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Progress on the Sustainable Development Goals in Asia requires ambitious climate targets combined with sustainability-focused measures

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Asian countries face the dual challenge of fulfilling ambitious climate commitments under the Paris Agreement while simultaneously advancing the United Nations Sustainable Development Goals (SDGs). This study develops an integrated analytical framework that links decarbonization pathways with SDG indicators across energy, air quality, health, and the food-water-land nexus, as well as policy cost-effectiveness, explicitly incorporating national circumstances. Our findings indicate that current climate pledges primarily deliver gains in SDG indicators related to energy and air quality. Achieving broader progress across other SDG dimensions requires combining more ambitious climate targets with diverse, sustainability-oriented mitigation measures tailored to domestic contexts. Middle- and low-income countries face greater pressure in balancing transition costs and target feasibility; therefore, strengthened international support and robust domestic policies are needed to advance climate ambition alongside sustainable development, including climate finance, technology transfer, and measures that can ensure a just transition for vulnerable industries.

Urgent global actions are required to meet the 1.5 °C target outlined in the Paris Agreement¹⁻³ as the negative impacts of climate change intensify. The Asian region accounts for over 40% of global greenhouse gas (GHG) emissions in 2023, including six of the world's top ten emitters: China, India, Indonesia, Japan, Iran and Saudi Arabia⁴. At the same time, Asian countries are also global hotspots of rapid industrial expansion and infrastructure construction, placing strains on energy, food, water, and land resources. The current fossil-energy-intensive development model has posed serious threats to public health, socio-economic equity, and ecosystem integrity⁵⁻⁸. The United Nations warns that under current trajectories, the Asia-Pacific region will be unable to achieve the 17 sustainable development goals (SDGs) until 2062, a 32-year delay from the 2030 target⁹. Therefore, it is critical for Asian countries to advance sustainable development initiatives alongside more ambitious climate actions^{10,11}.

However, advancing decarbonization and sustainable development in this region requires full consideration of substantial heterogeneity among countries in terms of economic development levels, industrial structure, and institutional capacity. Developed countries such as Japan and South Korea possess greater capacity and responsibility to lead decarbonization efforts. In

contrast, many South and Southeast Asian countries remain in early stages of industrialization, where alleviating poverty and ensuring access to energy remain pressing priorities. Such disparities fundamentally shape both the ambition and feasibility of climate action^{12,13}, underscoring the need for nationally tailored decarbonization strategies. All parties of the UNFCCC are required to submit their updated nationally determined contributions (NDCs) before COP30 in 2025. The new round of updates represents a crucial opportunity for Asian countries to align their NDCs with the advancement of sustainable development initiatives.

Existing studies have highlighted notable synergies between climate policies and SDGs, while also identifying potential trade-offs. Stringent climate policies can promote clean transition of energy systems and thereby improve air quality and bring public health benefits¹⁴⁻¹⁶, which align with SDG 3 (good health and well-being) and SDG 7 (affordable and clean energy). However, the large-scale deployment of low-carbon technologies, such as wind power, photovoltaics, and carbon dioxide removal (CDR) technologies, could bring negative impacts on food security (SDG 2), water resources (SDG 6), and land (SDG 15)¹⁷⁻¹⁹. Aggressive emission reduction pathways may increase energy and food prices, imposing an economic

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burden on poor populations, thus conflicting with SDG 1 (no poverty) and SDG 10 (reduced inequalities)^{20,21}. A series of studies applied integrated assessment models to evaluate the interactions between climate policies and multiple SDGs^{22–25}, while some other studies explored the capital investment requirements and the risks of stranded assets for achieving various climate ambitions^{26–30}. But geographically speaking, most existing studies focused on global or European perspectives. Very few studies^{31,32} have addressed the complicated trilemma of climate mitigation, livelihood improvements, and constrained financial capacity in Asia as well as the vast heterogeneity across Asian countries.

This study aims to deepen the understanding of how climate policies interact with SDG priorities in Asian countries facing diverse development

challenges. Previous studies have typically focused either on a single country or aggregated most Asian countries into a single region, overlooking Asia’s internal diversity. To address this, we disaggregate Asia into ten representative countries/regions that reflect varied development levels and formulate emission reduction targets tailored to their specific circumstances. We then employ an integrated analytical framework (Fig. 1), combining decarbonization pathway modelling, sustainable development indicator assessment, and economic impact analysis, to explore how countries at different development stages can achieve more ambitious climate goals while managing co-benefits and trade-offs. We propose that sustainable development priorities should be explicitly integrated into climate policy design to enable more ambitious, equitable, and context-specific climate

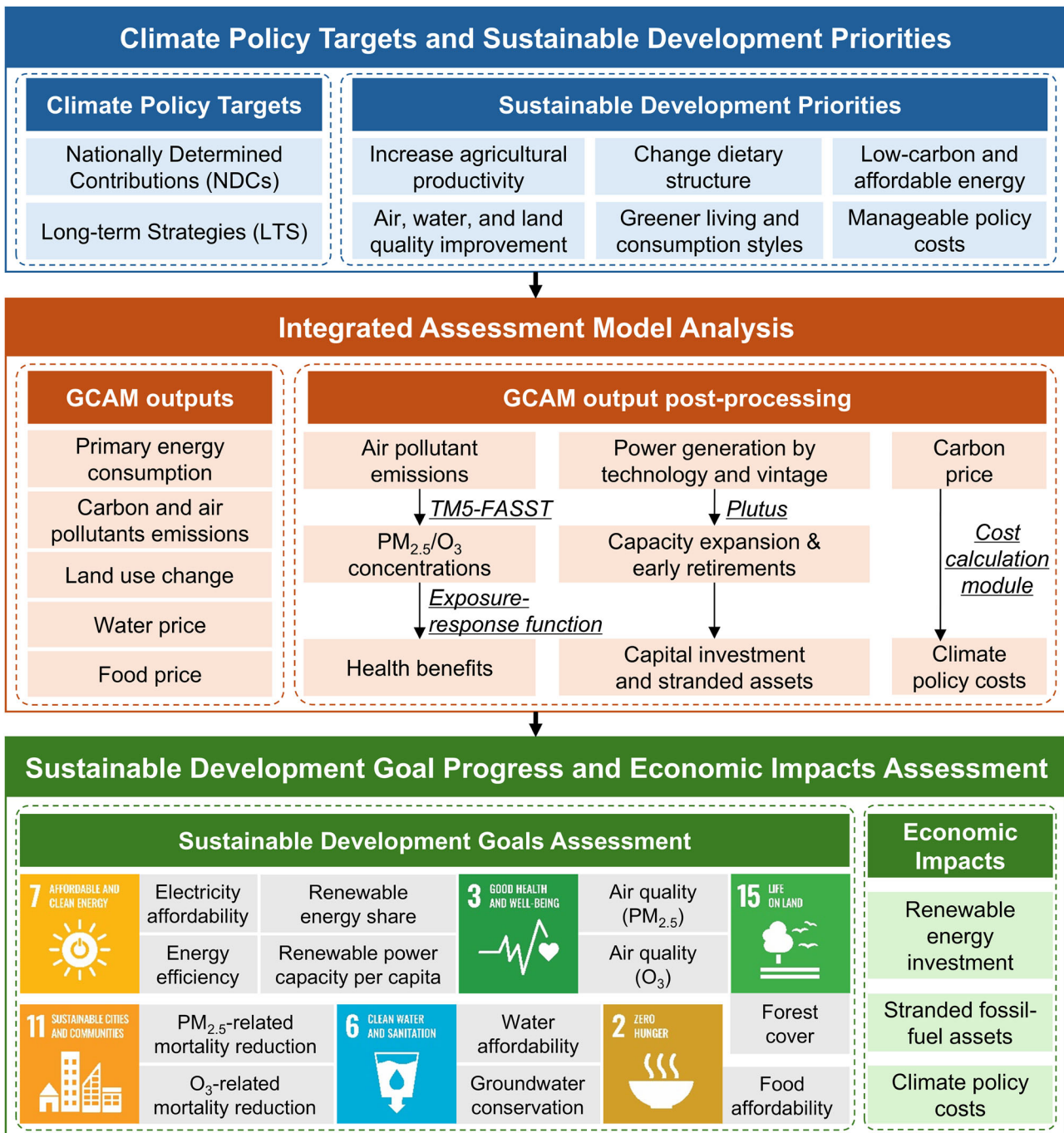


Fig. 1 | The comprehensive analytical framework of this study. The framework consists of three components. First, analyzing and quantifying climate policy documents, SDG priorities, and scenario assumptions (top box). Second, simulating

alternative decarbonization pathways and calculating SDG indicator outcomes using a multi-model approach (middle box). Third, assessing the implications for sustainable development goals and economic outcomes (bottom box).

targets. Achieving decarbonization in Asia cannot rely on a uniform approach; instead, differentiated low-carbon transition strategies are required, informed by the synergies and trade-offs between climate goals and national development priorities. This perspective is especially important for developing and underdeveloped countries, where economic constraints can be decisive factors in the feasibility of adopting ambitious climate targets. As the NDC targets are set for update at COP30, our research provides essential insights for policymakers in Asian countries to submit more ambitious climate targets and take synergistic actions on SDGs that align with their national contexts.

Results

Overview of the analytical framework and decarbonization scenarios design

To explore the synergies and trade-offs between climate mitigation and sustainable development in Asia, we integrated multiple models and datasets into a comprehensive analytical framework (Fig. 1). Our analysis focuses on 12 SDG-aligned indicators across six thematic areas (outlined in the green box of Fig. 1), including energy access (SDG7), air quality (SDG 3), public health (SDG 11), and the food-land-water nexus (SDG2, SDG6 and SDG15), which are closely linked to people's daily lives and fundamental aspects of human well-being in Asia. We use the Global Change Analysis Model (GCAM) to simulate interactions across energy, water, agriculture, and land-use systems under different climate mitigation pathways. To evaluate air quality and public health co-benefits, we apply the simplified air quality model (TM5-FASST) to simulate future $PM_{2.5}$ and O_3 concentrations resulting from air pollutants emission reductions. Then, we quantify associated premature mortality based on exposure-response functions and projected population dynamics. The economic impacts of each scenario, including renewable energy capital investments, stranded fossil fuel assets, and climate policy costs, are assessed using the R package Plutus and cost calculation module.

