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Fiscal Policies to Address Climate Change in Asia and the Pacific

Prepared by a joint team from the IMF Asia and Pacific and Fiscal Affairs Departments, led by Era Dabla-Norris, James Daniel, and Masahiro Nozaki, and comprising Cristian Alonso, Vybhavi Balasundharam, Matthieu Bellon, Chuling Chen, David Corvino, and Joey Kilpatrick.

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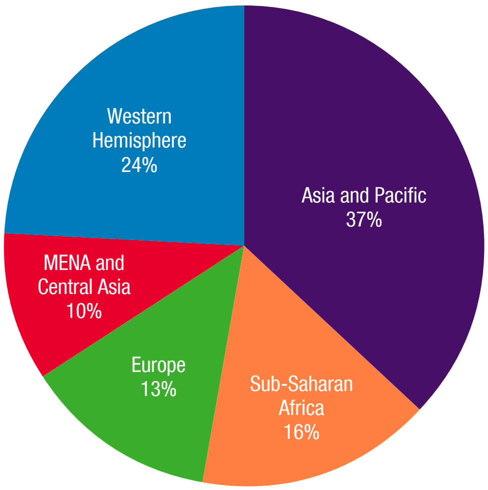
Executive Summary and Policy Implications

Climate change is one of the greatest challenges facing policymakers worldwide, and the stakes are particularly high for Asia and the Pacific.

- Climate change threatens long-term growth potential, livelihoods, and well-being in all countries in the region. Temperatures are rising faster than in any other region. It is already the region most susceptible to weather-related natural disasters, such as hurricanes, droughts, and wildfires, which will become more frequent and severe (Figure 1). Rising sea levels could directly affect a billion people in the region by mid-century, potentially submerge many mega cities, and pose existential threats to some Pacific island countries.
- Asia and the Pacific is critical to tackling climate change. Considering that the region has the majority of the world's population, is the main driver of global growth, and includes many countries with substantial development needs, Asia and the Pacific has not surprisingly become the main greenhouse gas (GHG)-emitting region, producing about half of the world's carbon dioxide (CO_2) emissions currently (Figure 2). The region also accounts for about half of world GHG emissions from the agricultural sector. Excluding China, however, the region's cumulative and per capita CO_2 emissions remain considerably lower than those of North America and Europe. At a time when the entire world needs to step up mitigation efforts, greater emissions reductions from China, India, and other large CO_2-emitting economies in Asia and the Pacific will need to play a key part of the global effort.
- Global efforts to reduce GHG continue, following the landmark Paris Agreement in 2015 and ahead of the critical 26th Conference of the Parties (COP26) UN climate change conference in November 2021, including recent commitments to net-zero carbon emissions by 2050–60 by China,

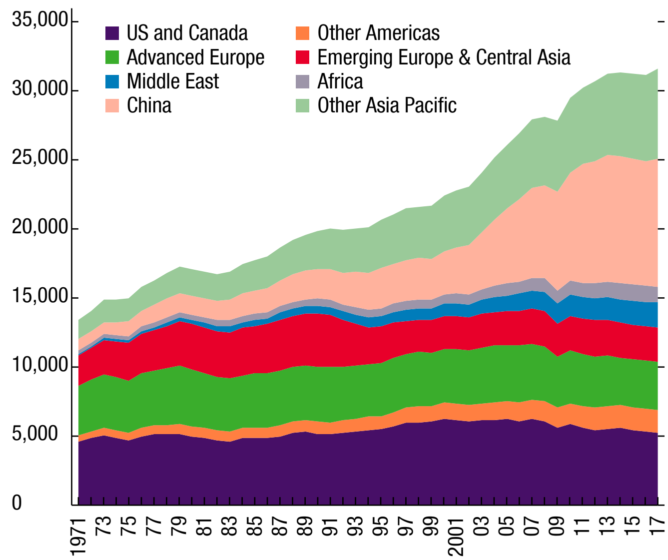
Figure 1. Occurrence, All Weather-Related Disasters, 2000–19



Source: EM-DAT 2020.

Figure 2. CO_2 Emissions, 1971–2017

(Tons of CO_2 millions)



Source: International Energy Agency 2020.

Japan, and Korea. But commitments to date, including these new ones, will likely fall well short of what is necessary to achieve the Paris Agreement's goal of keeping the global temperature increase to 1.5–2 degrees Centigrade above pre-industrial levels. And the window of opportunity is closing fast.

Fiscal policy plays a critical role in responding to climate change. *Climate change mitigation*, which refers to efforts to reduce or prevent emissions of GHGs, can be achieved by well-designed tax policies that raise the price of carbon, together with non-tax instruments such as emission trading systems, feebates, or regulations. *Climate change adaptation* refers to adapting to the effects of climate change and minimizing damage from climate-related natural disasters. This typically requires an increase in government spending, among other actions, which needs to be accommodated under the overall fiscal framework of a country. Further, fiscal policy can facilitate the *transition to a greener, low-carbon economy* by investing in climate-smart infrastructure such as renewable power generation and supporting research and development (R&D) in climate-smart technologies.

This paper analyzes how fiscal policy can address challenges from climate change in Asia and the Pacific. It aims to answer how policymakers can best promote mitigation, adaptation, and the transition to a low-carbon economy, emphasizing the economic and social implications of reforms, potential policy trade-offs, and country circumstances. The recommendations are grounded in quantitative analysis using country-specific estimates, and granular household, industry, and firm-level data. Specifically, this paper asks:

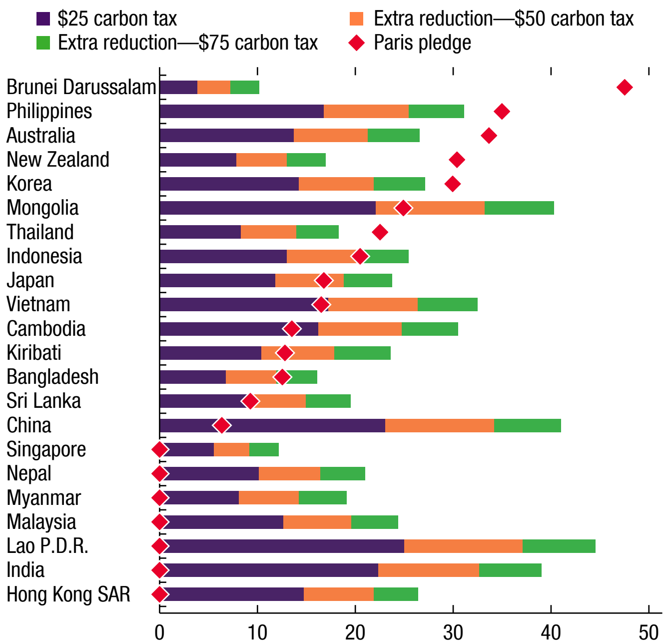
- Why is tackling climate change an imperative for Asia and the Pacific? Where does Asia stand on GHG emissions and the intensity of weather-related natural disasters relative to other regions? *(Chapter 1)*
- How can Asia and the Pacific accelerate mitigation efforts? What would be the implications of gradually introducing a carbon tax over the next decade on emissions and fiscal revenues? What are the complementarities and trade-offs between carbon taxes and other policy tools to cut emissions? *(Chapter 2)*
- How can carbon tax revenues be used to enhance economic efficiency and the political acceptability of higher carbon pricing? What complementary measures are required to address distributional consequences for households, industries, firms, and workers? How do these vary across countries? *(Chapter 3)*
- How can Asia and the Pacific adapt to climate change? What are the fiscal costs of making infrastructure more climate resilient across different countries? What are the costs and benefits of scaling up adaptation investment, and implications for debt sustainability? *(Chapter 4)*
- How can fiscal policy support a transition to a low-carbon economy? What kind of policy measures can promote innovation and investment in climate-smart technologies and their deployment in response to the COVID-19 crisis? *(Chapter 5)*

Three key policy implications follow from the answers to these questions:

First, carbon taxes, charged on the carbon content of fossil fuels, are little used in the region but can be a highly effective mitigation tool for Asia and the Pacific, especially when supported by complementary measures. Implementation can be gradual and tailored to country circumstances. Although non-tax mitigation measures would likely be less effective at reducing CO_2 emissions, they can usefully complement carbon taxes. Those affected by higher energy prices can be largely identified and should be compensated adequately.

- Asia and the Pacific would greatly contribute to global mitigation efforts through gradual and steady implementation of carbon taxes (Figure 3). Illustratively, a carbon tax of $25 per ton—relatively modest compared to the $50–$100 models suggested to be needed globally to keep global warming below 2 degrees—implemented collectively and gradually in the region over the next 10 years, would reduce regional emissions by 21 per-

Figure 3. CO_2 Reduction with Carbon Taxes, 2030
(Percent of the business-as-usual CO_2 emissions in 2030)



Source: IMF staff calculations.
Note: Countries with zero emission-reduction target from the Paris Agreement climate pledge are assumed to be able to achieve the target in the business-as-usual scenario. Paris pledges reflect newly submitted proposals and updates in 2020.

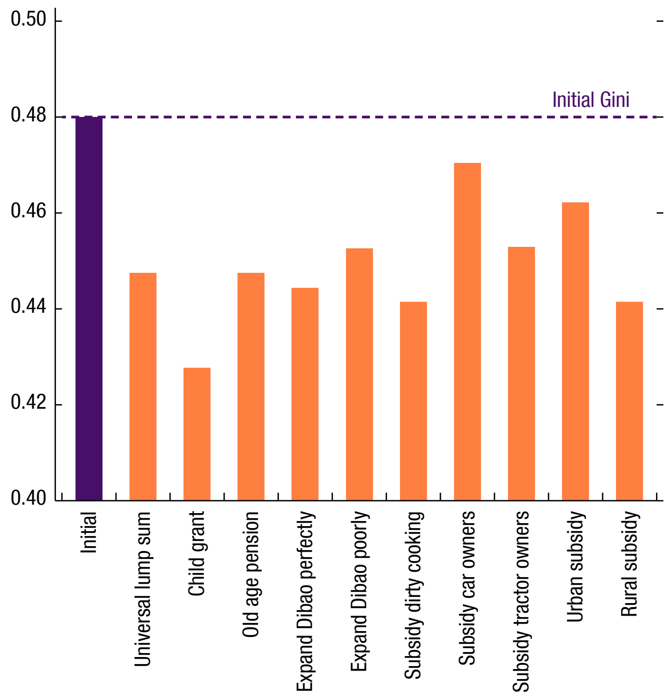
cent by 2030, overperforming the region's Paris Agreement targets on an aggregate basis (8 percent). At this tax rate, carbon taxes could produce additional revenue of about 0.8 percent of GDP, a significant but feasible fiscal effort over 10 years. This said, limiting global warming to 2 degrees or less would likely require a carbon tax rate significantly higher than $25 per ton.

- Carbon taxes can be substituted by specific taxes targeted at country-specific emission profiles. For example, a coal tax can be almost as effective at reducing CO_2 emissions as a carbon tax in coal-intensive countries such as China, India, and Mongolia. India's coal tax, introduced in 2010 and doubled in 2020, is welcome and can be further strengthened. Similarly, in countries where emissions originate mainly from the electricity sector, a carbon tax targeted at electricity generation can be highly effective.

- Raising carbon taxes would have many other benefits, especially for air pollution and health. For example, implementing a coal tax in China could save about 3 million lives by 2030.

- Households, workers, and firms vulnerable to higher energy prices can be largely identified and should be compensated adequately. Distributional impacts differ significantly across countries in Asia and the Pacific—for example, a carbon tax, if implemented, would be moderately regressive (disproportionately borne by poor) in Australia, China, and Mongolia, but moderately progressive (disproportionately borne by rich) in India and Philippines. A wide range of options are available to compensate households in each country (Figure 4). Universal transfers that distribute carbon tax revenues equally to the population can make the majority of households, including poor ones, better off. Most countries have more targeted schemes already in place that could be expanded leading to even better outcomes. For example, using the revenue from a carbon tax to expand China's minimum

Figure 4. China: Gini Coefficient after Carbon Tax of $25 per Ton and Compensation Measures

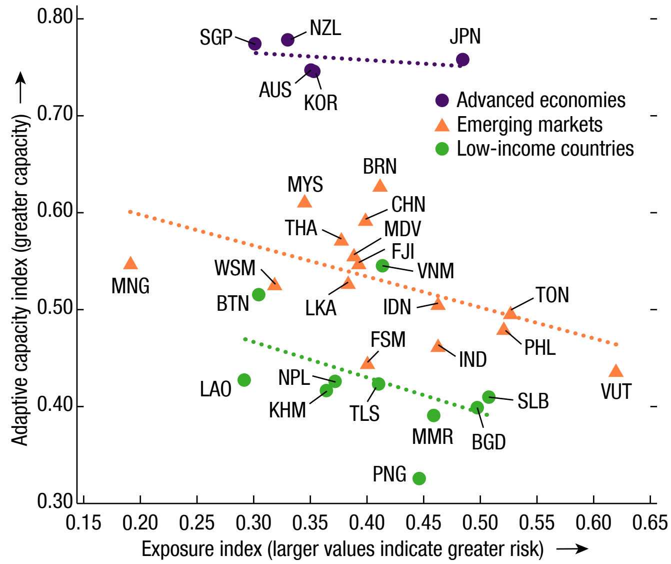


Source: IMF staff calculations.
Note: The dashed line marks the initial Gini coefficient, before a carbon tax is introduced.

guaranteed income scheme (Dibao) would substantially improve inequality compared to before the carbon tax. Our micro-level analyses indicate that the burden of a carbon tax can be concentrated geographically and in energy-intensive industries (for example, metals and chemicals) within countries, and firms that are less productive, smaller, or credit-constrained are more vulnerable to energy price increases. These incidence analyses can help identify the most affected areas and design country-specific compensatory schemes. Carbon taxes can also create fiscal space, after compensating the vulnerable, for other priority spending including green investment and spending for adaptation, or reducing distortionary taxes that reduce incentives to work and invest.

- The prospective imposition of border carbon adjustments (BCAs) by the EU and potentially other major advanced economies enhances the case for countries in Asia and the Pacific to introduce their own carbon tax. BCAs are import fees levied by carbon-taxing countries on goods manufactured in non (or inadequate) carbon-taxing countries. By imposing their own carbon taxes, countries in the region would reduce, or eliminate, BCAs on

Figure 5. Adaptive Capacity and Physical Exposure



Source: IMF staff calculations based on 2015–18 data from the EU commission, the United Nations University Institute for Environment and Human Security, the University of Notre Dame, and the IMF, *World Economic Outlook* database.
Note: Data labels in the figure use International Organization for Standardization (ISO) country codes.

their exports and allow them to keep the revenue themselves. And to boost the global mitigation effort and prevent their own mitigation efforts being undermined, the main emitters in Asia and the Pacific should coordinate with other key global emitters to agree on an international carbon price floor (IMF 2019d).

- Non-tax-mitigation measures can usefully complement gradual implementation of carbon taxes. While emissions trading systems, feebates, and regulations are generally less effective at reducing CO_2 emissions on their own than carbon taxes due to limited coverage and impacts on energy usage as well as foregone revenues, they have been widely implemented in the region and complemented carbon taxes in Japan and Singapore. Support for innovation on green technologies can further facilitate mitigation efforts.

Second, many countries in the region would greatly benefit from increasing their ability to adapt to climate change, but this may prove fiscally challenging, especially for low-income and Pacific island countries.

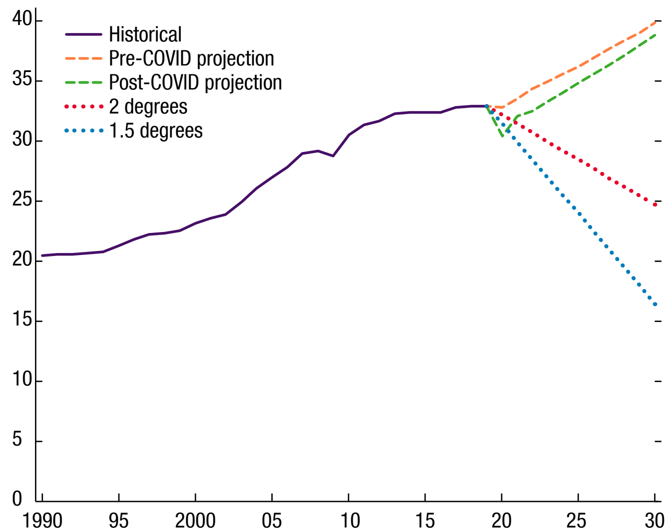
- Although Asia and the Pacific's adaptive capacity is merely average, it faces the highest climate risks (Figure 5). All countries in the region have the scope and need to increase their adaptive capacity, but the gap is largest for low-income countries and Pacific island countries, many of whom face the highest climate risks.

- This calls for mainstreaming adaptation into national budgets and fiscal strategies. While some progress has been made, for example in identifying climate-related spending, most countries in the region have yet to fully cost and prioritize their adaptation plans.
- Investing in adaptive infrastructure can yield high returns (for example, greater private investment, less damage and economic disruption from disasters, lower disaster recovery spending, and a quicker rebound in economic activity), especially if efficiently undertaken.
- Strengthening adaptive capacity will entail higher public investment spending—on average about 3.3 percent of GDP annually for the region, but much higher for many, especially some Pacific island countries. While for some countries this may entail only upgrading new investment projects to make them more climate resilient, which is relatively inexpensive, for others, it may mean retrofitting existing climate-exposed critical assets and/or developing coastal protection infrastructure, both of which are significantly more expensive. For countries with limited fiscal space, options to finance the additional investments include greater domestic revenue mobilization (for which there is considerable scope in the region) and/or improving spending prioritization and efficiency.
- Concessional financing will be critical for low-income countries with large adaptation investment needs and dwindling fiscal space due to the COVID-19 crisis, especially Pacific island countries, where adaptation needs tend to be large relative to their size of the economy and capacity to mobilize domestic revenue.

Third, the fiscal policy response to the COVID-19 crisis should aim toward a green recovery.

- The COVID-19 crisis does not alter the climate change challenge for Asia and the Pacific, but it does provide an opportunity to tackle it. Even a prolonged recession will make only a small dent in the stock of atmospheric GHG emissions in the longer term, which are projected to *rise* by about 20 percent by 2030 rather than *fall* 25–50 percent to be consistent with the 1.5–2 degrees warming target (Figure 6). Thus, the policy action required remains as ambitious. But the COVID-19 crisis does raise the stakes, and decisions taken now will shape the climate for decades. Since the onset of the COVID-19 crisis, governments across the world have provided policy support totaling about US$12 trillion, and more is on the way. These investments need to be allocated to green rather than carbon-intensive sectors to avoid locking in a high-carbon future.

Figure 6. Global Fossil Fuel CO_2 Emissions, 1990–2030
(Billion of tons)

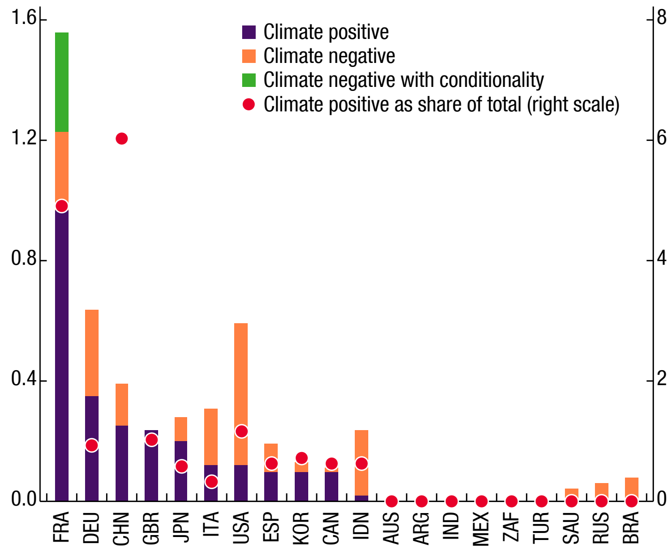


Sources: International Energy Agency (2020); and IMF staff calculations.
Note: 2 (1.5) degrees refers to the emissions that will keep a global temperature rise below 2 (1.5) degrees Celsius above the pre-industrial levels.

- In the recovery phase from the COVID-19 crisis, "green" fiscal measures, such as tax incentives for R&D and investment in low-carbon infrastructure, should be deployed to promote innovation and investment in climate-smart technologies (Figure 7). Macroeconomic simulations in IMF (2020d) find that an initial green investment push, combined with steadily rising carbon prices, would deliver the goal of net zero emissions by about 2050 at reasonable transitional global output costs (indeed initially positive output effects). Promoting green sectors, such as renewable energy and electric car production, can boost employment in the short and long term, because green sectors are typically more labor-intensive than carbon-intensive sectors such as fossil fuel energy, transportation, and heavy manufacturing.
- While some countries in the region have introduced policy packages with green measures (for example, Korea's Green New Deal), the green share is low and more can, and should, be done. Global efforts for promoting and financing the transfer of environmentally sound technologies to developing countries—a mandate of developed countries under the UN Framework Convention on Climate Change (UNFCCC)—should be stepped up. Expanding multilateral climate funds, such as the Green Climate Fund, and improving their accessibility could promote green growth in many developing countries in the region.

Figure 7. Climate Relevance of Fiscal Measures in the G20 Related to the COVID-19 Crisis

(Percent of GDP, left scale; percent of total, right scale)



Source: IMF, October 2020 *Fiscal Monitor*.

Note: Measures are categorized into positive and negative policy archetypes, based on the climate relevance of specific activities. A similar methodology is applied in the Greenness of Stimulus Index (https://www.vivideconomics.com/casestudy/greenness-for-stimulus-index). Data labels use International Organization for Standardization (ISO) country codes.

