Keywords*:* climate change, integrated assessment model, mitigation, energy,
Paris Agreement, NDCs

JEL codes*:* C61, D58, Q4, Q54

1. Introduction

Developing Asia has a special stake in the global climate crisis, as the region is both highly vulnerable to climate change and accounts for a growing share of the world's greenhouse gas (GHG) emissions. As of 2019, developing Asia is home to some of the biggest emitters and accounts for about 44% of global GHG emissions. Although per capita emissions from the region are well below advanced economies, they are rapidly increasing (World Resources Institute n.d.). If regional emissions trends continue, no matter whether other regions rapidly reduce emissions, achieving the Paris Agreement goal of limiting global mean temperature rise to well below 2°C will not be possible (Emmerling et. al. 2023).

As the largest source of emissions, the energy sector will need to undergo a transformation to achieve the region's climate goals. This is particularly important, given that energy consumption in the region is expected to rise rapidly from low levels. In the last 2 decades, developing Asia made rapid progress in expanding access to electricity. However, 112.5 million people in the region still do not have access to electricity, while 1.3 billion do not have access to clean cooking technologies (World Bank n.d.). Achieving this transformation of the energy system to meet development and climate goals will pose a range of challenges as well as opportunities for developing Asia.

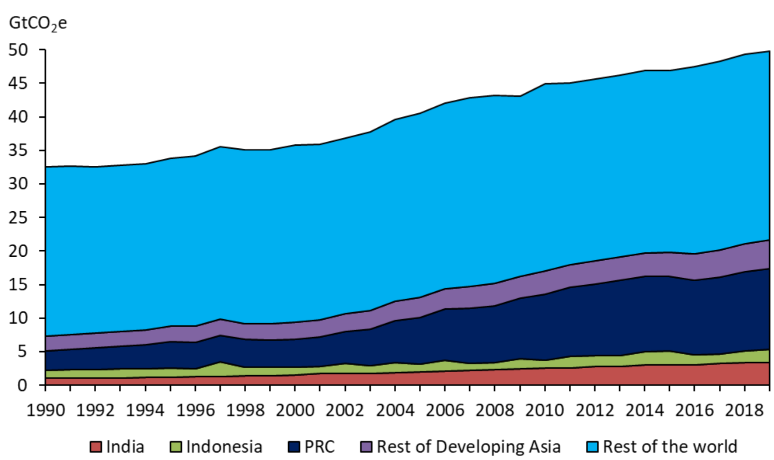
In recent years, integrated assessment modeling has made advances in the ability to consider low carbon development pathways. More integrated assessment models now endogenize technical change, and they have a growing range of energy technologies reflected (Wilson et al. 2021). To a greater degree, modelers have also worked together in intercomparison efforts to understand larger patterns in scenario results (O'Neill et al. 2020).

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) incorporated an ambitious model intercomparison effort that compiled thousands of submitted model-scenario combinations, each of which had thousands of outputs, in an integrated scenario database (Byers et al. 2022). This paper explores the evidence within that database to consider decarbonization pathways in developing Asia under current policies and commitments and pledges under Paris Agreement.

2. Context

Historically, GHG emissions from developing Asia were relatively low. In 1990, the region accounted for about a quarter of global GHG emissions and 54% of the global population. However, following rapid growth in major economies in the region, emissions from the region increased to about 44% of the global share in 2019. The region is now home to some of the biggest emitters in the world including India, Indonesia, and the People's Republic of China (PRC) (Figure 1). Together, these three economies account for about a third of global GHG emissions.

Figure 1: Global Annual Greenhouse Gas Emissions



$GtCO_2e$ = billion tons of carbon dioxide equivalent.

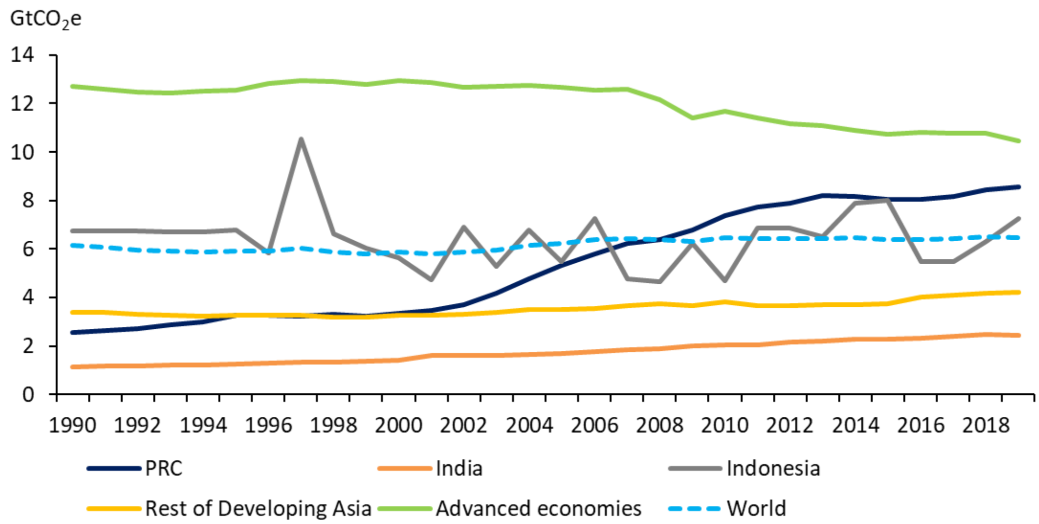
Note: Emissions from land-use change and forestry, which can be positive or negative, are included. Rest of developing Asia includes all remaining Asian Development Bank developing member economies, except for Hong Kong, China and Taipei,China for lack of data.

Source: World Resources Institute. Climate Watch (accessed 10 January 2023).

Per capita emissions from the region remain below advanced economies but are rapidly increasing (Figure 2). The increase has been particularly sharp for the PRC, where per capita GHG emissions increased more than threefold from 2.5 tons in 1991 to 8.6 tons in 2019.

Meanwhile, GHG emissions in advanced economies started to decline in the late 2010s but remain above the global average.

Figure 2: Greenhouse Gas Per Capita Emissions, 1990–2019



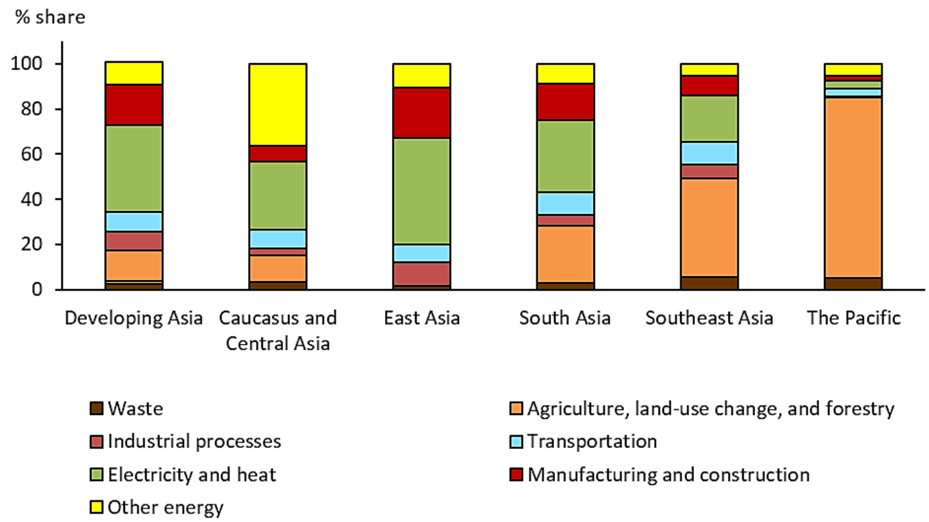
$GtCO_2e$ = billion tons of carbon dioxide equivalent; PRC = People's Republic of China.

Note: Greenhouse gas emissions include land use, land-use change, and forestry. "Rest of Developing Asia" includes all 46 Asian Development Bank member economies, excluding India, Indonesia, and the PRC. "Advanced economies" include 35 economies.

Source: World Resources Institute. Climate Watch (accessed February 2023).

The energy sector accounts for three-fourths of global GHG emissions and nearly as large a share in developing Asia. Within the energy sector, electricity and heat production are the biggest contributors, accounting for about 40% of emissions from developing Asia in 2019 (Figure 3). Electricity and heat production were the fastest-growing sources of GHG emissions in the region from 1991 to 2019 in both relative and absolute terms. Apart from electricity and heat production, other major sources of GHG emissions include manufacturing (18%), agriculture, and land-use change and forestry (14%), transportation (9%), and industrial processes (8%). At the same time, the sources of emissions vary among the economies. For instance, close to half of GHG emissions in Indonesia come from land use, including from deforestation of peat swamps containing thousands of tons of carbon per hectare. Meanwhile, agriculture remains a major source of GHG emissions in South Asian countries that include Nepal (54%) and Pakistan (44%).

Figure 3: Greenhouse Gas Emissions, by Sector, 2019

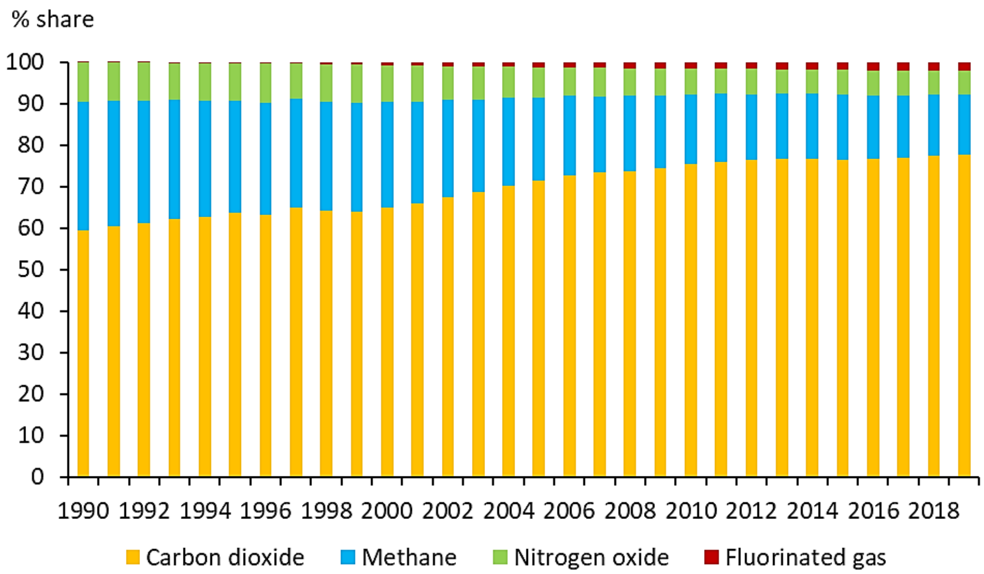


Note: Greenhouse gas emissions from land-use change and forestry, which can be positive or negative, are included. "Developing Asia" includes all Asian Development Bank member economies excluding Hong Kong, China and Taipei,China for lack of data.

Source: World Resources Institute. Climate Watch (accessed February 2023).

Much of the increase in GHG emissions in the region during the last 3 decades was driven by a sharp rise in carbon dioxide emissions. In 2019, carbon dioxide emissions accounted for 78% of the total GHG emissions, marking a notable rise from 60% in 1990 (Figure 4). Meanwhile, emissions from other sources, although increasing in volume, have been declining in shares. An exception to this trend is fluorinated gases, recognized as a potent GHG and commonly employed as substitutes for ozone-depleting substances. From 1991 to 2019, the share of fluorinated gases has slightly increased from 0.1% to 2.2%.

Figure 4: Greenhouse Gas Emissions in Developing Asia, by Gas Type, 1990–2019



Note: "Developing Asia" includes all Asian Development Bank member economies excluding Hong Kong, China and Taipei,China for lack of data.

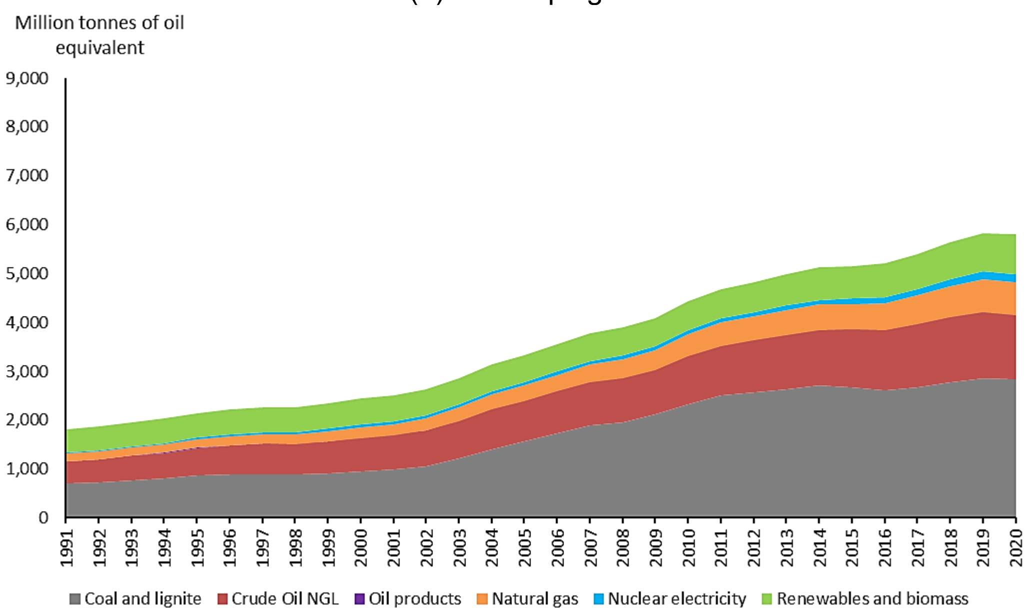
Source: World Resources Institute. Climate Watch (accessed February 2023).