Based on the above modeling framework, we simulate and evaluate three main policy scenarios. Current Pledge (CP) scenario reflects the implementation of nationally determined contributions (NDCs) and long-term strategies (LTS) as currently pledged in Asian countries. Faster Transition (FT) scenario assumes strengthened climate ambition aligned with a 1.5 °C-consistent trajectory but without explicit integration of sustainable development considerations. Faster Transition consistent with SDGs (FT-SDG) scenario builds upon FT scenario by incorporating five sustainability-oriented interventions aimed at enabling a more just and inclusive low-carbon transition. To further identify effective policy levers tailored to different national contexts, we designed five additional sensitivity scenarios, each applying a single intervention to the FT pathway, focusing respectively on agriculture and dietary patterns, sectoral energy demand, fossil fuel use, renewable energy expansion, and carbon dioxide removal (CDR) use. Further details are provided in the Methods section.

GHG emission trajectories under different transition scenarios

Figure 2 illustrates the trajectories of GHG emissions under the three main scenarios (CP, FT, and FT-SDG), for the overall Asian region, individual countries, and emission types. In all three scenarios, GHG emissions in Asia are projected to peak around 2030, reaching approximately 31 GtCO₂eq. Under the CP scenario, emissions in Asia are projected to remain at 17 GtCO₂eq by 2050, as only a few major emitters, such as Japan and South Korea, have set carbon neutrality targets for 2050. In the FT and FT-SDG scenarios, more ambitious post-2030 decarbonization targets are established for various countries and regions, taking into account the 1.5 °C target and the anticipated 2035 NDC updates. Under these two more ambitious scenarios, GHG emissions in Asia decrease to 24.5 GtCO₂eq by 2035 and 7.6 GtCO₂eq by 2050, representing reductions of 12% and 55%, respectively, compared to the CP scenario.

Although overall GHG emissions in Asia show a declining trend after 2030 across all three scenarios, there are marked disparities across countries

and regions (Fig. 2b). Under the CP scenario, Japan, South Korea, Indonesia, and China would reduce 100%, 89%, 68%, and 66% of emissions compared to 2030 levels, respectively. But India would only achieve 35% GHG emissions reduction by 2050, because India's long-term target is to achieve carbon neutrality by 2070, focusing solely on CO₂ emissions. For the other major countries and regions, including Pakistan, Central Asia, the Middle East, South Asia, and Southeast Asia, emissions after 2030 would follow historical decarbonization trends or a minimum decarbonization rate of 2%, which is insufficient to offset the emissions increase driven by economic growth (Supplementary Fig. 1). In the FT and FT-SDG scenarios, almost all countries and regions would experience a rapid decline in GHG emissions after 2030 compared to CP scenario, except of India and Indonesia, where emission reductions are relatively moderate due to their less ambitious long-term targets. The four regions with the highest residual emissions in 2050 under the CP scenario (China, India, Southeast Asia, and the Middle East) would achieve further reductions of 70%, 11%, 64%, and 65%, respectively, making the 1.5 °C target more attainable.

In 2050, the positive GHG emissions in Asia in the three scenarios are projected to be 21.8, 14.2, and 12.3 GtCO₂eq, respectively, whereas negative emissions would be 4.8, 6.4, and 4.8 GtCO₂eq (Fig. 2c, d). Compared to the CP scenario, net GHG emissions in Asia under the FT scenario would decrease by 9.2 GtCO₂eq in 2050, with carbon dioxide removal (CDR) technologies contributing 18% of this reduction. The deployment of CDR technologies, such as bioenergy with carbon capturing and storage (BECCS) and direct air capturing (DAC), is important to offset emissions in the hard-to-abate sectors³³. However, over-reliance on CDR can result in a series of adverse impacts on SDGs discussed below. To address these concerns, the FT-SDG scenario incorporates a range of SDGs-consistent actions in the fields of agriculture, land use, living and consumption styles, and clean energy options. The next subsection presents detailed analysis of the interactions of different SDGs.

Interactions between ambitious climate targets and SDG indicators

Figure 3 presents the scores of the 12 indicators in Asian countries and regions for 2020, as well as under the three main scenarios for 2050. Under the CP scenario, only five indicators are projected to achieve substantial improvements by 2050: renewable energy share, energy efficiency, renewable power capacity per capita, air quality ($PM_{2.5}$), and air quality (O_3). In contrast, the remaining indicators show varying degrees of deterioration. In the FT and FT-SDG scenarios, more ambitious climate goals and sustainable practices would lead to further improvements in the above five indicators. However, the benefits and trade-offs associated with other indicators vary considerably across countries (Fig. 3). To further investigate these complicated relationships, we introduce five additional sensitivity scenarios with more specific sustainable practices (Fig. 4 and Supplementary Note 3), and categorize the 12 indicators into three groups (including energy systems, air pollution and public health, and water-land-food systems) in the following analyses.

Energy system. Indicator scores in Fig. 4 reveal profound trade-offs between low-carbon transition, technology options, and energy affordability. In the FT scenario, energy transition would follow the least-cost pathway, which is featured by mid-level electrification of end-use sectors and moderate renewable energy shares (Supplementary Fig. 3), coupled with extensive use of CDR technologies, such as BECCS and DAC. The downside is that over-reliance on CDR would slow the decarbonization pace in energy-intensive sectors³⁴. Moreover, heavy use of DAC consumes a substantial amount of energy, while the widespread use of bioenergy demands vast amount of land and water resources. For instance, China's DAC energy consumption is estimated to reach 6.5 EJ in 2050 under FT scenario, accounting for 5.7% of total energy consumption (Supplementary Fig. 4). Compared to the FT scenario, the FT-LimitCDR scenario would result in a 6% reduction in end-use energy consumption.

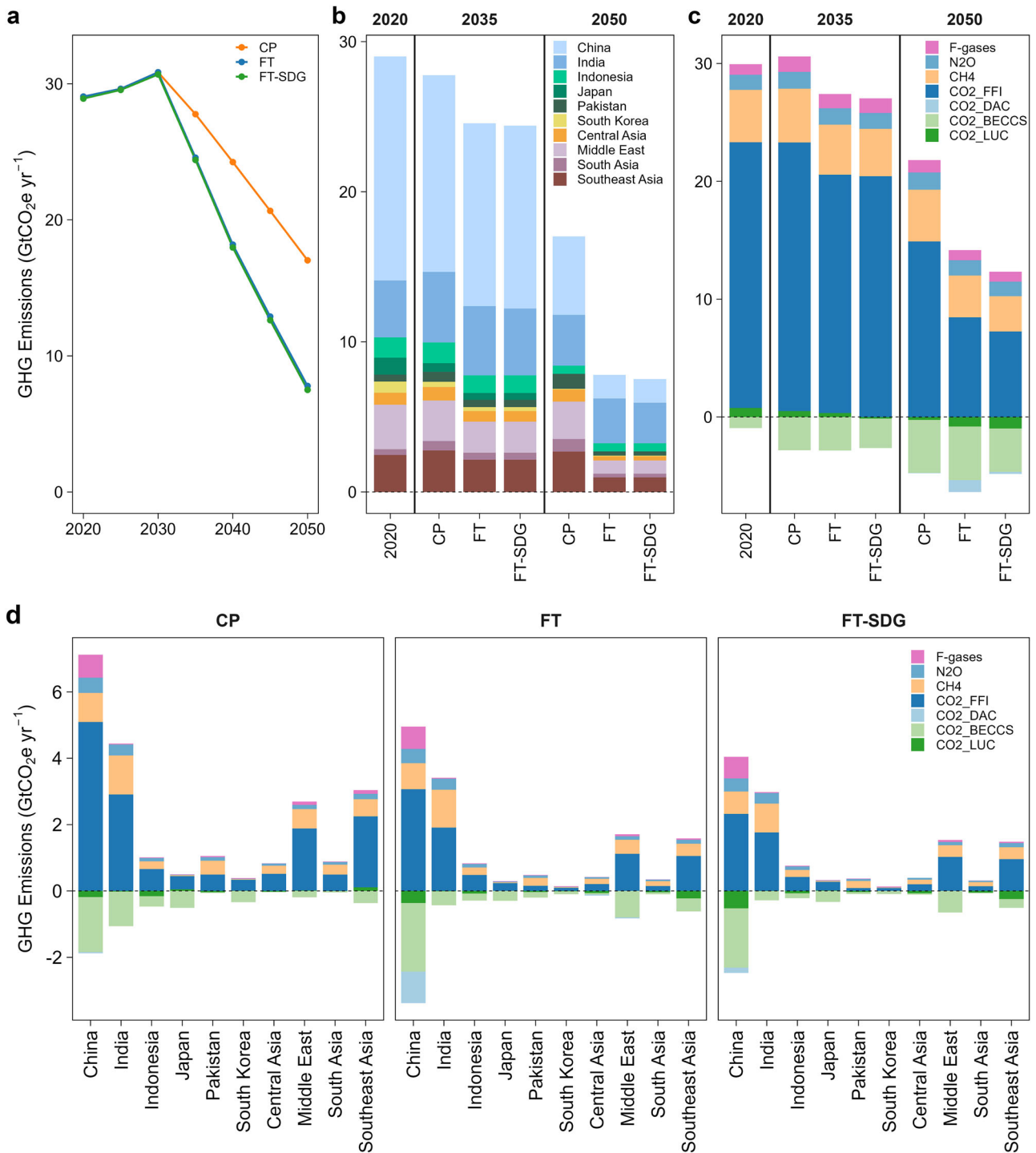


Fig. 2 | GHG emissions in Asia under different scenarios. **a** Total GHG emission trajectories for Asia from 2020 to 2050, under the current climate pledges (CP), fast low-carbon transition (FT), and fast low-carbon transition aligned with sustainable development goals (FT-SDG). **b** Net GHG emissions for different countries and regions in 2020, 2035, and 2050. **c** Different types of GHG emissions in Asia for 2020,

2035, and 2050. **d** Distribution of positive and negative emissions across different countries and regions in 2050. FFI, DAC, BECCS, LUC stand for fossil fuel and industrial processes, direct air capturing, bioenergy with carbon capturing and storage, and land use change, respectively.