The IMF can help countries in the region implement these policies. IMF surveillance increasingly focuses on how countries and global and regional institutions should assess the macroeconomic implications and policy responses to climate risks, and the trade-offs involved. The IMF's capacity development can help countries integrate climate into their fiscal strategies and budgets, implement carbon taxes, reduce fossil-fuel subsidies, and enhance the climate-responsiveness of their investment spending. In particular, the IMF country-specific spreadsheet model can help countries calibrate the carbon pricing and other mitigation instruments needed to achieve their climate objectives. And, the IMF lending toolkit includes facilities that provide rapid support to countries hit by weather-related natural disasters.

Chapter

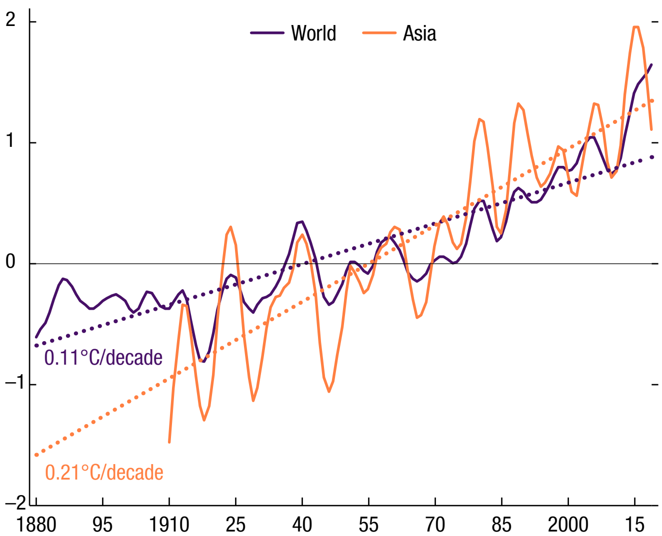
1 Climate Change in Asia and the Pacific: Stylized Facts

Asia and the Pacific is heavily impacted by, and greatly contributing to, climate change. The region has experienced fast-rising temperatures and has suffered more weather-related natural disasters than any other region. Looking forward, as climate change intensifies, rising sea levels could directly affect a billion people in the region by mid-century. Weather-related disasters could be more severe, highlighting the urgent need to accelerate adaptation. The region, which accounts for the majority of the world's population and has been the main driver of global growth in recent decades, has become a major GHG emitter, accounting for about half of global emissions now. Excluding China, the region's cumulative and per capita emissions remain considerably lower than those of North America and Europe. Nonetheless, as the entire world needs to step up mitigation efforts, much greater emissions reductions from China, India, and other large CO_2-emitting economies in Asia and the Pacific will need to play a key part of the global effort. The key to mitigation is to contain the use of coal, which is responsible for more than half of the region's emissions.

Climate Change and Its Impact in Asia and the Pacific

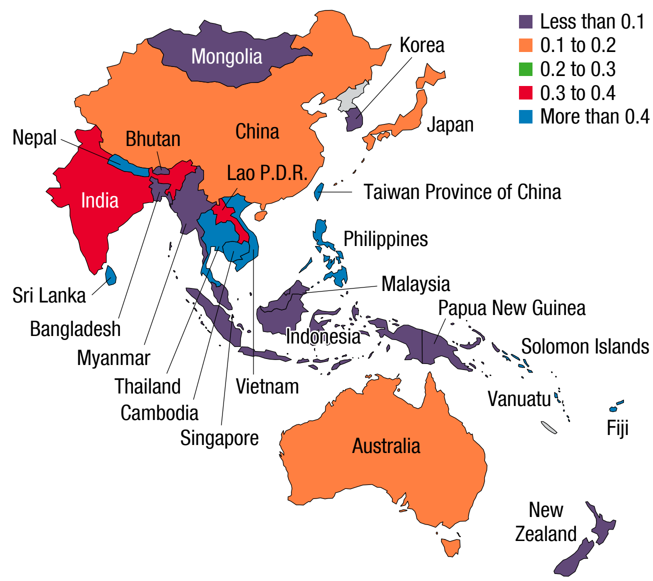
Human-induced warming is accelerating worldwide and particularly in Asia and the Pacific. The pace and scale of global warming is unprecedented and attributable to human-induced GHG emissions and in particular CO_2 (IPCC 2014). Global temperatures have reached 1°C above pre-industrial levels, rising on average by 0.1°C per decade, and the pace has accelerated in recent decades. The 2010s were the warmest decade ever recorded globally, and nine of the 10 warmest years on record have occurred since 2005 (NASA and NOAA 2020). Owing to its large land mass, Asia's temperatures have risen faster than in any other region, two times faster than the world average (Figure 8). They have risen by up to 0.5°C per decade in northern Asia as part of the polar amplification (IPCC 2013). Because oceans are warming

Figure 8. Temperature Anomalies, 1880–2019[1]
(Degrees Celsius)



Source: NOAA – National Centers for Environmental information.
Note: The series are filtered with a Hodrick-Prescott filter (lambda = 6.25). The dotted lines are the linear trend.
[1]Departures from 20th-century temperature average (1910–2000 for Asia).

Figure 9. APD: Damage from Climate-Related Events, 2010–19
(Percent of GDP)

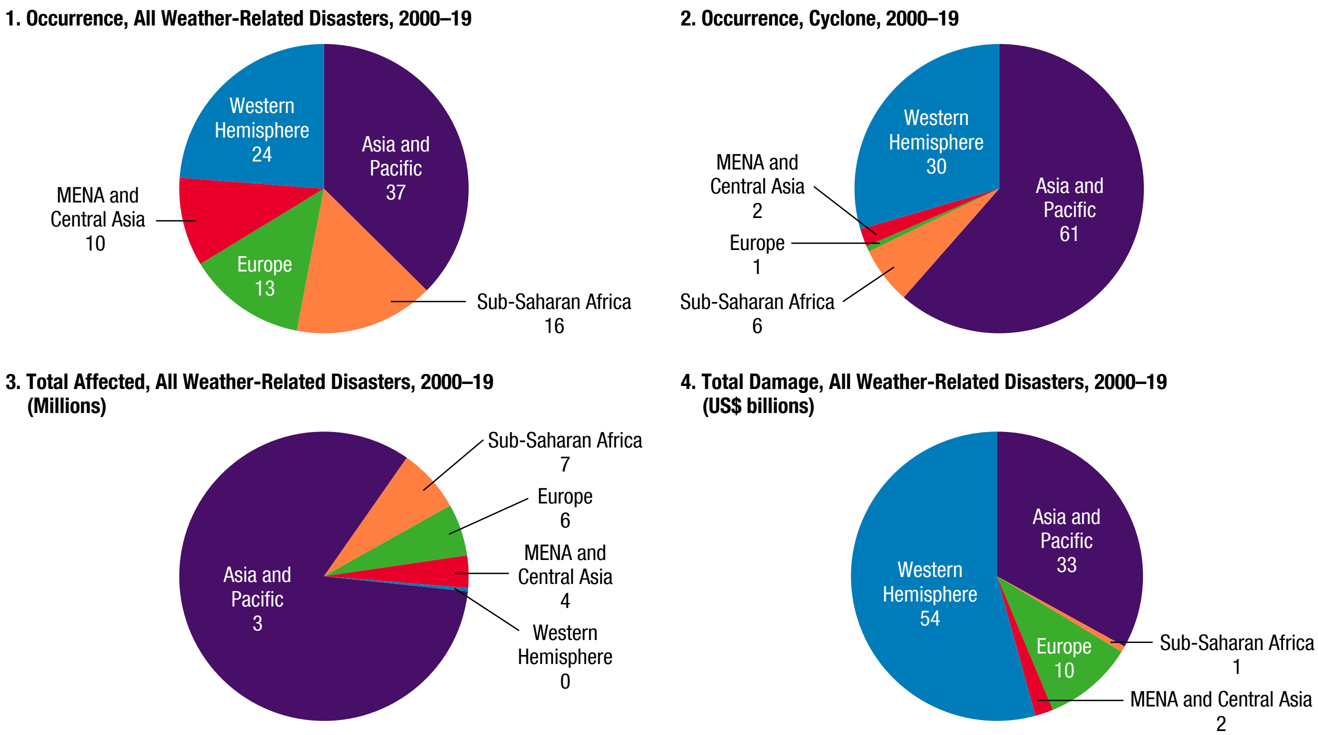


Source: EM-DAT 2020.

at a slower pace than land, temperatures in the Pacific islands have increased more modestly.

Asia and the Pacific are increasingly exposed to weather-related natural disasters. Warmer temperatures have increased the frequency and severity of weather-related natural disasters, with damage estimated at $50 billion annually over 2010–19 in the region. Warmer oceans have also caused tropical storms to gain in intensity and to deviate from their usual trajectories, making them harder to predict. Greater monsoon variability in South and Southeast Asia has led to more extreme rainfalls in some areas, and rainfall deficits and droughts in others. Relatedly, floods and droughts have increased significantly by 150 percent and 50 percent over the four decades, respectively, in Asia and the Pacific (EM-DAT 2020). In 2019 alone, the region experienced a severe heatwave in India that led to water scarcity in some regions; torrential rains in South Asia, causing large-scale population displacement; unprecedented low water levels in the Mekong Delta due to intense dry weather; historic bushfires in Australia and catastrophic fires in Indonesia, fueled by a particularly harsh dry season; and more than 25 typhoons damaging the Pacific and Indian Ocean coasts (Figure 9).

Figure 10. Weather-Related Disasters by Region
(Percent)



Source: EM-DAT 2020.
Note: MENA = Middle East and North Africa.

Asia and the Pacific has suffered more from weather-related disasters than any other region.[1] The region accounts for 37 percent of the total occurrences of such disasters during 2000–19, the highest share among all regions, although it accounts for only 23 percent of the world's land area (Figure 10). Notably, more than 60 percent of cyclones during this period hit Asia and the Pacific. The region has been prone to landslides (accounting for 54 percent of the global occurrences during 2000–19), floods (33 percent), storms (30 percent), heatwaves (30 percent), and droughts (23 percent). As a result, Asia and the Pacific suffered from the highest human cost and significant physical damage. The region is home to 60 percent of the world's population but accounts for 83 percent of people worldwide affected by weather-related

[1]The analysis is based on the EM-DAT database on historical natural disasters (EM-DAT 2020). The database contains disaster data on date, location, disaster type, the number of affected people requiring immediate assistance, and damage to property, crops, and livestock. In this analysis, six types of disasters are identified as weather-related natural disasters: cyclone, storm, flood, landslide, drought, and heatwave. Countries are grouped into five regions: Asia and the Pacific; Europe; Middle East, North Africa, and Central Asia; sub-Saharan Africa; and North, Central, and South America.

disasters and a third of total damage from such disasters over the last two decades. Within Asia and the Pacific, disasters occurred more frequently in large emerging market economies, including China, India, Indonesia, and the Philippines. More than 3 billion people in the region have been affected by disasters over the last two decades, with China and India accounting for 86 percent of this total. Asia and the Pacific is also home to many Pacific island countries, which are prone to intense weather events such as cyclones, droughts, and flooding.

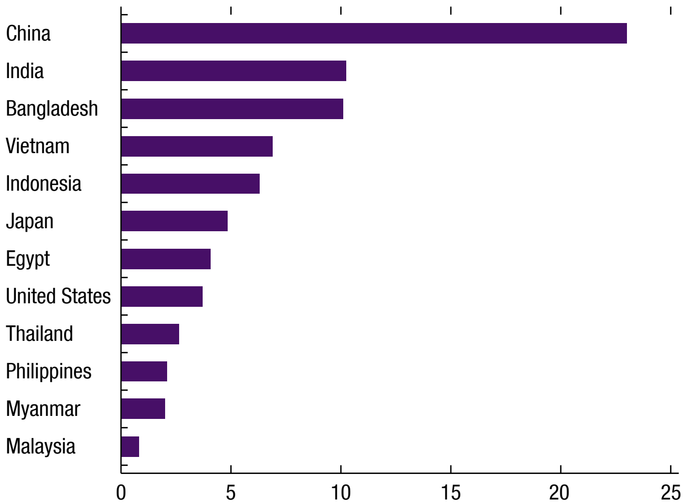
Rising sea levels are another threat for Asia and the Pacific. Warmer temperatures are causing thermal expansion of oceans and hastening melting of ice sheets and glaciers around the world, causing sea levels to rise. Since 1900, the global mean sea level has risen by about 20 centimeters and, as with temperature, the pace is accelerating (NASA and NOAA 2020). Asia and the Pacific is particularly vulnerable to rising sea levels on several accounts.

- About 13 percent of its population (450 million people) live in low-elevation coastal zones (LECZs; Figure 11).[2] Many of them live in fast-growing urban areas such as Mumbai, Dhaka, Bangkok, Ho Chi Minh City, Jakarta, and Shanghai, and are increasingly prone to flooding episodes. Indonesia has already announced plans to move its capital, as models suggest that by 2050 about 95 percent of North Jakarta will be submerged.
- Rising sea levels could affect fishing and cause erosion of arable land for agricultural production, posing risks to food security. For instance, the low-lying Mekong Delta, where a large share of Vietnam's rice is produced, has been regularly subject to salinization, with thousands of tons of crops destructed in each episode. In Bangladesh, erosion from flooding eats up about 10,000 hectares of land annually, resulting in large population displacement and loss of crops, cattle, habitations, and public infrastructure (World Bank 2016a).
- Small Pacific islands, such as Kiribati, Maldives, Marshall Islands, and Tuvalu, have very low elevation (as low as 2 meters on average) and are increasingly exposed to floods and coastal erosion.

The macroeconomic impact of climate change can be significant. Global warming affects economic growth and output through lower agricultural production, depressed labor productivity, reduced capital accumulation, and poorer human health. The short-term macroeconomic effect is uneven across countries and is found to disproportionately affect countries with relatively high annual average temperature, most of which are developing economies. The 2017 *World Economic Outlook* (IMF 2017) found that a 1°C increase

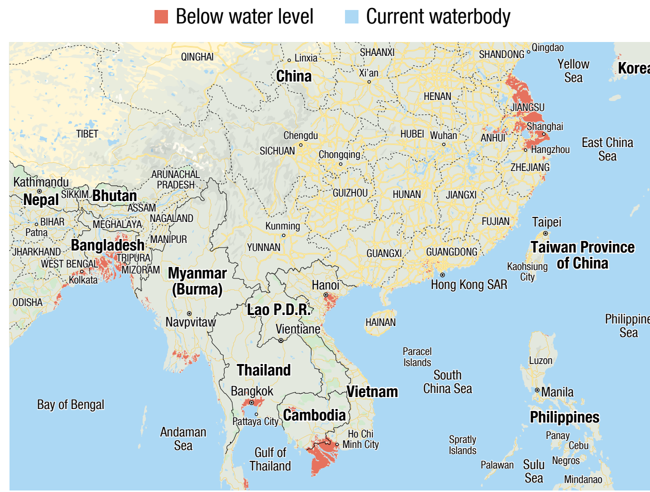
[2]Low-elevation coastal zones are defined in the paper as coastal zone bands ranging from 1- to 10-meter elevation above the sea level.

Figure 11. Low-Elevation Coastal Zone Population, 2000
(Percent of global LECZ population)



Source: Neumann and others (2015).
Note: LECZ = low-elevation coastal zone.

Figure 12. Asia: Land Below One Meter



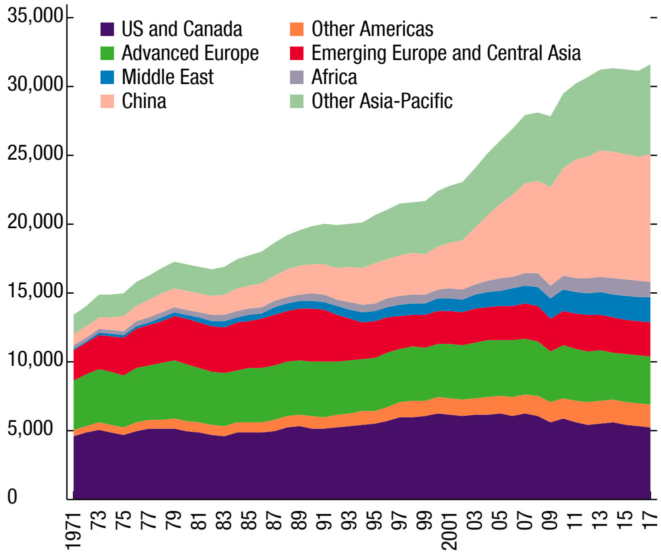
Source: Climate Central, https://www.climatecentral.org/.

in the temperature lowers the same year's growth by 0.9 percentage point in the median emerging market economy and 1.2 percentage points in the median low-income economy.[3] The study also found that the average loss of per capita output is estimated at almost 1 percent seven years after an average cyclone strikes. The per capita output loss is higher for small states, estimated at 2.5 percent.

Climate change and its effects are projected to intensify in Asia and the Pacific. According to the IPCC (2014), under a catastrophic, business-as-usual (BAU) scenario (RPC8.5) where countries fail to reduce GHG emissions, temperatures could increase by 5°C globally on average by 2100, up to 6°C in northern Asia. Consequently, weather-related natural disasters would continue to intensify and cause greater damage to the region. Under this scenario, oceans could rise by more than 1 meter by 2100 and submerge many megacities and small islands in the region (Figure 12). By mid-century, low-elevation urban areas in Asia and the Pacific are projected to be home to about 500 million people and low-elevation rural areas to another 400 million (Neumann and others 2015). The region thus needs to step up its effort to adapt to rising sea levels and more frequent natural disasters, as well as protect people and economic assets.

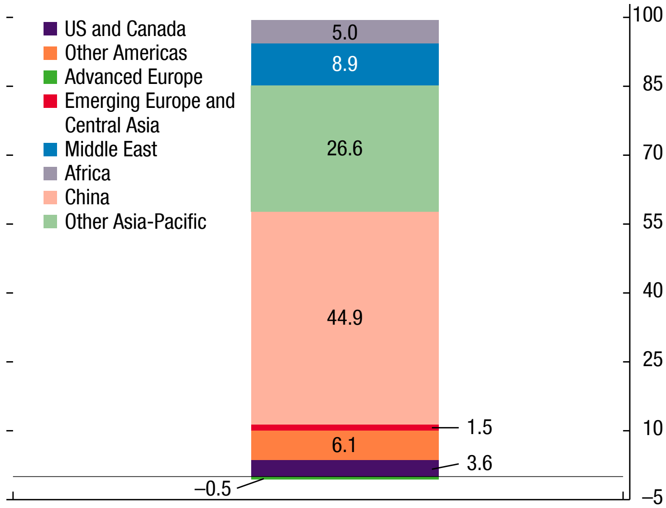
[3]Because of their cold average annual temperatures, Mongolia and areas in China would, in contrary, benefit from a marginal temperature increase until their average annual temperature reaches a 13–15°C threshold.

Figure 13. CO_2 Emissions, 1971–2017
(Million tons CO_2)



Source: International Energy Agency 2020.

Figure 14. Contribution to Growth, 1970–2017
(Percent)



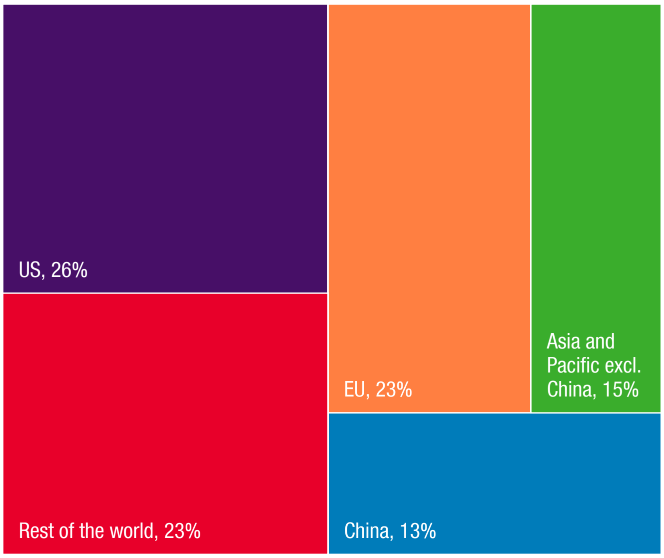
Source: International Energy Agency 2020.

The 2015 Paris Agreement, now ratified by 189 countries, aims to lower GHG emissions to keep global warming below 2°C and to pursue efforts to limit it to 1.5 degrees Celsius 1.5°C. The objective to limit global warming to 1.5°C above pre-industrial levels is meant to prevent dangerous anthropogenic interference with the climate system that could lead to catastrophic and irreversible climate change. Achieving this goal would help slow the rise in sea levels, limit the intensity and frequency of weather-related disasters, and reduce the impact on biodiversity and ecosystems. Risks to health, livelihoods, food security, water supply, human security, and economic growth would also be lowered. As a result, adaptation needs and related costs would be significantly lower than under a higher GHG emissions scenario. However, global emissions continue to rise and the window of opportunity to keep global warming below 2°C is rapidly closing.