Developing Asia's primary energy supply increased by 218% from 1,820 million tons of oil equivalent (Mtoe) in 1991 to 5,800 Mtoe in 2020 (Figure 5), which is far above the 15% growth in the rest of the world.[1] The increase is driven mainly by the PRC, whose primary energy supply increased four-folds from 848 Mtoe (accounting for 46.8% of developing Asia's thermal energy storage [TES]) to 3,470 Mtoe (59.9%). The surge in energy demand, driven by rapid economic growth and population expansion, has primarily been met through the extensive use of coal as an energy source. Coal accounted for 48.7% of total primary energy in 2020, followed by crude oil at 23.7%, and natural gas at 11.6%. In contrast, coal provided only 11.3% of primary energy in the rest of the world.

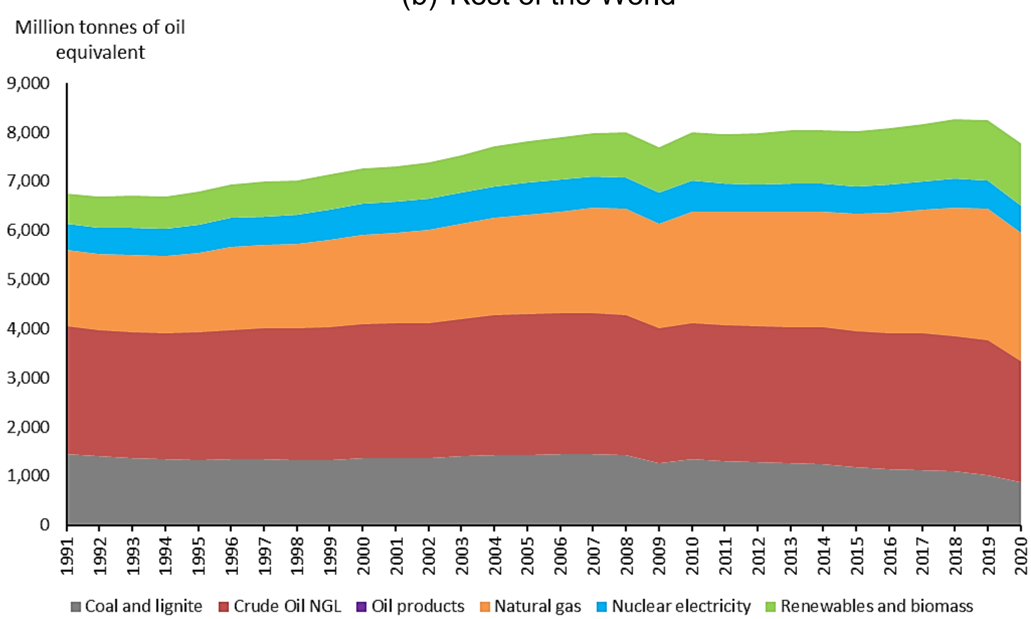
[1] Primary energy supply is the total amount of primary energy that an economy has at its disposal, which includes imported energy, exported energy (subtracted off), and energy extracted from natural resources (energy production).

Figure 5: Primary Energy Supply, 1991–2020

(a) Developing Asia



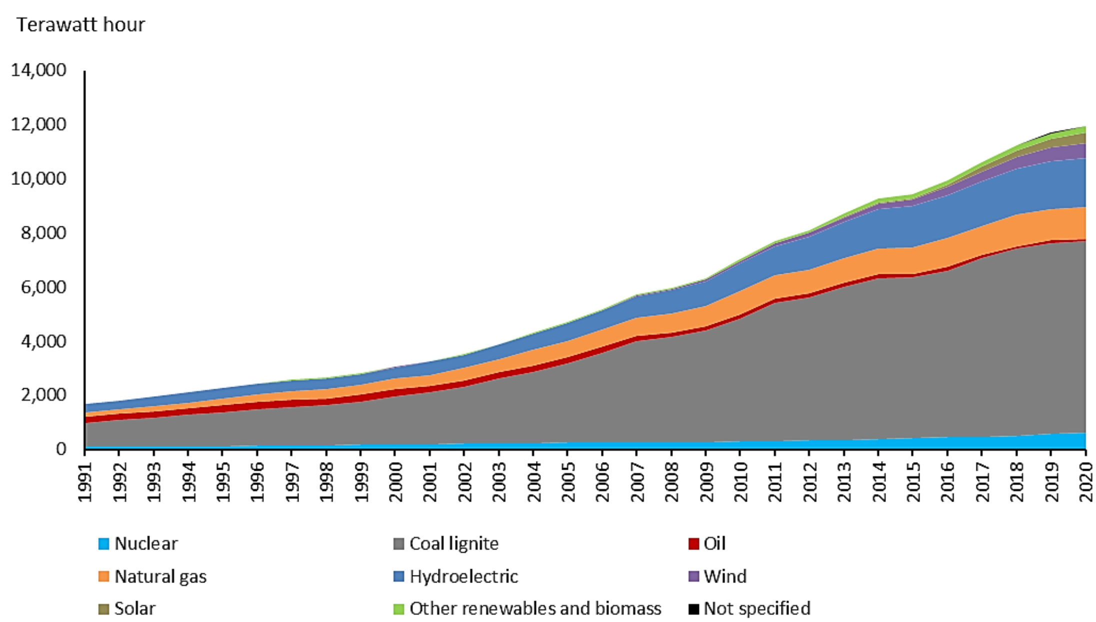
(b) Rest of the World



NGL = natural gas liquids.
Note: "Developing Asia" includes all 46 developing members of the Asian Development Bank with available data.
Source: Enerdata. Global Energy and CO_2 Data (accessed 20 September 2022).

Total electricity supply in developing Asia increased from 1,691 terawatt-hours (TWh) in 1991 to 11,932 TWh in 2020. Coal, the most carbon intensive major source of electricity, remains the primary source of power in the region, although its share started to decline in the last decade (Figure 6). Coal's shares in the generation mix increased from 52.5% in 1991 to an all-time high of 66.3% in 2011, thereafter starting a period of decline, reaching 59.5% in 2020.

Figure 6: Electricity Generation in Developing Asia, 1991–2020



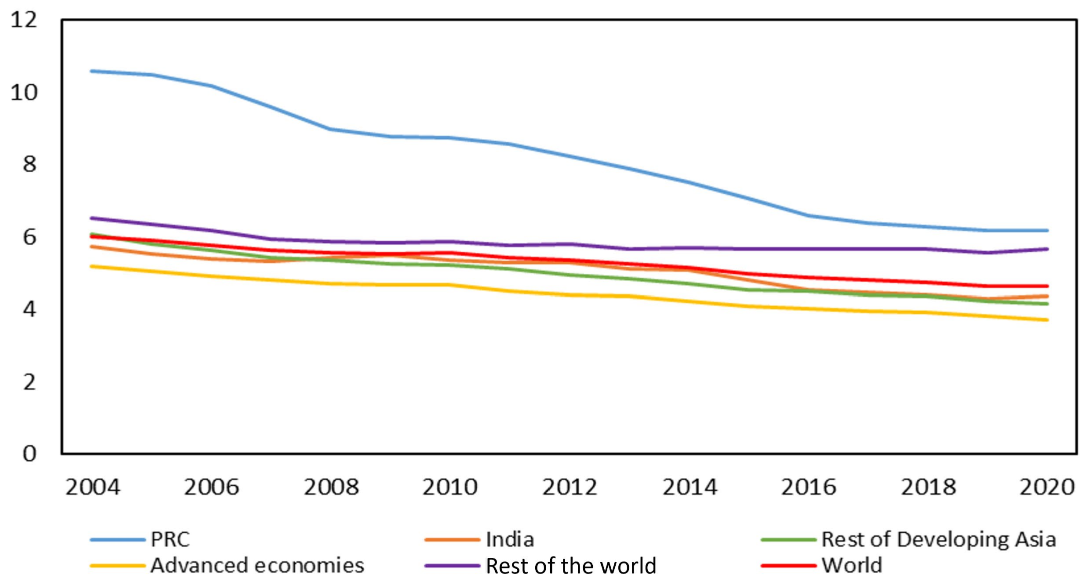
Source: Enerdata. Global Energy and CO_2 Data (accessed 20 September 2022).

Energy intensity in developing Asia is far above that of advanced economies, which implies economic growth has more potential to increase energy demand. This is especially so in the PRC and in Central Asia. At the same time, energy intensity has fallen over time. This is in part due to increasing efficiency with technical change and in part due to a structural shift of the economy toward services (Figure 7).[2] Between 2004 and 2019, global energy intensity declined

[2] Energy intensity refers to the physical energy required to generate each unit of gross domestic product. The International Energy Agency uses energy intensity as the indicator used to track progress on global energy efficiency.

by 21.7% to reach 4.7 megajoules (MJ) per 2017 United States dollar ($) purchasing power parity (PPP). The Sustainable Development Goal (SDG) target of 3.4 MJ per 2017 $PPP by 2030 will require an annual reduction of 2.6% until 2030. The world, however, has failed to deliver on this, with reductions ranging from 0.8% to 2.2% during 2016–2019 (IEA 2022). Energy intensity still varies widely across the region, although most economies remain well above the SDG, and the region remains above the world average (Figure 8).

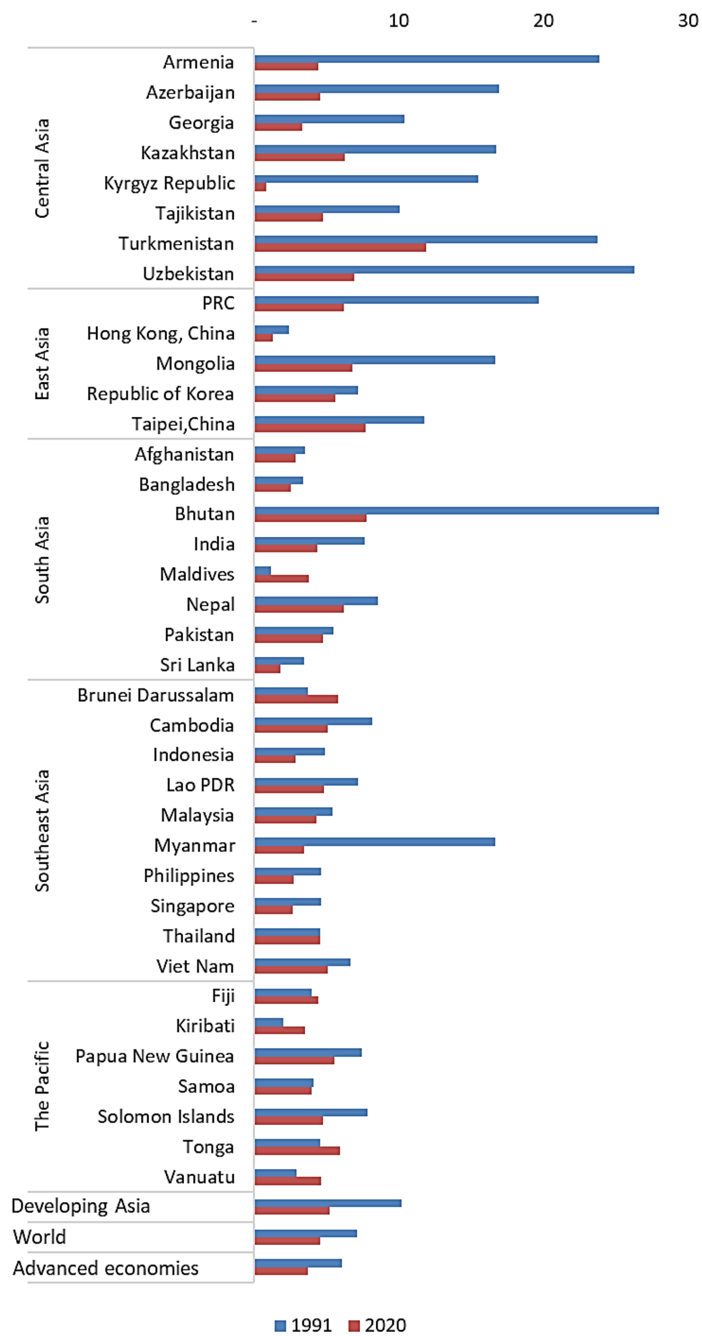
Figure 7: Trends in Energy Intensity, 2004–2020
(megajoule per 2015 $PPP)



PRC = People's Republic of China, PPP = purchasing power parity.
Note: "Advanced economies" include 36 economies.
Source: Enerdata. Global Energy and CO_2 Data (accessed 20 September 2022).

It is however only an imperfect proxy to energy efficiency indicator as it can be affected by several factors not necessarily linked to pure efficiency such as climate.