However, while limiting CDR improves energy efficiency indicators, it leads to a deterioration in electricity affordability indicators. In the absence of CDR, the energy system requires a higher electrification rate to achieve the same level of carbon mitigation, which increases electricity demand and the use of more expensive power generation options. For example, China's electricity consumption by DAC is 0.9 EJ lower in the FT-LimitCDR scenario compared with FT in 2050, while electricity use in the buildings,

industry, and transport sectors combined increases by 4.1 EJ (Supplementary Fig. 16). This ultimately leads to a rise in electricity prices in most countries (Fig. 4). In contrast, the FT-LowED and FT-HighRE scenarios assume greener living styles and faster drop in renewable power costs than the FT scenario, thereby alleviating the upward trend in electricity prices, particularly in major developing countries that face challenges in electricity affordability, such as India, Indonesia and Pakistan (Fig. 4 and

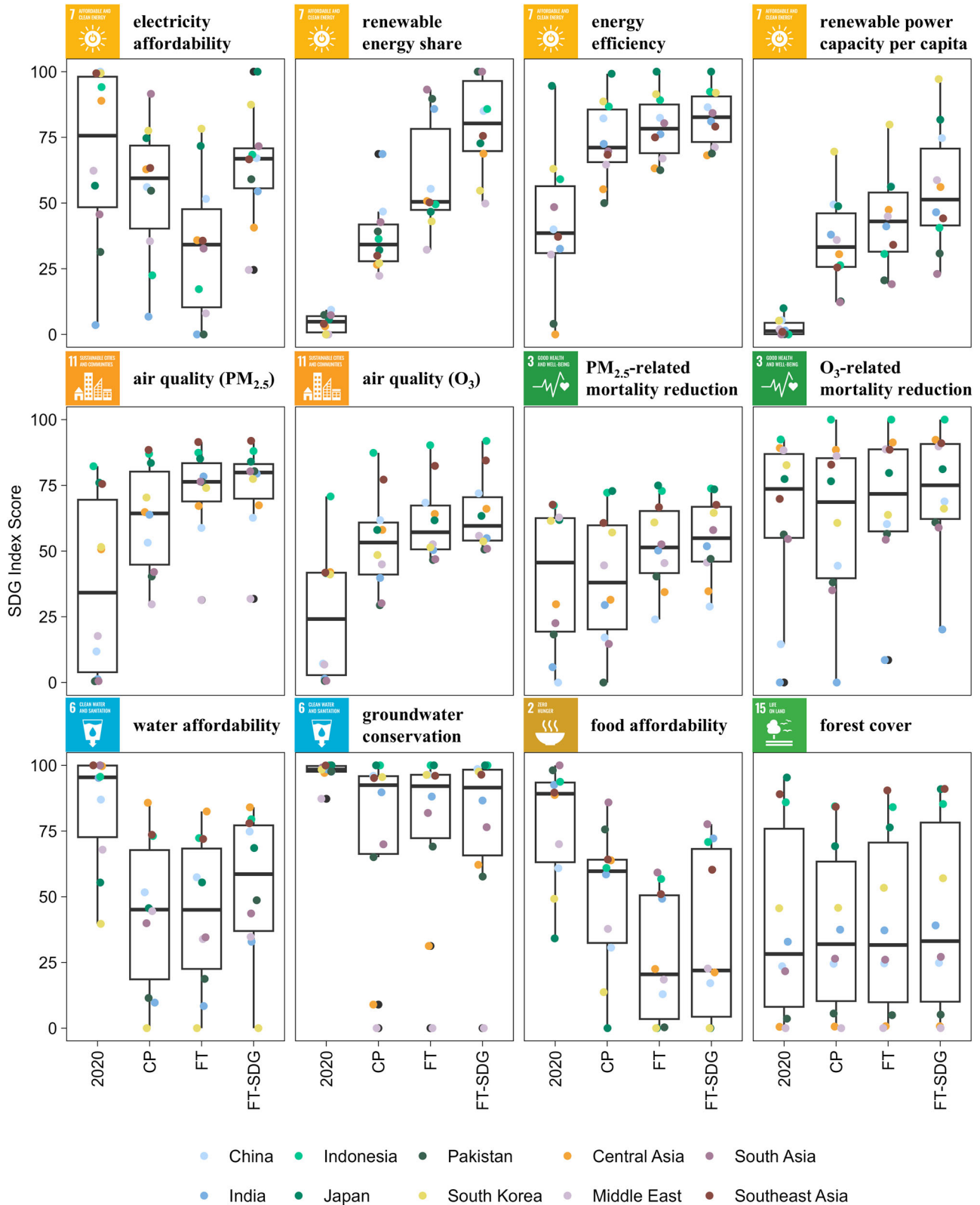


Fig. 3 | SDG indicator scores for Asian countries and regions in 2020 and 2050 under three scenarios. 12 SDG indicators are assessed for the ten countries and regions. A score of 100 represents the best performance, while a score of 0 indicates

the worst performance. Boxplots summarize the distribution of scores across countries, with the central line representing the median, the edges of the box indicating the 25th and 75th percentiles.

Supplementary Fig. 5). In addition, under the FT-SDG scenario, the share of renewable energy increases substantially compared to FT in almost all countries, and the underlying drivers are further analyzed in Supplementary Fig. 15 and its accompanying note.

Air pollution and health. Air pollutants and carbon emissions largely share common sources, primarily from fossil fuel combustion. Therefore, more ambitious climate policies to promote clean energy transition will also mitigate air pollution^{35,36}. Figures 3 and 4 show that compared to

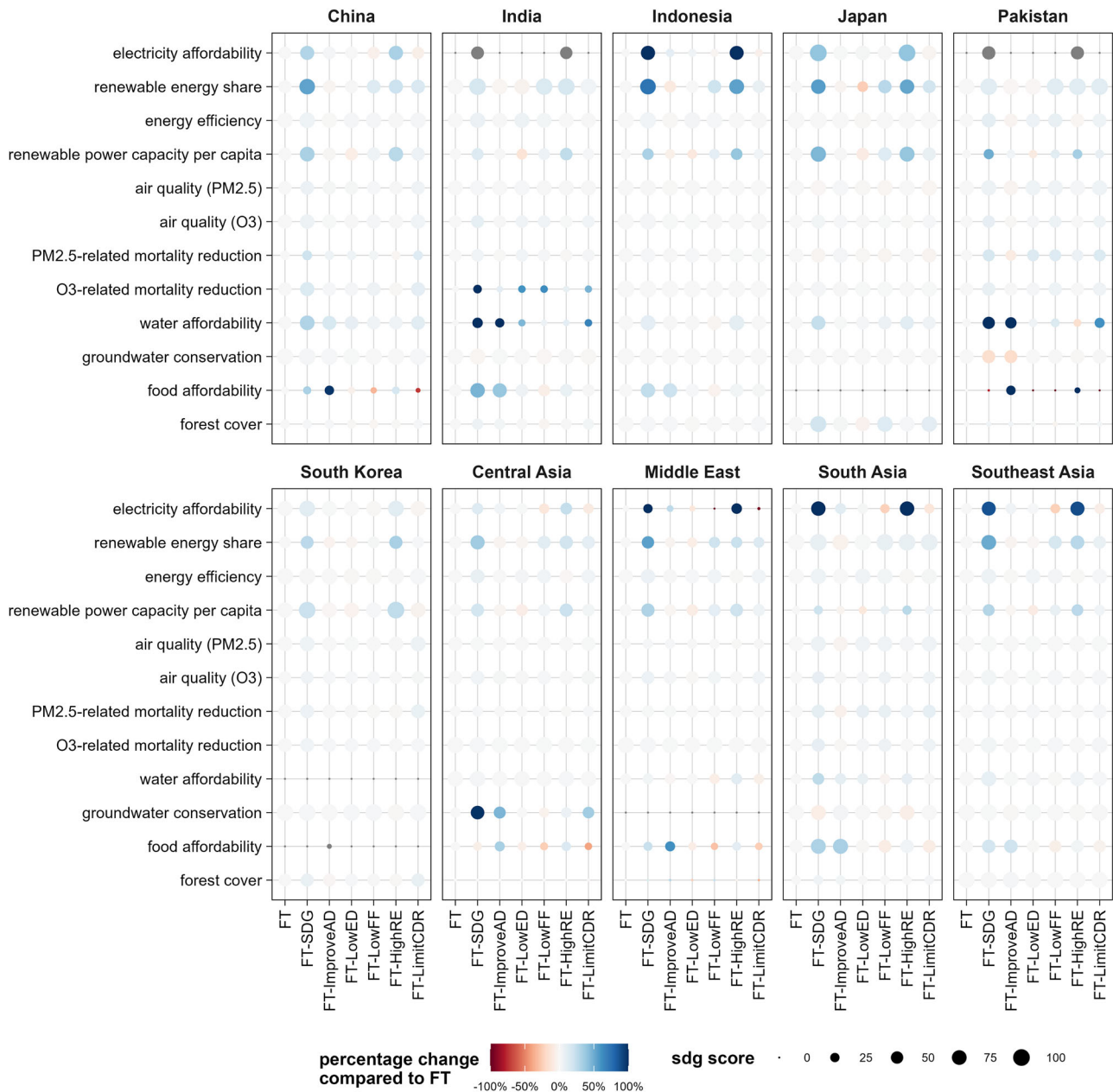


Fig. 4 | Interactions between ambitious climate targets and SDG indicators in different countries and regions. The bubble colors represent the rate of change compared to the FT scenario, with blue indicating an increase in scores and red indicating a decrease. The size of the bubbles reflects the indicator scores for 2050 under each scenario.