CO_2 Emissions and Environmental Degradation in Asia and the Pacific

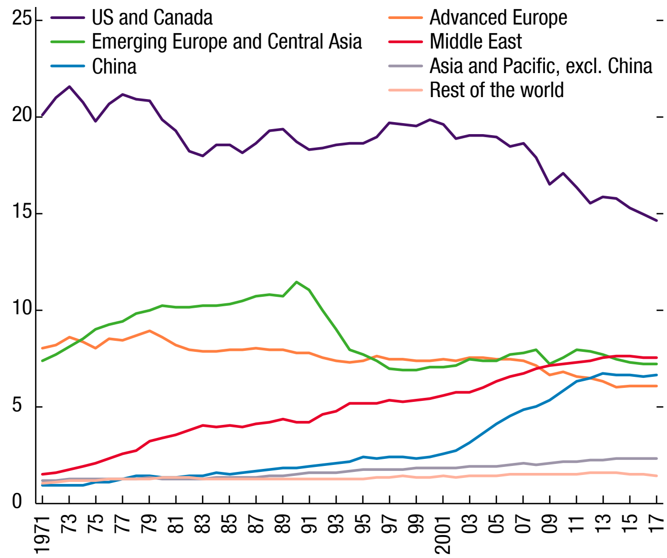
Asia and the Pacific has become the main GHG-emitting region. The region emitted 15.7 billion tons of CO_2 in 2017, equivalent of 48 percent of global emissions (Figures 13 and 14). China's emissions (9.2 billion ton) exceeded those of North America (5.3 billion ton) and advanced Europe (3.5 billion ton) combined. Other than China, Asia also has a number of large CO_2-emitting countries such as India (2.1 billion ton). Since 1970, global

Figure 15. Cumulative CO_2 Emissions, 1971–2017
(Percent of global emissions)



Sources: Carbon Dioxide Information Analysis Center; and the Global Carbon Project.

Figure 16. CO_2 Emissions per Capita, 1971–2017
(Tons of CO_2 per capita)



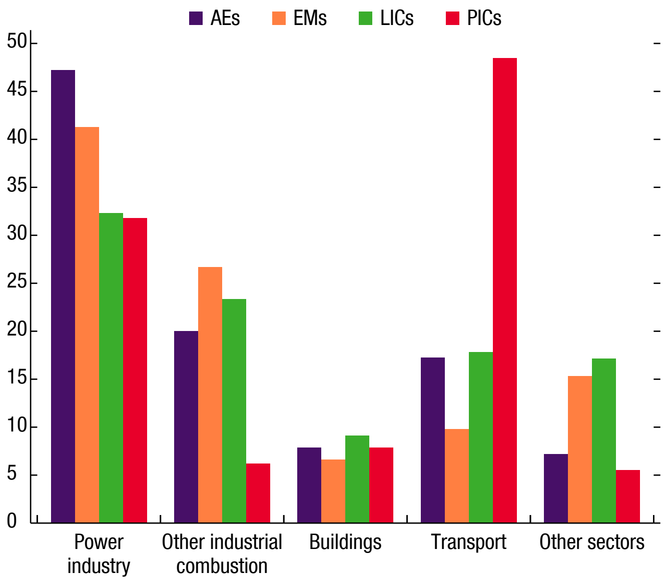
Sources: International Energy Agency; and UN Population Division.

CO_2 emissions have grown by 135 percent with Asia and the Pacific contributing to more than 70 percent of this growth, reflecting the region's rapid economic development and transformation into the world's manufacturing hub. In contrast, emissions growth since 1970 in developing Europe, Central Asia, Latin America, Middle East, and Africa is relatively limited.

Excluding China, the region's cumulative and per capita emissions are very low compared with North America and Europe. Since 1751, the world has cumulatively emitted more than 1.5 trillion tons of CO_2. The United States has emitted more CO_2 than any other country (26 percent of the global cumulative total; see Figure 15). Economies in the European Union are also major contributors, with their combined share in the global cumulative emissions at 23 percent. In Asia and the Pacific, China accounts for 13 percent of the global cumulative total, and the rest of the region for 15 percent. In per capita terms, North America emits much more than any other region (14.7 tons of CO_2) in 2017 (Figure 16). China's per capita emissions (6.7 tons of CO_2) have risen close to that of the EU and the Middle East, while the average for the rest of Asia and the Pacific stands low (2.4 tons of CO_2).

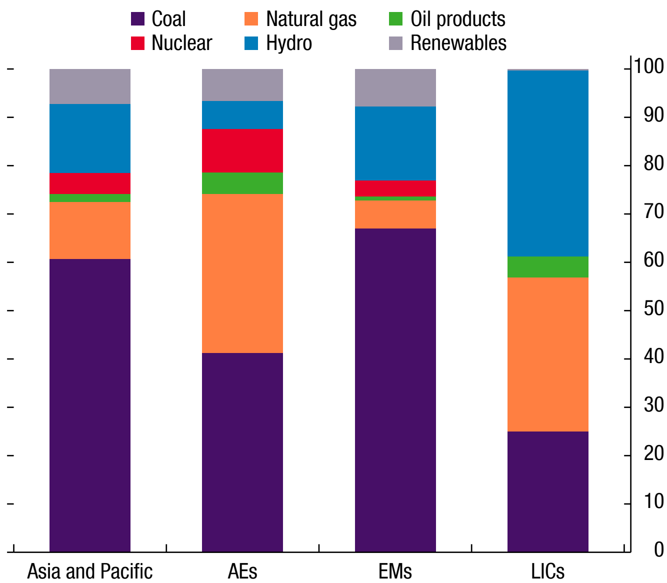
Within Asia and the Pacific, emerging market economies are responsible for three-quarters of the regional emissions, while advanced economies emit much more per capita. China and India are the largest CO_2-emitting coun-

Figure 17. Asia and the Pacific: Fossil CO_2 Emissions per Sector, 2014–2018
(Percent of total)



Source: European Commission – EDGAR Database.
Note: AEs = advanced economies; EMs = emerging markets; LICs = low-income countries; PICs = Pacific island countries.

Figure 18. Asia and the Pacific: Source of Electricity Generation, 2017
(Percent of total)



Source: International Energy Agency 2020.

tries in Asia and the Pacific in absolute terms, accounting for 60 percent and 14 percent of the region's emissions in 2018, respectively. On the other hand, emissions growth has declined steadily in advanced economies in the region over the last three decades, owing to increasing investment in cleaner power generation technology and offshoring manufacturing industries to developing economies. Nonetheless, CO_2 emissions per capita in advanced economies in the region remain 2½ times more than in emerging market economies (five times if excluding China) and 10 times more than in low-income economies and the Pacific islands.

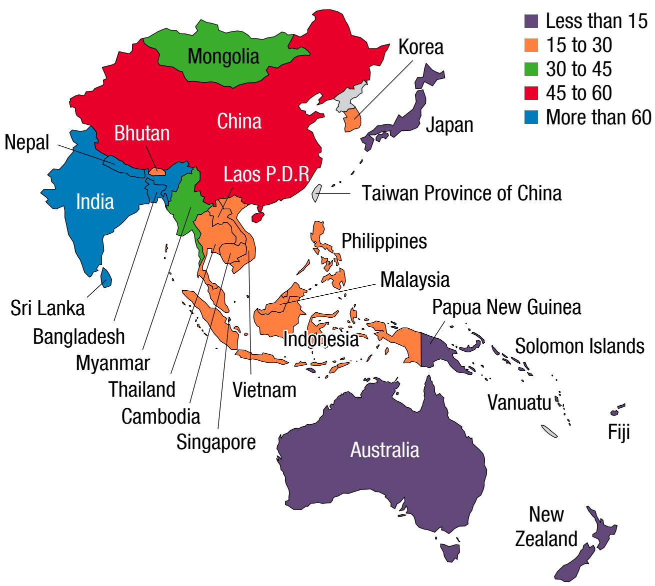
A key to climate change mitigation in Asia and the Pacific is to reduce the use of coal. Except for the Pacific islands, power generation is the most important source of CO_2 emissions in Asia and the Pacific, accounting for more than 40 percent of emissions in advanced and emerging market economies (Figure 17). The region relies heavily on coal-based electricity generation (Figure 18): coal comprises 60 percent of the region's generation mix, higher than the world average of 40 percent, according to IEA (2020). Further, 90 percent of the region's CO_2 emissions from electricity generation originate from coal. Thus, ongoing plans to invest massively in coal-fired power plants do not bode well.[4] In low-income economies in the region, the share of coal in the generation mix remains smaller than hydropower and natural gas but has doubled to a quarter over the last decade, as coal-fired generation capacity grew by 20 percent annually in average, according to IEA (2020). As a bright spot, the share of renewable in the region's energy mix has increased during the last decade, reaching 7 percent in 2017, aided by falling costs. New Zealand is the by far the "greenest" Asian country, with renewable energy (excluding hydropower) accounting for a quarter of electricity production. Australia, Japan, the Philippines, and Thailand have also made significant progress in recent years.

Agriculture is also a prominent source of GHG emissions in the region. Together with related emissions from land use change and forestry, agriculture accounts for nearly 15 percent of the Asia and the Pacific total GHG emissions (FAO 2020). Agricultural activity, including fertilizer application, livestock rearing, and land management produced about 3.7 billion tons of CO_2 equivalent in the region in 2017, corresponding to 48 percent of world emissions in the agricultural sector. Climate change is expected to lead to the deterioration of crop yield in most areas of the region, with subsequent impacts on food prices, trade, and food security disproportionately affecting the vulnerable (Rosegrant 2010). Aligning growing demand for agricultural products with sustainable and emissions-saving development paths will prove challenging. For economies where large amount of GHG emission originates from agriculture and land use, in addition to measures such as soil carbon sequestration, rice cultivation, and grazing land management, consideration could be given to imposing taxes on heads of cattle, fertilizer inputs, and profits for farming from deforestation, together with assessing and alleviating the impact on the vulnerable groups.

Air pollution has become a major problem for many developing economies in the region. In addition to causing global warming, GHG emissions from power generation (especially coal-based), industries, road vehicles, agriculture, and domestic cooking and heating have contributed to harmful levels of pollution in most large cities in developing Asia (Figure 19). Notably, Delhi, Dhaka, Ulaanbaatar, Kathmandu, Beijing and Jakarta are among the top 10 most-polluted cities in the world (as of 2018). Air pollution is estimated to cause more than 3 million premature deaths in Asia and the Pacific every year, accounting for two-thirds of the global total (GAHP 2019). Developing economies in East and South Asia have the highest casualties per 100,000 people from air pollution in the world; in these economies, air pollution accounts for 14 percent of mortality (World Bank 2016b). Air pollution is estimated to cause annual labor income losses through premature death

[4] At the start of 2020, more than 350 gigawatts (GW) of coal-fired capacity were in the planning phase in the region, including 180 GW in China, 100 GW in India, and 95 GW in Southeast Asia.

Figure 19. Asia and the Pacific: Mean PM2.5 Annual Exposure, 2017
(μg/m³)



Source: World Development Indicators (2020).

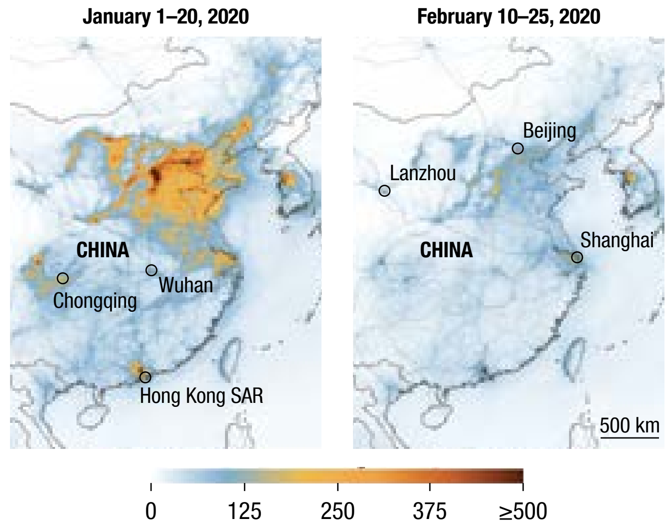
amounting to nearly 1 percent of GDP in developing economies in South Asia and 0.25 percent in East Asia. Welfare losses from air pollution are estimated to be about 7½ percent of GDP in developing economies in the region. As such, reducing air pollution can have large positive effects. For instance, implementing a carbon or coal tax in China progressively to reach $70 per tons could save an estimated 3 million lives from lower pollution by 2030, while raising more than 3 percent of GDP in revenue and enabling the country to meet its Paris Agreement pledge (Parry and others 2016).

Climate Change and the COVID-19 Pandemic

There are intrinsic links between the pandemic and climate change. First, the risk of pandemics has increased with environmental degradation. The loss of animal habitat, for instance due to deforestation or wildfires, and the decline of biodiversity create more opportunities for pathogens to enter new hosts and increases the likelihood of transmission to humans. Second, exposure to air pollution is found to increase COVID-19 mortality (Wu and others 2020). Third, as disasters become more frequent and severe, they facilitate the spread of the pandemic given the damage done to physical infrastructure, food, and water safety and by causing people to congregate in common places following disasters. Hence, pandemics with more-deadly impacts are likely to become more frequent in the future if climate change continues on its current path. Finally, the pandemic may help policymakers focus on challenges from the natural world, possibly making them more receptive to the idea of acting on climate change.

The pandemic has caused a sudden but temporary drop in GHG emissions. The near-halting of global activity from stringent containment measures to limit the spread of the virus is estimated to have reduced daily GHG emissions by nearly 20 percent (Le Quéré and others 2020). This decline, unprecedented since the beginning of the industrialized era, led to a string of positive developments. The decline in CO_2 and particulate matter 2.5 is

Figure 20. China: Mean Tropospheric NO2 Density
(μmol/m²)



Source: NASA (2020).

estimated to have saved nearly 80,000 lives in China alone, in just two months (Burke 2020) (Figure 20). Earth Overshoot Day—the day when humanity has exhausted the year's quota of natural resources—was pushed back by 3 weeks to August 22. The overall 2020 decrease of emissions is projected to be from –4 to –8 percent compared to 2019 (Le Quéré and others 2020). However, the decline is expected to be temporary and the impact on the stock of CO_2 in the atmosphere trivial, given the magnitude of the problem.

Chapter

2 How to Accelerate Mitigation Efforts in Asia and the Pacific

Carbon taxes are a highly effective but little-used tool for reducing fossil fuel CO_2 emissions in Asia and the Pacific, as they allow firms and households to find the lowest-cost ways of reducing energy use and shifting toward cleaner alternatives. Implementation can be gradual and tailored to country circumstances. The illustrative simulations here show that gradually implementing a carbon tax of $25 per ton over the next decade would reduce the region's emissions by 21 percent by 2030, overperforming its Paris Agreement targets on an aggregate basis, while generating additional revenue of about 0.8 percent of GDP per country. Limiting global warming to 2 degrees or less, however, would likely require a significantly higher carbon tax. While non-tax mitigation measures, such as ETSs, feebates, and regulation, are less effective at reducing CO_2 emissions and would therefore constitute only a second-best approach for advancing mitigation efforts, they can usefully complement carbon taxes. The prospective imposition of border carbon adjustments by advanced economies outside the region enhances the case for countries in Asia and the Pacific to introduce their own carbon tax.

How Has Asia Tackled Climate Change Mitigation?

Countries in the region have adopted a range of mitigation measures in recent years to address climate change.[1] Practically all countries have made commitments under the Paris agreement on climate change in 2016.[2] Recently major emitters in the region have stepped up their commitments and intervention. For example, China has vowed to be carbon neutral (net

[1]Because of data constraints, this chapter focuses on CO_2 emissions, which account for nearly 80 percent of Asia's GHG emissions. Emissions from forestry, methane from fossil fuel fields, F-gases (for example, from refrigerants), livestock emissions, and other gases currently account for more than 20 percent of GHG emissions. Mitigation policies for these different types of emissions should be more tailored and specific. For example, a tax on clinker (used for cement production) or F-gases and methane can help reduce the emission from these sources, and feebates can be used to encourage more efficient and environment-friendly technology.

[2]See Annex 1 for more details on the Paris Agreement pledges by countries in Asia and the Pacific.

Table 1. Carbon Tax and Emissions Trading Systems in Asia and the Pacific

Country	Initiative	Type	Status	Coverage	Year	GHG Emissions ($MtCO_2e$)	Global Share (percent)
China	China national ETS	ETS	Scheduled	National	2021	3453	6.37
	Beijing pilot ETS	ETS	Implemented	Subnational	2013	85	0.16
	Chongqing pilot ETS	ETS	Implemented	Subnational	2014	122	0.22
	Fujian pilot ETS	ETS	Implemented	Subnational	2016	200	0.37
	Guangdong pilot ETS	ETS	Implemented	Subnational	2013	366	0.68
	Hubei pilot ETS	ETS	Implemented	Subnational	2014	208	0.38
	Shanghai pilot ETS	ETS	Implemented	Subnational	2013	170	0.31
	Shenzhen pilot ETS	ETS	Implemented	Subnational	2013	61	0.11
	Tianjin pilot ETS	ETS	Implemented	Subnational	2013	118	0.22
Indonesia	Indonesia ETS	ETS	Under consideration	National	TBC		
Japan	Japan carbon tax	Carbon tax	Implemented	National	2012	909	1.68
	Japan ETS	ETS	Under consideration	National	TBC		
	Saitama ETS	ETS	Implemented	Subnational	2011	7	0.01
	Tokyo CaT	ETS	Implemented	Subnational	2010	13	0.02
Korea	Korea ETS	ETS	Implemented	National	2015	489	0.90
New Zealand	New Zealand ETS	ETS	Implemented	National	2008	45	0.08
Singapore	Singapore carbon tax	Carbon tax	Implemented	National	2019	45	0.08
Thailand	Thailand undecided	Undecided	Under consideration	National	TBC		
Vietnam	Vietnam ETS	ETS	Under consideration	National	TBC		
Total						**6292**	**11.61**

Source: World Bank Carbon Pricing Dashboard, August 2020.
Note: ETS = emissions trading system; TBC = ???.

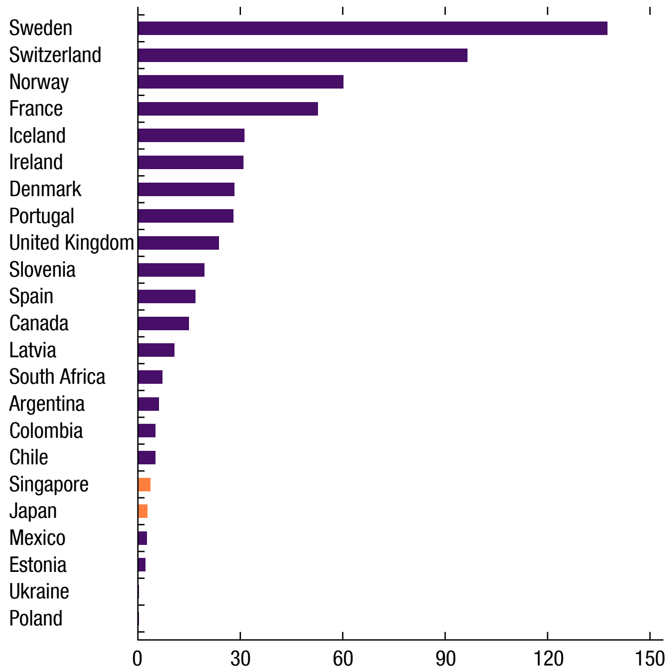
zero emissions)[3] by 2060, followed by Japan and Korea who pledged the same goal by 2050. A few countries including Mongolia, Nepal, Thailand, and Vietnam, have recently submitted updates of their targets. India doubled the coal tax in July 2020. Japan and Singapore have implemented carbon taxes. Several countries have introduced emissions trading systems (ETS), under which firms can trade their allowances for CO_2 emissions at market prices and the government sets a ceiling on total allowances or emissions. These measures cover about 12 percent of total global greenhouse emissions (Table 1). In addition to these market-based tools, other measures implemented in the region include feebates and regulations on air quality, fuel quality, and vehicle emission standards, as well as incentives to encourage investments and shift to clean technology and alternative energies.

A carbon tax is implemented only in Japan and Singapore. Carbon taxes and other similar arrangements to increase the price of carbon are considered as the most effective tool to reduce CO_2 emissions.[4] The tax is charged on the carbon content of fossil fuels and other GHG emissions, allowing firms and households to find the lowest-cost ways of reducing energy use and shifting toward cleaner alternatives (IMF 2019d; see Box 1). Allowing energy prices to reflect supply and environmental costs and ensuring a credible increase

[3]Carbon neutrality refers to achieving net-zero CO_2 emissions by absorbing carbon dioxide emissions with reduction measures or simply eliminating CO_2 emissions altogether.

[4]In this chapter, the effectiveness of a mitigation measure is measured by its capacity to reduce CO_2 emissions. More specifically, measures can be compared for the same (explicit or implicit) CO_2 price and differ by the range of mitigation responses they promote (IMF 2019c).

Figure 21. Carbon Taxes in Selected Countries
(US dollars per ton of CO_2 emissions)



Source: World Bank Carbon Pricing Dashboard, November 2020.

in carbon prices, the tax can promote investment in clean technologies and a green recovery from the COVID-19 pandemic. The tax is easy to administer in countries with an established fuel tax system and generates additional and predictable fiscal revenue. However, the political sensitivity of higher energy prices could hamper its introduction in some countries (see Chapter 3 for discussion on how to compensate vulnerable households and firms). Japan started a carbon tax in 2012 and currently charges US$3 per ton of CO_2 emission, and Singapore adopted a carbon tax in 2019 at the level of US$4 per ton of CO_2 equivalent.[5] The headline tax rates and revenues are relatively low compared to other countries that have implemented the carbon tax (Figure 21), suggesting room for increasing.

ETSs, an alternative measure more widely used in Asia and the Pacific, could be made more effective. An ETS can work as effectively as a carbon tax if the coverage is comprehensive with no free allowances (see Box 1). In practice, however, ETSs are usually limited to power generators and large industries and do not cover emissions from the use of vehicles and buildings or by small enterprises. Because of this, ETSs typically cover about half of national emissions (IMF 2019c). ETSs could be easier to implement than a carbon tax with lower political resistance (for example, because their impact on energy costs can be lower and less visible), but their revenue and emissions impact might be limited due to free allowances, narrower coverage and uncertain effects on energy prices. In addition, administration of ETSs would

[5]Singapore will review the carbon tax rate by 2023 and intends to double or triple it by 2030.

also require new capacity to monitor the allowance-trading market and report emissions, which might not be practical for capacity-constrained countries. Among the countries in the region, China, Japan, Korea, and New Zealand have adopted ETSs at either national or subnational levels, while Indonesia and Vietnam are considering adopting them.[6] The shortcomings of the ETSs could be overcome by extending coverage, for example, to small-scale users; introducing minimum auction prices to promote price stability; and fully auctioning allowances with revenues remitted to finance ministries (IMF 2020d).