Figure 8: Energy Intensity, 1991 and 2020
(megajoule per 2015 $PPP)



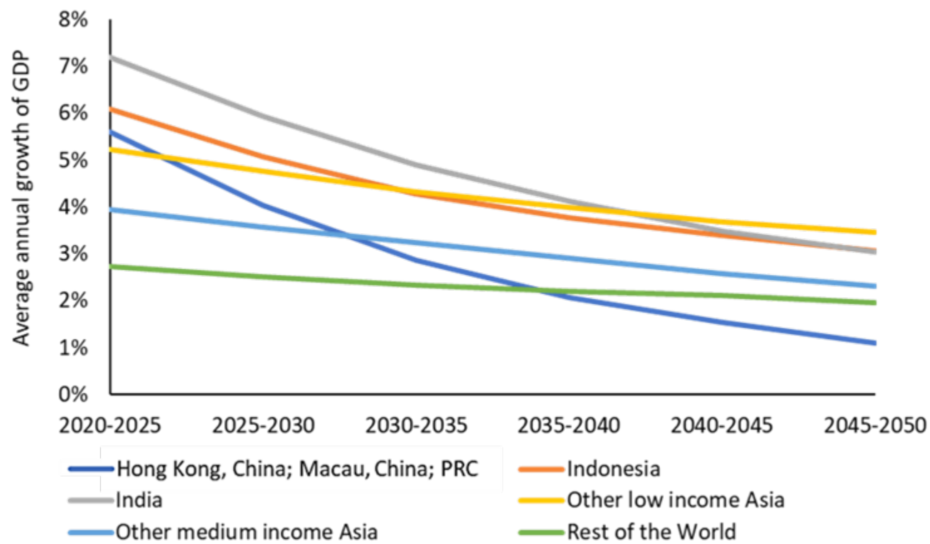
Lao PDR = Lao People's Democratic Republic, PRC = People's Republic of China, PPP = purchasing power parity.

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

Source: Enerdata. Global Energy and CO_2 Data (accessed 20 September 2022).

The high energy intensity in developing Asia, supplied by a carbon intensive energy system, means that future economic growth can greatly increase greenhouse gas emissions. Compared with the rest of the world, growth in gross domestic product in developing Asia is expected to be much more rapid. Projections agreed by the international modelling community for the "middle of the road" scenario of the shared socioeconomic pathways (SSP2) show the region growing more than twice as fast as the rest of the world in the coming decades, with certain large economies, such as India and Indonesia, growing even faster (Figure 9). Unless that growth is much greener than the patterns to date, achieving the goals of the Paris Agreement will not be possible.

Figure 9: Projected Growth of Gross Domestic Product under the "Middle of the Road" Scenario



GDP = gross domestic product, PRC = People's Republic of China.

Note: Values reflect an average of results from models in the Shared Socioeconomic Pathway Scenario Database.

Source: Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O'Neill, et al. 2016. "The Shared Socioeconomic Pathways and their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview." *Global Environmental Change* 42, 153–68.

Within developing Asia, there is recognition of the importance of changing course. All of the eligible economies in the region have agreed to the Paris Agreement, which seeks to limit global warming to well below 2°C and pursue efforts to 1.5°C compared to preindustrial levels. All Paris Agreement parties in the region have submitted nationally determined contributions (NDCs), most of which contain commitments to reduce emissions by 2030. Going beyond these short-term commitments, 19 developing Asian economies, accounting for about 80% of the region's 2019 total GHG emissions, have made pledges to achieve carbon neutrality (or net zero) within the 21st century. However, those pledges are nonbinding and largely remain to be reflected in specific plans and policies.

3. Objectives

With rapidly growing economies and nearly half of global GHG emissions, the development trajectory of Asia is critical to achieving the goals of the Paris Agreement. Only if Asia changes course dramatically in terms of energy and land use can global warming be kept contained. The question then, is how Asia would need to transform to achieve the goals of the Paris Agreement. This study attempts to answer the following questions, drawing on an international database of results from leading climate-energy-economy models.

(i) How would Asia's emissions evolve under current policies, compared with NDCs, and a world that meets the Paris Agreement goal of a high probability of keeping warming well below 2°C?

(ii) How would Asia's energy mix evolve under current policies, compared with NDCs and under a well below 2°C scenario?

(iii) What would be the implications for investment and economic growth of pursuit of the decarbonization scenarios?

4. Methods

Integrated assessment models (IAMs) combine different strands of knowledge to provide insights on how the global economy, along with energy, land, and agriculture systems, interacts with the environment. IAMs provide the bulk of evidence relied on by the IPCC for insights into alternative mitigation strategies and their feedbacks and tradeoffs. As part of the IPCC's Sixth Assessment (AR6) Report, authors of the Working Group III on Mitigation of Climate Change undertook a comprehensive exercise to collect and assess quantitative, model-based scenarios. The compilation and assessment of the scenarios, collectively referred to as the AR6 scenario explorer and database, is hosted by the International Institute for Applied Systems Analysis (IIASA). The database contains 3,131 scenario runs from 188 models, with data on 1,775 variables on socioeconomic development, GHG emissions, and sectoral transformations across energy, land use, transportation, and industry.

The submitted scenario runs represent the latest scientific understanding of the pathways of evolution of global energy systems and associated emissions, as well as implications for economies in major world regions. This paper harnesses this understanding from the AR6 Scenario Database to understand patterns in modeled results of different climate policy scenarios for developing Asia. By using a database reflecting a range of models for analyzed scenarios, the paper avoids the biases that may be embedded in one specific model and relies on larger patterns of findings representing a range of model structures and perspectives.

To encapsulate a range of climate policy futures, the analysis selected IAMs and scenario runs from the AR6 database that correspond to four climate policy scenarios:

(i) ***Current policies*** assume no additional effort on climate change mitigation beyond that is already included in current energy and climate policies.

(ii) ***NDC effort*** assumes implementation of NDCs until 2030, with gradual strengthening thereafter.

(iii) ***2°C*** assumes economies follow their NDCs until 2030 and a coordinated effort thereafter to stay within the carbon budget consistent with the well below 2°C goal of the Paris Agreement. After reaching the budget, emissions need to stay at or close to zero and not rely on negative emissions to take care of an “overshoot” of the carbon budget.

(iv) ***2°C early action*** assumes economies take early action and follow an accelerated path to meet Paris Agreement goals of limiting warming to well below 2°C, without overshoot.

The analysis excludes scenario runs that did not pass historical and future vetting by the IPCC, as indicated in the database. In terms of shared socioeconomic pathways (SSPs) that determine population and growth projections, it only includes scenarios that are consistent with the SSP2 ‘middle of the road’ category. The scenario runs are then filtered based on the policy category name. For the 2°C scenarios, additional filtering is carried out to ensure a carbon budget that is consistent with well below 2°C warming.[3] This also excludes scenario runs that allow for overshoot of the carbon budget to be remedied through negative emissions. Details of the filtering methodology are summarized in Table 1.

Table 1: Selection Criteria for Scenarios from the AR6 Database

Scenario	**Policy Category Name**	**Carbon Budget** ($GtCO_2$, 2020-2100)
Current Policies	P1b: current policies	-
NDC Effort	P1c: NDC	-
2°C	P3b: NDC + delayed global action	1035 to 1265
2°C early action	P2a: Immediate global action without transfers	1035 to 1265

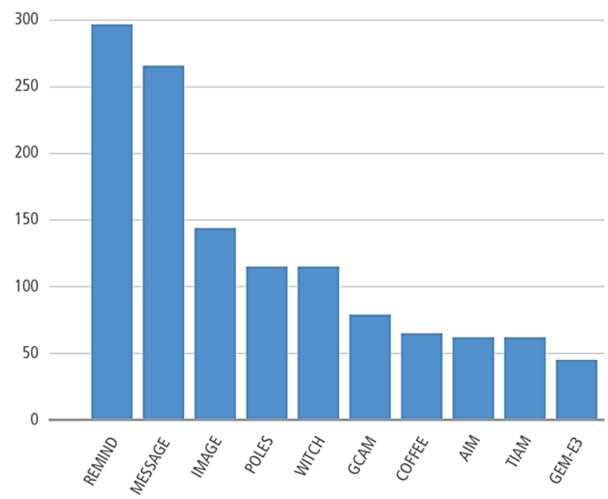
AR6 = Sixth Annual Report of the Intergovernmental Panel on Climate Change, $GtCO_2$ = billion tons of carbon dioxide, NDC = nationally determined contributions.

Source: Authors.

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

The remaining AR6 scenario runs across the 4 climate scenarios are from 11 common IAMs. After dropping older versions of the models, the screening left just 9 models. Figure 10 shows that the selected 9 IAMs are among the top 10 models that contributed the most scenarios to IPCC AR6 Working Group III report.

Figure 10: Number of Scenario Runs from the Top 10 Model Families



AIM = Asia-Pacific Integrated Modeling; COFFEE = Computable Integrated Framework for Energy and the Environment; GCAM = Global Change Analysis Model; GEM E-3 = General Equilibrium Model for Economy-Energy-Environment; IMAGE = Integrated Model to Assess the Global Environment; MESSAGE = Model for Energy Supply Strategy Alternatives and their General Environmental Impact; POLES = Prospective Outlook on Long-term Energy Systems; REMIND = REgional Model of INvestment and Development; TIAM = TIMES Integrated Assessment Model; WITCH = World Induced Technical Change Hybrid.

Source: Intergovernmental Panel on Climate Change. 2022*. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

Table 2 lists the scenario runs that were included in the analysis. In the case of multiple scenarios of the same model, results are averaged across the scenarios. The Appendix provides more details on the IAMs.

Table 2: Scenario Runs and Models Included in the Analysis

Models	Current Policies	NDC Effort	2°C	2°C early action
AIM/CGE 2.2	EN_NPi2100	EN_INDCi2100	EN_INDCi2030_1200	--
COFFEE 1.1	EN_NPi2100 CO_CurPol	EN_INDCi2100_COV_NDCp CO_NDCplus	EN_INDCi2030_1200 EN_INDCi2030_1000	--
GEM-E3_V2021	EN_NPi2100_COV	EN_INDCi2100_COV_NDCp	EN_INDCi2030_1400	EN_NPi2020_1400
IMAGE 3.0	EN_NPi2100 CO_CurPol	EN_INDCi2100 CO_NDCplus	EN_INDCi2030_1200	EN_NPi2020_1200
MESSAGE ix-GLOBIOM _1.1	EN_NPi2100_COV NGFS2_Current Policies	EN_INDCi2100_COV_NDCp NGFS2_NDCs	EN_INDCi2030_1400_COV_NDCp	EN_NPi2020_1400_COV
POLES ENGAGE	EN_NPi2100_COV	EN_INDCi2100_COV_NDCp	EN_INDCi2030_1200 EN_INDCi2030_1000_COV_NDCp	EN_NPi2020_1000_COV EN_NPi2020_1200
REMIND-MAgPIE 2.1-4.2	EN_NPi2100_COV NGFS2_Current Policies CEMICS_SSP2-Npi SusDev_SSP2-NPi	EN_INDCi2100_COV_NDCp NGFS2_NDCs SusDev_SSP2-NDC	EN_INDCi2030_1200	EN_NPi2020_1200
TIAM-ECN 1.1	EN_NPi2100_COV	EN_INDCi2100_COV EN_INDCi2100_NDCp	EN_INDCi2030_1400 EN_INDCi2030_1200	EN_NPi2020_1200 EN_NPi2020_1400
WITCH 5.0	EN_NPi2100 CO_CurPol	EN_INDCi2100_NDCp CO_NDCplus	EN_INDCi2030_1200_NDCp	EN_NPi2020_1200

AIM/CGE = Asia-Pacific Integrated Modeling/Computable General Equilibrium; CEMICS = Contextualizing Climate Engineering and Mitigation: Illusion, Complement or Substitute; CO = COMMIT or Climate pOlicy assessment and Mitigation Modeling to Integrate national and global Transition pathways; COFFEE = Computable Integrated Framework for Energy and the Environment; COV = COVID-19; COVID-19 = coronavirus disease; CurPol = current policies; EN = Exploring National and Global Actions to reduce Greenhouse gas Emissions (ENGAGE); GEM E-3 = General Equilibrium Model for Economy-Energy-Environment; IMAGE = Integrated Model to Assess the Global Environment; INDC = Current Intended Nationally Determined Contributions; MESSAGEix-GLOBIOM = Model for Energy Supply Strategy Alternatives and their General Environmental Impact-GLobal BIOsphere Management; NGFS = Network for Greening the Financial System; Npi = implemented national policies; POLES = Prospective Outlook on Long-term Energy Systems; REMIND-MAgPIE = REgional Model of INvestment and Development-Model of Agricultural Production and its Impact on the Environment; SSP = shared socioeconomic pathways; SusDev = sustainable development; TIAM-ECN = TIMES Integrated Assessment Model-Energy Research Centre of the Netherlands; WITCH = World Induced Technical Change Hybrid.

Source: Authors based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

A majority of scenario runs submitted to the AR6 database is by model inter-comparison projects. Model inter-comparison projects have been important for the development of IAMs since the early 1990s. IAMs encompass a heterogenous groups of modelling frameworks that borrow from various intellectual traditions including energy systems modelling and macroeconomic forecasting. This means that IAMs have different sets of strengths and limitations. Model intercomparison projects allow a more consistent and systematic assessment across the IAMs and organize research toward providing policy-relevant insights (Beek et al. 2020, Cointe et al. 2019). Table 3 provides a brief overview of the major intercomparison projects that submitted scenario runs to the AR6 database. The scenario runs selected for this paper are broadly representative of the major model intercomparison projects (Figure 11) and include scenarios from Exploring National and Global Actions to Reduce Greenhouse Gas Emissions (ENGAGE), Climate Policy Assessment and Mitigation Modeling to Integrate National and Global Transition Pathways (COMMIT), SSP, and Network for Greening the Financial System (NGFS) projects.