2020, all countries are projected to achieve some degree of reduction in PM_{2.5} and O₃ concentrations in 2050 even under the CP scenario, and the FT and FT-SDG scenarios will further improve air quality. Japan, Indonesia, and Southeast Asia would experience relatively modest improvements due to their already favorable air quality, while China, India, Pakistan, and South Asia would experience the most pronounced air quality improvements.

Substantial health benefits could be achieved across Asia through air quality improvement. Notably, under the FT and FT-SDG scenarios, compared to the CP scenario, an additional 763,000 and 929,000 premature deaths attributable to air pollution could be avoided in 2050, respectively (Supplementary Fig. 6). However, the extent of mortality reduction associated with PM_{2.5} and O₃ varies considerably across countries, partly because air pollution-related mortalities are influenced not only by pollutant concentrations but also by demographic changes, such as population aging. Figure 5 presents the age-specific mortality rates attributable to PM_{2.5} and O₃ in different countries. Despite reduction in air pollutant concentrations, mortality

rates among the elderly population (aged over 65) are projected to increase in most countries, largely due to fast population aging in the next three decades. Figure 4 shows that the FT scenario can moderately reduce mortality caused by air pollution, because the ambitious climate goals are achieved largely through CDR technologies that allow high level of fossil fuel use. In comparison, the FT-limitCDR, FT-lowED, and FT-lowFF scenarios more explicitly reduce fossil fuel consumption and thus can further reduce mortality.

Water-land-food system. The trade-offs between low-carbon transition and the water-land-food system are more complex compared to the first two categories of SDG indicators. Under the CP scenario, most countries would show obvious deterioration in water affordability, groundwater conservation, and food affordability in 2050, with only a few countries, such as India, Pakistan, and South Asia, experiencing an increase in forest cover (Fig. 2 and Supplementary Figs. 7–9). More ambitious climate policies under the FT scenario will even exacerbate the four indicators, as the large-scale use of bioenergy requires substantial water and land

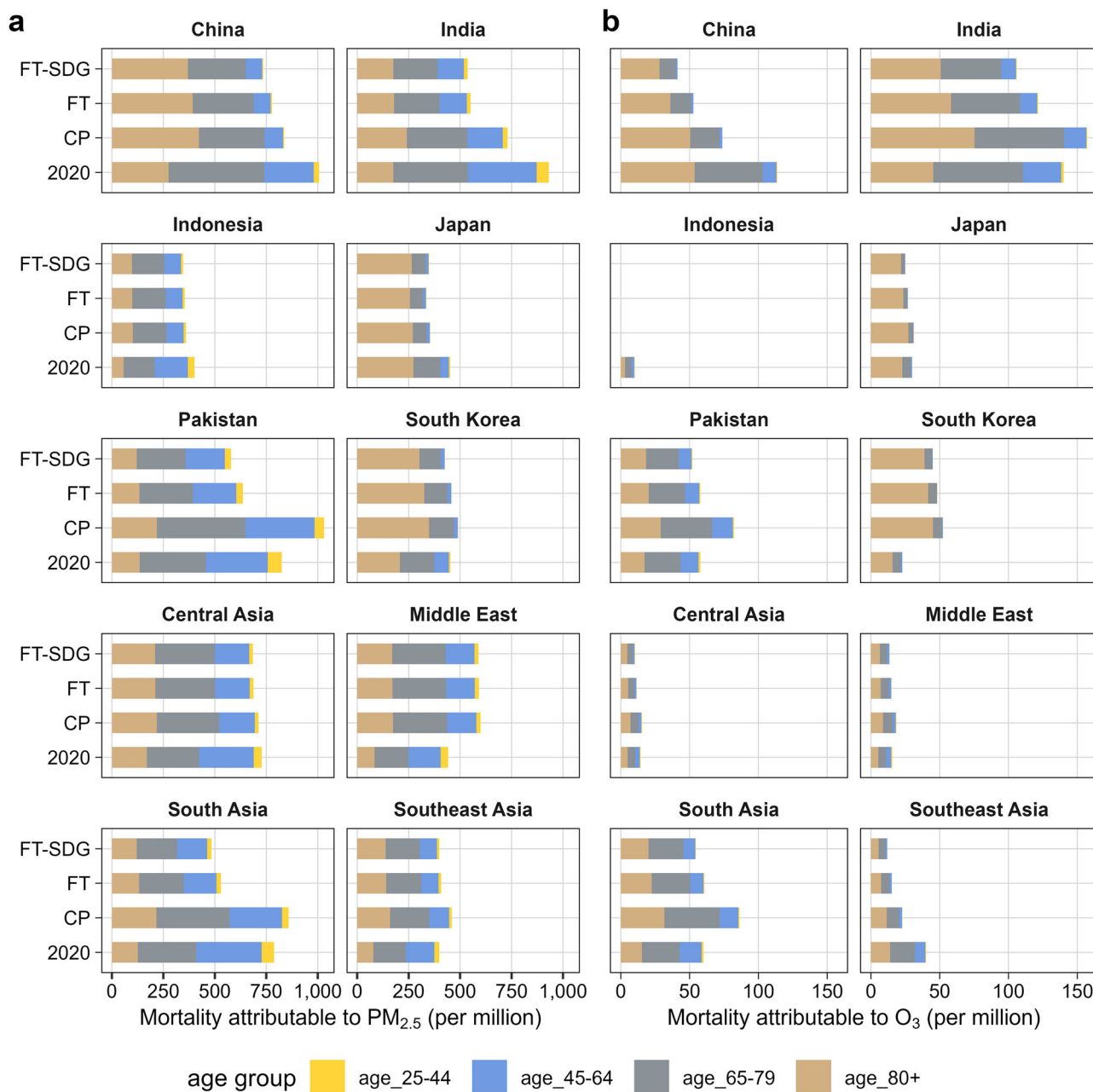


Fig. 5 | Mortality per million people divided by age groups attributable to PM_{2.5} and O₃ pollution in 2020 and 2050, under CP, FT, and FT-SDG scenarios. **a** Mortality rates attributable to PM_{2.5}. **b** Mortality rates attributable to O₃. The O₃ concentration in Indonesia in 2050 is below the theoretical minimum risk exposure level, and therefore no value is presented.

resources. Figures 4, 6 and Supplementary Fig. 10 provide more detailed results of water, food, and land indicators under various scenarios. By implementing specific sustainable practices in the agriculture and land use sectors (FT-ImproveAD) while limiting the use of BECCS (FT-LimitCDR), most countries would show improvements in scores for water affordability, groundwater conservation, and forest cover (Fig. 4). However, a few countries and regions, such as China, South Korea, and Central Asia, would experience further deterioration in food affordability. While restricting bioenergy would reduce direct land competition with food production, it could indirectly increase food production costs. This is because limiting bioenergy use would increase the carbon price needed to meet ambitious climate targets (Supplementary Fig. 11), thereby raising fertilizer production costs and incentivizing landowners to high-carbon-intensity land uses.

Economic impacts of different transition pathways

Large scale deployment of solar, wind, and other low-carbon energy sources is the most crucial practice for achieving ambitious climate goals. In our three main scenarios (CP, FT, and FT-SDG), the cumulative additional installed capacity of low-carbon power in Asia from 2020 to 2050 reaches 5926, 7887, and 9117 GW, respectively (country-specific data in Supplementary Fig. 12). The corresponding cumulative capital investments would be approximately \$14 trillion, \$19.5 trillion, and \$17.6 trillion, respectively (country-specific values in Fig. 7a). The substantial capital investment increase in the FT and FT-SDG scenarios can pose a considerable burden for economically disadvantaged countries. For instance, Pakistan’s cumulative investment as a percentage of GDP rises from 14.5% (CP) to 35% (FT) and 40% (FT-SDG); and Central Asia’s rises from 18.7% (CP) to 38% (FT) and 33.5% (FT-SDG) (Fig. 7a).