Feebates and regulations are less effective and forego potential revenue but can complement mitigation efforts. Feebates impose a sliding scale of fees or rebates for particular products and activities above or below certain emission rates, such as standards for the emission rates of vehicles and power generators. As an example of a feebate, Singapore introduced the Carbon Emissions-Based Vehicle Scheme (CEVS) in 2013 and replaced it in 2018 with the Vehicular Emission Scheme (VES). It will be enhanced in 2021 with higher rebates for clean vehicles and also higher fees for high emission vehicles, together with a new Electric Vehicle Early Adoption Incentive (EEAI).[7] Many countries in the region have regulations on emission standards for vehicles such as nonroad engines, motorcycles, light duty and heavy duty vehicles (for example, China, India, Indonesia, Japan, Korea, Thailand, and Vietnam), fuel quality standards for diesel and gasoline (for example, Australia, China, India, Indonesia and Japan), and air quality standards (for example, China, India, Japan, and Korea). Feebates and regulations have more limited mitigation impact due to targeted products or activities and are usually revenue neutral, but they avoid raising energy prices significantly. In addition, feebates can lead to a transparent energy pricing plan for the years ahead, improving energy price predictability and fostering investment in green energy (IMF 2019d). They can be complementary to more comprehensive market instruments for mitigation purposes.

Mitigation measures can be packaged to meet different policy objectives and implementation challenges. In practice, a combination of mitigation measures is often adopted in the region. For example, Singapore has both a carbon tax and a feebate system, together with a fuel excise tax for the transport sector, and Japan has both a carbon tax and regional ETSs, while China, Korea and New Zealand have regulations on air quality and fuel standards to complement their ETS systems. The mix of measures depends on implementation challenges and specific policy objectives that take into account development

[6]See Annex 2 for descriptions of ETSs in China, Korea, and New Zealand.

[7]The enhanced VES will increase the rebates and fees from SGD20,000 to SGD25,000 for cars and from SGD30,000 to SGD37,500 for taxis. Under the EEAI, buyers of fully electric cars and taxis will receive a rebate of up to 45 percent on the Additional Registration Fee, capped at SGD20,000.

goals, institutional constraints, revenue impact, technical and implementation capacity and political economy factors. For example, if reducing emissions in the transportation sector requires prohibitive tax rates, a lower carbon tax together with feebates can provide incentives for shifting to low-emission vehicles without overburdening average users. In countries where only ETSs are in place, feebates can be considered to enhance the mitigation impact in some targeted sectors. In cases where political economy considerations make a carbon tax difficult to implement, options such as lower carbon taxes or ETS with broader coverage together with more forceful feebates or regulations could be considered. The introduction of a carbon tax should be well communicated in advance and implemented gradually to allow necessary adjustment by households and businesses, with accompanying measures to alleviate the impacts especially for the vulnerable groups (see Chapter 3).

Asia and the Pacific could usefully contribute toward collective global actions for mitigation. The prospective imposition of border carbon adjustments (BCAs) by the European Union[8] and potentially other major advanced economies enhances the case for countries in Asia and the Pacific to introduce their own carbon tax. BCAs are import fees levied by carbon-taxing countries on goods manufactured in non (or inadequate) carbon-taxing countries. By imposing their own carbon taxes, countries in the region would reduce, or eliminate, BCAs on their exports and allow them to keep the revenue themselves. To boost the global mitigation effort and prevent their own mitigation efforts being undermined, the main emitters in Asia and the Pacific should coordinate with other key global emitters to agree an international carbon price floor (IMF 2019d).

How Much Mitigation Effort Is Needed?

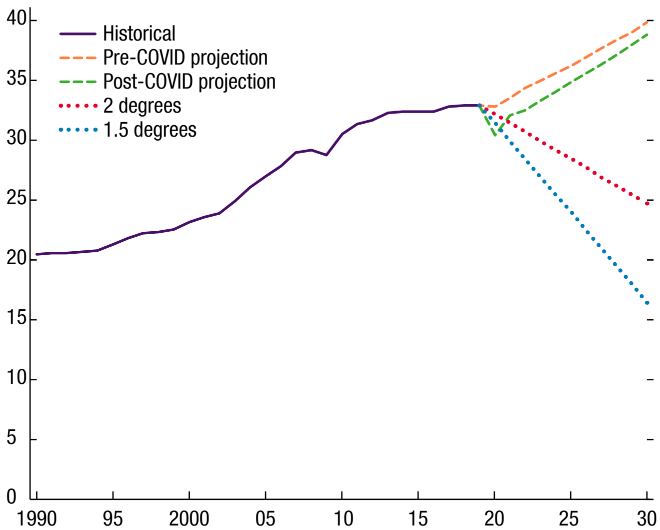
We analyze quantitatively the effectiveness of carbon taxes in reducing long-term emissions in Asia and the Pacific. We follow IMF (2019c) to estimate the mitigation efforts needed to deliver emission reductions in the region.[9] The model generates emission projections for 22 economies in Asia and the Pacific under both baseline scenarios (business as usual, or BAU) and various mitigation scenarios.

- To produce forecasts of future energy consumption and emissions, the model makes assumptions about future growth, future energy prices,

[8]The European Commission developed the European Green Deal, a roadmap to achieve the goal of being the first climate-neutral continent by 2050. It covers policies in seven areas including clean energy, sustainable industry, building and renovation, farm to fork, eliminating pollution, sustainable mobility, and biodiversity. The Green Deal proposed BCAs to counteract carbon leakage.

[9]For details on the methodology, see IMF (2019c) and Annex 3.

Figure 22. Global Fossil Fuel CO_2 Emissions, 1990–2030
(Billion of tons)



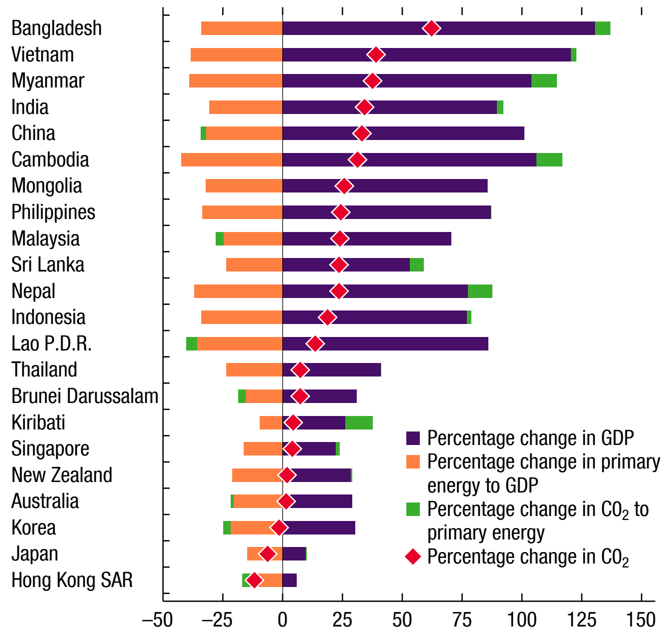
Sources: International Energy Agency (2020); and IMF staff calculations.
Note: 2 (1.5) degrees refers to the emissions that will keep a global temperature rise below 2 (1.5) degrees Celsius above the pre-industrial levels.

income elasticity for energy products and technological changes. The assumptions of behavioral responses to higher energy prices and the transition to low-carbon technology could be highly uncertain given current low energy prices. These uncertainties should be kept in mind when interpreting the results.

- We estimate (1) carbon tax rates that would meet a country's commitment under the Paris Agreement and (2) the amount of emissions in a country that can be reduced in 2030 against the BAU scenario with carbon tax rates of $25, $50, and $75 per ton. The carbon tax level is assumed to be reached only gradually in 10 years. The IMF staff estimated that the $75 tax would lead to the amount of emissions that scientists estimate is consistent with 2 degrees Celsius warming (IMF 2019d).
- The BAU estimates include the potential impact from the COVID-19 pandemic, which causes a drop in emissions, some of which would persist over the long term. However, emissions will still rise considerably over the coming decades and does not change the long-term climate change challenges (Figure 22).

Without a step-up in mitigation efforts, CO_2 emission growth will concentrate in the largest and fastest-growing emerging economies, driven by GDP growth. Under the BAU scenario, Bangladesh will see emissions increase by more than 60 percent between 2017 and 2030, while Cambodia, China, India, Myanmar, and Vietnam will increase their emissions by more than 30 percent, mainly driven by fast economic growth (Figure 23). Advanced economies such as Australia, Hong Kong SAR, Japan, Korea, New Zealand, and Singapore will see emissions drop or grow minimally. China and India will remain the largest CO_2-emitting countries in the region, accounting for more than 80 percent of the region's emissions in 2030. Australia, Brunei, and Korea will have the highest per capita CO_2 emissions in 2030. In terms of emission intensity, measured by emissions per GDP, China, India, and Mongolia will be the highest, followed by Brunei, Malaysia, and Vietnam.

Figure 23. Baseline CO_2 Emission Change
(Percentage change from 2017 to 2030)



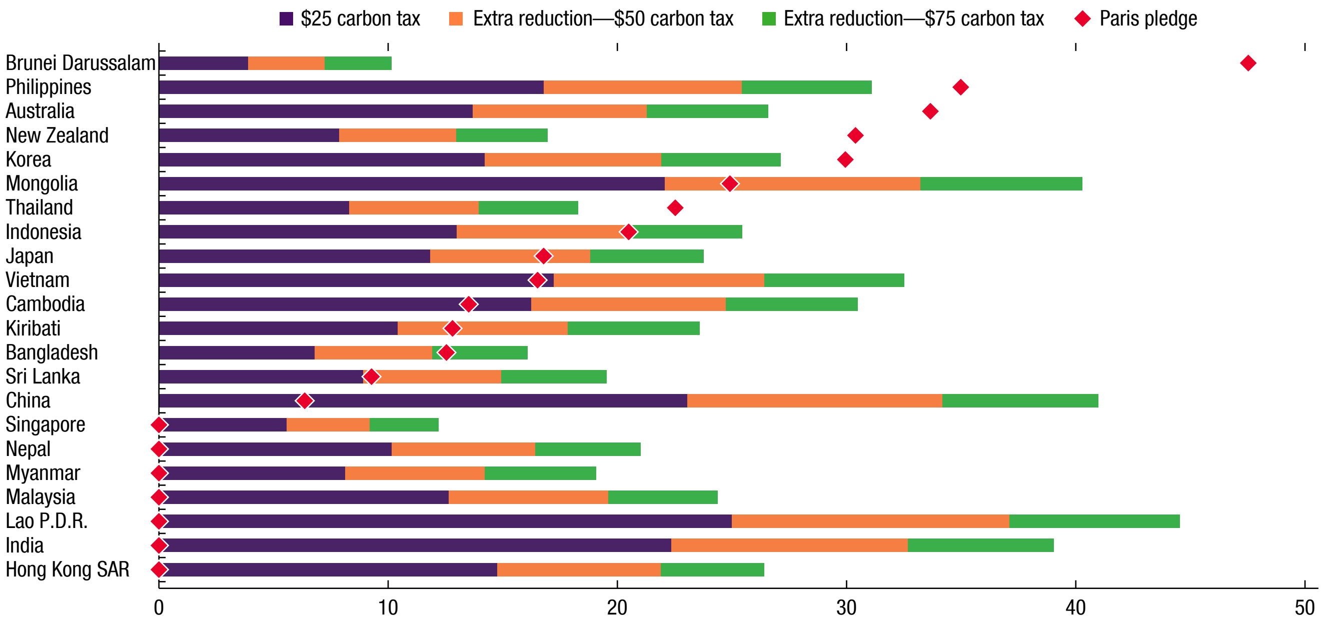
Source: IMF staff calculations.

Mitigation efforts committed under the Paris Agreement imply uneven emission reduction targets and a relatively modest emission reduction for the region as a whole. Commitments under the Paris pledges vary in terms of target variables, baseline years, the size of reductions and whether they are conditional on financing or not. Taking these into account, we project long-term emissions under the Paris pledge scenario. Our estimates suggest that a few countries have committed to reduce emissions by more than 30 percent in 2030 vis-à-vis the BAU scenario (Australia, Brunei, Korea, New Zealand, Philippines). On the other hand, China and Sri Lanka have committed to less than 10 percent of reduction in 2030 against the BAU scenario. Aggregating over the 22 countries, the region's emissions under the Paris pledge scenario in 2030 are 8 percent lower than in the BAU scenario. Advanced economies in the region committed to reduce 23 percent, while emerging market economies and developing countries committed to reduce 6 percent.

Simulation exercises with a carbon tax as the main mitigation tool indicate a wide range of tax rates to achieve Paris pledges. For countries with relatively high-emission reduction targets, a carbon tax of more than $75 per ton of CO_2 emission would be needed, assuming that the carbon tax is the only instrument used. For countries with lower reduction targets such as China, a modest carbon tax of less than $10 per ton of CO_2 will be sufficient. For most of the remaining countries, the carbon tax rate needed to meet their Paris pledges ranges from $10 to $75. The dispersion of the needed carbon tax rates mainly reflects underlying cross-country differences in commitment

Figure 24. CO_2 Reduction with Carbon Taxes

(Percent before 2030 BAU)



Source: IMF staff calculations.

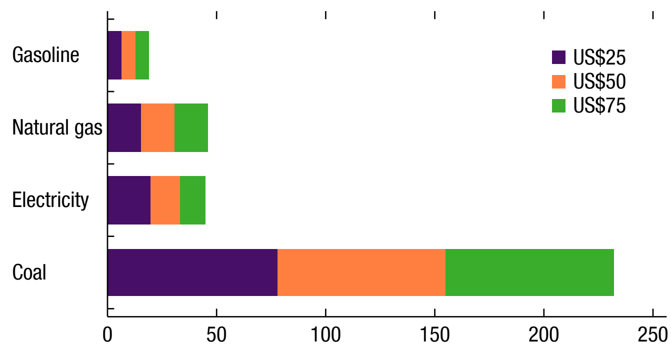
Note: Countries with zero emission-reduction target from the Paris Agreement climate pledge are assumed to be able to achieve the target in the business-as-usual scenario. Paris pledges reflect newly submitted proposals and updates by October 2020.

levels and energy sources,[10] which calls for stronger international coordination in mitigation targets across the region.

Large emitters could make a substantial contribution to global emission reduction with even a relatively modest carbon tax of $25 per ton. Although most countries in the region would need a carbon tax of at least $30 per ton to achieve their Paris pledge goals, with a carbon tax of $25 per ton, 10 countries will meet their Paris mitigation targets, and total CO_2 emission will be reduced by 21 percent for the 22 countries in the region, higher than the estimated reduction under the Paris pledges (Figure 24). This is mainly attributed to the higher than committed reduction from the largest emitters including China (23 percent) and India (22 percent). However, more would need to be done to meet long-term objectives to limit global warming. IMF (2019d) points out that limiting global warming to 2 degrees Centigrade or less requires policy measures on an ambitious scale such as an immediate global carbon tax that will rise rapidly to $75 per ton of CO_2 in 2030. Assuming that the 22 countries introduce a carbon tax of $50 and $75 per ton, regional emissions would decrease by 31 and 37 percent, respectively.

[10]The dispersion also reflects differences in the share of coal, oil, and natural gas in emissions, which lead to differences in the responsiveness of emissions to prices.

Figure 25. Impact of Carbon Tax on Energy Prices, 2030
(Percent increase from the BAU scenario)



Source: IMF staff calculations.
Note: BAU = business as usual.

Carbon taxes will make energy more expensive and particularly for products with a high carbon content such as coal. With a carbon tax of $25, the price of coal will increase by an average of 77 percent in the region, while the increase is relatively small for gasoline at 6 percent, and for natural gas at 15 percent (Figure 25). Carbon taxes of $50 and $75 per ton imply a substantial increase in prices for coal, electricity, and natural gas, while the price of gasoline only goes up moderately by 13 to 19 percent.[11] This said, the price impact of carbon taxes would vary by country, depending on the energy mix and energy price levels. For example, gasoline price increases are disproportionately high in Brunei, Cambodia, and Indonesia, while electricity price increases are relatively low in Myanmar, Nepal, and New Zealand.

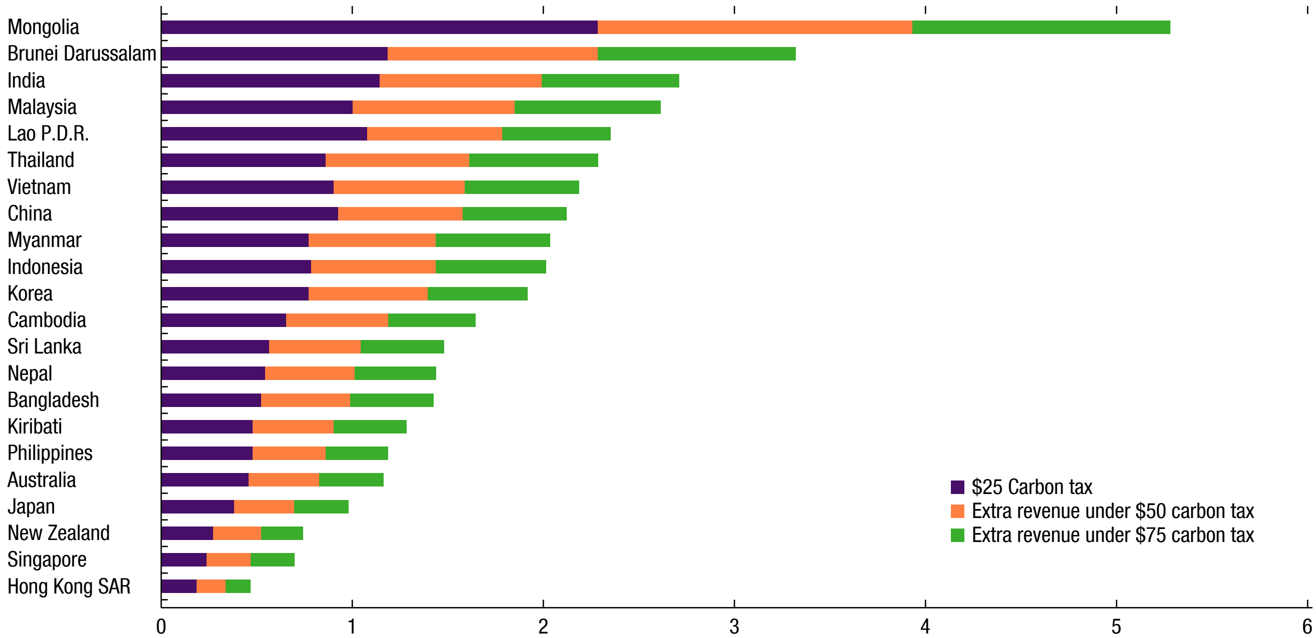
Carbon taxes can also mobilize additional fiscal revenue. At $25 per ton of CO_2, additional revenue from a carbon tax is estimated to be 0.8 percent of GDP, on average, in the region (Figure 26).[12] The additional revenue is 1.4 percent of GDP for a tax rate of $50, and 1.9 percent of GDP for $75. The marginal gain from higher tax rates declines due to erosion of the tax base caused by higher energy prices. The revenue from carbon taxes can, in turn, be used for compensating for those affected negatively by carbon taxes (see Chapter 3); financing priority spending including health, education, infrastructure, green investment, and adaptation spending; and reducing distortionary taxes that reduce incentives to work and invest.

Targeted measures to address country-specific emission challenges, focusing on coal usage and power generation, can also be effective in Asia and the Pacific. Although narrower mitigation measures are less effective compared to the carbon tax (see Table 2—for example, ETSs are 40–70 percent as effective

[11]The lower price increase for gasoline is mainly due to its relatively lower carbon content and relatively higher baseline price.

[12]Introduction of a carbon tax reduces the base of pre-existing fuel taxes and hence imply loss of revenues for the latter. The revenue estimate presented here shows net revenue gains (that is, revenue from a carbon tax net of the revenue loss for the pre-existing fuel tax).