For each climate policy scenario considered, a range of outcomes is summarized and reviewed. These include emissions pathways, the primary energy mix, electricity generation, investment needs for electricity supply, energy intensity, and policy costs. To put the outcomes into perspective, contextual information on the current status of energy relative variables is presented prior to the modeling results.

Table 3: Major Model Intercomparison Studies that Submitted Scenarios to the AR6 Scenario Database

Project	Description	Publication Year	Number of Vetted Scenarios
ENGAGE	Exploring new climate policy scenarios on the global level and in different parts of the world.	2021	591
EMF36	Energy Modelling Forum study into the role of carbon pricing and economic implications of NDCs.	2021	305
SSP	The SSPs are part of a new framework that the climate change research community has adopted to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation (II.1.3).	2018	77
EMF30	Energy Modelling Forum study into the role of non-CO_2 climate forcers	2020	69
EMF33	Energy Modelling Forum study into the role of bioenergy	2020	68

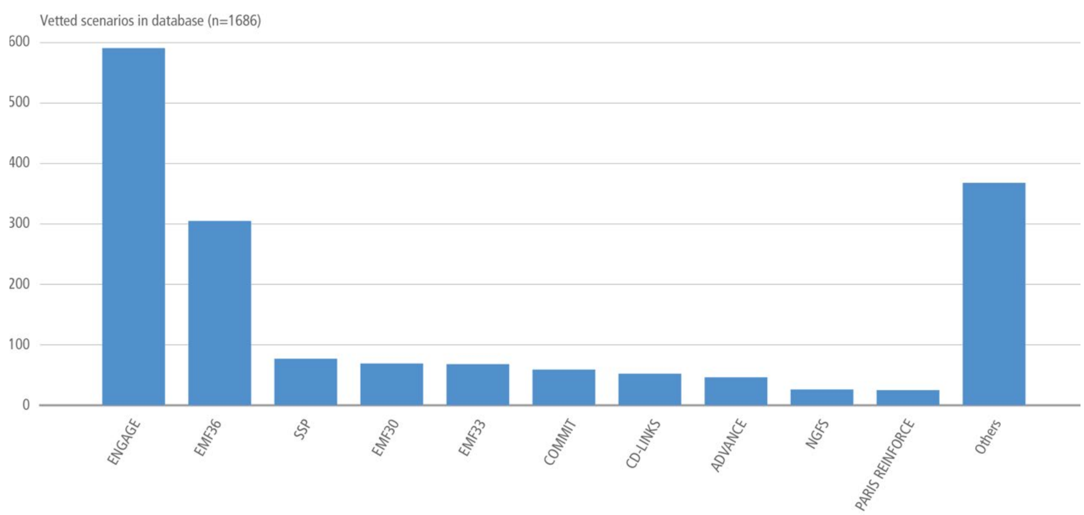
Continued on the next page

Project	Description	Publication Year	Number of Vetted Scenarios
ADVANCE	Developed a new generation of advanced IAMs and applied the improved models to explore different climate mitigation policy options in the post-Paris framework.	2018	40
COMMIT	Exploring new climate policy scenarios on the global level and in different parts of the world.	2021	52
CD-LINKS	Exploring the complex interplay between climate action and development, while simultaneously taking both global and national perspectives and thereby informing the design of complementary climate-development policies.	2018	52
PARIS REINFORCE	Study on the long-term implications of current policies and NDCs.	2020	25
NGFS1	Study for scenario-based financial risk assessment with details on impacts, and sectoral and regional granularity.	2021	24

AR6 = Sixth Assessment Report of the Intergovernmental Panel on Climate Change, CO_2 =carbon dioxide, IAM = integrated assessment model, NDC = nationally determined contribution, SSP = shared socioeconomic pathway.

Source: Intergovernmental Panel on Climate Change. 2022*: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

Figure 11: Number of Scenarios from Each Model Family



CEMICS = Contextualizing Climate Engineering and Mitigation: Illusion, Complement or Substitute; NGFS = Network for Greening the Financial System; SSP = shared socioeconomic pathway.

Source: Intergovernmental Panel on Climate Change. 2022*: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

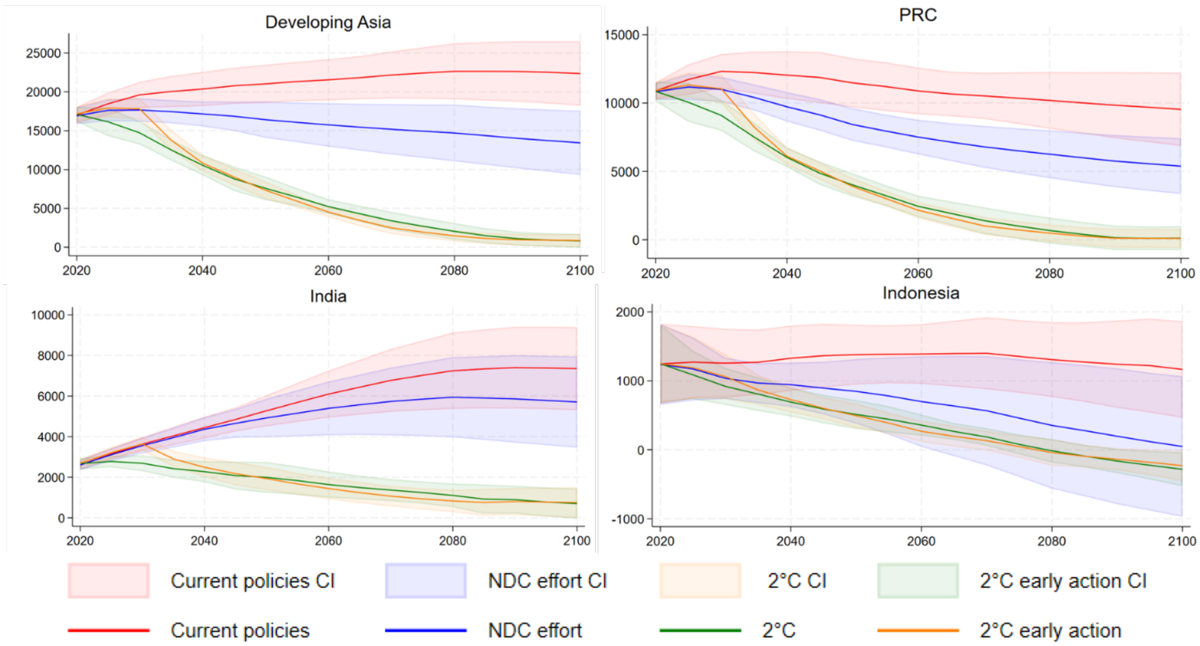
5. Emissions Pathways

Figure 12 shows the trajectories of carbon dioxide (CO_2) emissions from developing Asia and select economies under the models depicting the four climate policy scenarios. The chart shows the mean and confidence intervals calculated across the IAMs. Under the current policies scenario, CO_2 emissions from the region are expected to keep increasing until 2080. The continued rise in emissions means that Paris Agreement goals are missed, and warming likely exceeds 3°C.

Under the NDC effort scenario, CO_2 emissions are lower, but continue to increase until 2030, after which they will start to gradually decline. The NDC effort scenario is associated with about 2.5°C of warming, which means that achieving the Paris Agreement goal of limiting global mean temperature rise to well below 2°C will not be achieved.

Under the 2°C scenarios, as expected, emissions fall quickly to have a high probability of meeting Paris Agreement goals. Like the rest of the world, CO_2 emissions from developing Asia decline sharply, reaching close to net zero by the end of the century. However, emissions from energy still account for 83% of CO_2 emissions from the region in 2070.

Figure 12: Carbon Dioxide Emission Pathways of Developing Asia under Different Scenarios
($MtCO_2$)



CI= confidence interval, $MtCO_2$ = metric tons of carbon dioxide, NDC = nationally determined contribution, PRC = People's Republic of China.

Note: Developing Asia does not include Central and West Asian countries.

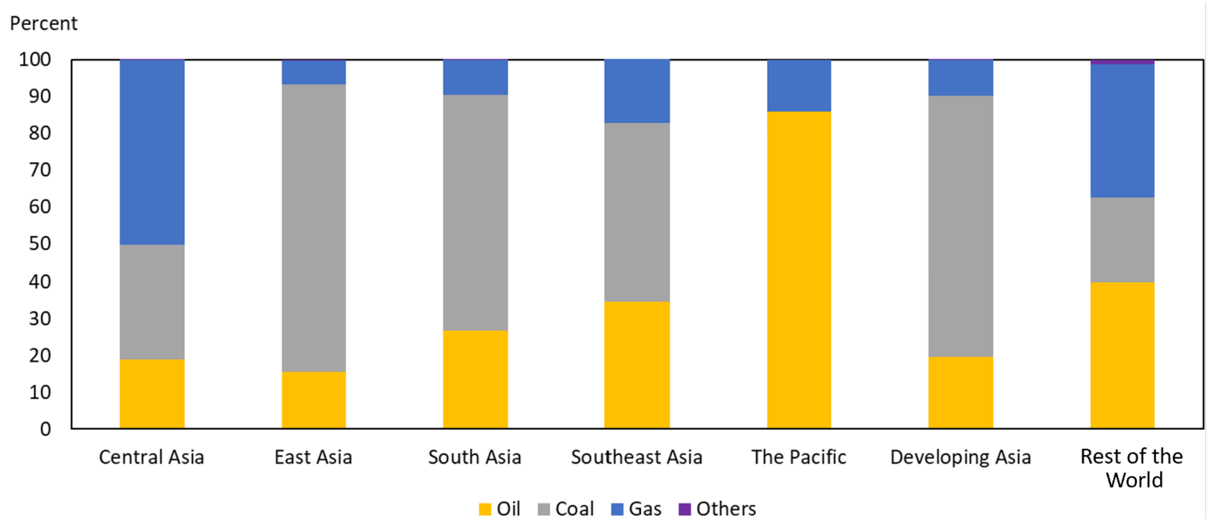
Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

6. Energy Mix

A. Primary Energy

Developing Asia's primary energy mix is particularly carbon-intensive. In 2020, about 70% of energy-emissions from the region came from combustion of coal, the most carbon-intensive energy source, 20% from oil, and 10% from gas (Figure 13), a structure that has remained largely unchanged for the past 30 years. In contrast, for the rest of the world there are higher shares of emissions from oil (40%) and gas (36%), with coal accounting for only 23%. There is also variation within the region. For instance, oil is the primary source of energy emissions in the Pacific, while it is gas in Central Asia. Nevertheless, at a regional level, achieving a low carbon development trajectory depends on rapidly replacing coal in the mix.

Figure 13: Energy-Sector CO_2 Emissions by Fuel, 2020

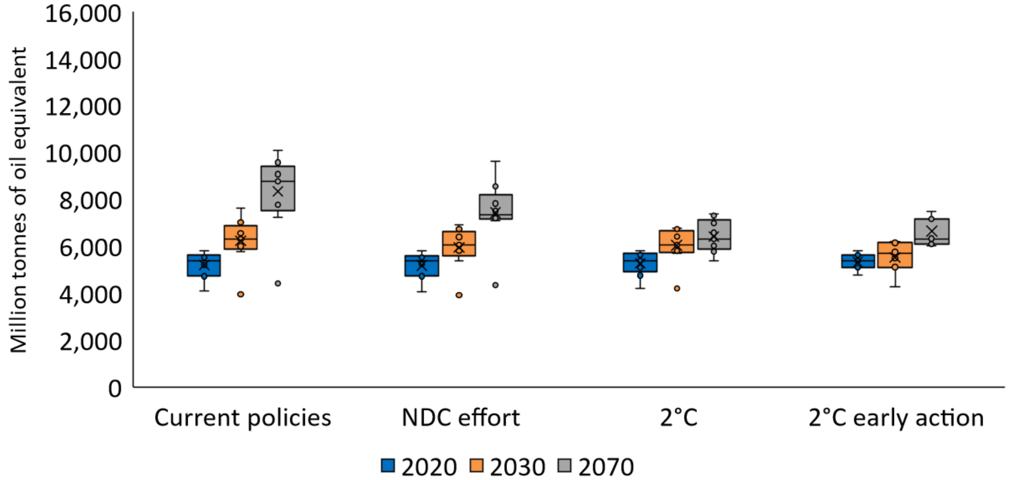


Source: Enerdata. Global Energy and CO_2 Data (accessed 11 July 2022).