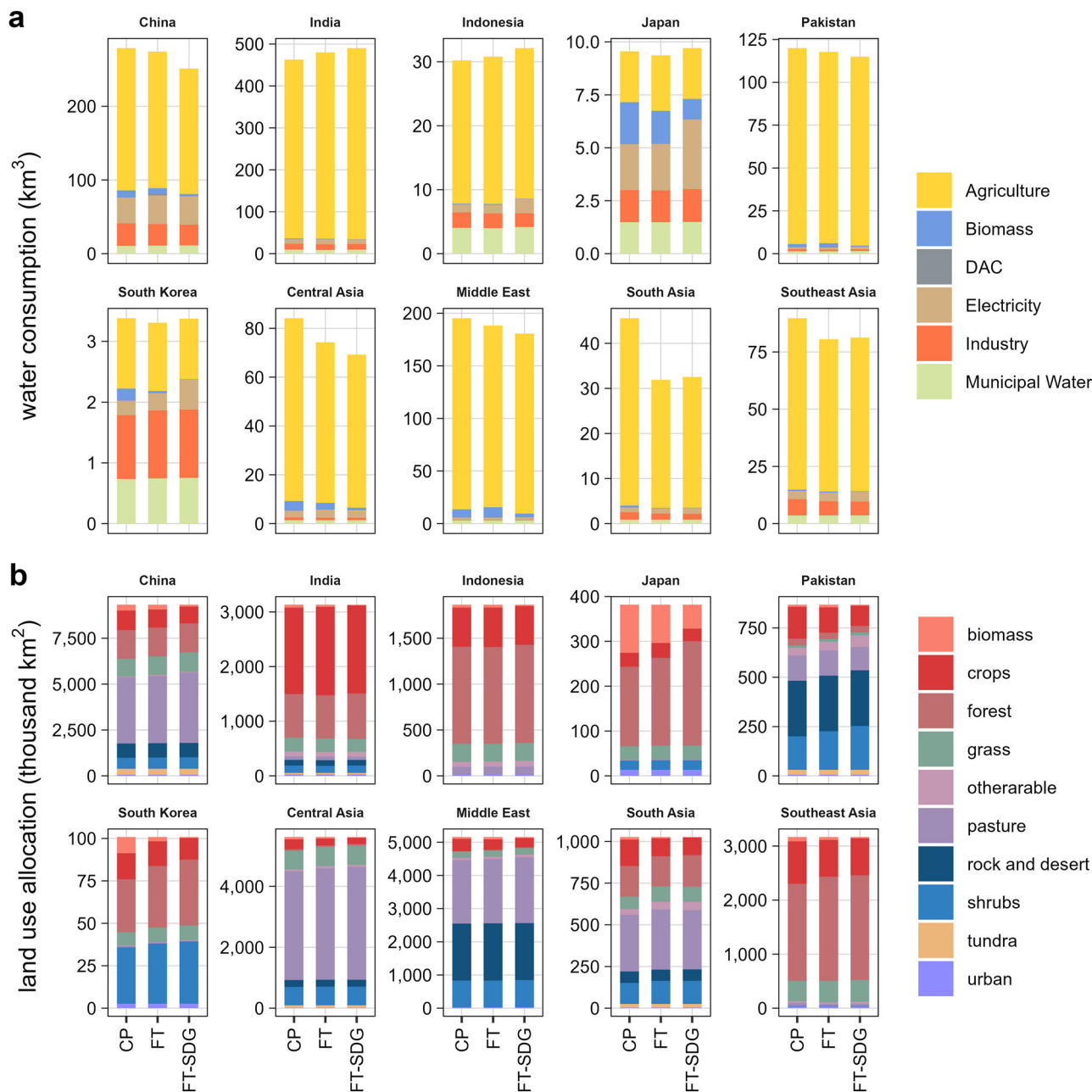


Fig. 6 | Sectoral water consumption and land use for different countries in 2050 under the CP, FT, and FT-SDG Scenarios. a Sectoral water consumption. **b** Sectoral land use.

Our study also quantifies the fossil fuel-fired power generation capacity that will be retired prematurely during energy transition (Supplementary Fig. 12), along with the corresponding stranded assets values (Fig. 7b). The cumulative prematurely retired fossil fuel-fired power capacities in Asia are 816 GW, 1214 GW and 1236 GW in the CP, FT and FT-SDG scenarios, respectively. The cumulative stranded assets in these three scenarios would be \$3.9 trillion, \$5.6 trillion, and \$5.6 trillion, respectively. Stranded assets are primarily concentrated in China and India, accounting for nearly 50% and 20% of the total value in Asia in three main scenarios. Although the stranded assets in each country represent a small proportion of GDP, these losses can be substantial for the power companies and their employees, highlighting the importance of just transition in the power sector.

We further estimated that the overall policy cost for meeting current climate pledges in Asia is \$2.82 trillion (Fig. 7c). Under the FT and FT-SDG scenarios, more aggressive climate policies across sectors will increase the

costs by 162% and 163%, reaching \$7.4 trillion and \$7.42 trillion, respectively. Notably, in the FT-SDG scenario, Japan, South Korea, and the Middle East will face substantial costs increase, because the restriction of CDR would incur very high carbon prices that drive up abatement costs across sectors (Supplementary Fig. 11).

Integrated assessment of climate, SDG, and economic outcomes

Figure 8 provides a comprehensive view of the interactions between greenhouse gas (GHG) mitigation, SDG-related outcomes, and economic risks across countries. Under the CP scenario, most countries perform relatively well in economic indicators but lag substantially in both climate and SDG-related targets. In the FT scenario, only four countries/regions, namely China, the Middle East, South Asia, and Southeast Asia, show a modest overall improvement. Strengthening climate targets alone yields limited benefits for most countries in terms of SDG-related outcomes and may even lead to adverse effects, such as the decline in the S1 indicator in the

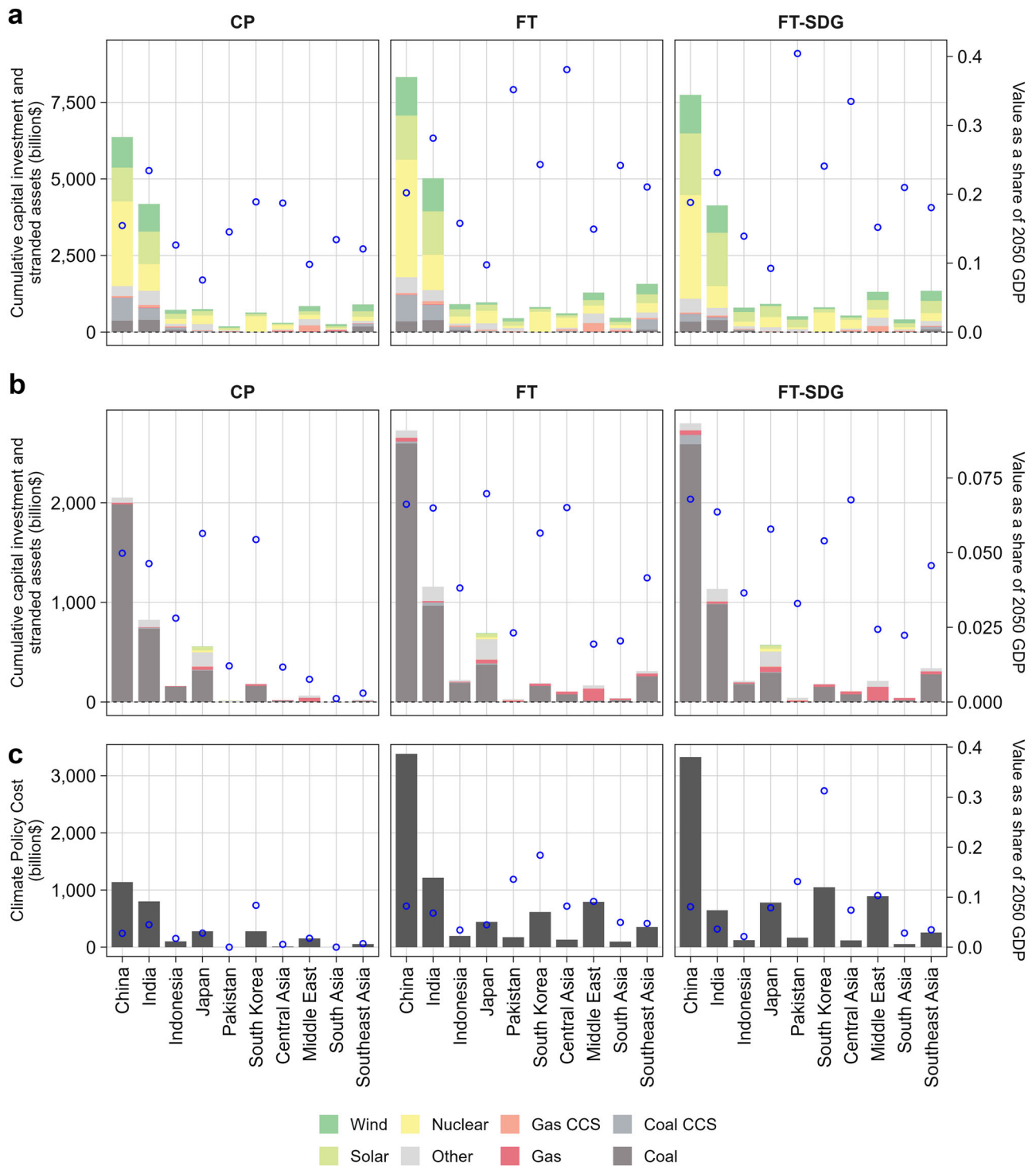


Fig. 7 | Cumulative renewable energy investment, stranded assets, and the overall climate policy costs from 2020 to 2050, under CP, FT, and FT-SDG Scenarios.
a Cumulative capital investment by technology type. **b** Cumulative stranded assets

by technology type. **c** Climate policy costs for different countries and regions in Asia. In each sub-figure, the left axis represents the absolute values, shown as the bar chart, while the right axis represents their shares in 2050 GDP, shown as blue circles.

Middle East and deterioration in the S3 indicator in all countries except Japan and South Korea. Moreover, under this scenario, all countries experience varying degrees of deterioration in economic performance, with notable declines in E1 and E3 indicators for Pakistan and in E2 indicator for Central Asia. The FT-SDG scenario achieves a more balanced advancement of climate and SDG-related targets in most regions, though the trade-offs in economic dimensions vary by country. For example, China and India experience reduced economic impacts relative to the FT scenario, whereas Japan and South Korea see improvements in E1 and E2 indicators but

deterioration in E3 indicator. In contrast, Pakistan undergoes a deterioration in both E1 and E2 indicators.