Figure 26. Fiscal Revenue from Carbon Taxes
(Percent of GDP)



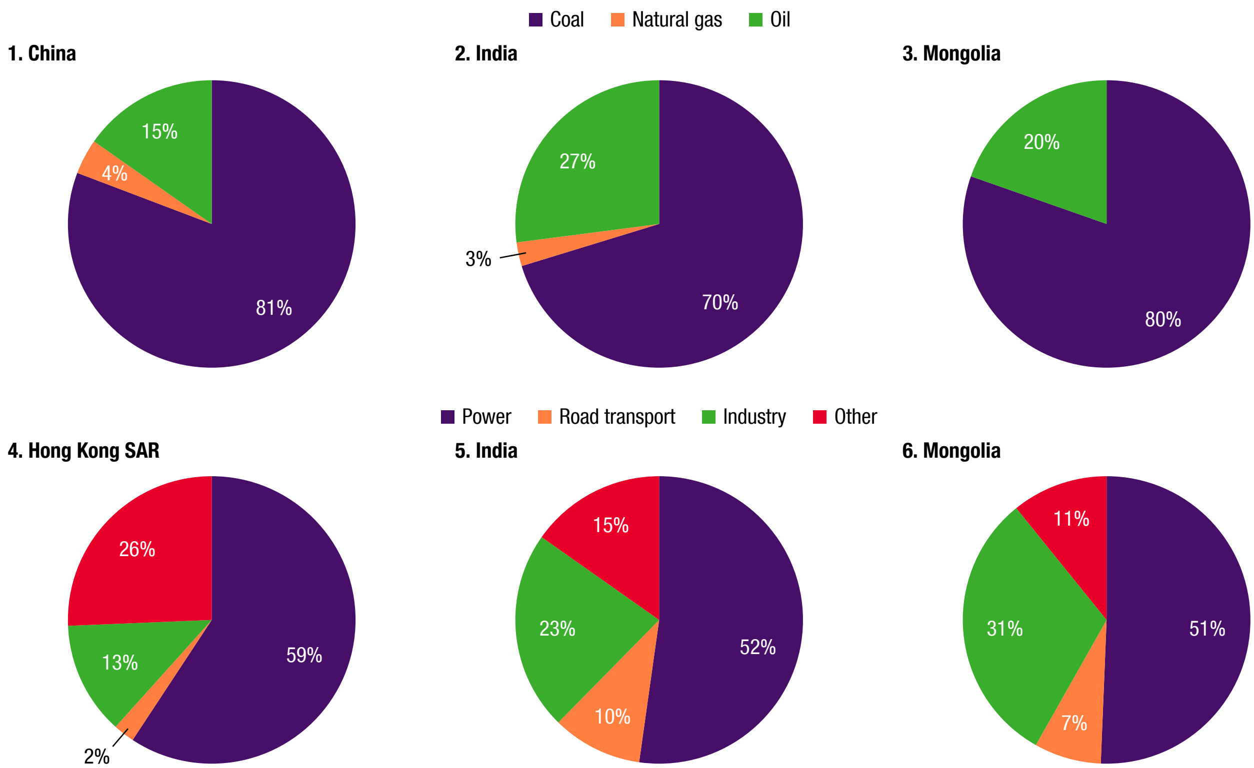
Source: IMF staff calculations.

Table 2. CO_2 Reduction from Alternative Mitigation Instruments
(Fraction of CO_2 reductions from a carbon tax at US$70 per ton)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO_2 Tax	Road Fuel Taxes
Australia	0.77	0.83	0.36	0.84	0.03
Bangladesh	0.19	0.59	0.27	0.51	0.03
Brunei Darussalam	0.00	0.31	0.29	0.30	0.11
Cambodia	0.67	0.71	0.16	0.70	0.17
China	0.95	0.79	0.20	0.73	0.01
Hong Kong SAR	0.92	0.93	0.57	0.89	0.00
India	0.94	0.87	0.30	0.83	0.01
Indonesia	0.68	0.72	0.27	0.68	0.12
Japan	0.69	0.67	0.26	0.63	0.02
Korea	0.81	0.71	0.21	0.68	0.01
Malaysia	0.71	0.77	0.31	0.74	0.08
Mongolia	0.95	0.85	0.36	0.84	0.01
Myanmar	0.15	0.57	0.07	0.52	0.04
Nepal	0.65	0.49	0.00	0.33	0.16
New Zealand	0.44	0.43	0.01	0.35	0.11
Philippines	0.82	0.85	0.24	0.81	0.05
Singapore	0.14	0.84	0.57	0.79	0.00
Sri Lanka	0.66	0.71	0.23	0.70	0.12
Thailand	0.46	0.58	0.21	0.52	0.03
Vietnam	0.86	0.85	0.15	0.71	0.03

Source: IMF 2019c.
Note: Alternative policies assume the same CO_2 price on emissions affected by the policy. Electricity CO_2 tax is carbon tax on electricity production. Road fuel taxes on fuels used to power motor vehicles on roads and highways. ETS = emissions trading system.

Figure 27. CO_2 Emission by Energy Source and Sector, 2017



Source: IMF staff calculations.

as their coverage is limited mostly to power generation and large industries), understanding the main emission sources would help identify more tailored and effective mitigation tools.

- For coal-intensive countries in the region, such as China, India, and Mongolia, where 70–80 percent of emission comes from coal (Figure 27), a specific tax on coal produced or consumed at an equivalent carbon tax rate can achieve an emission reduction of about 95 percent as much as in the case of a carbon tax. In countries where coal companies are state owned, this tax should also be coordinated with other state-owned enterprise reforms to reduce fiscal risks. In India, while a coal tax was enacted in 2010, increasing the effectiveness of this tax would require reform of subsidies for coal production and usage in power generation (Agarwal and others forthcoming).
- For economies in which emissions originate mainly from power generation rather than industry and road transport sectors—such as Hong Kong SAR, India, and Mongolia where power generation accounts for 50–60 percent of total emissions (Figure 27)—a carbon tax on power sector emissions can achieve an emission reduction of 80–90 percent as much as a full carbon tax.

Box 1. Carbon Pricing, Carbon Tax, and Emission Trading Systems

Carbon pricing is an instrument that internalizes the external costs of greenhouse gas (GHG) emissions, usually in the form of a price. By passing these costs to the source of emissions carbon pricing will reduce the carbon emission through reduced usage of fossil fuels (or other carbon emission sources) or more incentives for clean energy.

A carbon tax is a tax levied on the carbon content of fossil fuels and other GHG emissions. It can also more broadly refer to taxes on other types of GHG emissions from other sources, such as methane. A carbon tax can be paid by either an entity who generates GHG emissions from a production process, or an entity who consumes goods or services that generate GHGs, such as a carbon tax on gasoline.

An emissions trading system (ETS) can have two forms. In a cap-and-trade system, the government sets a cap on total emissions and regulated entities receive permits or allowances for their emissions, which can be traded privately or through auction among themselves. In a baseline-and-credit system, the baseline emission levels are set for regulated entities, who can earn credits if their emissions are below the baseline levels and trade these credits with others who need them.

Both carbon pricing instruments aim to put a price on emissions through market mechanisms, and generate fiscal revenue. However, there are also important differences. A carbon tax provides price certainty without explicit emission reduction targets, while an ETS provides certainty in emission target but allows the price to fluctuate with the market. In addition, a carbon tax may be easier to implement through existing tax systems (for example, as an extension of fuel taxes), but an ETS would require new infrastructure to allocate and auction emission allowances.

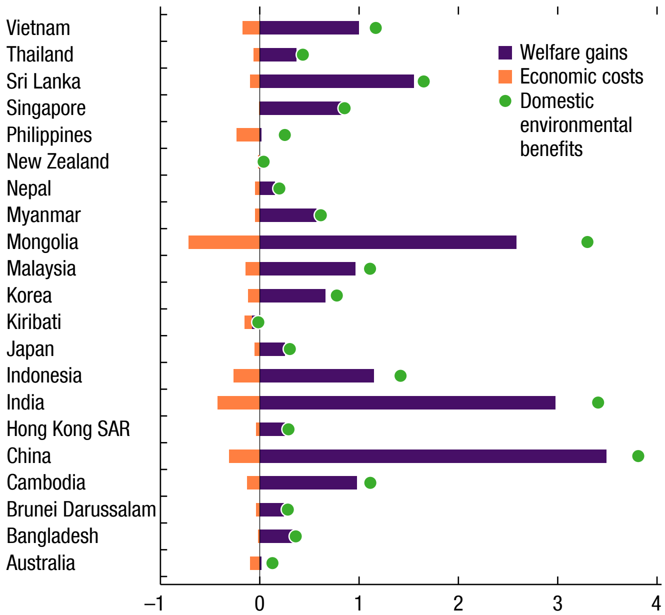
Chapter

3 Compensating Households, Industries, and Firms for Higher Carbon Prices

Mitigation efforts and higher energy prices can disproportionately affect certain types of households, regions, industries, and firms, calling for measures to compensate the affected groups. Appropriate measures vary by country because distributional impacts differ significantly across the region, including the progressivity of a carbon tax. Those affected by higher energy prices can be largely identified and should be compensated adequately, and a wide range of options are available for each country, using higher revenues from a carbon tax. Universal transfers can make the majority of households, including poor ones, better off; most countries have more targeted schemes already in place that could be expanded. Our micro-level analyses indicate that the burden of a carbon tax can be concentrated geographically and in energy-intensive industries (for example, metals and chemicals) within countries, and firms that are less productive, smaller, or credit-constrained are more vulnerable to energy price increases. These incidence analyses can help countries identify those most affected and design country-specific compensatory schemes.

The political economy of climate change is complex. Consumers and firms often fail to internalize the externalities and public good aspects associated with climate mitigation. The costs of climate change policies can fall disproportionally on specific economic sectors, groups, or regions (for example, in the form of job losses), who then have strong incentives to lobby against them. On the other hand, because climate change is a global problem, the benefits of climate change policies tend to be more diffused and accrue to much wider groups, including people in faraway regions or in the distant future. And there is often a failure to recognize the environmental and health gains from the policies, which are difficult to measure. Protests against energy and transport price hikes in many corners of the globe highlight how sensitive populations can be to changes in the prices of basic commodities. Concerns about trade competitiveness from higher energy prices and carbon

Figure 28. Environmental Benefits Net of Economic Costs from a Carbon Tax of US$25 per Ton
(Percent of GDP)



Source: IMF staff calculations.
Note: Domestic environment benefits include values estimated from reduced mortality, traffic congestions, accidents, road maintenance, etc. Economic costs mainly include losses from lower energy consumption and higher production costs (net of any gains). The welfare gain equals the net benefit from the two.

leakage if other countries fail to follow suit can also make them politically unattractive.

A stylized calculation, however, suggests that a carbon tax could generate considerable **welfare benefits.** These accrue from the domestic environmental benefits from reduced pollution, traffic congestion, and accident casualties, which outweigh the domestic economic costs from a decline in overall economic activity and a shift to cleaner but costlier technology or equipment due to higher energy prices (IMF 2019d).[1] At a carbon tax of $25, for instance, nearly all countries in Asia and the Pacific would benefit from this mitigation measure, as the domestic environmental benefits greatly outweigh the foregone fossil fuel consumption. In particular, the net benefits could exceed 3 percent of GDP for China and India; for Cambodia, Malaysia, Mongolia, Indonesia, Sri Lanka, and Vietnam gains could exceed 1 percent of GDP (Figure 28). In addition, a better environment could improve health outcomes and reduce mortality rates. For example, with a $25 per ton carbon tax, premature death due to fossil fuel air pollution could decline by 29 percent in China (about 300,000 lives a year) and 40 percent in India, and more than 20 percent in Cambodia, Hong Kong SAR, Mongolia, Sri Lanka, and Thailand. Further, underpricing for the full costs of energy use (including the environmental costs discussed above) is tantamount to energy subsidies, which are large in many Asia-Pacific countries.[2] Introducing carbon taxes reduces such subsidies.

[1]The economic costs include losses in consumer surplus from lower energy usage and higher costs to produce cleaner energy, less net revenue gains to the government.

[2]For example, post-tax coal subsidies amounted to 11 and 7 percent of GDP in China and India in 2017, respectively, while petroleum subsidies reached 11 and 9 percent of GDP for Malaysia and Indonesia. See Annex 3 for more detailed data on energy subsidies in Asia and the Pacific.

Those affected by higher energy prices can be largely identified and should be compensated adequately, using higher revenues from a carbon tax. In this chapter, we shed light on the design of carbon taxation policies by studying the distributional implications for households, industries, and firms in the region. We use household surveys for five countries to trace the impact of a carbon tax on households through higher prices and lower labor income in the energy sector and evaluate country-specific compensatory policies. Industry and firm-level data are used to show the heterogenous impacts of carbon taxation on industries, firms, and workers.

Mitigating the Impact of Carbon Pricing on Households

A carbon tax affects households based on their consumption choices and employment status. Higher carbon prices affect households directly by raising the prices of energy goods, and indirectly through the effect on the price of other goods. To assess the distributional implications, we conduct incidence analysis for Australia, China, India, Kiribati, Mongolia, and the Philippines.[3] Country-specific input-output tables are used to trace the impact of a carbon tax of $25 per ton described in Chapter 3 on consumer goods prices. Household surveys allow us to evaluate the impact of those higher prices on the consumption of different groups (for example, urban and rural households, along the expenditure distribution, or across regions).[4] Using household surveys, we also identify workers employed in energy sectors, who would be directly hurt by the carbon price hike, and evaluate measures to compensate households. We express welfare as percent of household consumption before the carbon tax is enacted. The approach has several limitations. While we allow for a negative price elasticity in energy goods, this incidence analysis does not incorporate other possible behavioral responses to a carbon tax (or its associated compensatory measures). For example, full pass-through of higher energy prices to consumers is assumed. We also abstract from any institutional settings that may prevent such pass-through. We also do not account for the new jobs that would be created in other industries and other general equilibrium effects, although they could be substantial (IMF 2020d).[5]

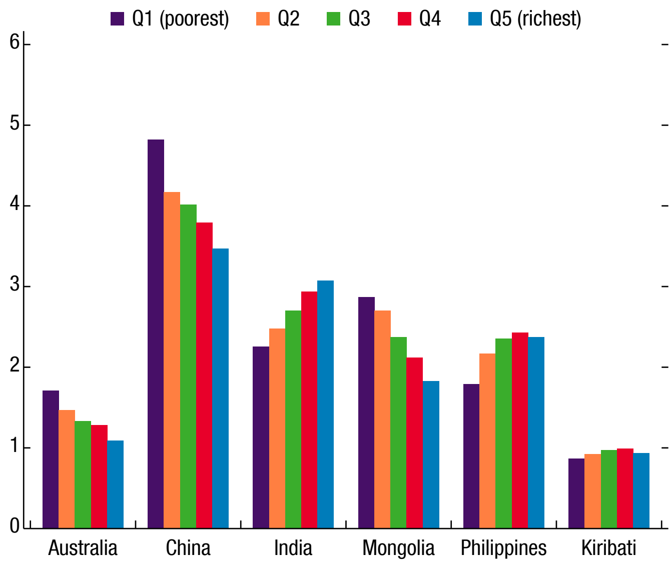
Carbon taxes can be progressive or regressive, depending on energy consumption patterns. A tax is considered to be regressive (progressive) if it is

[3]See Annex 4 for details on the data and methodology. For Australia, we did not have access to the microdata of the household survey, so the analysis was limited to using the average consumption shares for each income quintile as reported by the national statistics agency.

[4]This type of incidence analysis has been used extensively in the literature. Recent examples include IMF (2019a), IMF (2019c), Parry, Mylonas, and Vernon (2018), and Flues and Thomas (2015).

[5]Several of these channels would reduce the negative impact on households from what is presented in this chapter.

Figure 29. Burden of a $25 Carbon Tax via Higher Prices
(Percent of total household consumption, by quintile)



Source: IMF staff calculations.
Note: See Annex 4 for methodology. Burden is defined as the impact of higher prices on households' consumption. Q = per capita expenditure quintile for every country except Australia.

borne disproportionately by poor (rich) households. Our incidence analysis finds that a carbon tax is moderately regressive in Australia, China, and Mongolia, but moderately progressive in India and the Philippines, and roughly neutral in Kiribati (Figure 29). The heterogeneity reflects differences in consumption bundles across households. For example, in China, coal and electricity represent a larger share of the consumption basket for poorer households. In Australia, while electricity accounts for 2.9 percent from the budget of the poorest households, it accounts for only 1.2 percent from the budget of the richest households. In Mongolia, the poorest households, on average, spend 6.8 percent of their budget on coal, electricity, and gasoline as opposed to 4.2 percent for the richest ones. On the other hand, in India and the Philippines, electricity and fuel are consumed disproportionately by the richest households. In Kiribati, richer households consume more electricity and gasoline, but this is offset by stronger indirect effects from price increases in non-energy goods on poorer households, leading to a relatively flat incidence. Except for the case of Kiribati, the indirect effects tend to be fairly neutral across the distribution.[6]

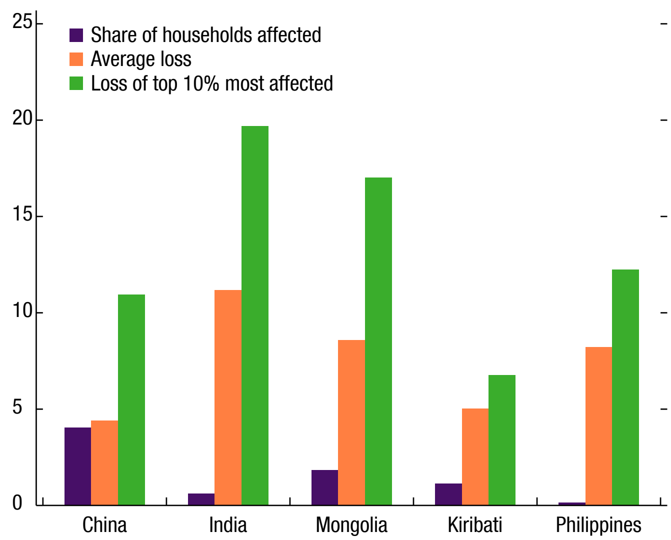
A carbon tax could hurt labor income of energy sector workers, but their share in total employment is relatively small. A carbon tax that increases energy prices would reduce demand for energy products, leading to significantly lower wages or employment for workers in the energy sectors.[7]

[6]These results also underscore the importance of expanding energy access to low-income households using low-carbon technologies.

[7]We identify energy sector workers using their occupation or industry reported in the household survey. We assume a price elasticity of energy goods of –0.25. Assuming constant labor productivity, this means that a 10 percent increase in the price of each energy good would reduce quantity demanded by 2.5 percent, translating into a 2.5 percent drop in labor demand for energy workers. As a result, labor income would decline by 2.5 percent either through lower wages or lower employment. This burden is expressed as a fraction of household consumption.

- The impact on labor income for energy sector workers is substantial. A $25 carbon tax could lead to an average labor income loss for households employed by energy sectors, ranging from 4 percent in China to 11 percent in India (Figure 30). This would be a concern especially in China and Mongolia, where coal miners tend to be relatively poor. Energy sector workers are relatively rich in India, Kiribati, and the Philippines.

Figure 30. Impact of a $25 Carbon Tax via Lower Labor Income
(Percent)



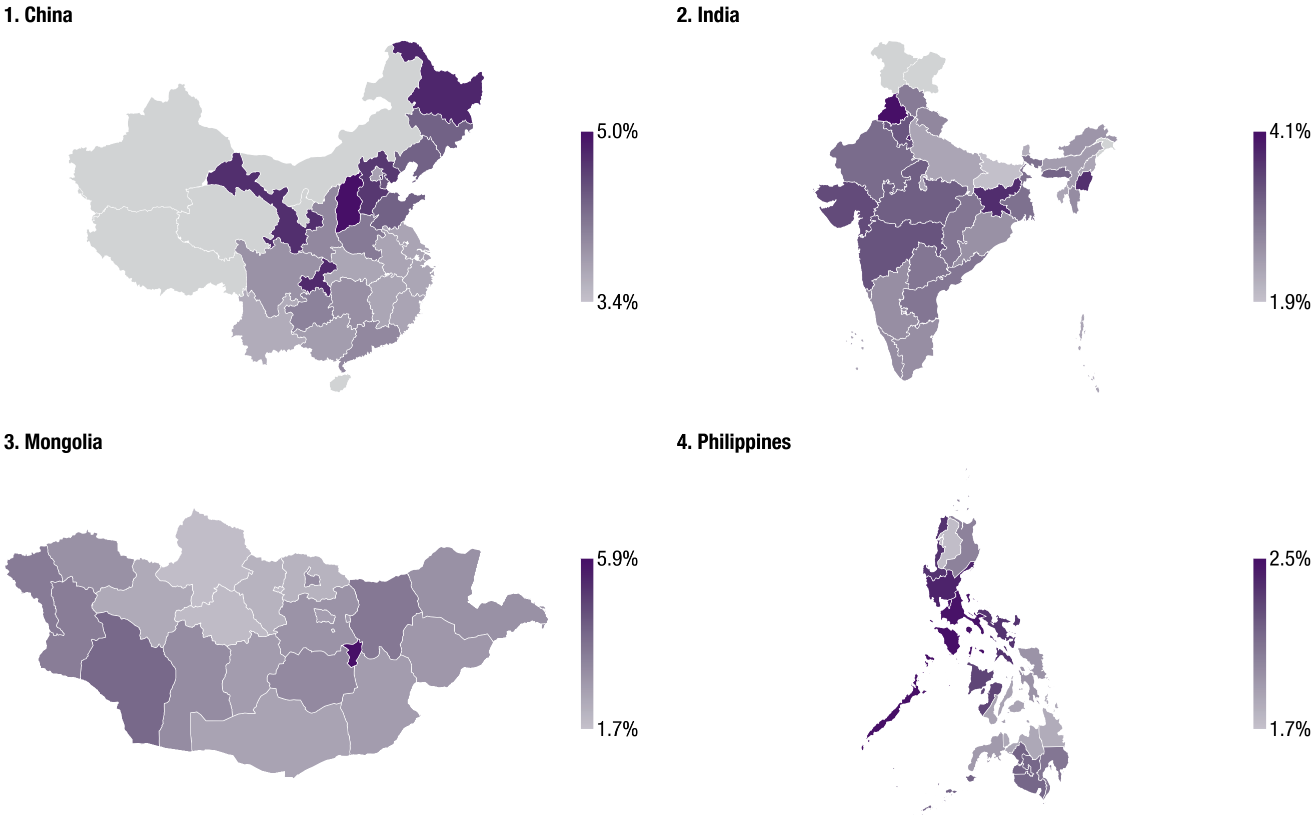
Source: IMF staff calculations.
Note: See Annex 4 for methodology. The purple columns show the share of households in the country with at least one member employed in the energy sector, and thus directly affected by lower labor demand induced by a carbon tax. The orange columns show the average loss of labor income for the households employed in the energy sector, while the green columns show the loss for the top 10 percent most affected households employed in the energy sector. Both the average loss and the loss of the top 10 percent are expressed as percent of total household consumption.

- Nonetheless, energy sectors account for a relatively small share of total employment.[8] The share ranges between 0.2 and 1.2 percent in India, Kiribati, and the Philippines (Figure 30). The share is higher in countries with large energy sectors such as China and Mongolia.