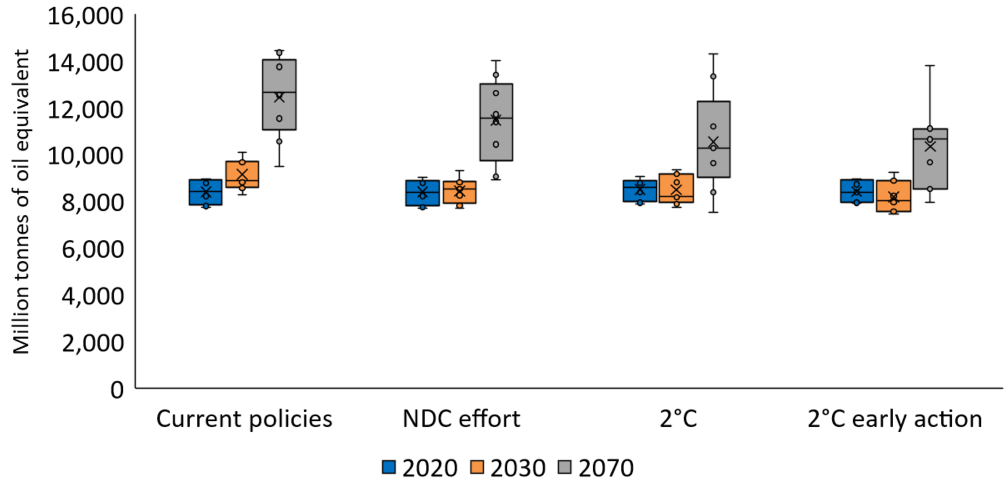
Under the current policies scenario, primary energy supply in the region is expected to grow to reach 6,230 Mtoe by 2030 and 8,340 Mtoe by 2070 (Figure 14A). Developing Asia accounts for 40% of global primary energy supply in 2070 in the models, which is less than the share of the global population. Coal remains the biggest source of energy, accounting for 39% of total primary energy in 2070, which is a modest reduction from 50% in 2020 (Figure 14B).

Figure 14A: Primary Energy Supply, Total, Developing Asia vs Rest of the World

(a) Developing Asia



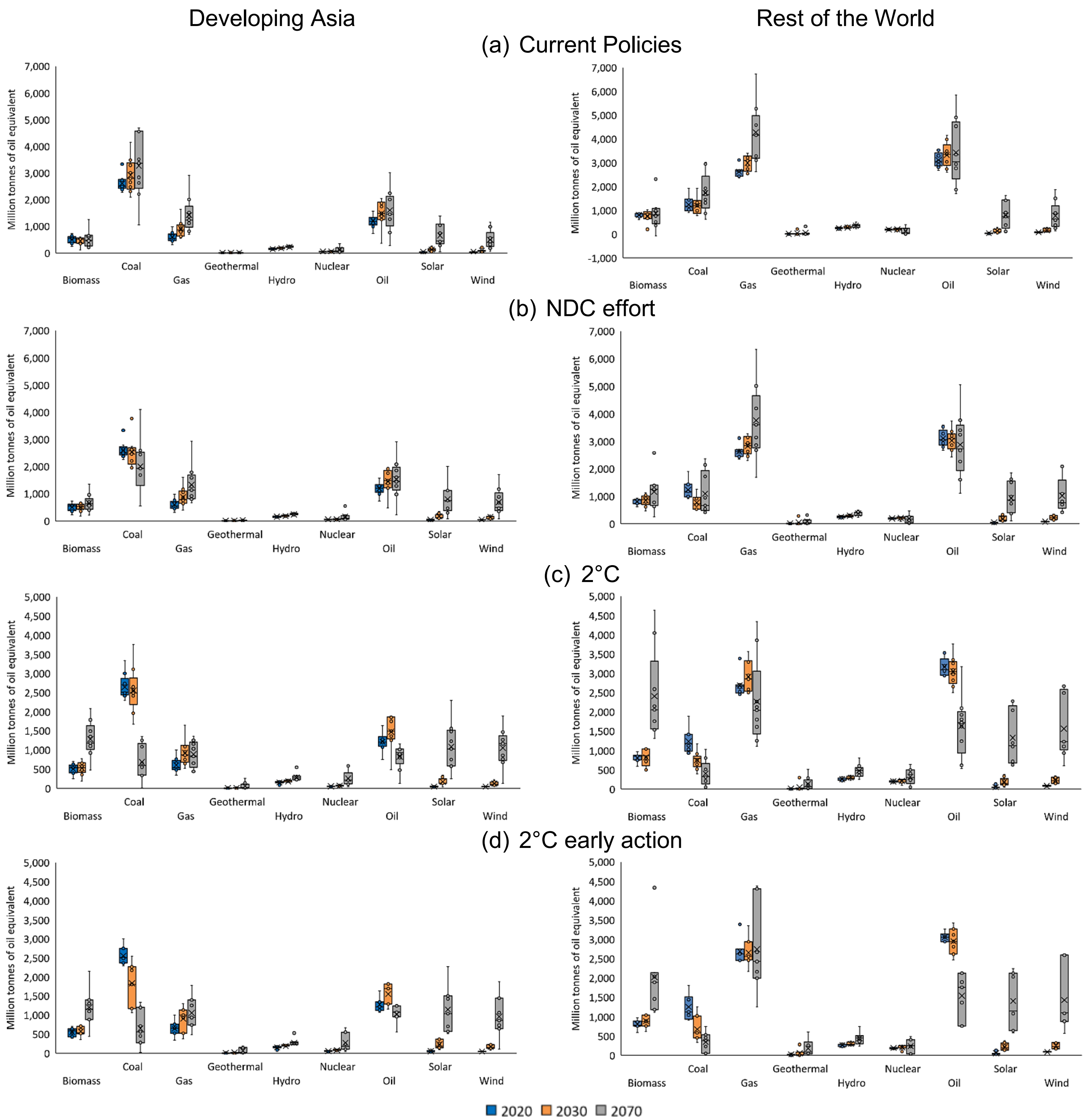
(b) Rest of the World



Note: Developing Asia does not include Central and West Asian countries; X is mean, the solid line is median, boxes are the range of values between the first and third quartile, and whiskers are minimum and maximum data.

Source: Authors calculations based on the AR6 scenario explorer.

Figure 14B: Primary Energy Supply, By Source and Scenario, Developing Asia vs Rest of the World



Note: Developing Asia does not include Central and West Asian countries; X is mean, the solid line is median, boxes are the range of values between the first and third quartile, and whiskers are minimum and maximum data.

Source: Authors calculations based on the AR6 scenario explorer.

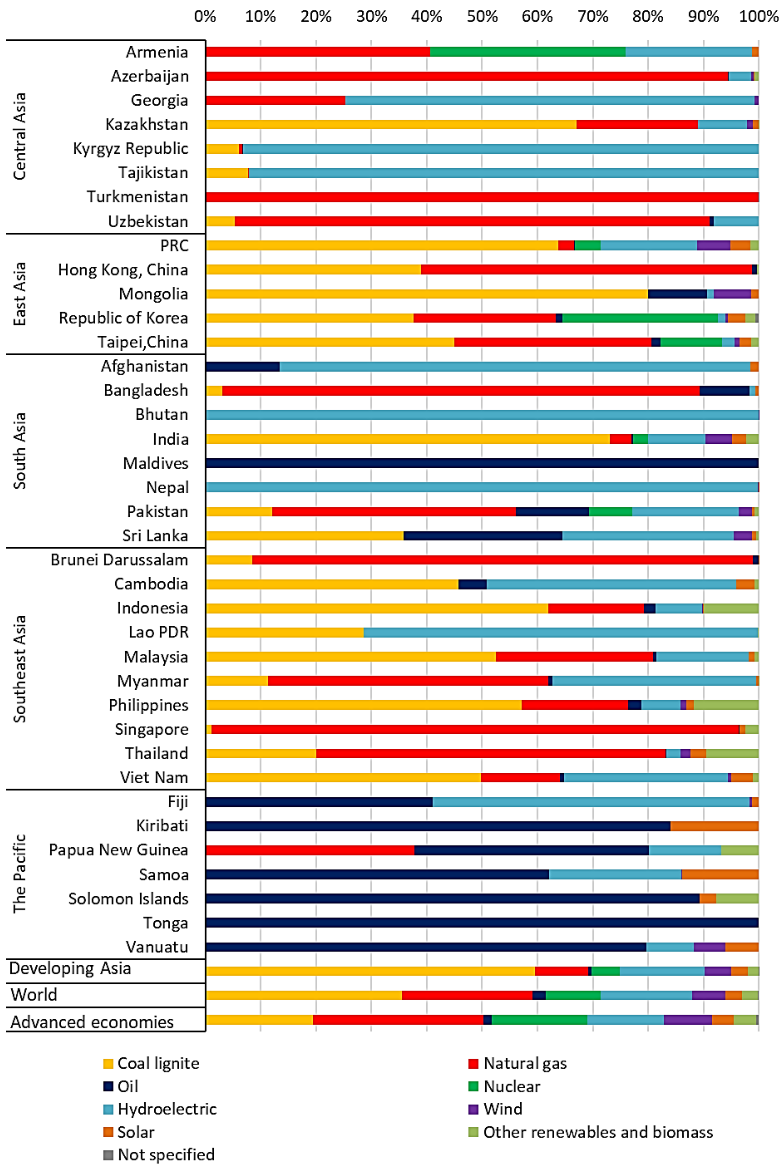
Under the NDC effort scenario, the share of coal declines somewhat faster to 27% by 2070. In the well below 2°C scenario, primary energy supply will be compressed to about 6,400 Mtoe by 2070 (Figure 14A), with coal accounting for only about 11% of supply in the region (Figure 14B), while the early action scenario compresses it further. Coal shares still remain above the rest of the world in all scenarios. Gas and oil have less pronounced compression under the 2°C scenarios, as they are used more outside of power generation, where substitution is more difficult. Biomass, solar, and wind dominate Asian primary energy by 2070 only in the 2°C scenarios, where the long-term energy mix is profoundly different than under current policies or NDCs.

B. Electricity Mix

The largest responses to climate policies can be found in the power sector, where coal substitution is easiest to achieve. Current electricity mixes in the region are highly reliant on coal. Coal is the dominant source of power in 12 developing Asian economies, with Mongolia having the highest share of 80.0% in 2020 (Figure 15). Meanwhile, Cambodia registered the biggest absolute increase in coal shares of 41.1 percentage-points within a decade (4.6% in 2011 to 45.7% in 2020). Hydropower is the main power source in eight Asian Development Bank developing member economies and is the one and only source in Bhutan and Nepal. The share of solar energy in the power mix is particularly high in Kiribati (16.0%) and Samoa (13.8%). Power from natural gas is the only source in Turkmenistan and the dominant source in eight other developing member economies from Central Asia, South Asia, and Southeast Asia. Almost all Pacific Island members and Maldives mainly source power from oil except Fiji where hydropower (57.3%) accounts for a bigger share than oil (41.1%) in 2020.

Developing Asia's three biggest economies—India, Indonesia, and the PRC—continue to rely on coal for electricity production but show different trends in the last decade. The share of coal in the PRC's power mix has steadily declined from 78.7% in 2011 to 63.8% in 2020, India's remained steady and hovered between 68% and 76%, while Indonesia's continuously increased from 44.2% to 62.0% over the same period. Other economies, including the Philippines and Viet Nam, are also increasingly becoming reliant on coal for power.

Figure 15: Electricity Generation Mix, Select Developing Member Economies, 2020



Lao PDR = Lao People’s Democratic Republic, PRC = People’s Republic of China.

Notes:

1. ADB placed on hold its regular assistance in Afghanistan effective 15 August 2021. This report was prepared based on information available for Afghanistan as of 31 July 2021.

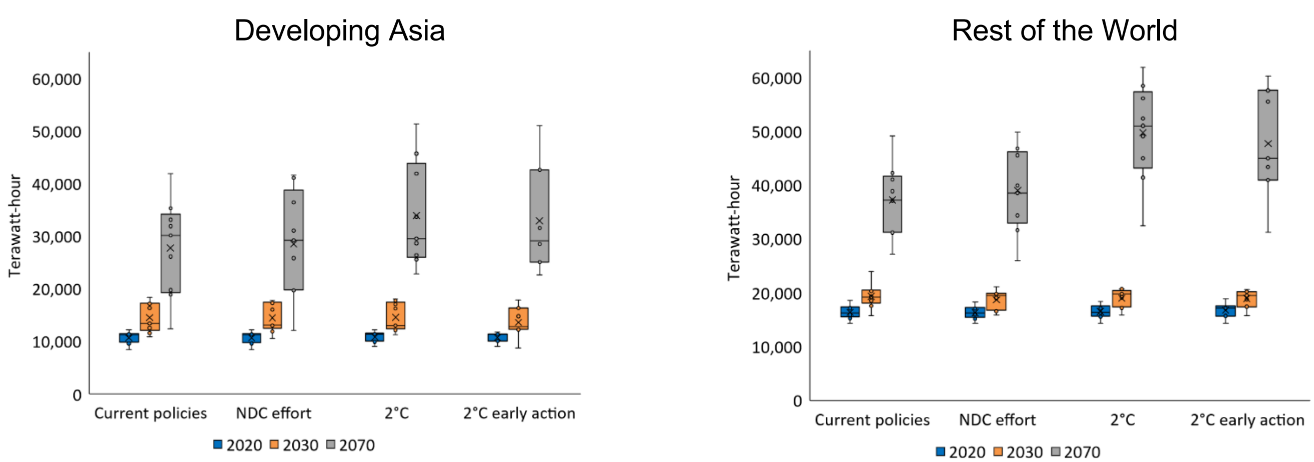
2. Effective 1 February 2021, ADB placed a temporary hold on sovereign project disbursements and new contracts in Myanmar.

Source: Enerdata. Global Energy and CO_2 Data (accessed 20 September 2022).

Under current policies, a coal-intensive power mix will continue for some time. Electricity demand in developing Asia will reach 14,560 TWh by 2030 and about 27,740 TWh by 2070, under the current policies scenario (Figure 16A), with coal accounting for 48% and 28% of generation by 2030 and 2070 respectively (Figure 16B). Solar and wind power will account for 43% of supply by 2070. The NDC scenario accelerates coal substitution slightly, as solar and wind reach 54% of generation by 2070.