Extending the analysis to the five sensitivity scenarios reveals that countries respond differently to specific sustainability-oriented interventions (see Supplementary Fig. 13, where values represent the average score across all eight indicators). Among these, lowering renewable energy costs (FT-HighRE scenario) delivers uniformly positive effects, particularly in the Middle East and Pakistan, where overall performance even exceeds that under FT-SDG scenario. Conversely, restricting the use of carbon dioxide

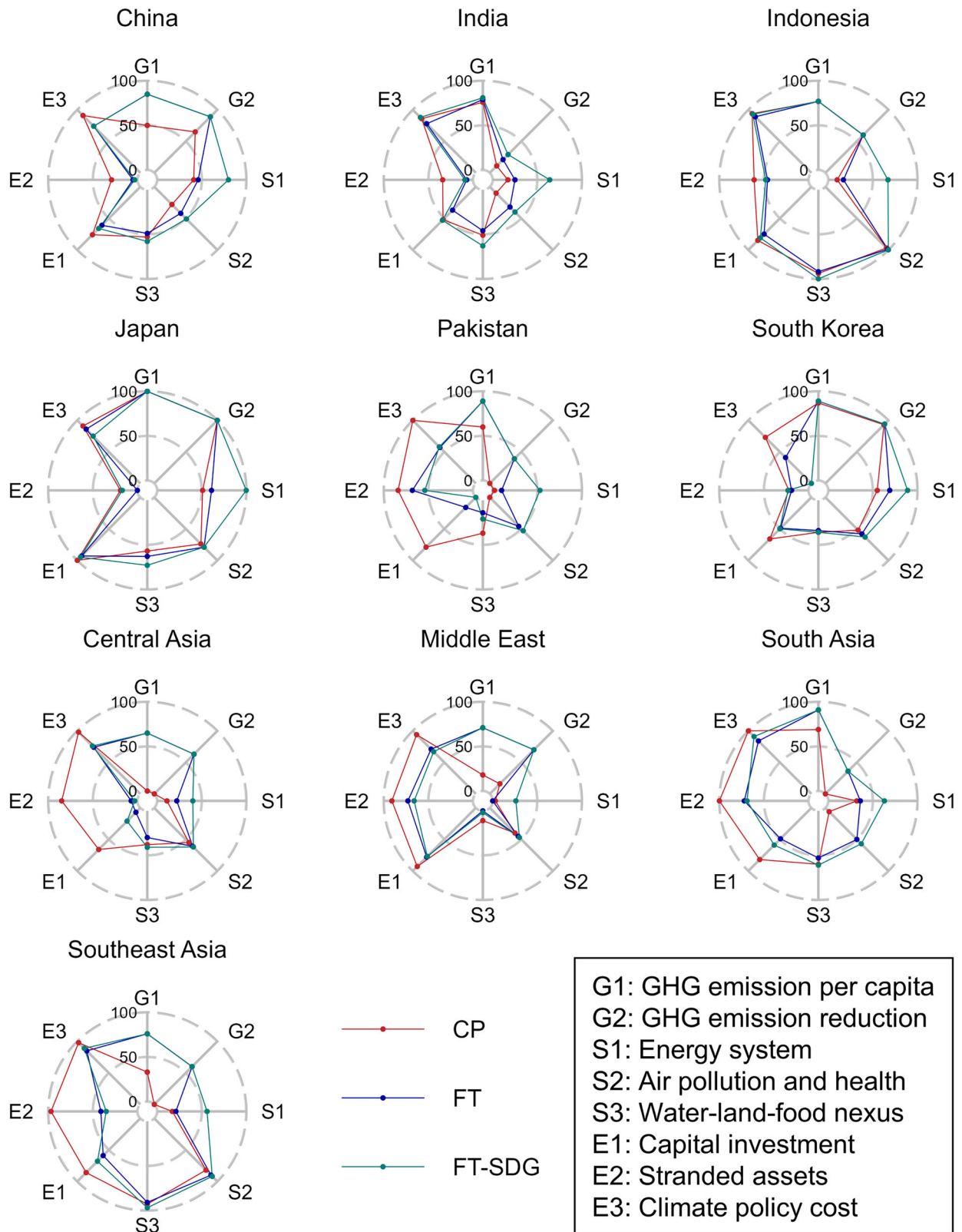


Fig. 8 | Interactions among greenhouse gas (GHG) mitigation, sustainable development, and economic impacts across ten countries/regions. G1 represents per capita GHG emissions in 2050, and G2 denotes the percentage reduction in GHG emissions in 2050 relative to 2020. S1–S3 indicators correspond to three aggregated groups of 12 SDG-related indicators: energy systems, air pollution and public health,

and water-land-food systems, respectively. E1–E3 indicators represent the shares of cumulative capital investment, stranded assets, and climate policy cost in national/regional GDP, respectively. We standardized the values of all eight indicators, enabling cross-indicator and cross-country comparisons. Higher value indicates better performance for the corresponding indicator.

removal (CDR) exerts a negative effect on aggregate scores in most countries, with the strongest adverse impact observed in South Korea.

Discussion

Asian countries have the highest shares of global GHG emissions, and the pace of decarbonization in Asia will strongly influence the global climate governance process. Our study identifies the limitations of current climate pledges in meeting the 1.5 °C target and the United Nations' SDGs, and further points out the opportunities and challenges for different Asian countries to align more ambitious national climate targets with sustainable development priorities. Setting more ambitious climate targets will achieve 53% additional reduction in GHG emissions compared to the current climate pledges, and make substantial progress in SDG indicators for energy, air quality, public health, and the water-food-land nexus. However, achieving all the climate and SDG targets simultaneously will result in a 163% increase in policy costs, or an additional \$4.6 trillion, which would be a tremendous burden for the developing countries in Asia. Different countries face unique challenges and trade-offs in achieving these goals, given their different socioeconomic and natural conditions. Our research provides a robust analytical framework for Asian countries to choose transition pathways that are tailored for their national circumstances and can bring greater synergies and minimize the trade-offs.

The relationship between achieving climate goals and Sustainable Development Goals (SDGs) is complex, involving both synergies and trade-offs. For instance, restricting the use of BECCS can reduce land use pressures, avoiding competition with food crops and thereby lowering food production costs. However, under more ambitious climate targets, this restriction may lead to higher carbon prices, which could increase fertilizer costs and, consequently, food prices. Although decarbonization pathways relying on negative emissions technologies can alleviate short-term transition pressures, they may undermine synergies with SDGs, or even worsen certain SDG outcomes. Overall, more ambitious climate action shows considerable synergies with sectors such as energy and health, but potential trade-offs in areas such as water resources conservation, land use, and food security require greater attention. Policymakers need to design multi-sectoral collaborative low-carbon transition strategies that take into account the domestic context, in order to strike a balance between achieving more ambitious national climate goals and promoting sustainable development.

Large-scale deployment of renewable energy to replace fossil fuel power generation is critical for achieving climate targets and advancing multiple sustainable development indicators, such as access to clean energy and improving air quality. However, such a transition requires substantial infrastructure investments, including wind and solar power facilities and power grid expansion. Under the FT and FT-SDG scenarios, the capital investment required for rapid decarbonization rises sharply across all countries, posing considerable financial and technological challenges for many developing nations, particularly those with constrained fiscal capacity and limited access to international climate finance. At the same time, the premature retirement of fossil fuel facilities can lead to substantial stranded asset risks, especially in countries still operating large-scale or newly built fossil fuel power plants. These losses are particularly prominent in contexts where state-owned enterprises dominate the energy sector and infrastructure investments are often backed by public debt. Collectively, these economic pressures raise critical concerns about the feasibility and equity of implementing ambitious climate targets in low- and middle-income countries. Without adequate financial and technological support mechanisms, these countries may face difficult trade-offs between pursuing climate goals and safeguarding macroeconomic stability or social welfare.

When Asian countries prepare updated Nationally Determined Contributions (NDCs) under the Paris Agreement, it is essential to align these commitments with SDG priorities, while accounting for national circumstances to ensure targets that are both ambitious and feasible. For advanced economies with established industrial structures and strong financial capacity, priority should be placed on accelerating technological innovation and strengthening carbon pricing mechanisms. For middle-income and

low-income countries, climate policies should integrate SDG indicators related to public health and the affordability of energy, water, and food, as these are closely tied to daily well-being and can strengthen public support for more ambitious climate actions. Achieving stringent climate targets will require rapid, cross-sectoral transformations, inevitably driving up policy costs. Therefore, countries must evaluate the feasibility and cost-effectiveness of mitigation strategies in light of their domestic economic and social conditions. In particular, countries with limited fiscal space or a high dependence on fossil fuels may require targeted international assistance, such as climate finance and technology transfer, to manage the socioeconomic impacts of a rapid low-carbon transition. At the same time, robust domestic mechanisms are critical to ensuring a just transition, including labor market policies for reskilling and job matching, social safety nets to protect vulnerable populations, and public investment in clean infrastructure to create new employment opportunities.

Future studies can make further improvements in two respects. First, our SDG assessment does not include the broader social dimensions of sustainable development, such as gender equality (SDG 5) and decent work and economic growth (SDG 8), which are also essential components of a comprehensive sustainability framework. As these social indicators interact with climate policies in complex ways that exceed the current capabilities of GCAM, future studies could integrate this framework with macroeconomic models, computable general equilibrium (CGE) models, or input-output models to enable a more holistic assessment of the linkages between climate policies and the full spectrum of SDG objectives. Second, realizing national low-carbon transition and sustainable development pathways requires consideration of real-world technological and political factors. For instance, future transitions will be constrained by uncertainties in technology development and deployment, including the pace of cost reductions for key mitigation technologies, the emergence of breakthrough innovations, and the availability of carbon storage resources. Moreover, the stability and ambition of national climate pledges depend on evolving domestic and international dynamics, which may shift over time. Future studies could incorporate these real-world uncertainties into modeling frameworks to better reflect the complex and dynamic nature of transition processes.

In conclusion, accelerating the low-carbon transition in Asian countries is essential for achieving the Paris Agreement's 1.5 °C target and advancing the United Nations' SDGs. However, achieving ambitious climate targets involves complex synergies and trade-offs among energy, socioeconomic development, and environmental sustainability. National policymakers must adopt tailored strategies to maximize synergies while effectively managing trade-offs, ensuring a more sustainable low-carbon transition. There is also an urgent need to enhance international climate finance support and foster technological cooperation to promote global low-carbon transition and help developing countries overcome the challenges.