The burden of a carbon tax can be geographically concentrated within countries. Figure 31 illustrates geographical differences in the burden of a $25 carbon tax (combined impact of higher prices and lower labor income on households' consumption). In Mongolia, households in Govisumber, the most heavily affected province (that is, *aimag*), would lose on average 5.9 percent of their total consumption, more than three times more than households in Orkhon, the least affected province, reflecting Govisumber residents' higher carbon intensity in their consumption bundles and dependency on

[8]Employment shares are defined at the household level, rather than at the worker level for consistency across data sets. They represent the share of households with at least one worker employed in the energy sector.

Figure 31. Burden of a $25 Carbon Tax by Region
(Percent of total household consumption, average by region)



Source: IMF staff calculations.
Note: See Annex 4 for methodology. Burden is defined as the impact of higher prices and lower labor income for energy sector workers on households' consumption. Data are missing for regions shaded in grey. The boundaries, colors, denominations, and any other information shown on the maps do not imply, on the part of the IMF, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.

carbon jobs. There is also substantial geographic heterogeneity in China and India, but much less so in Kiribati and the Philippines. The burden also differs between urban and rural areas. In India, urban households would lose on average 3.5 percent of their consumption from the higher carbon tax as opposed to 2.4 percent for rural households. In the Philippines, households with access to electricity would experience a consumption loss of 2.3 percent on average, compared to a 1.4 percent loss for those without access. This heterogeneity can be usefully exploited to target compensatory policies during the phased introduction of a carbon tax and build public support for the reform.

Social transfer programs, financed by higher revenues from a carbon tax, could be used to compensate affected households. Even in countries for which a carbon tax is progressive, poorer households suffer welfare losses. Part or all of carbon tax revenues can be redistributed to households either uniformly through a universal lump sum transfer, or conditionally based on their characteristics. In some countries, even with universal lump sum transfers, the majority of households can end up receiving more money than the carbon taxes they pay, because rich households tend to consume more energy and pay much more carbon taxes than poor ones. Transfers could be made further pro-poor by employing means testing. In addition, displaced workers employed in the energy sectors could be supported by extended unemployment benefits, training and reemployment services, and financial assistance for job search. Such assistance would cost a small fraction of the additional revenues raised by a carbon tax (IMF 2019d).

Our incidence analysis for the five Asian countries shows that there are many ways to compensate.[9] For illustrative purposes, we assume that governments use all carbon tax revenues estimated in Chapter 2 to compensate households' welfare losses (from direct and indirect price increases as well as labor income losses for energy sector workers). We assess various compensatory programs, ranging from uniform to targeted transfers (including the expansion of existing social safety net programs and the introduction of new ones), and their distributional consequences. We find that each country has options to make the majority of households, especially the poorest ones, better off or reduce income inequality, compared with the situation before the carbon tax (Figure 32).[10]

- In **China**, both a universal lump sum transfer per person and a subsidy to rural households would leave more than half of the households better off and would also reduce inequality as measured by the Gini coefficient. The universal transfer would improve welfare for more than 95 percent of the poorest households, raising it by 10 percent on average. In this case, the cost of the reform would be borne by the richest households who, on average, would lose 2 percent of their original consumption. Even better for reducing inequality would be a child grant,[11] although it would leave only 37 percent of the households better off. An expansion of China's minimum guaranteed income scheme (Dibao), even if imperfectly targeted, would substantially reduce inequality.

[9]Using model-based simulations for China and United States (rather than an incidence analysis exercise), IMF (2020b) finds that recycling part of carbon tax revenues as targeted transfers could compensate the poorest 20 percent of households.

[10]These simulations do not account for administrative costs to implement the compensatory measures. For analytical purposes, subsidies to electricity users, car owners, etc., are assumed to be made available to households that already have these goods or access to the service at the time the policy is implemented and are lump sum, not proportional, so as to not distort consumption decisions.

[11]A transfer to every child younger than 14.

Figure 32. Welfare and Inequality Impact of Alternative Compensatory Measures

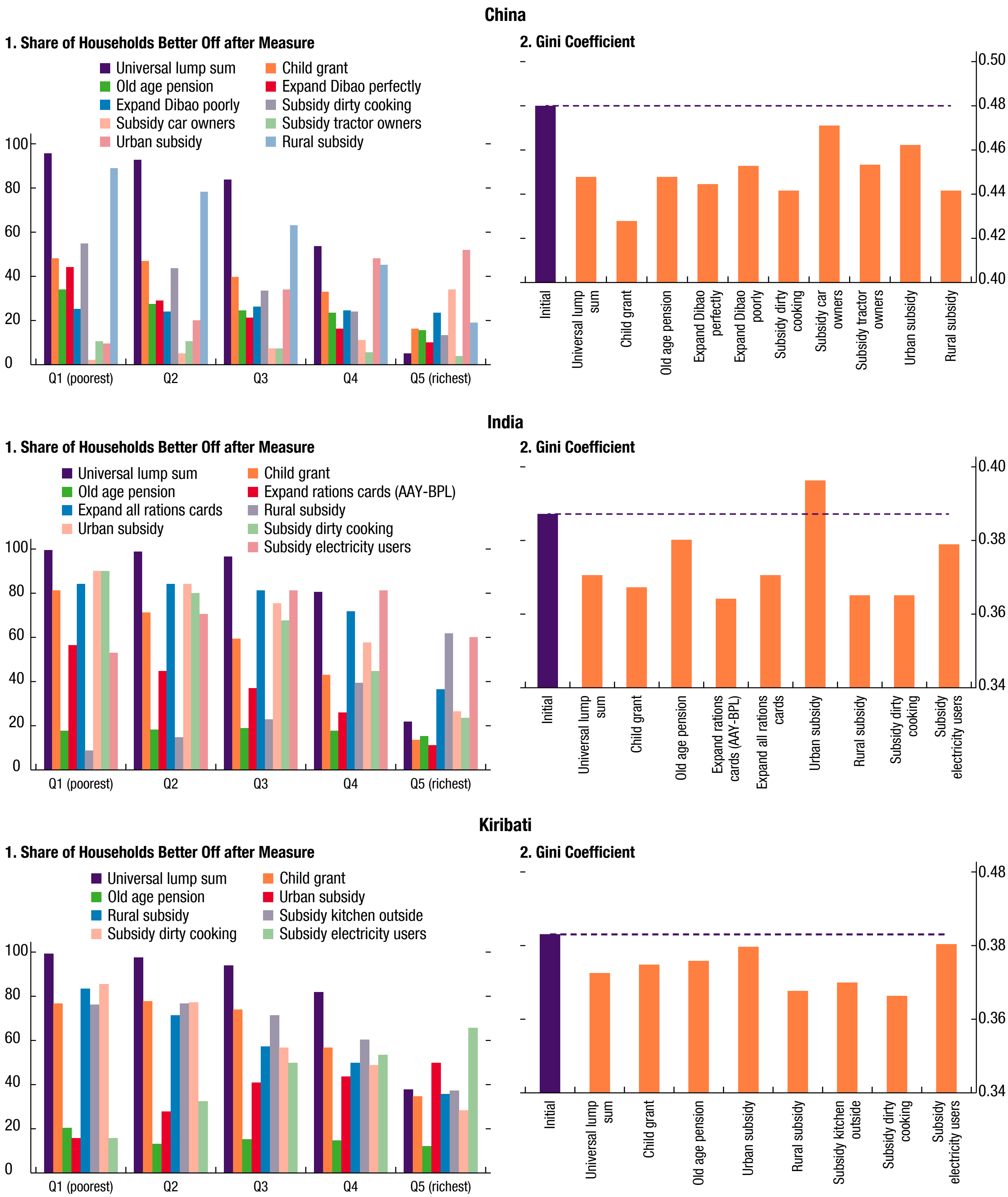
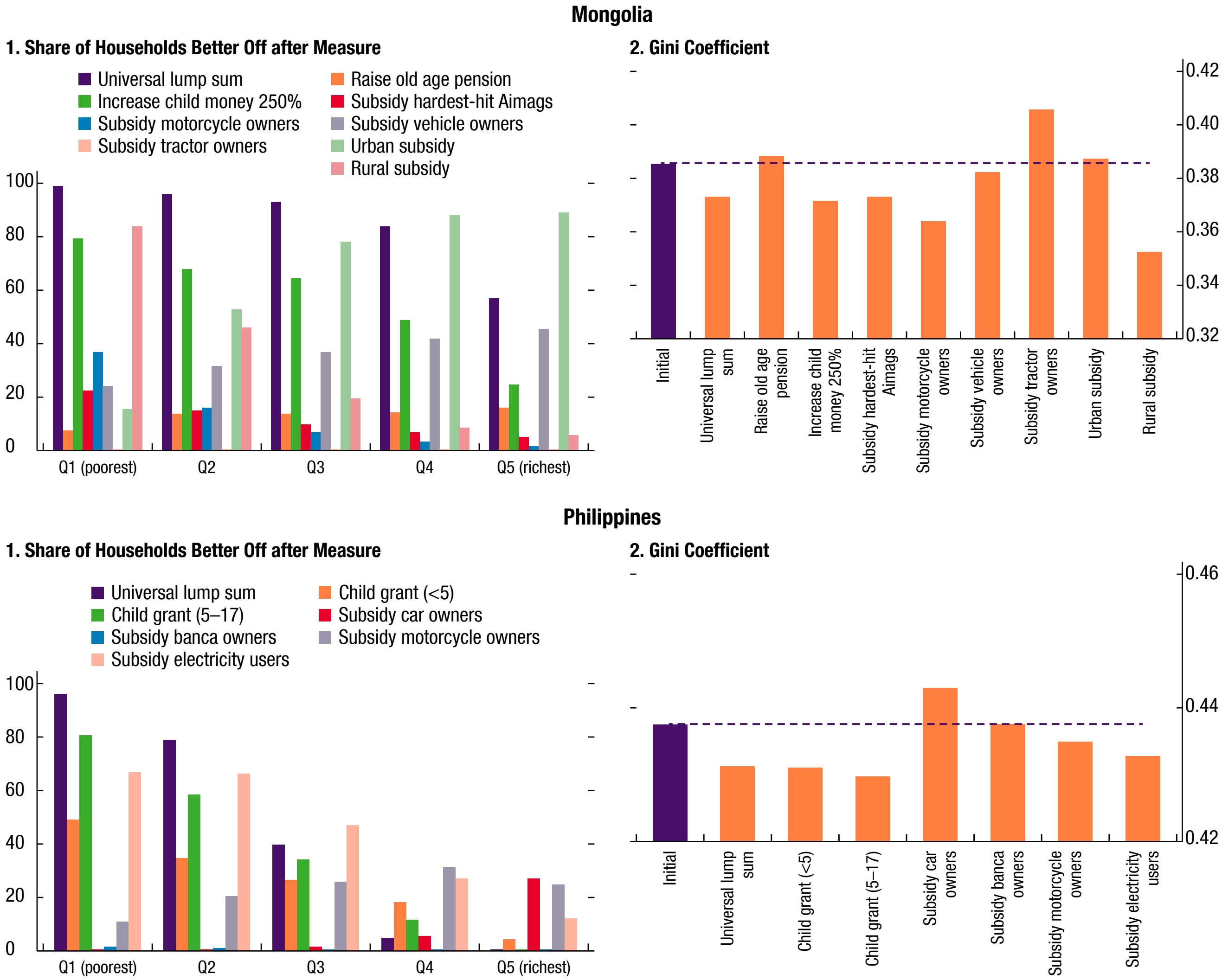


Figure 32. Welfare and Inequality Impact of Alternative Compensatory Measures (concluded)



Source: IMF staff calculations.
Note: See Annex 4 for methodology. A household is defined as "better off" if the negative impact of higher prices and lower labor income is more than compensated by the transfers. The dashed line in panels 2, 4, 6, 8, and 10 marks the initial Gini coefficient, before a carbon tax is introduced. Q = per capita expenditure quintile.

- In **India**, a universal lump sum transfer (possibly using Aadhaar unique identity numbers) would leave 80 percent of the households better off and reduce inequality. It would improve the welfare of virtually all the poorest households, raising it on average by 9 percent, while the loss for the richest households would be of only 1 percent on average. Most of the households would also be better off with other compensatory measures such as a lump sum to all current recipients of ration cards as reported in the household survey, a subsidy to rural households, to those that do not have access to clean cooking fuel, and to electricity users. A child grant would raise welfare for 54 percent of the households.

- In **Kiribati**, the introduction of a universal lump sum transfer would improve welfare for 82 percent of the households, with average gains of 7 percent for the poorest households. Better targeting could be attained with a rural subsidy or a subsidy to households who do not have access to clean cooking or do not have a kitchen inside the house. A child grant would improve the welfare of almost two-thirds of the households and reduce inequality.
- In **Mongolia**, a universal lump sum transfer would raise welfare for more than four-fifths of the households. Better targeting to the most vulnerable households could be achieved by a rural subsidy, although this would raise welfare for only a third of the households. On the other hand, an urban subsidy would leave 65 percent of the households better off, although at the cost of a slight increase in inequality. Raising the benefit of the child grant program by 250 percent, as reported in the household survey, would reduce inequality and leave 57 percent of the households better off.
- In the **Philippines**, a carbon tax of $25 per ton would raise fewer resources than in other countries in the regions—it would raise 0.5 percent of GDP compared to the 2.2 percent that would be collected in Mongolia. As a result, there would be more limited room to compensate households. A universal lump sum transfer would raise welfare for 44 percent of the households and reduce inequality, increasing welfare by 3 percent, on average, for the poorest households and reducing it by 2 percent for the richest. Better targeting would be achieved through child grants. Although less well targeted to the most vulnerable, a lump sum subsidy to electricity users would raise the welfare of 44 percent of the households and still reduce inequality.

The choice of compensatory programs should be informed by the country's ability to implement targeted transfers and the need to build support. The specific design of compensatory programs and the share of the population that receives support are a matter of political choice, societal preferences, fiscal structure, as well as the country's capacity to target vulnerable groups. Universal transfer programs may be advisable for countries with limited means-testing capacity or a large informal sector or when policymakers seek to build broad support for carbon taxes. Nonetheless, the lack of a comprehensive identification system and/or a cashless delivery system such as mobile money can challenge implementation of universal transfers (IMF 2020e). Countries with strong means-testing mechanisms can consider expanding existing programs or creating new ones that provide support for the most vulnerable or affected. Besides financing transfers, carbon tax revenues could also be used productively by financing higher spending on health, education, and infrastructure and reducing distortionary taxes that reduce incentives to work and invest.

Sectoral and Firm Perspective

We analyze the potential impact of carbon taxation on the cost of production for industries through direct and indirect channels. Carbon taxes increase the cost of energy itself, a primary input in production. In addition to this direct increase in productions costs, industries are also part of an intricate production network connected through input-output linkages. Carbon taxes increase the production costs for upstream industries that supply intermediate inputs to downstream sectors, thereby pushing up intermediate input costs in the latter. In what follows, we analyze these effects quantitatively by country and industry. Energy-dependence of each industry is measured as the sum of its direct energy consumption and the energy-dependence of its intermediate inputs, weighted by their input shares using country-specific input-output tables for a range of countries. The burden of carbon taxation is the average cost increase from a $25 per ton carbon tax on energy prices in 2030.[12]

Carbon taxes have uneven impacts across countries in Asia and the Pacific. Taking the output-weighted average cost increase for each industry from a $25 per ton carbon tax in 2030, China and India are the most affected countries, mainly due to their energy mix and longstanding policies that subsidize energy prices (Figure 33). Note, however, that the burden of a gradually implemented carbon tax will be spread over many years, thereby moderating the economic impact. Also, loss of competitiveness could be abated, assuming other countries raise their carbon taxes. For the rest, the average impact on industry costs of a $25 per ton carbon tax is less than 3 percent including the energy-producing sectors such as coal and electricity, and less than 2 percent excluding the energy-producing sectors. These results suggest that a $25 per ton carbon tax would have a relatively modest growth and competitiveness impact for majority of the countries in the region.[13]

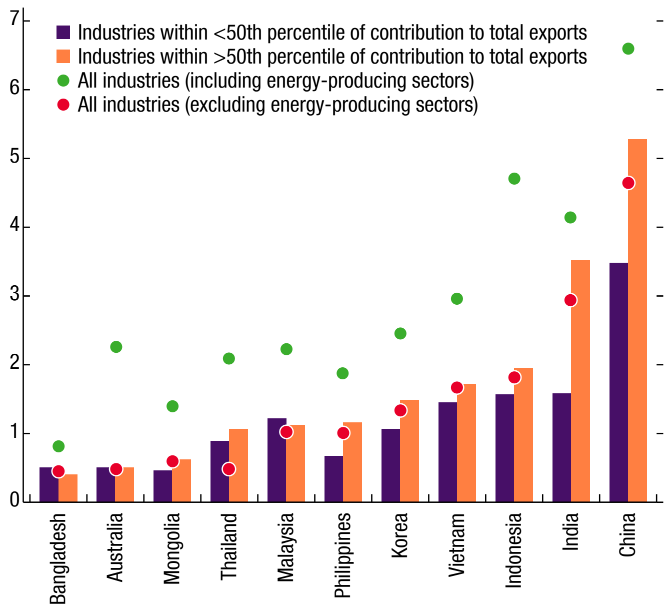
Industries that contribute to a large share of the total exports are generally not more vulnerable to higher costs from a carbon tax, with exceptions of China and India. The impact of higher energy costs on energy-intensive, export-oriented sectors, is a political concern with carbon pricing. Assuming that a carbon tax is not applied to exports of energy or extractive products such as coal and natural gas, we find no significant differences in the average impact for exporting industries relative to non-exporting industries in most

[12]See Annex 5 for details on the data and methodology.

[13]Existing evidence studying the EU ETS also finds limited impact on competitiveness (Branger, Quirion, and Chevallier 2016; Koch and Basse Mama 2019; Venmans, Ellis, and Nachtigall 2020).

Figure 33. Burden of $25 per Ton Carbon Tax on Industries in 2030, Selected Countries

(Output-weighted average cost increase, percent)



Sources: IMF staff calculations.

Note: See Annex 5 for the data and methodology. The green dots show the average production cost increases as a result of the carbon tax including the energy-producing sectors, weighted by the output shares. The red dots exclude the energy-producing sectors. The bars show production cost increases from carbon tax, split at the median by industry exports as a share of total exports and excluding energy-producing industries.

countries (Figure 33). Two exceptions are China and India, where the large exporting industries are likely to face significantly higher industry costs, thereby potentially undermining export receipts.[14] These results highlight the value of an international carbon price floor arrangement among heavily emitting countries and border adjustment schemes—such arrangements would provide some reassurance against losses in international competitiveness.

Excluding energy-intensive sectors, the differences in impact of carbon tax across industries within a country are generally not large. Sectors that would be most affected are extractive industries such as coal and natural gas and energy-producing sectors such as electricity, where impact of a $25 per ton carbon tax would be large (see Chapter 2). In addition, sectors that rely on carbon-intensive inputs would be heavily burdened (Table 3).[15] Examples of carbon-intensive industries include metals, chemicals, rubber, and plastic manufacturing. However, excluding these outliers, variation across industries is limited within each country.

There is significant heterogeneity in affected industries across countries. For example, in China and India, metal manufacturing could face some of the highest cost increases, but this is not the case for other countries in the region. Similarly, textile manufacturing in Mongolia could see a relatively

[14]This analysis assumes full cost pass-through of the carbon tax from energy-producing and other upstream sectors to downstream sectors. The pass-through rates are likely to be partial due to the market structure, elasticity and curvature of demand, cost structure, and other institutional factors that reduce the cost impact. For example, state-owned enterprises might receive government support because of its status as a large employer, weakening the effects of carbon taxation.

[15]For each industry, we use the share of total inputs from each energy-producing sector and the energy-intensity of its intermediate inputs from other industries to determine its overall production cost increase from a $25 per ton carbon tax. We assume that both the energy-producing sectors and the intermediate input-producing sectors fully pass through their cost increase carbon taxation.

Table 3. Burden of a $25 per Ton Carbon Tax on Industries in 2030, Selected Countries
(Percent)

	Bangladesh	China	India	Malaysia	Mongolia	Thailand	Vietnam
Agriculture, Forestry, and Fisheries	0.13	1.98	1.06	1.11	0.32	0.46	2.11
Basic and Fabricated Metals	1.49	9.53	11.67	1.18	0.47	0.79	1.06
Chemicals and Chemical Products	0.81	8.91	4.10	2.10	0.32	1.76	1.23
Electrical and Electronic Products	0.69	4.32	6.08	0.62	0.24	1.12	0.51
Food and Beverages	0.50	2.36	1.83	1.04	0.23	1.04	1.78
Machinery and Other Equipment	1.20	5.39	5.80	0.78	0.81	0.93	1.06
Rubber, Plastic, and Other Non-metallic	1.61	8.95	5.06	0.70	0.54	0.93	0.81
Textiles and Leather Products	0.47	3.62	2.69	1.29	2.18	1.74	0.79
Transport Equipment	0.26	4.61	5.23	0.68	0.90	0.66	0.88
Wood and Paper Products	0.40	5.02	2.87	1.27	0.38	0.72	1.62
Other Manufacturing	0.42	8.84	2.83	0.81	0.46	0.80	1.38
Services	0.41	2.69	1.78	1.19	0.46	1.09	1.92
Minimum	**0.13**	**1.98**	**1.06**	**0.62**	**0.23**	**0.46**	**0.51**
Maximum	**1.61**	**9.53**	**11.67**	**2.10**	**2.18**	**1.76**	**2.11**
Average	**0.70**	**5.52**	**4.25**	**1.06**	**0.61**	**1.00**	**1.26**

Source: IMF staff estimates.