Under the well below 2°C scenario, as more energy end uses are electrified, demand for electricity reaches about 34,000 TWh by 2070.[4] By that year, coal only accounts for 3.7% of the generation mix in the 2°C scenario and only 3.1% in the 2°C early action scenario. Solar and wind power account for 66% of power under the 2°C scenarios, while the share of biomass increases from 1% in 2070 under current policies to between 4.3% and 5.4% under the well below 2°C scenarios.

Figure 16A: Electricity Supply, Total, Developing Asia vs. Rest of the World



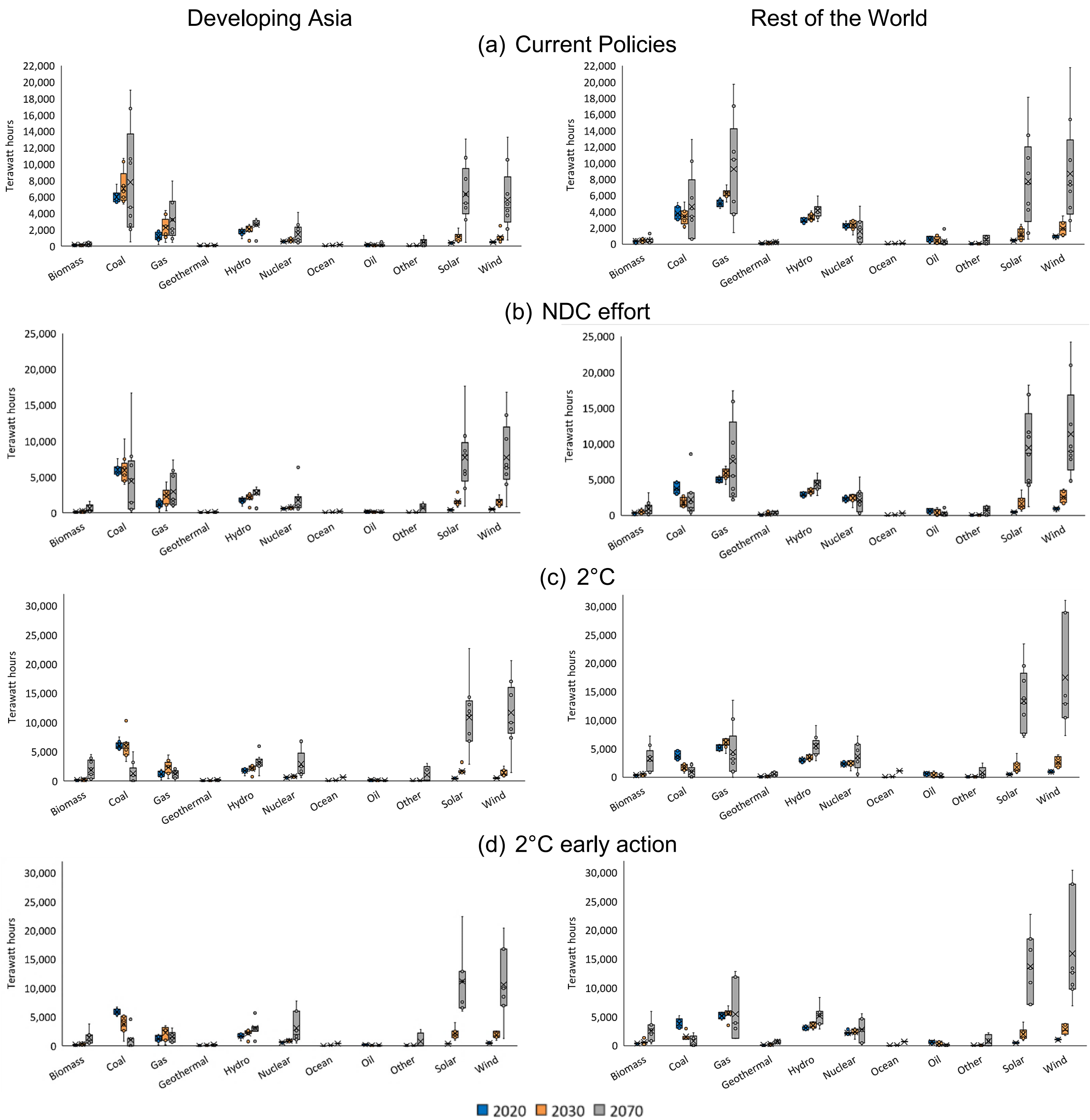
NDC = nationally determined contribution.

Note: Developing Asia does not include Central and West Asian countries; X is mean, the solid line is median, boxes are the range of values between the first and third quartile, and whiskers are minimum and maximum data.

Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

[4] 32,080 TWh under the 2°C scenario and 30,213 TWh under accelerated 2°C scenario by 2070.

Figure 16B: Electricity Supply, By Source and Scenario, Developing Asia vs. Rest of the World



NDC = nationally determined contribution.

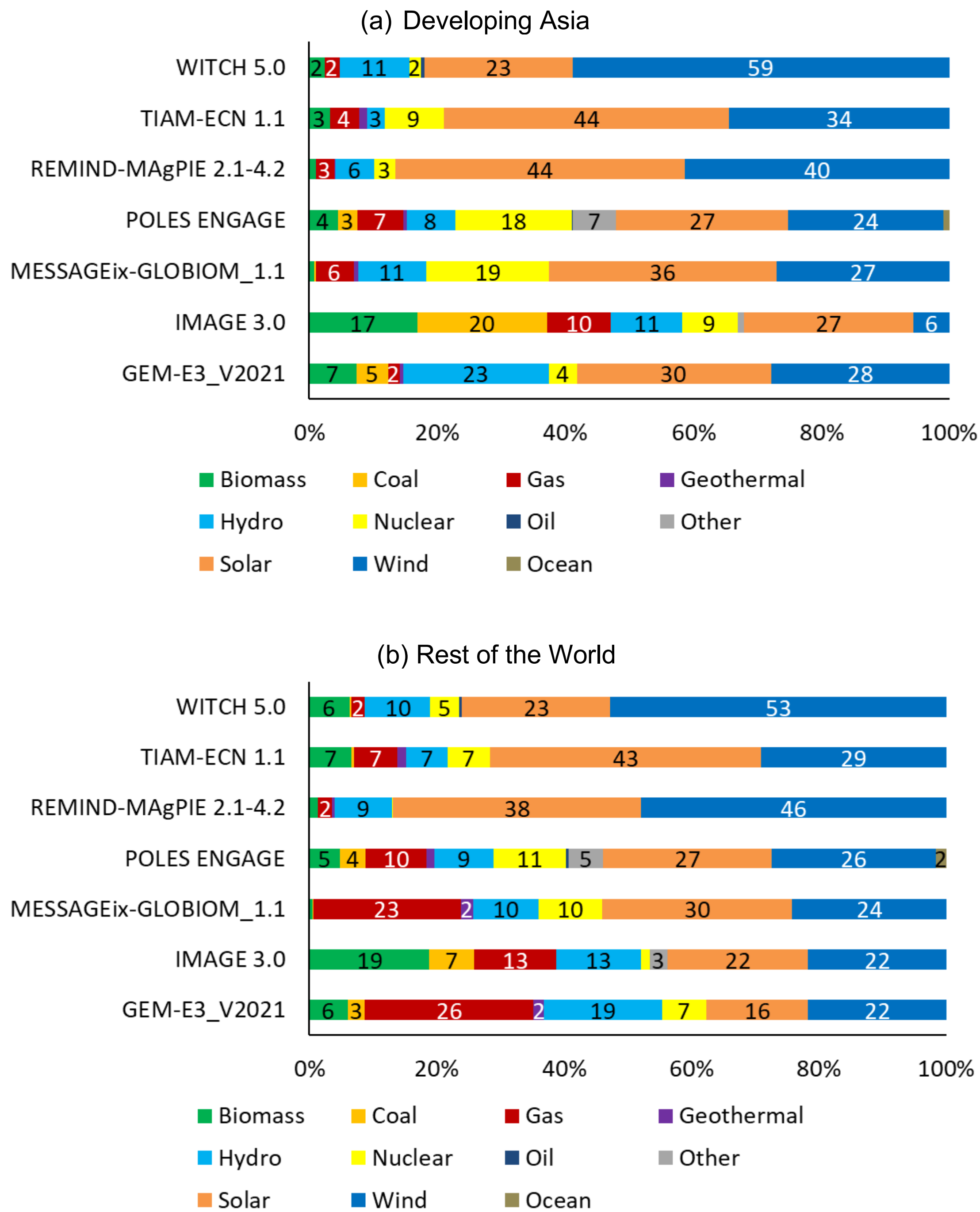
Note: Developing Asia does not include Central and West Asian countries; X is mean, the solid line is median, boxes are the range of values between the first and third quartile, and whiskers are minimum and maximum data.

Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

Figure 17 illustrates the share of secondary energy supply in the region under the 2°C early action scenario by the year 2070 across various models. These models exhibit substantial differences in which renewables dominate the electricity mix, although they all show similar domination of renewables in aggregate. In the case of WITCH 5.0, wind power will dominate, accounting for 59% of the electricity supply in developing Asia. Conversely, in TIAM-ECN 1.1 and REMIND MAgPIE 2.1-4.2, solar power is more dominant. In contrast, the remaining models do not exhibit such clear-cut dominance by any single energy source. Instead, they depict a more diverse array of energy sources.

The first signs of a profound electricity transition in line with the 2°C scenarios are potentially emerging. Until recently, the process of replacing fossil fuels has remained slow and uneven in developing Asia. There was a period of decline from the 1990s to 2007 following declining shares of hydropower and a period of growth from 2008–2020 driven by the development of wind and solar power. In the last decade, solar and wind power have emerged from an expensive niche to outcompeting fossil sources (IRENA 2020). Between 2010 and 2021, global renewable electricity capacity increased 2.5-fold from 1,220 gigawatts (GW) to 3,070 GW. Developing Asia's renewable power capacity increased 3.3-fold from 347 GW to 1,310 GW. Owing to these capacity additions, the share of renewables in world power generation capacity increased from 24% to 38% between 2010 and 2021, while it increased from 25% to 40% in developing Asia. Between 2010 and 2021, installation of new solar photovoltaic (PV) systems worldwide increased by 21-fold to reach 848 GW.

Figure 17: Secondary Energy Supply, 2°C Early Action, 2070



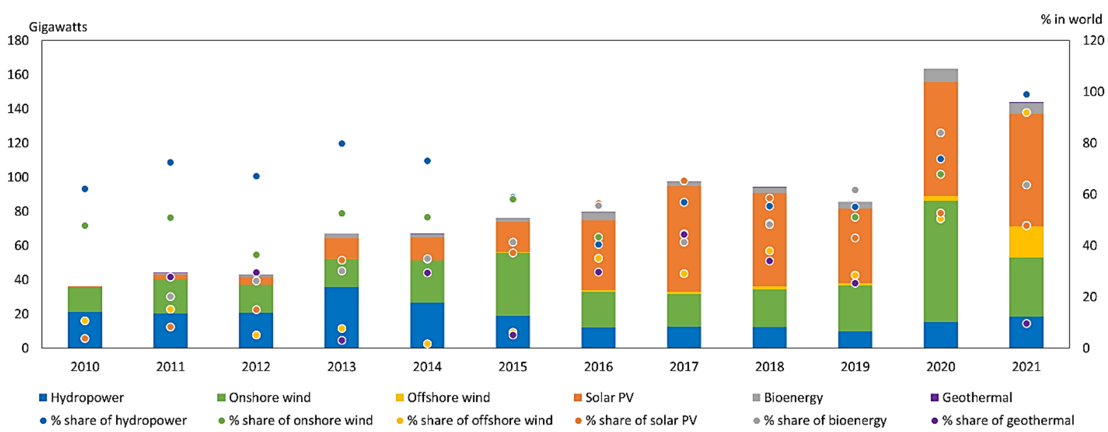
Note: Developing Asia does not include Central and West Asian countries.

Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

Since 2013, developing Asia has led in new solar installation additions, contributing about 35% of new PV systems installed from 2013 to 2015, and further to about 50% per year from during 2016–2021 (Figure 18). Global cumulative capacity of onshore wind has increased 4-fold from 177.8 GW in 2010 to 769.2 GW in 2021. Developing Asia is at the forefront of onshore wind additions, accounting for 43% or more of new wind turbines installed during 2010–2021 (except in 2012 when it slightly dipped to 36.4%). Global cumulative installed capacity of offshore wind also increased more than 17-fold between 2010 to 2021, from 3.1 GW to 54.3 GW. During 2010–2015, developing Asia was responsible for less than 15% of new offshore turbines installed per year, but this increased substantially to upwards of 30% thereafter.

Much of this growth has been driven by the PRC. Between 1991 and 2020, its share of global wind electricity production increased from 0.2% to 32.9%, and solar electricity production from 0.2% to 29.2%. In 2021, the country added about 173,000 GWh to its wind electricity production and 80,000 GWh to its solar electricity production—the highest increase ever recorded (IEA 2021).