Methods

Description of the study region

Asia is selected as the focus of this study for two key reasons. First, the region's ability to balance economic development with emission reduction is of critical importance to global climate governance. Asia is currently the world's largest primary energy consumer and the highest greenhouse gas (GHG) emitter³⁷, while serving as the main driver of global economic growth. Second, home to over 60% of the world's population, Asia is also among the most vulnerable regions to the adverse impacts of climate change, such as extreme weather events and is experiencing the worst air pollution. Accelerating a sustainable low-carbon transition in this region is therefore not only a climate imperative, but also a pressing issue of environmental justice and public health.

The region exhibits pronounced heterogeneity in socioeconomic development levels and climate policy ambitions. It encompasses developed, developing, and least developed countries, each facing distinct challenges in achieving both sustainable development and deep decarbonization. In this study, we explicitly disaggregate Asia into ten representative countries/

aggregated regions covering the full spectrum of Asian economies (detailed in Supplementary Table 1). Supplementary Fig. 2 presents the historical and projected trends in gross domestic product (GDP), population, and GDP per capita for these countries/regions, illustrating the magnitude of intra-regional socioeconomic disparities. Regarding climate targets, several countries have announced carbon neutrality targets (Supplementary Table 4), but their target years differ substantially, ranging from 2050 in Japan and South Korea, to 2060 in China, to 2070 in India, while many others have not yet to formalize such commitments. Notably, Bhutan has already achieved carbon neutrality³⁸ and pledged in its Second NDC to maintain this status. Previous studies have shown that even if Asia and other regions globally achieve their stated climate goals, the global temperature rise cannot be limited to 1.5 °C without more ambitious action^{1,2}. This underscores the urgent need for more ambitious climate goals. Discussing low-carbon transition strategies for countries at different development stages within the Asia region provides valuable insights into the distinct interplays between decarbonization and sustainable development, and can help encourage more ambitious and actionable climate commitments across Asia.

Global change analysis model (GCAM)

This study utilizes the GCAM model to simulate pathways for achieving national climate goals and explore interactions between social and natural systems. GCAM is an open-source integrated assessment model and is developed by the Joint Global Change Research Institute at the Pacific Northwest National Laboratory. It is a widely recognized integrated assessment model featured in the IPCC Sixth Assessment Report and extensively applied in global climate policy studies^{39–41}. It integrates energy, water, agriculture, land use, socioeconomics, and climate feedback within a single framework, enabling comprehensive assessment of cross-sectoral synergies and trade-offs between climate mitigation and sustainable development goals. Furthermore, GCAM's regional disaggregation into 32 global regions, including ten distinct Asian countries/regions (the corresponding countries for each aggregated region are listed in Supplementary Table 1), provides the necessary granularity to explore differentiated low-carbon transition pathways tailored to varying national contexts in Asia, which is central to the focus of this study. To further clarify our rationale for employing GCAM rather than other integrated assessment models, we provide in Supplementary Table 7 a comparison between GCAM and several commonly used IAMs, highlighting why GCAM is particularly well-suited for this study.

For this study, we employed the GCAM v6.0, and a comprehensive description of this model is available at <https://jgcri.github.io/gcam-doc/v6.0/>, as well as in multiple previous studies^{37,41,42}. The GCAM model contains five key sectors: energy, economy, agriculture and land use, water, and climate. It divides the global energy and economic systems into 32 geopolitical regions. The model is initially calibrated to 2015 and runs from 2015 to 2100 in 5-year time steps, solving for equilibrium prices and quantities in the markets for energy, agriculture, land use, water, and greenhouse gases in each region and time period. A more detailed description of our application of the model, including the energy system, agriculture and land use systems, water system, and GHG and air pollutant emissions, is provided in Supplementary Note 1.

To better align the GCAM model with the objectives of this study, we implemented several targeted modifications. First, given that the power sector is central to our analysis and closely linked to multiple SDG indicators as well as economic impact metrics, we recalibrated renewable power generation in Asian countries to 2020 levels based on IRENA data⁴³, and adjusted fossil-based generation to match historical trends. Second, to address concerns about over-reliance on biomass-based carbon dioxide removal (CDR), we imposed stricter upper bounds on biomass use, drawing on recent estimates of sustainable biomass availability in Asia^{37,44}. Supplementary Fig. 14 compares our modeled biomass consumption and direct air capture (DAC) deployment levels with those from the IPCC AR6 Scenario Database⁴⁵, confirming that our

assumptions remain within plausible and sustainable ranges. Third, we incorporated scenario-specific assumptions by adjusting key input parameters, such as income elasticities, per-capita floor area trajectories, and transport mode shares, to capture structural changes in different sectors under different pathways. Beyond internal model adjustments, we also developed a broader analytical framework based on GCAM model. This includes a process to convert targets in climate policy documents into GCAM-compatible emissions constraint files, as well as a post-processing module to quantify Sustainable Development Goal (SDG) indicators and estimate economic impacts. Together, this integrated framework enables a comprehensive assessment of the multidimensional implications of policy choices across the energy–socioeconomic–environmental system. The modified GCAM version used in this study, the full set of parameter modifications, and all pre-processing and post-processing codes are provided in the Code availability section.

Future emissions pathways and scenario settings

Three main scenarios are analyzed in this study:

Current Pledge (CP): We collect the latest nationally determined contributions (NDCs) (Supplementary Table 2) and long-term strategies (LTS) (Supplementary Table 4) documents of Asian countries, and convert them into GHG emission constraints based on the method outlined in Ou, et al.⁴⁰ and Iyer, et al.⁴¹. The detailed method for converting NDC targets into 2030 emission constraints is explained in Note S2. After 2030, for countries with carbon neutrality targets, GHG emissions are assumed to decrease linearly to zero by the target year of carbon neutrality. For countries without carbon neutrality targets, it is assumed that the post-2030 decarbonization rate remains the same as the average annual rate from 2015 to 2030, with a minimum decarbonization rate set at 2%. To better reflect actual national commitments, we further updated post-2030 trajectories for countries that have announced quantified 2035 NDC targets or specified pathways in their LTS.

Faster Transition (FT): In this scenario, it is assumed that all Asian countries adopt more ambitious long-term climate goals, resulting in faster decarbonization after 2030, so that the emission pathways under this scenario are consistent with the 1.5 °C target. For countries that have already set carbon neutrality targets, it is assumed that they achieve 90% of GHG emissions reduction ten years before their carbon neutrality target year. For other countries, the minimum post-2030 decarbonization rate is set to 8%.

Faster Transition consistent with SDGs (FT-SDG): Building on the FT scenario, this scenario incorporates a series of practices to better align climate policies with SDGs. These practices include: improving agricultural productivity and changing dietary structure (ImproveAD), greener living and consumption styles that demand less energy (LowED), increasing overall costs of fossil fuels to reduce fossil fuel consumption (LowFF), faster deployment of renewable energy due to cost reduction (HighRE), and limiting the use of CDR (LimitCDR). Detailed descriptions of these practices are provided in Supplementary Note 3. The FT-SDG scenario that integrates all these five practices serves as the main scenario in the results section for comparison with the CP and FT scenarios.

In addition to the FT-SDG scenario, five sensitivity scenarios, namely FT-ImproveAD, FT-LowED, FT-LowFF, FT-HighRE, and FT-LimitCDR, with each integrating one of the five sustainable development practices into the FT scenario, are also analyzed to investigate more complicated interactions between SDG indicators.

As GCAM model includes 32 countries and regions globally, for non-Asian countries and regions, we also collected their NDCs and long-term strategies documents (Supplementary Tables 3 and 5) and applied the same processing rules as those used for Asian countries to create their emission constraints.

Sustainable development Goals (SDGs) indicators

Based on the latest assessment framework for the United Nations SDGs⁴⁶ and the modeling capabilities of GCAM, we selected 12 indicators for assessment in this study. These indicators are associated with SDG 2, SDG 3,

SDG 6, SDG 7, SDG 11, and SDG 15, as outlined in Table 1. The 12 indicators are further divided into three groups: energy system, air quality and public health, and water-land-food system. Some indicators are directly derived from the output parameters of the GCAM model, while others are post-processed using additional models and algorithms based on the GCAM outputs, described in the following subsections. Supplementary Table 6 also provides additional descriptions of the calculation processes for each indicator.

We selected 2050 as the timeframe to assess the achievement of SDGs in Asia based on the following considerations. Although the SDG agenda was initially set for completion by 2030, recent global assessments^{9,47} indicate that the likelihood of achieving all targets by this deadline is very low, particularly for countries in the Global South. Several studies^{23,47,48} have also extended the SDG framework to 2050 in their analyses to better reflect the long-term transformations required for sustainable development. Evaluating progress in 2050 therefore provides a broader perspective that goes beyond the 2030 horizon. In addition, 2050 is a critical milestone for achieving global net-zero emissions under the 1.5 °C pathway. Using this year as a common evaluation benchmark enables consistent comparison between SDG outcomes and long-term climate mitigation scenarios, thereby allowing for a more comprehensive assessment of their potential synergies and trade-offs.

Since many SDG indicators lack quantifiable targets, we standardized the scores of the indicators to ensure comparability both between countries and across different indicators. For each indicator, we first rank the values of the 32 countries or regions represented in the GCAM model in all scenarios, and give the values at the 2.5th percentile the lowest score (0) and the values at the 97.5th percentile the highest score (100) to exclude the extreme values. Then, we standardize all sustainable development indicator scores using Eq. (1). This approach has been employed in multiple studies assessing sustainable development indicators^{23,48,49}. The upper and lower bound of each indicator score, as well as the units of each indicator, are provided in Table S6. This study also evaluates overall SDG trends in Asia using national scores. Equal weight is assigned to all countries for two main reasons. First, the indicators are normalized on a per capita, per unit land area, or price basis, thereby reducing concerns over cross-country differences in

population or land area. Second, this approach reflects the Sustainable Development Goals' guiding principle of leaving no one behind.

$$S_{i,r,t} = \frac{V_{i,r,t} - LB_i}{UB_i - LB_i} \times 100 \quad (1)$$

Where $S_{i,r,t}$ represent the score of indicator i for region r in year t . $V_{i,r,t}$ represent the actual value of indicator i for region r in year t . LB_i represent the value of indicator i at the 2.5th percentile across all countries and years. UB_i represent the value of indicator i at the 97.5th percentile across all countries and years.