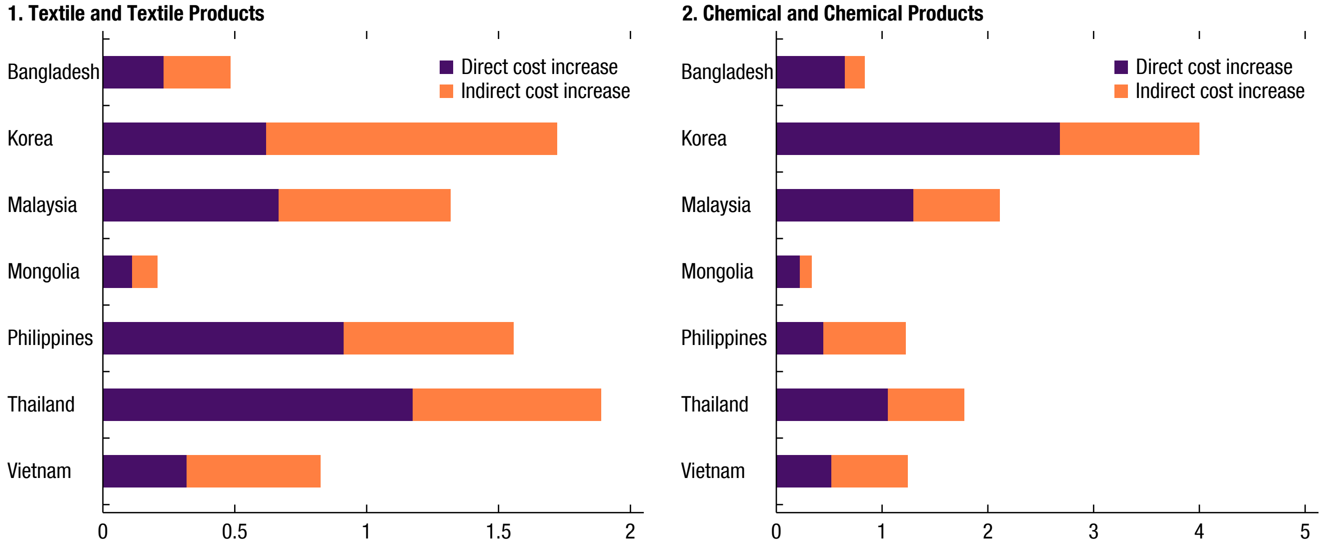
Note: See Annex 5 for methodology. The table shows the production cost increase from higher energy prices, both direct and indirect, as a result of carbon tax assuming full pass-through in upstream sectors. Green cells will face the least cost increases in the region, while red cells will have the higher cost increases in the region.

higher cost increase from a carbon tax compared to other less-affected countries. Within each industry, the cost increase varies across countries due to differences in the energy composition, intensity of energy use and intermediate inputs in production. Again, without a global carbon price floor arrangement or border carbon adjustments, these differences could impair international competitiveness for some countries. Even without trade concerns, there could be resistance from the most affected industries. There is no one-size-fits-all solution. For countries considering an effective carbon tax rate that varies by industry, as in Norway (OECD 2019), subsidizing or compensating the most-burdened industries temporarily could make carbon taxation more politically palatable.

Alternatively, if countries choose a uniform carbon tax policy, as in Singapore, or one that only taxes at source, such as the coal tax in India, complementary measures could moderate losses in downstream sectors as they transition to greener technologies. A rapid transition to low-carbon technologies could lead to wealth losses and financial stability risks from stranded assets and investment costs (IMF 2020d). Countries could pair the carbon taxes with a temporary cut in the corporate income tax, extend production and investment tax credits, offer accelerated depreciation, research and development tax credits, and rebates to accelerate deployment of less carbon-intensive technology in their production process.

Decomposing the increase in costs from carbon taxation into direct and indirect effects illustrates the substantial role of linkages across industries in magnifying the burden of carbon taxation. In China, for example, the average indirect impact on industry production costs from the potential increase

Figure 34. Burden of a $25 per Ton Carbon Tax on Industries in 2030, Selected Countries
(Percent)



Source: IMF staff estimates.
Note: See Annex 5 for methodology. The figure shows the breakdown of production cost increase from higher energy prices (direct cost increase) and higher intermediate input costs (indirect cost increase) as a result of carbon tax assuming full pass-through in upstream sectors.

in intermediate input costs (3.1 percent) is twice the direct impact from increase in energy prices itself (1.5 percent). As shown in Figure 34, even industries with comparatively similar increases in direct energy consumption costs across countries could exhibit variation in their overall production costs due to differences in their input-output linkages (for example, textile industry in Malaysia versus Korea). Additionally, the magnitude of indirect cost effects varies across industries, with more downstream sectors like textiles typically facing a higher burden from higher intermediate input prices. These results reinforce the need for temporary compensatory measures to alleviate the burden in downstream sectors as they transition to greener production processes.

Jobs-at-risk in manufacturing vary across countries and industries but would be manageable at the aggregate level with appropriate complementary policies. The employment impact from downstream manufacturing industries depends on the industry's energy-dependence and share of manufacturing employment. China would be one of the most impacted because of its carbon-intensive industries, with a maximum of about 6 percent potential loss in manufacturing employment (2.5 percent of total employment) spread over many years. These job loss estimates are an upper bound as we assume unitary price elasticity of demand, complete pass-through of the cost increase, and static production technology with perfect complementarity between all

Table 4. Jobs at Risk in Manufacturing from a $25 per Ton Carbon Tax in 2030, Selected Countries
(Percent of total manufacturing employment)

	Bangladesh	China	India	Malaysia	Mongolia	Thailand	Vietnam
Basic and Fabricated Metals	0.01	1.27	0.35	0.09	0.05	0.09	0.09
Chemicals and Chemical Products	0.05	0.93	0.39	0.20	0.02	0.07	0.12
Coke and Refined Petroleum Products	0.00	0.03	0.17	0.01	0.00	0.00	0.00
Electrical and Electronic Products	0.09	0.61	0.20	2.56	0.03	1.33	1.18
Food and Beverages	0.03	0.17	0.12	0.10	0.09	0.11	0.05
Machinery and Other Equipment	0.00	0.64	0.40	0.02	0.00	0.08	0.02
Rubber, Plastic, and Other Non-metallic	0.12	1.13	0.60	0.11	0.04	0.14	0.07
Textiles and Leather	0.11	0.51	0.56	0.06	0.09	0.09	0.65
Transport Equipment	0.00	0.27	0.37	0.08	0.00	0.08	0.09
Wood and Paper Products	0.13	0.35	0.18	1.05	2.02	0.73	1.98
Other Manufacturing	0.01	0.32	0.14	0.15	0.01	0.17	0.77
Total in Manufacturing	**0.55**	**6.24**	**3.46**	**4.43**	**2.35**	**2.89**	**5.04**

Source: IMF staff estimates.

Note: See Annex 5 for methodology. The table shows the jobs at risk from potential decrease in manufacturing employment due to production cost increase from a $25 per ton carbon tax in 2030. This assumes that all cost increase is fully passed-through to consumers and unitary price elasticity of demand, so any difference compared to the heat map on industry-level cost increases (Table 3) is due to variations in the share of manufacturing labor force employed.

inputs.[16] In reality, consumers could be less sensitive to price increases, or firms could shift to more labor-intensive or greener production processes to lower their costs, thereby mitigating job losses. In assessing the burden, we also assume a stagnant economy. Accounting for the projected growth of the economy over the next decade would further reduce the impact.[17] Thus, dynamic adjustments in markups, productivity, and production technology, compensatory programs such as targeted transfers and rise of new industries could alleviate the onus on workers.[18]

While the cost increase by industry is relatively uniform, potential job losses can vary significantly due to its share of total employment. As shown in Table 4, while Mongolia and Vietnam could face largest job losses from wood and paper manufacturing, electrical and electronics manufacturing could be the biggest contributor to job losses in Malaysia and Thailand. For example, in Mongolia, 85 percent of manufacturing job losses could be from the wood and paper manufacturing sector. For countries considering variable carbon tax by industry, lower rates for such industries in the near term could reduce overall job losses. Finally, despite the large cost increase in coke and refined

[16]These assumptions would mean that a 10 percent increase in the production cost would result in a 10 percent increase in the price of each good, which would reduce quantity demanded by 10 percent, translating into a 10 percent drop in labor demand for workers. As a result, 10 percent of the jobs in the industry would be at risk. This burden is expressed as a fraction of total manufacturing employment.

[17]IMF (2020b) estimates that a combination of green fiscal stimulus and carbon taxes would result in moderate output losses (1–6 percent of GDP by 2050) in the context of an expected 120 percent cumulative global GDP growth over the next 30 years.

[18]For instance, employment opportunities could potentially emerge in other areas as workers reallocate across sectors. The growth in renewable energy sector could also absorb some of the jobs that are at risk due to carbon pricing (IMF 2020b).

Table 5. Differences in Energy Dependence of Firms by Specific Firm Characteristics

Firm Performance				Firm Characteristics			
Profitability		*Labor Productivity*		*Size*		*Age*	
Low	High	Low	High	Small	Large	Old	Young
■		■		■			■
Labor				**Financial Access**		**Trade**	
Labor Intensity		*Skill Intensity*		*Access to Credit*		*Export Status*	
Low	High	Low	High	Yes	No	Yes	No
	■	■			■		■

Source: IMF staff estimates using World Bank Enterprise Survey firm-level data.
Note: See Annex 6 for methodology. A red cell indicates that a firm below/above the median of a certain characteristic in a specific industry within a country has significantly more energy-intensive production process, so it is more vulnerable to carbon taxes. The difference in coefficient is significant at least at the 10 percent significance level. Results are obtained from fixed-effects regressions controlling for differences in industry and country characteristics.

petroleum products, overall jobs-at-risk for the economy are limited because they employ relatively few workers.

Countries could deploy measures to mitigate potential permanent job losses and compensate affected workers. The goal should be to support workers and not particular jobs or sectors. Targeted policies in the short term could range from transition assistance for affected workers and communities, vocational training programs to re-train the workforce for new industries and job search assistance. These support programs could be funded with carbon tax revenue left over after directly compensating at the household-level through targeted or universal transfer programs. Over the medium-term, policies that promote green industries compatible with the skillsets of the existing labor force could accelerate decarbonization (see Chapter 5).

A carbon tax could affect firms differently, even within the same industry and country. Using the World Bank Enterprise Surveys that cover a broad range of firm-level performance measures, we investigate how vulnerability to carbon taxation varies by firm characteristics after controlling for country and industry characteristics.[19] Incorporating such a firm incidence analysis when formulating a carbon tax regime would help design appropriate compensatory policies to transition to a green economy (Bumpus 2015). Results are shown in Table 5.

Better-performing firms, measured by profitability and productivity, tend to have fewer energy-intensive production processes and hence are less vulnerable to carbon taxation. Studies show that exporters are generally more productive across a wide range of countries and industries (Melitz 2003, Bernard and others 2007). Consistent with this finding, the analysis also finds that exporting firms are less vulnerable to carbon taxation. Therefore, carbon taxation could result in the entry and growth of more productive firms and

[19]See Annex 6 for details on the data and methodology.

exit of less-productive firms, resulting in overall efficiency gains, a potential co-benefit of carbon taxation. In addition, political concerns about the impact on trade competitiveness could be dampened as exporting firms in non-energy sectors typically have less energy-intensive production processes.

Younger and smaller firms are potentially more vulnerable to carbon taxation. For countries in the region with large informal sectors, carbon tax can be an effective revenue mobilization tool.[20] However, small and medium enterprises (SMEs) hold a large share of employment in many countries, and young enterprises disproportionally contribute to job creation (Ghani, Kerr, and O'Connell 2011). Therefore, compensatory policies that protect young and small firms to survive higher costs from carbon taxation and decarbonize their production processes could be critical to abating job loss and promoting growth. Alternatively, SMEs could be exempt for carbon taxation as the emission levels of individual SMEs are generally small so that a carbon tax on SMEs will not achieve much in reducing emissions while costing employment significantly. In Korea, for instance, ETS and renewable portfolio standards (RPS) do not apply to SMEs (Lee and Yu 2019). Given that many Asian countries already have policies and programs in place for SMEs, exempting or compensating them would be relatively straightforward.

To address financial constraints for firms during the transition, governments could consider market-based incentives that promote access to green finance. As reported in Table 5, we find a strong relationship between limited access to financing and energy-intensive production processes amongst firms. This implies a more challenging transition for the most vulnerable firms who might not have sufficient funds to invest in green technology, reinforcing the need for complementary policies in financial inclusion and green financing. For countries with relatively large and developed financial capital markets, such as China, India, and Korea, a regulated and well-defined green bonds market could provide the financing for large corporations to catalyze low-carbon investment. Equity financing, particularly through venture capital funds, could play an important role for promoting innovation in climate-smart technologies. Bangladesh, India, and Sri Lanka are also nudging their commercial banks and financial institutions to lend to green projects and setting up appropriate targets. For example, Bangladesh Bank now requires every commercial bank and financial institution under its jurisdiction to disburse 5 percent of the total loan amount to green projects (IMF 2019a). Targeting this financing and any technical assistance to the most vulnerable firms in the most exposed industries can help ease transitions.

[20]By reducing tax evasion, Liu (2013) estimates that the welfare cost of carbon tax is reduced by 89 percent in China and 97 percent in India, thereby potentially paying for itself through improvements in the efficiency of the tax system.

Firm-level results need to be interpreted with some caution. First, the results are not from a fully representative sample for any country. This is primarily because of missing data on electricity consumption across the sample, potentially resulting in selection bias. However, our results are broadly consistent with studies using country-level representative samples (EBRD 2018, Sahu and Narayana 2011, Golder 2011). In addition, the analysis does not account for dynamic effects. Firms could respond to increases in electricity prices by switching to less electricity-intensive productions process within narrowly defined industries and reducing their machine intensity. At the same time, firms could respond by making productivity-enhancing investments that reduce their burden from carbon taxation.[21] These dynamic responses would vary with the ability to switch production processes in an industry, the level of economic development, and availability of compensatory measures.

Lessons from International Experience

International experience highlights the importance of political and social context in the design and efficacy of climate policies. For instance, the Canadian province of British Columbia used carbon-pricing revenue to cut distortionary labor and corporate income taxes, making the reform revenue neutral (British Columbia 2020). The federal Canadian scheme instead uses lump sum payments to compensate households for higher energy prices (Carattini and Kallbekken 2019), while Singapore has provided temporary grants to households to offset part of the utility bill (NCCS 2020). In France, surveys suggest that while there is limited public support for lump sum payments, subsidizing non-polluting transport or cutting VAT would create broader support for climate action (Douenne and Fabre 2020). Cuts in personal or corporate income taxes can mitigate competitiveness concerns and could raise employment and output yielding a “double dividend” (Bovenberg 1999), but could be less progressive than lump sum transfers or social programs targeting the most vulnerable.[22] Investments in health, education, and infrastructure can raise productivity.

Carbon pricing needs to be implemented in a sequential and credible way to give households and firms time to adjust. For instance, Sweden introduced a tax on motor and heating fuels in 1991 at a rate of $28 per ton, which was

[21]For example, a study of the United Kingdom’s flagship carbon taxation policy found that the tax reduced energy intensity by 18.1 percent and electricity use by 22.6 percent with no adverse impacts on employment, revenue, or plant exit (Martin, de Preux, and Wagner 2014). Ley, Stucki, and Woerter (2016) find that a 10 percent increase of energy prices results in a 3.4 percent increase in the number of green innovations.

[22]Lower rates for the top brackets would disproportionately benefit richer households and negative rates for low-income households (as in the earned-income tax credit in the United States) usually have less than full take-up. In the case of the United States, it is about 80 percent (IRS 2020).

gradually increased, reaching $127 per ton by 2019 (IMF 2019a). Similarly, Colombia's carbon tax was introduced in 2017 at about $5 per ton and is expected to increase annually by 1 percentage point above inflation until reaching slightly less than $10 per ton (El Congreso de Colombia 2016). India's nationwide tax on coal, both produced and imported into India, has gradually increased from $1 per ton in 2010 to about $6 per ton by 2020 (Singh 2020). Ireland and the Netherlands are aiming at carbon taxes of 100 and 125 euros by 2030, respectively. Preannouncing (and sticking to) an increasing path for the carbon tax can strengthen the incentives for households and firms to adjust.

Simplicity in design can be complemented with additional policies to provide support to the most affected sectors and regions and reinforce incentives. Switching from the existing capital stock designed for a fossil fuel-based economy to green or low-carbon-intensive production processes often entails large fixed costs for firms and industries (Kemp-Benedict 2014). To alleviate this, countries have adopted a variety of approaches. For instance, Norway's carbon tax varies by sector, while Sweden's fuel tax originally had a lower rate for industry (IEA 2017, IMF 2019a). Singapore has instead opted for a broad-based carbon tax without exemptions for all facilities emitting above a certain threshold and has mitigated competitiveness concerns by providing grants to incentivize companies to adopt energy efficiency measures (NCCS 2020). In principle, it would be desirable to avoid exemptions to the carbon tax and instead compensate the most affected industries with an output-based subsidy or set a lower tax rate and reinforce incentives with feebates.

Carbon tax revenues have been used to support green investment. Well-targeted support for green investment and resilient infrastructure for hard hit sectors and regions could be an important element of an effective package that addresses climate objectives (see next chapter; Kemp-Benedict 2014). India, for example, keeps its revenue from the coal tax in a National Clean Energy and Environment Fund to finance the growth of a renewable energy sector (Singh 2020). In Singapore, carbon tax revenue will be used to support worthwhile projects which deliver the necessary abatement in emissions. In Germany, all revenues from new domestic ETS will be used for green investment and just transition.

Renewable subsidies and tax incentives could also facilitate political acceptability and limit carbon leakage by keeping the carbon price relatively low. Subsidizing renewables can mitigate the required level of carbon prices compared to other revenue recycling options, as it lowers the relative price of renewables without the need to tax carbon (Chen and others 2020). This would increase the political attractiveness of a package of carbon pricing combined with investment subsidies or tax credits, albeit at a higher fiscal cost. Countries could also reduce competitiveness concerns through output-based rebates for firms most likely to suffer from leakage. In addition to collective global actions such as border carbon adjustments and an international carbon price floor, lowering barriers to trade in climate change goods and services, and developing complementary job training programs for reskilling and upskilling the labor force are additional policy tools that could be deployed to facilitate the shift to a green economy.[23]

[23]For example, the Asia-Pacific Economic Cooperation countries agreed on reducing tariffs on low-carbon goods such as solar panels and energy-efficient lightbulbs (World Bank 2015).

CHAPTER

4 Adaptation Challenges in Asia and the Pacific

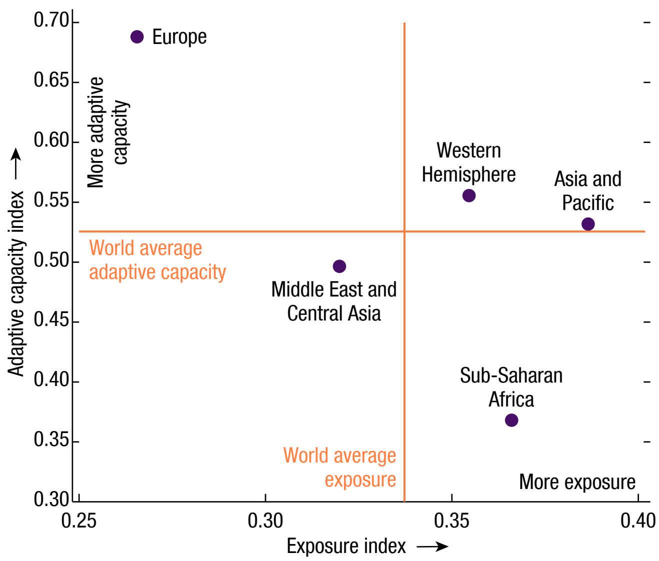
Accelerating climate change adaptation in Asia and the Pacific is critical. Investing in adaptive infrastructure can yield high returns as it entails greater private investment, less damage and economic disruption from disasters, lower disaster recovery spending, and a quicker rebound in economic activity, especially if efficiently undertaken. Although worth pursuing, they are initially costly. We estimate investment needs for climate-proofing infrastructure to average 3.3 percent of GDP annually for the region during the next decade, with the amount being much higher for some Pacific island countries. Adaptation investment would entail higher debt unless financed by domestic revenue mobilization or spending prioritization and efficiency. For highly vulnerable Pacific island countries suffering deteriorating fiscal space due to COVID-19, large adaptation investment would be difficult to accommodate without concessional loans or donor grants.

How Has Asia and the Pacific Tackled Climate Change Adaptation?

Asia and the Pacific needs to adapt to climate change. While global efforts to reduce emissions need to be strengthened, as discussed in Chapter 2, the region has been, and will be, suffering from more frequent and extreme weather-related disasters, rising sea levels, productivity changes in agriculture and fisheries, and other climate change phenomena. Adaptation to climate change includes strengthening early warning systems, improving dryland agriculture, protecting mangroves, managing water resources better, and making infrastructure more resilient (GCA 2018a). Although costs for adapting to this reality are very high, growth and development will be significantly threatened without effective adaptation. Many small island states in the region are particularly vulnerable. Financial resilience will also be critical.[1]

[1]IMF (2019d) discusses a three-pillar approach to address natural disaster risks. See Annex 7 for details.

Figure 35. Adaptive Capacity and Exposure Indexes by Region



Source: IMF staff calculations based on 2015–18 data from the EU commission, the United Nations University Institute for Environment and Human Security, the University of Notre Dame, and Phillis and others (2018).
Note: Regional classification as per the IMF grouping.

We start by assessing the adaptive capacity of countries in the region. Using publicly available indicators for climate adaptation, we construct country-by-country composite indices on adaptive capacity and exposure to climate change risks (see Box 2 for details). These indices capture characteristics that indicate higher adaptive capacity, such as sound socioeconomic characteristics, strong institutions (including national planning), well-developed disaster relief mechanisms, and capacity to develop and maintain infrastructure that is resilient to natural hazards.