Figure 18: Renewable Electricity Capacity Additions, Developing Asia, 2010–2021



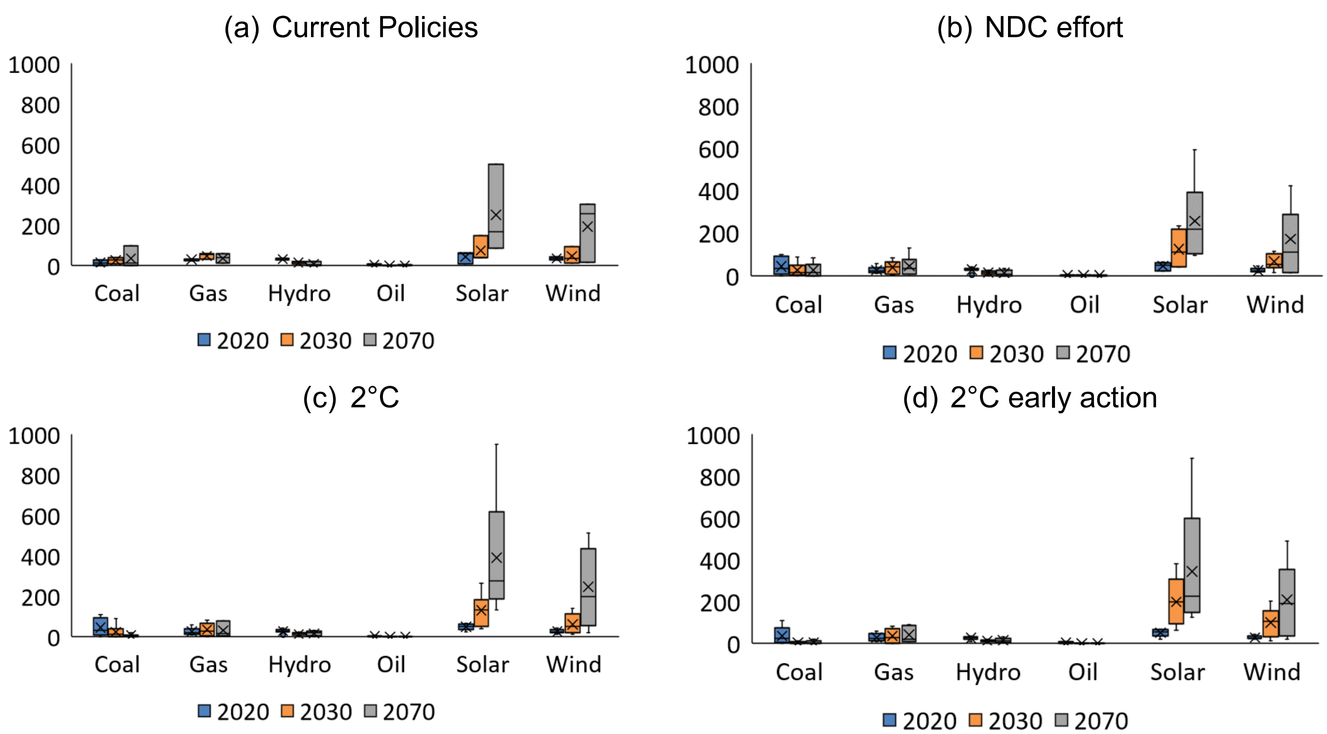
PV =photovoltaic.

Source: International Renewable Energy Agency. 2022. *Renewable Energy Statistics 2022*. Abu Dhabi.

Under the current policies scenario, new coal capacity continues to be added, but the share declines from 12% of total capacity additions in 2030 to 7% in 2070 (Figure 19). The NDC effort scenario cuts the share of additions in half, so that there is little new coal if the NDCs are to be achieved.

In the well below 2°C scenario, coal-fired electricity has little future. Coal capacity additions are negligible, reaching just 1% of total capacity additions in 2030 under the 2°C early action scenario and by 2035 under the 2°C scenario. Solar and wind power dominate new capacity additions across all scenarios by 2030, with current policies with a combined share of 58% of total capacity additions and 2°C early action at 85%. By 2070, this increases to 84% under current policies, and to 90% under the 2°C early action.

Figure 19: Annual Electricity Capacity Additions, Developing Asia
(Gigawatts)



NDC = nationally determined contribution.

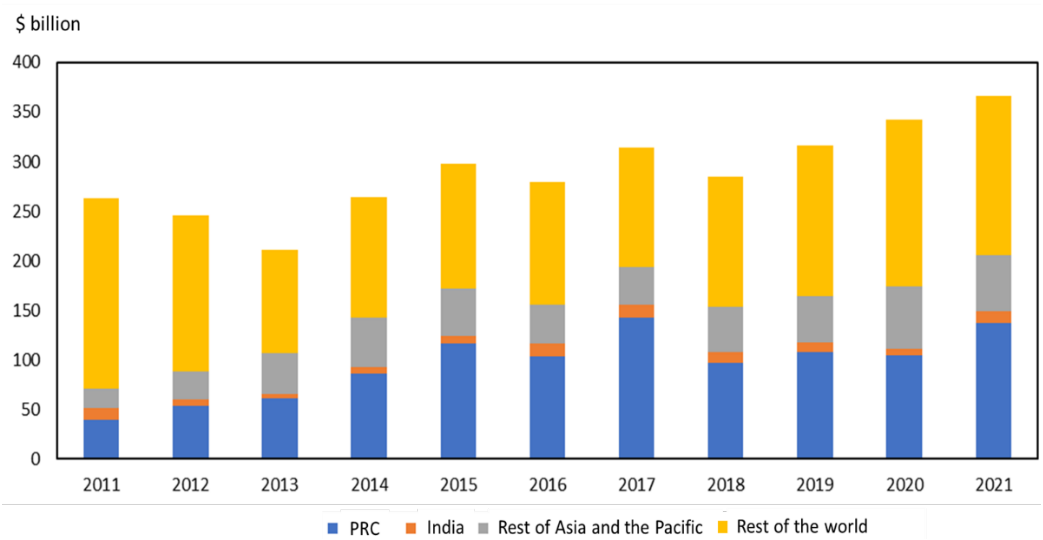
Note: Developing Asia does not include Central and West Asian countries.

Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis (IIASA). AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

7. Investment Needs

Achieving this profound transition requires rapidly scaled up investment in clean energy. While investment is rising, it is not rising fast enough to align with the modelled decarbonization scenarios. Global investment in renewable energy capacity increased by $23.1 billion to reach a record-high of $365.8 billion in 2021, which is progress. Much of this increase came from solar PV and wind power (REN21 2022). Investments have risen faster in developing Asia than globally over 2011–2011, but the investments have been concentrated in a few economies, and the time trends are noisy (Figure 20). Investment has been concentrated in the PRC. From a low of 15.0% in 2011, the PRC's share of global investment in renewable energy peaked at 45.3% in 2017, before declining to about 32% in 2021. At the same time, investments in renewable energy capacity in India did not show significant movements during 2011–2021, hovering between $4.7 billion and $13.4 billion in amount. Overall investment is dominated by solar, followed by wind.

Figure 20: Capacity Investment in Renewable Energy Capacity, 2011–2021

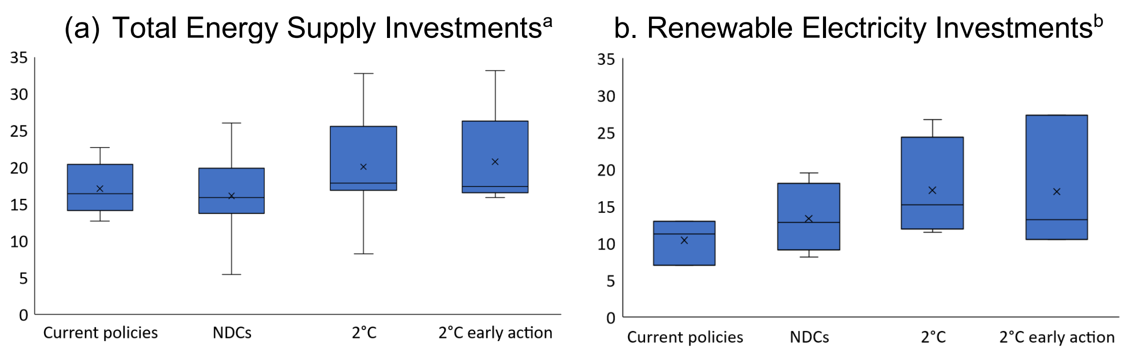


PRC = People's Republic of China.

Source: Renewable Energy Policy Network for the 21st Century. 2022. *Renewables Global Status Reports*. Paris.

While global renewable investments have risen, they are far below what is needed to achieve Paris Agreement goals. Under current policies, cumulative energy supply investment requirements range from about $13 trillion to $23 trillion between 2020 to 2050 across the models, with a mean of about $17 trillion (Figure 21). About $10 trillion of this investment is required for renewable electricity supply, including grid and storage. Total energy supply investments under NDC effort are estimated at $16 trillion (range of $5.5 trillion to $26 trillion), with $13 trillion in renewable electricity supply. To achieve the Paris Agreement goals, cumulative energy investments of $21 trillion (range of $16 trillion to $33 trillion) is required between 2020–2050, of which $17 trillion will go toward renewable electricity supply. About $9 trillion of renewable electricity investments is required in the PRC, $5 trillion in India, and about $500 billion in Indonesia.[5]

Figure 21: Energy Investments, 2020–2050
(trillion 2010 US$)



NDC = nationally determined contribution, US = United States.

Note: Developing Asia does not include Central and West Asian countries; X is mean, the solid line is median, boxes are the range of values between the first and third quartile, and whiskers are minimum and maximum data.

[a] Includes investments in CO_2 transport and storage, electricity (including storage, transmission, and distribution), energy extraction, heat, hydrogen and liquids

[b] Includes investments in electricity storage, transmission and distribution, biomass, solar, wind, and hydro energy.

Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis. AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

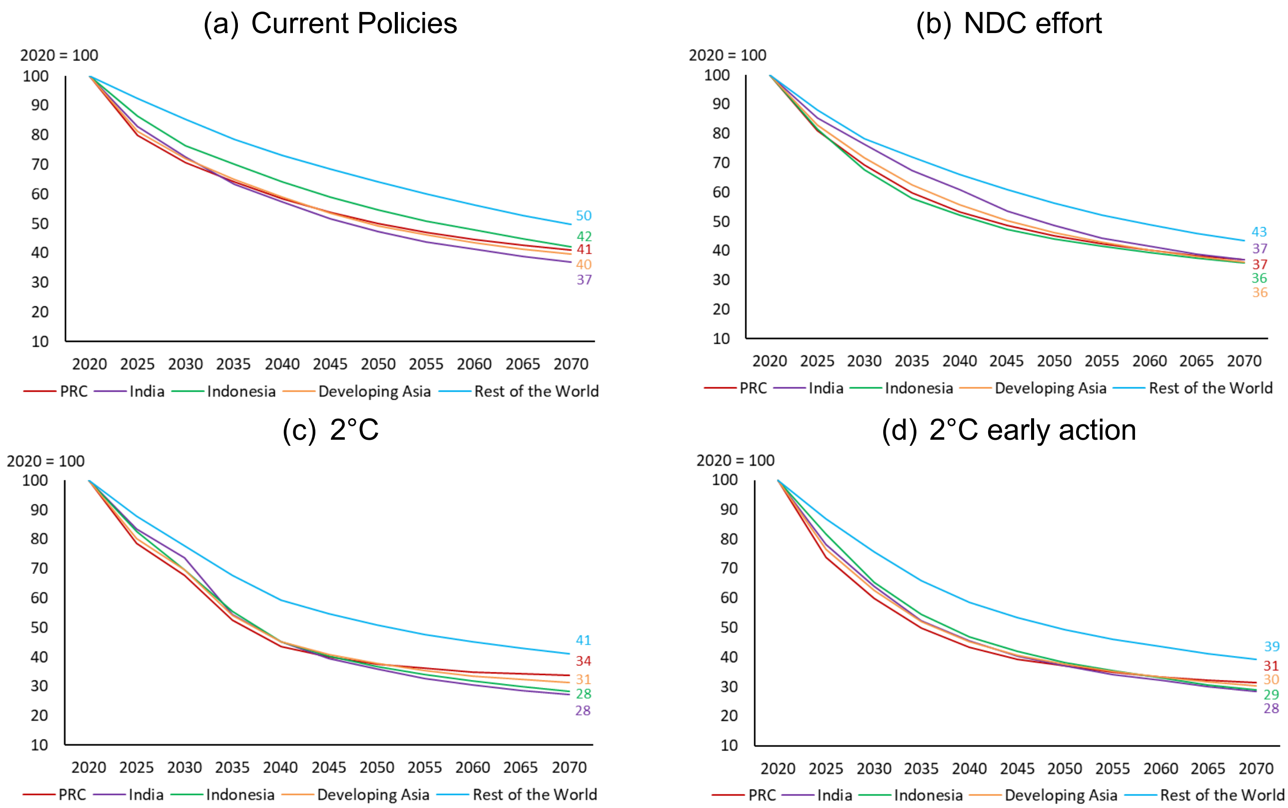
[5] Investments are expressed in 2010 United States dollars.

8. Energy Intensity

More efficient use of energy under more ambitious climate policies allows more economic output per unit of energy consumed. Figure 22 illustrates the energy intensity of gross domestic product (GDP) presented as an index with the base year set as 2020. The decline in energy intensity is larger in the 2°C degree scenarios compared to current policies. Under the current policies scenario, developing Asia's energy intensity is expected to decline to 72% of its 2020 values by 2030, and further to 40% of its 2020 values by 2070. Under the more ambitious 2°C early action scenario, energy intensity will decline even further to 63% of its 2020 values by 2030 and to 30% by 2070. The decline is faster across scenarios in developing Asia compared with the rest of the world.