Air quality modelling

To quantify the impact of the energy transition on air quality, we convert the air pollutant emissions derived from the GCAM model into PM_{2.5} and O₃ concentrations. The common approach involves combining future emission trajectories with gridded emission inventories and using atmospheric chemical transport models, such as GEOS-Chem or CMAQ, to simulate the spatial and temporal variations in PM_{2.5} and O₃ concentrations^{36,50,51}. But this method is overly time-consuming and requires substantial computational resources when performing multi-scenario analyses. To address this challenge, this study utilizes the simplified TM5-FASST model to simulate changes in national air pollution concentrations in different scenarios. It applies linear source-receptor coefficients to efficiently simulate the impact of air pollutant emissions on PM_{2.5} and O₃ concentrations, both within and between countries⁵², as Eq. (2) presents. The TM5-FASST model has been widely adopted in previous studies to simulate regional air quality, demonstrating its effectiveness in capturing air pollution trends in response to emission changes^{53–55}.

$$C_r(x) = C_{r,base}(x) + \sum_{s=1}^{n_s} \sum_{i=1}^{n_i} SRC_{s,r} [y_i, x] \times [E_s(y_i) - E_{s,base}(y_i)] \quad (2)$$

Where $C_r(x)$ represents concentration of air pollutants x in region r . $C_{r,base}(x)$ represent concentration of air pollutant x for region r in base year.

Table 1 | The 12 SDGs indicators adopted in this study and their associated United Nations Sustainable Development Goals (SDGs)

Goals	SDG Indicators	Indicators in this study	source
Goal 2. Zero Hunger	2.c.1 Indicator of food price anomalies	food affordability	GCAM
Goal 3. Good Health and Well-being	3.9.1 Mortality rate attributed to household and ambient air pollution	PM _{2.5} -related mortality reduction	GCAM, TM5-FASST and Exposure-Response Function
Goal 3. Good Health and Well-being	3.9.1 Mortality rate attributed to household and ambient air pollution	O ₃ -related mortality reduction	GCAM, TM5-FASST and Exposure-Response Function
Goal 6. Clean Water and Sanitation	6.1.1 Proportion of population using safely managed drinking water services	water affordability	GCAM
Goal 6. Clean Water and Sanitation	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	groundwater conservation	GCAM
Goal 7. Affordable and Clean Energy	7.1.1 Proportion of population with access to electricity	electricity affordability	GCAM
Goal 7. Affordable and Clean Energy	7.2.1 Renewable energy share in the total final energy consumption	renewable energy share	GCAM
Goal 7. Affordable and Clean Energy	7.3.1 Energy intensity measured in terms of primary energy and GDP	energy efficiency	GCAM
Goal 7. Affordable and Clean Energy	7.b.1 Installed renewable energy-generating capacity in developing and developed countries (in watts per capita)	renewable power capacity per capita	GCAM and plutus
Goal 11. Sustainable Cities and Communities	11.6.2 Annual mean levels of fine particulate matter (e.g. PM _{2.5} and PM ₁₀) in cities (population weighted)	air quality (PM _{2.5})	GCAM and TM5-FASST
Goal 11. Sustainable Cities and Communities	11.6.2 Annual mean levels of fine particulate matter (e.g. PM _{2.5} and PM ₁₀) in cities (population weighted)	air quality (O ₃)	GCAM and TM5-FASST
Goal 15. Life on Land	15.1.1 Forest area as a proportion of total land area	forest cover	GCAM

For SDG indicator 7.1.1 (Proportion of population with access to electricity), due to methodological and model constraints, we are unable to quantify the national-level share of the population with electricity access. Instead, we use electricity affordability as a proxy indicator.

$SRC_{s,r}[y_i, x]$ represent the emission of precursor y_i to the concentration of air pollutants x coefficient for source region s and receptor region r , which is derived by Van Dingenen, et al.⁵². $E_s(y_i)$ represents the emission of precursor y_i in region s . $E_{s,base}(y_i)$ represents the emission of precursor y_i for region s in base year.

Markandya, et al.¹⁴ and Sampedro, et al.¹⁵ developed an R version of TM5-FASST, and we utilize its code and data in this study. Given that the GCAM model provides output data for 32 regions, while TM5-FASST covers 56 regions, we use the CEDS⁵⁶ 2019 emission inventory to allocate the emission data from GCAM to 219 countries/regions. These countries/regions are then grouped into the 56 regions required by TM5-FASST.

Health impact calculation

This study quantifies the health impacts of air pollution under different emission scenarios by calculating the number of deaths attributable to long-term exposure to PM_{2.5} and O₃. According to the Global Burden of Disease (GBD) study 2019⁵⁷, long-term exposure to PM_{2.5} is linked to six diseases: chronic obstructive pulmonary disease (COPD), type II diabetes mellitus, ischemic heart disease (IHD), lung cancer, lower respiratory infections, and stroke. Long-term exposure to O₃ is associated with COPD.

First, we calculate the relative risks (RR) for different diseases associated with varying concentrations of PM_{2.5} and O₃. For PM_{2.5}, we utilize the MR-BRT exposure-response function developed in the GBD study 2019, which provides relative risk values for six diseases within a concentration range of 0 to 600 µg/m³. Among these, ischemic heart disease (IHD) and stroke have age-specific relative risk values, while the remaining four diseases do not differentiate by age.

For O₃, we calculate the relative risks using Eq. (3), where C represents the average maximum eight-hour ozone concentration from April to September; C_0 denotes the theoretical minimum risk exposure level, which ranges from 29.1 to 35.7 ppb⁵⁷; and RR_{k10} indicates the relative risk of disease for each 10 ppb increase in O₃ concentration, set at 1.06 (95% CI: 1.03–1.10)⁵⁷.

$$RR = RR_{k10}^{\left(\frac{C-C_0}{10}\right)} \quad (3)$$

Using the exposure-response relationships outlined above, we calculate the number of deaths caused by long-term exposure to air pollution using Eqs. (4) and (5).

$$AF = \frac{RR - 1}{RR} \quad (4)$$

$$Mort = Pop \times y_0 \times AF \quad (5)$$

where AF represents the attributable fraction of disease mortality due to exposure to air pollution. Pop refers to the population size by age group for country in a specific year, using future population projections from the IIASA SSP database⁵⁸ under the SSP2 scenario, which include population breakdowns by five-year age intervals for each country. y_0 denotes the baseline mortality rate for different diseases, using the future mortality data under the SSP2 scenario derived from Huang, et al.⁵⁹, which include future age-specific baseline mortality rates for six diseases under different SSP scenarios. $Mort$ represents the number of deaths attributable to PM_{2.5} and O₃.

Capital stock turnover in the power sector

In the GCAM model, the turnover of installed capacity and capital stock in the power sector is calculated using methods proposed by Iyer, et al.⁴², Binsted, et al.²⁷ and Ou, et al.²⁹. The model tracks the capacity and lifecycle of power plants based on technology, vintage year, and geographical location. Plant retirement occurs through two mechanisms: natural retirement at the end of the plant's physical lifespan, and early retirement due to insufficient profitability, often referred to as stranded assets. The GCAM model

simulates the effects of both natural and profit-induced early retirement by tracking data across different technologies (T), vintage (V, representing the year of capital investment), regions or countries (R), and periods ($t > V$), as shown in Eq. (6).

$$G_{T,V,R}(t) = G_{T,V,R}(t-1) * \left(1 - \gamma_{T,V,R}^n(t)\right) * \left(1 - \gamma_{T,V,R}^p(t)\right) \quad (6)$$

Where $G_{T,V,R}(t)$ represents the electricity generation in country or region R for technology T and vintage V during modeling period t . $\gamma_{T,V,R}^n(t)$ and $\gamma_{T,V,R}^p(t)$ denote the proportion of natural retirements and profit-driven early retirements, respectively, during modeling period t .

Based on the principles outlined above, we used the open-source R package `plutus`⁶⁰, to calculate new installed and early retirement capacity, as well as the corresponding capital investments and stranded assets in the power sector.

Climate policy cost

To calculate climate policy costs, GCAM adopts the concept of deadweight loss to quantify the welfare loss associated with climate mitigation. The GCAM model computes the marginal abatement cost curve for each period and uses Eq. (7) to determine the policy cost for that period^{14,61}.

$$C_t = \int P_t \times \Delta E_{abated} \quad (7)$$

Where C_t represents the climate policy cost for period t . P_t is the carbon price for period t . E_{abated} is the amount of carbon emissions abated in period t compared to the reference scenario.

We developed an external program to calculate the policy cost for each period using a simplified assumption based on Eq. 7. We assume that the marginal carbon price will increase linearly from the first ton of mitigation to the last ton. This assumption may slightly overestimate the policy cost for each period, as the marginal abatement cost curve is typically a concave function.

Data availability

All datasets used in this study are reported in the manuscript and the supplementary information file. In addition, all datasets have been deposited in Zenodo and are available at <https://doi.org/10.5281/zenodo.16834819>.

Code availability

The standard version of the GCAM model is available at: <https://github.com/JGCRI/gcam-core/releases>. The GCAM version model used in this study, the R script used to process the data, calculate the SDG indicator score and economic impact, make the plots are available at <https://doi.org/10.5281/zenodo.16834819>.

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Author contributions

H.Z. and P.W. conceived the study and designed the research framework. H.Z., P.W. and Y.O. developed the scenarios and conducted the model

simulations. H.Z., M.R. and Y.S. contributed to data analysis and figure production. H.Z. drafted the manuscript, and all authors contributed to reviewing and editing the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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