This decline is driven by two factors. Firstly, the increasing share of nonthermal renewables relative to fossil fuel in the primary energy mix leads to a higher delivery of final energy as the latter entails large thermal losses. Secondly, in response to climate policies, there is an enhancement in energy efficiency through energy efficient behavior and efficient energy consuming devices, which reduce the energy inputs required to provide basic energy services, such as lighting, cooking, heating, and cooling.

Figure 22: Energy Intensity across Different Scenarios



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

Note: Developing Asia does not include Central and West Asian countries.

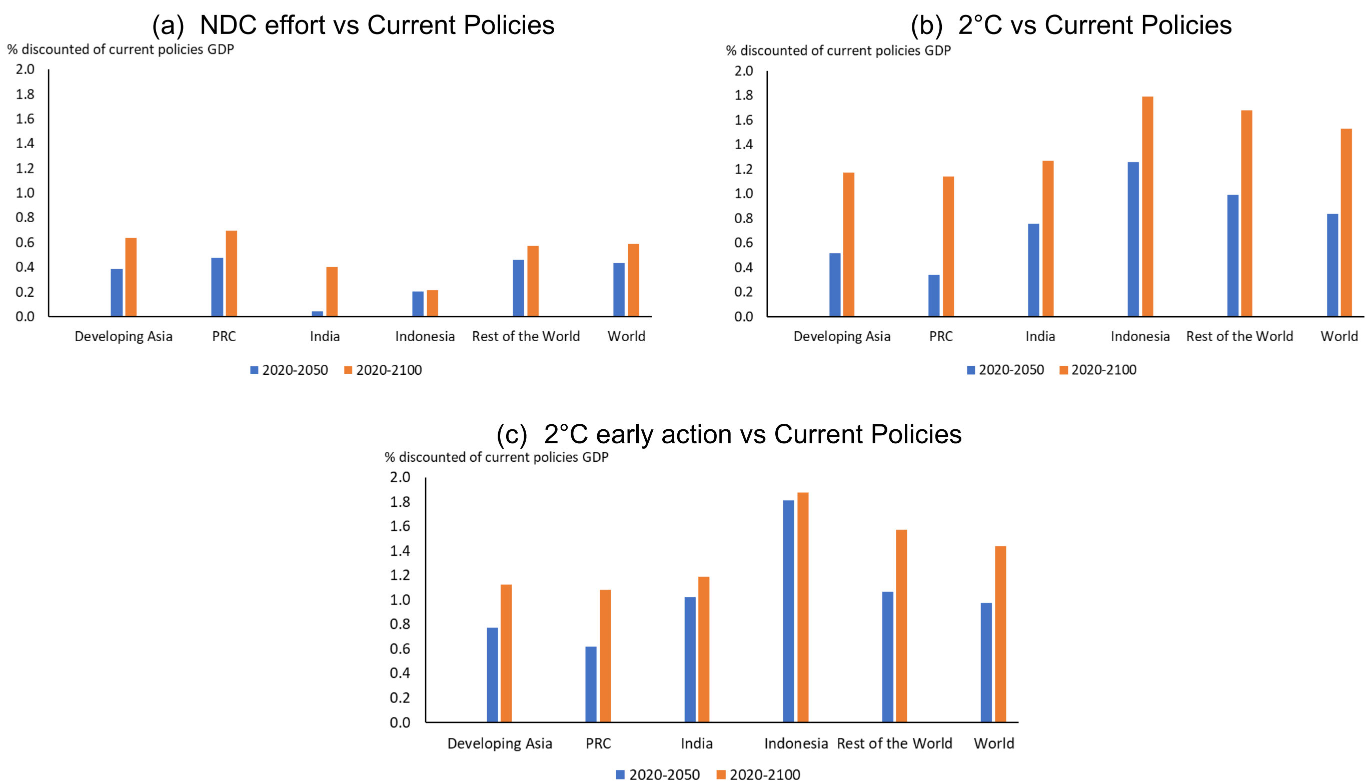
Source: Authors' calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis. AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

9. Policy Costs

A less energy-intensive economy powered by cleaner sources of electricity with reduced recurrent expenses for fuels is found across the models to lead to low costs for decarbonization. Under the NDC effort scenario, costs through 2050 are 0.38% of GDP for developing Asia as whole, rising to 0.64% if the period through 2100 is considered (Figure 23). This low cost may be expected, due to the modest emissions reduction and energy transformation found for the scenario. Under the 2°C scenario, costs through 2050 are 0.52% of GDP for the region, increasing to 1.18% if the analysis extends to 2100.

Under the profound transitions of the 2°C early action scenario, costs increase to 0.77% of GDP for developing Asia during 2020-2050. This is lower in the PRC at 0.62% of GDP, and higher in India at 1.03% and Indonesia 1.81%. The higher cost for Indonesia likely stems from its higher level of carbon intensity when land use emissions are included. Policy cost for the region increases to 1.12% through 2100 under the 2°C early action scenario, which is slightly lower than the 2°C scenario (1.18%) and suggests that early action reduces long term costs. Notably, Asian decarbonization costs are lower than for the rest of the world under both 2°C scenarios under both the shorter and longer time horizons.

Figure 23: Policy Costs for the Modeled Scenarios, Relative to Current Policies



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

Notes:

1. Developing Asia does not include Central and West Asian countries.
2. Number of models per scenario: NDC = 5 models; 2°C and 2°C early action = 2 models.

Source: Authors calculations based on the AR6 scenario explorer. International Institute for Applied Systems Analysis. AR6 Scenario Explorer. https://data.ece.iiasa.ac.at/ar6/ (accessed 13 April 2023).

It should be noted that these costs are calculated without including any transfers from a global carbon market or climate finance. Were those included, costs to low per capita emitting economies, such as India, would likely be lower. The costs also exclude any benefits from reduced climate change or cobenefits from improved air quality. In that context, loss of some months of economic growth over many decades is a very low cost, compared with the risks posed by much more profound climate change.

10. Conclusion

This paper draws on a collection of model-based scenario runs undertaken under the IPCC's AR6 Working Group III to consider decarbonization pathways for developing Asia. Results indicate that under the current policies scenario, GHG emissions from the region will continue to increase until around 2080. Under the NDC effort scenario, regional emissions are somewhat lower, but the Paris Agreement goal of limiting the global temperature rise to well below 2°C is missed. Paris Agreement-consistent scenarios of 2°C and 2°C early action will require rapid reductions in emissions, with CO_2 emissions from the region reaching net zero by the latter part of the century.

As the largest source of emissions, the energy sector will need to undergo rapid transformation to meet the Paris Agreement objectives. Under the current policies scenario, primary energy supply in the region will grow, with coal remaining as the biggest source of energy, providing about 40% of the region's energy needs until 2070. In the 2°C scenarios, the growth in primary energy is tempered and coal provides only about 10% of the energy supply in the region by 2070.

Within the energy sector, the largest responses to climate policies can be found in the power sector, where coal substitution is easiest to achieve. Under current policies, a coal-intensive power mix will continue for some time, providing about half of the electricity supply in 2030 and about one-third in 2070 in the region. Under the 2°C scenarios, as more energy end uses are electrified, demand for electricity is 15% higher than under current policies in 2070. By that point, coal only accounts for less than 5% of the generation mix in the 2°C scenarios, while solar and wind power account for 65% of power supply.

Overall, a comparison of the major IAMs submissions to the AR6 Working Group III indicates strong consistency in the transformation of the energy sector required to achieve Paris Agreement goals. This includes a rapid decline in the share of coal—a mainstay of the power sector in developing Asia—and a rapid rise in renewable energy. Although given the uncertainty in technological improvements in the future, the models exhibit substantial differences in which renewable energy source dominates the electricity mix, with some more optimistic about wind (WITCH) and others about solar (REMIND and TIAM).

Achieving this profound transition requires rapidly scaled up investment in clean energy. Under 2°C early action, there is a 63% increase in renewable investment compared with current policies over 2020–2050. However, much of this cost is offset by reductions in other energy investment, particularly for fossil fuel extraction.

At the same time, modelling results indicate that the overall policy cost of the transition can be relatively low if mitigation efforts are allocated efficiently. Under the NDC effort scenario, policy costs relative to current policies are less than 0.4% of the GDP for developing Asia through 2050, while under the 2°C scenarios, this increases to 0.8%, which is equivalent to only a few months of growth.

Appendix: Description of Models

	AIM/CGE	COFFEE	GEM E-3	IMAGE	MESSAGEix-GLOBIOM	POLES-ENGAGE	REMIND-MAgPIE	TIAM-ECN	WITCH
Degree of detail	Hybrid		Hybrid			Bottom-up	Hybrid	Bottom-up	Hybrid
Solution	Simulation	Optimization	Simulation	Simulation	Optimization	Simulation	Optimization	Optimization	Optimization
Temporal perspective	Recursive dynamic	Perfect foresight	Recursive dynamic	Recursive dynamic	Perfect foresight	Recursive dynamic	Perfect foresight	Perfect foresight	Perfect foresight
Level of representation	General equilibrium	General equilibrium	General equilibrium	Partial equilibrium	General equilibrium	Partial equilibrium	General equilibrium	Partial equilibrium	General equilibrium
Greenhouse gases covered	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2, black and organic carbon, NMVOC	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2, black and organic carbon, NMVOC	CO_2, CH_4, N_2O, HFCs, SF_6, SO_2, black and organic carbon, NMVOC	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2, black and organic carbon, NMVOC	CO_2, CH_4, N_2O, SO_2, black and organic carbon, NMVOC	CO_2, CH_4, N_2O	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, SO_2, black and organic carbon, NMVOC
Energy technological change			Semi-endogenous learning by doing effects	Endogenous	Exogenous	Endogenous	Learning by doing		Endogenous. Learning by doing and learning by researching
Major AFOLU measures	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management	Reduced deforestation, forest protection, avoided forest conversion, methane reductions in rice paddies, livestock and grazing management
Major demand side measures	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,	Energy efficiency improvements in energy end use, electrification of transport, building and industrial energy demand, higher share of useful energy in final energy, reduced energy and service demand in industry,

Continued on the next page

	AIM/CGE	COFFEE	GEM E-3	IMAGE	MESSAGEix-GLOBIOM	POLES-ENGAGE	REMIND-MAgPIE	TIAM-ECN	WITCH
	buildings, transport, international transport, dietary changes,	buildings, transport, international transport, dietary changes,	buildings, transport, dietary changes,	buildings, transport, international transport, dietary changes,	buildings, transport, international transport, dietary changes,	buildings, transport, international transport	buildings, transport, international transport, dietary changes,	buildings, transport, international transport	buildings, transport, international transport
Major energy technologies included	Solar PV, CCS, hydropower, nuclear, high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV, CCS, hydropower, nuclear, geothermal, wind, biomass	Solar PV and CSP, CCS, hydropower, nuclear, SMR fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, SMR fuel cells (hydrogen), high-temperature geothermal heat, offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)	Solar PV and CSP, CCS, hydropower, nuclear, fuel cells (hydrogen), offshore and onshore wind, biomass, hydrogen (from electrolysis and biomass with CCS)
Carbon removal technologies	BECCS, afforestation/reforestation	BECCS, DAC, afforestation/reforestation		BECCS, DAC, afforestation/reforestation	BECCS, afforestation/reforestation	BECCS, DAC, afforestation/reforestation (implicit)	BECCS, DAC, afforestation/reforestation	BECCS, DAC, afforestation/reforestation (exogenous)	BECCS, DAC, afforestation/reforestation
Developed by	National Institute for Environmental Studies and Kyoto-University (Japan)	COPPE/UFRJ (Cenergia) (Brazil)	Institute of Communication and Computer Systems (Greece)	PBL Netherlands Environmental Assessment Agency (Netherlands)	International Institute for Applied Systems Analysis (Austria)	JRC - Joint Research Centre - European Commission (Belgium)	Potsdam Institute for Climate Impact Research (Germany)	The Netherlands Organization for Applied Scientific Research (TNO) (Netherlands)	European Institute on Economics and the Environment (Italy)

BECCS = bioenergy production with carbon capture and sequestration, CCS = carbon capture and storage, CH_4 = methane, CO_2 = carbon dioxide, CSP = concentrated solar power, DACS = direct air capture and storage, N_2O = nitrous oxide, HFCs= hydrofluorocarbons, PFCs = perfluorocarbons, SF_6 = sulfur hexafluoride, SMR = advanced small modular nuclear reactor designs SO_2= sulfur dioxide, NMVOC = non-methane volatile organic compounds.

Source: Intergovernmental Panel on Climate Change. 2022*: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York: Cambridge University Press.

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Decarbonization Pathways in Developing Asia

Evidence from Modeling Scenarios

The Sixth Assessment Report of the Intergovernmental Panel on Climate Change incorporated an ambitious model intercomparison effort that compiled thousands of model-scenario combinations to consider low carbon development pathways. This paper explores the evidence within that database to consider decarbonization pathways for developing Asia. Overall, a comparison of the major models finds strong consistency in the transformation of the energy sector required to achieve Paris Agreement goals. This includes a rapid decline in the share of coal—a mainstay of the power sector in developing Asia—and a substantial rise in renewable energy. The cost of the transition can be relatively low if mitigation efforts are efficient, as assumed in the models.

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