Overall, the adaptive capacity of Asia and the Pacific is broadly comparable to the rest of the world. On average, the region has an adaptive capacity index of 0.53, which is in line with the world average (also 0.53). However, Asia and the Pacific needs to further improve its capacity, since it is the region in the world most highly exposed to climate change risks, with an average of 0.39, substantially above the world average (Figure 35).

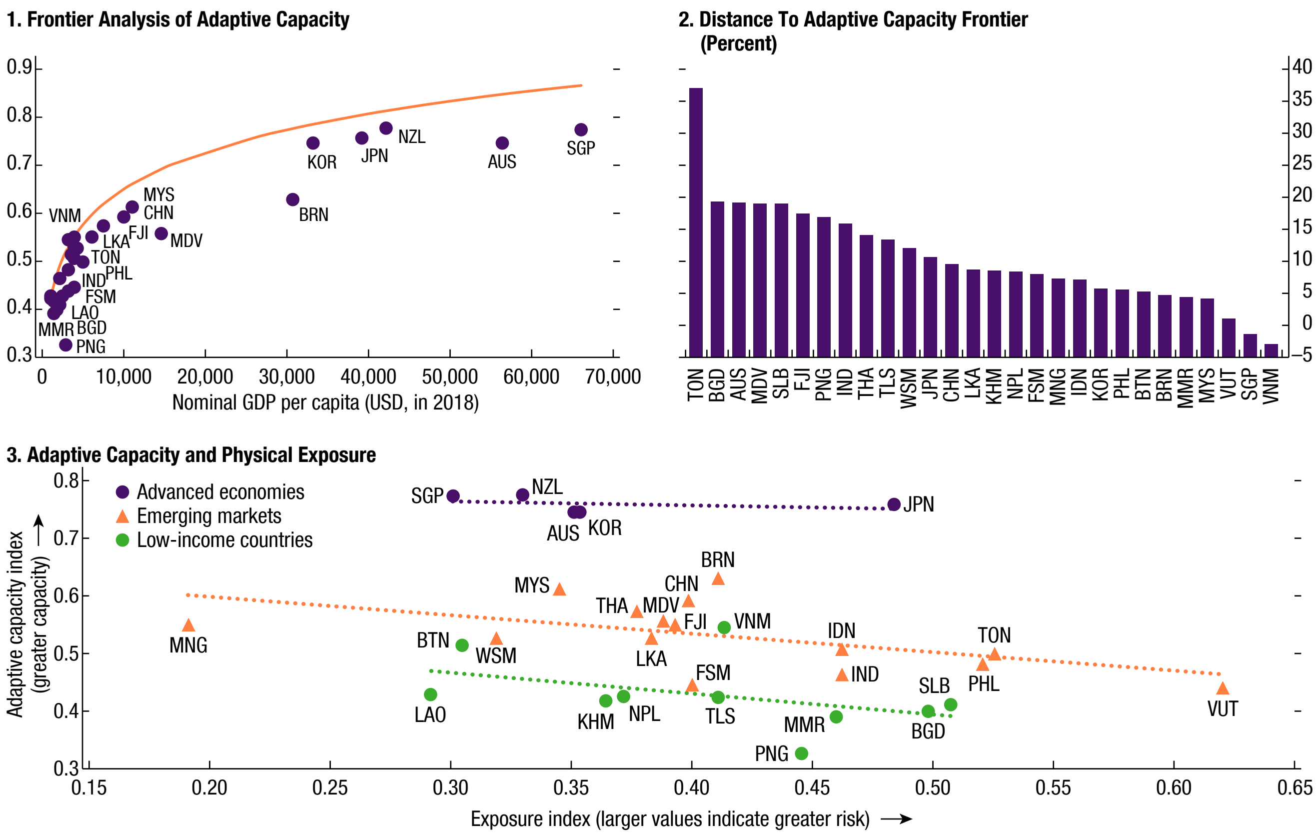
The adaptive capacity index is positively correlated with income levels, suggesting development matters for climate resilience. The positive correlation, as shown in the upper left panel of Figure 36, is consistent with findings that policies that reduce poverty and promote robust economic development are the most effective way to reduce vulnerability to climate change (World Bank 2020).[2]

Within Asia and the Pacific, all countries have considerable scope to improve adaptive capacity.

- Frontier analysis based on the positive relationship between the adaptation index and income levels suggests that distance to the frontier is large for several countries (Figure 36, panel 2). These countries—notably Brunei

[2]It is also the case that resilience matters for development as natural disasters may undo years of progress in growth and poverty reduction.

Figure 36. Adaptive Capacity and Exposure Indexes by Region



Source: IMF staff calculations based on 2015–18 data from the EU commission, the United Nations University Institute for Environment and Human Security, the University of Notre Dame, Phillis and others (2018), and the IMF World Economic Outlook database.
Note: Frontier analysis methodology: we fit a stochastic production model of log adaptive capacity with a single input, the logarithm of log GDP per capita in US dollars. The linear relationship between the two variables is estimated assuming disturbances that are a mixture of two components. One has a strictly nonnegative half-normal and the other a symmetric normal distribution. The linear coefficient is estimated to be 1.5 with a *p*-value below 0.001 and the null hypothesis of no technical inefficiency is rejected at the 0.001 level. Data labels in the figure use International Organization for Standardization (ISO) country codes.

Darussalam, Maldives, and Papua New Guinea—have low adaptive capacity relative to their per capita income. Brunei scores relatively low due to the lack of adequate disaster preparedness, vulnerabilities in the agricultural sector, and low scores on governance and business environment. Papua New Guinea's adaptive capacity is low due to fragile health and education systems as well as insecurity of water supply. But even the countries that are doing relatively well compared to peers need to continue strengthening their adaptive capacity (for example, Vietnam), given their high exposure to climate risks.

- Countries with high exposure to climate change risks tend to have lower adaptive capacity, even after controlling for income levels (Figure 36, panel 3). The vulnerable group of countries with low adaptive capacity and high exposure to climate risks includes Pacific island countries such as Micronesia, Solomon Islands, Tonga, and Vanuatu; low-income countries such as Bangladesh, Papua New Guinea, Myanmar, and Timor-Leste; and emerging market economies such as India, Indonesia, and the Philippines.

At the same time, countries in Asia and the Pacific have been at the forefront of adaptation efforts.

- *Disaster Risk Reduction (DRR)* is a systematic approach to identifying, assessing, and reducing natural disaster risks. Advanced economies as well as Thailand and Bhutan are best performers on adopting and implementing DRR frameworks, including at the local level (an indicator of progress under the UN Sustainable Development Goals (SDGs) for climate action). Indonesia's disaster recovery agency set up after the 2004 tsunami has become a role model (GFDRR 2017). Japan imposes requirements and targets for companies to adopt a business continuity plan in case of disasters. In the Indian state of Odisha, improvements in disaster preparedness, for example by developing evacuation procedures, contributed to a reduction of the death toll from hurricanes by more than 99 percent (World Bank 2013).
- *Mainstreaming adaptation in national budgets* allows adaptation needs to be considered in the context of other national development priorities, while transparently allocating budgets for climate-specific projects (Sawhney and Perkins 2015). Bangladesh, Cambodia, Nepal, the Philippines, and Vietnam were the first to prepare Climate Change Public Expenditure and Institutional Reviews (CPEIRs), followed by Fiji, Indonesia, Samoa, Thailand, and Tonga.[3] Building on the CPEIRs, Bangladesh, Cambodia, Indonesia, Nepal, and the Philippines have subsequently led the way in budget tagging as part of the routine, annual budget process (Hallegatte, Rentschler, and Rozenberg 2019).
- *National Adaptation Plans (NAPs)* have been adopted by many countries in the region (see Box 3). The integration of climate change into national policy is an action target under the climate action SDG. Some countries have included NAPs as part of their national climate change action plans (for example, China, Indonesia, the Philippines, Samoa, Sri Lanka), whereas others have chosen to develop a separate, more comprehensive, specific adaptation framework (for example, Maldives, Mongolia, Papua New Guinea, Thailand, and Vietnam). In some countries, NAPs are being complemented with adaptation plans at the local level. However, most

[3]CPEIRs contributed to budget marking and tagging in Indonesia and Nepal, assessing climate-related expenditure needs and sources of financing in Bangladesh's climate fiscal framework, climate change financing framework at national and subnational levels in Cambodia, and focused sectoral analyses in Cambodia and Thailand. See the website for the Governance of Climate Change Finance for Asia-Pacific.

countries in the region have yet to cost and prioritize their adaptation options, a clear next step toward strengthening the adaptation planning process (NAP-GSP 2016).

How Large Are the Region's Investment Needs to Adapt to Gradual and Repeated Adverse Climate Effects?

Strengthening climate resilience of physical assets is a key component of adaptation policies. Among various adaptation policies, investing in infrastructure resilience is by far the costliest (GCA 2018a) although it is essential for reducing climate hazards and safeguarding economic growth. Knowing the size of adaptation investment needs would be critical for policymakers in designing an affordable adaptation strategy.

We estimate costs for three types of public and private adaptation investment: upgrading new projects, retrofitting existing assets, and developing coastal protection infrastructure.[4] The costs for private and public assets are estimated for more than 25 countries in Asia and the Pacific as follows:[5]

- *Upgrading new projects.* Upgrading new investment projects with relatively minor tweaks in the design or choice of materials can help foster the resilience of capital stock against climate hazards over time. For example, new roads can incorporate drainage to sustain heavier rainfall or be built on more-elevated terrain to reduce flood risk. To estimate such upgrading costs, we start with annual investment projected during 2021–25 for private and public capital that is exposed to climate risks, and calculate additional costs needed for climate proofing. The share of capital exposed to climate risks by country is estimated by overlapping two detailed global maps, one on natural hazards and another on road and railway assets (Koks and others 2019).[6] The additional climate-proofing costs are set at 15 percent of total investment costs (World Bank 2019b).
- *Retrofitting existing assets* aims to modify existing capital stock exposed to natural hazards to improve resilience, and hence would be substantially more expensive than upgrading new projects. We compute annual retrofitting costs by estimating the value of capital stock that is exposed to natural

[4]We do not estimate the costs of other, relatively cheaper, components of adaptation such as strengthening early warning systems and improving productivity in agriculture. GCA (2018a) presents some of those estimates.

[5]See Annex 8 for details on the data and methodology.

[6]The cost of increasing resilience of exposed investment projects can also be expressed as a share of all investment projects including those that are not subject to climate hazards. Using this alternative metric, the costs represent a 3 percent increase (Hallegatte, Rentschler, and Rozenberg 2019).

hazards (using the same map-crossing methodology as above) and applying a strengthening unit cost of 50 percent that is spread over 10 years.[7]

- *Developing coastal protection infrastructure.* We present country-level cost estimates needed to build and maintain new infrastructure such as dikes and storm surge barriers, which correspond to the global-level estimates presented in Rozenberg and Fay (2019). Annual costs include investment and maintenance costs, assuming a 10-year construction period.

On average, upgrading new investment projects for climate resilience would cost 0.7 percent of GDP annually for 2021–25 in Asia and the Pacific. The country-by-country estimates are presented in Figure 37. Upgrading costs are 33 percent larger in emerging market economies and low-income countries than in advanced economies, reflecting both higher exposure and public investments. The costs are relatively high in Indonesia, Lao P.D.R., and the Philippines because of the significant exposure of physical capital to climate risks, and in China, Bangladesh, and Myanmar because of their large investment plans. The costs are higher for private investment (0.55 percent of GDP) than for public investment (0.13 percent of GDP). This follows because private investment is much larger than public investment in the region, while public investment is more important in emerging market economies (accounting for one-fifth of total investment) and low-income countries (a quarter) than in advanced economies (5 percent).

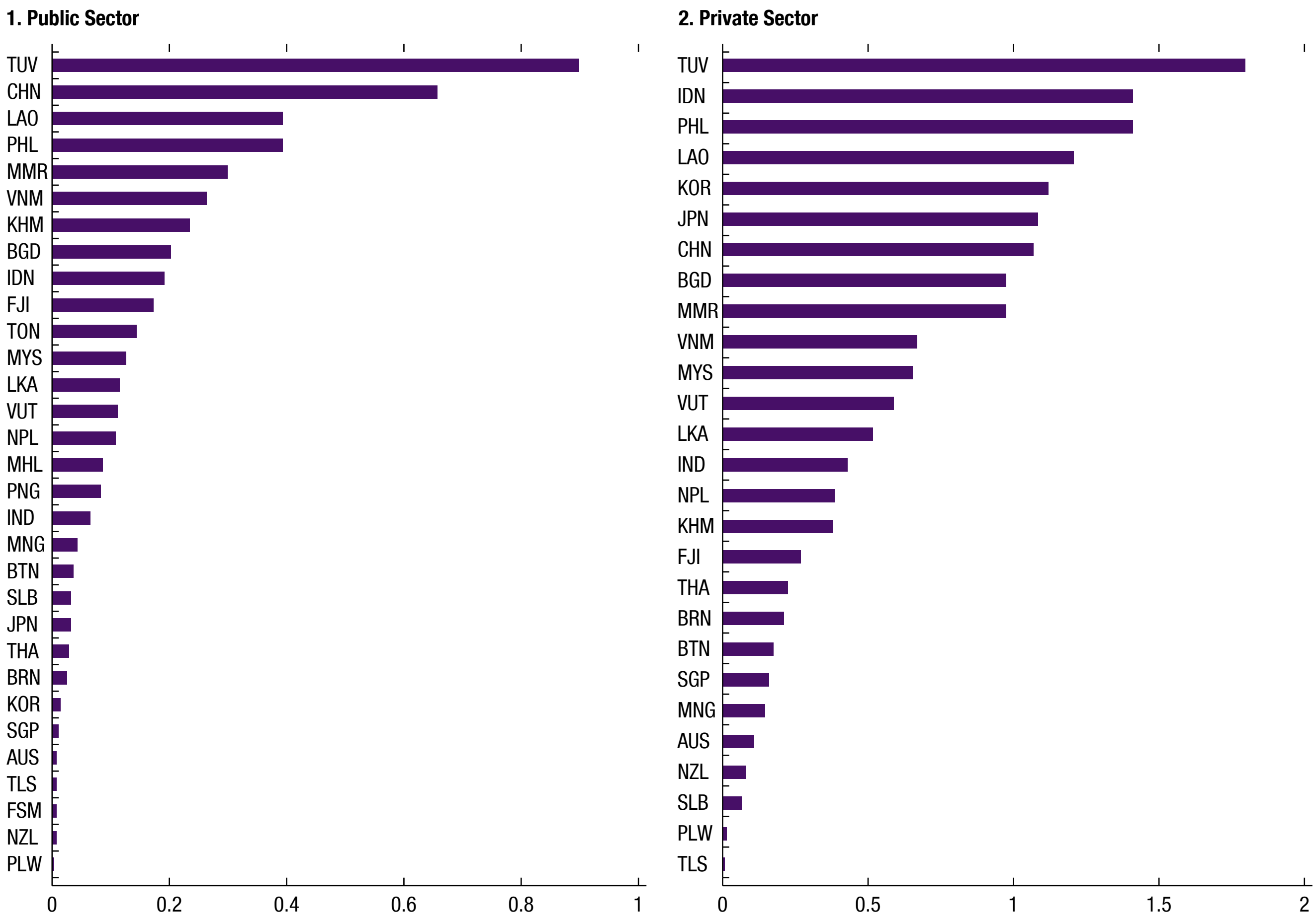
Retrofitting existing assets is more expensive, with average costs estimated at 2.3 percent of GDP annually for 10 years in the region. The estimated costs, shown in Figure 38, are particularly large in advanced economies (3.3 percent of GDP on average), especially for private assets (2.3 percent of GDP). They are also large in Indonesia and Lao P.D.R., where the share of physical capital exposed to hazards is high. The high costs highlight the importance and urgency of starting to build better to avoid further accumulation of vulnerable assets (Hallegatte, Rentschler, and Rozenberg 2019).

The costs of developing coastal protection infrastructure differ significantly across countries and crucially depend on risk tolerance. Panel 1 in Figure 39 presents estimated annual costs, assuming a “cost-minimizing” strategy (aimed at minimizing the sum of the expected investment costs and residual flood damage). As expected, costs are disproportionately high in many Pacific island countries, averaging almost 8 percent of GDP annually for the group.[8] The costs are also significant in Myanmar, Timor-Leste, and Vietnam, ranging between 1 and 5 percent of GDP. Under an alternative, “risk-intolerant”

[7]Adaptation plans frequently refer to 10-year horizons for large project implementation (IMF 2020c, Climate Change Secretariat of Sri Lanka 2016).

[8]In the case of small island countries, the estimation techniques that rely on topological information are less accurate because the maps’ definition becomes relatively less precise.

Figure 37. Additional Annual Adaptation Costs of Upgrading New Projects
(Percent of GDP)

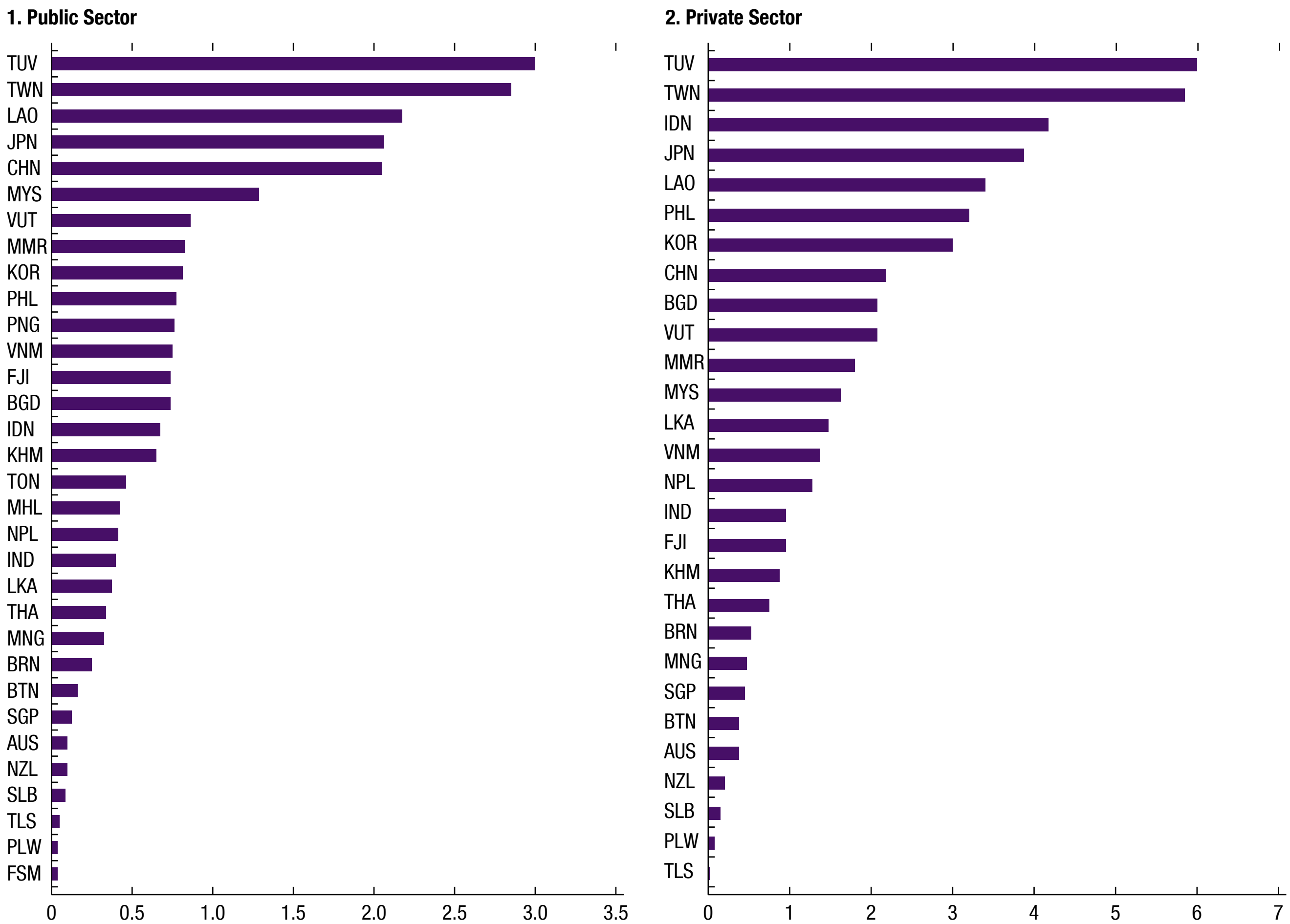


Sources: Hallegatte, Rentschler, and Rozenberg (2019); Nicholls and others (2019); Rozenberg and Fay (2019); IMF, Capital Stock 2019 Dataset; IMF, World Economic Outlook database; and IMF staff calculations.
Note: All estimates are at the country level. Upgrading cost estimates are constructed using projected investment spending, the likely exposure of investment projects, and upgrading unit costs. Retrofitting costs are constructed using capital stock estimates, estimates of the average exposure of physical assets, and retrofitting unit costs. Coastal protection estimates were obtained with the methodology of Rozenberg and Fay (2019). Data labels in the figure use International Organization for Standardization (ISO) country codes.

strategy (aimed at building coastal protection infrastructure that limits average losses below 0.01 percent of GDP), estimated costs are higher, averaging 9.1 percent of GDP annually for small Pacific island countries (Figure 39, panel 2).

Overall, public sector investment costs for adaptation are disproportionately high in countries exposed more to climate hazards, especially in a few Pacific island countries. As shown in Figure 40, public investment needs for making infrastructure climate resilient are estimated to average 3.3 percent of

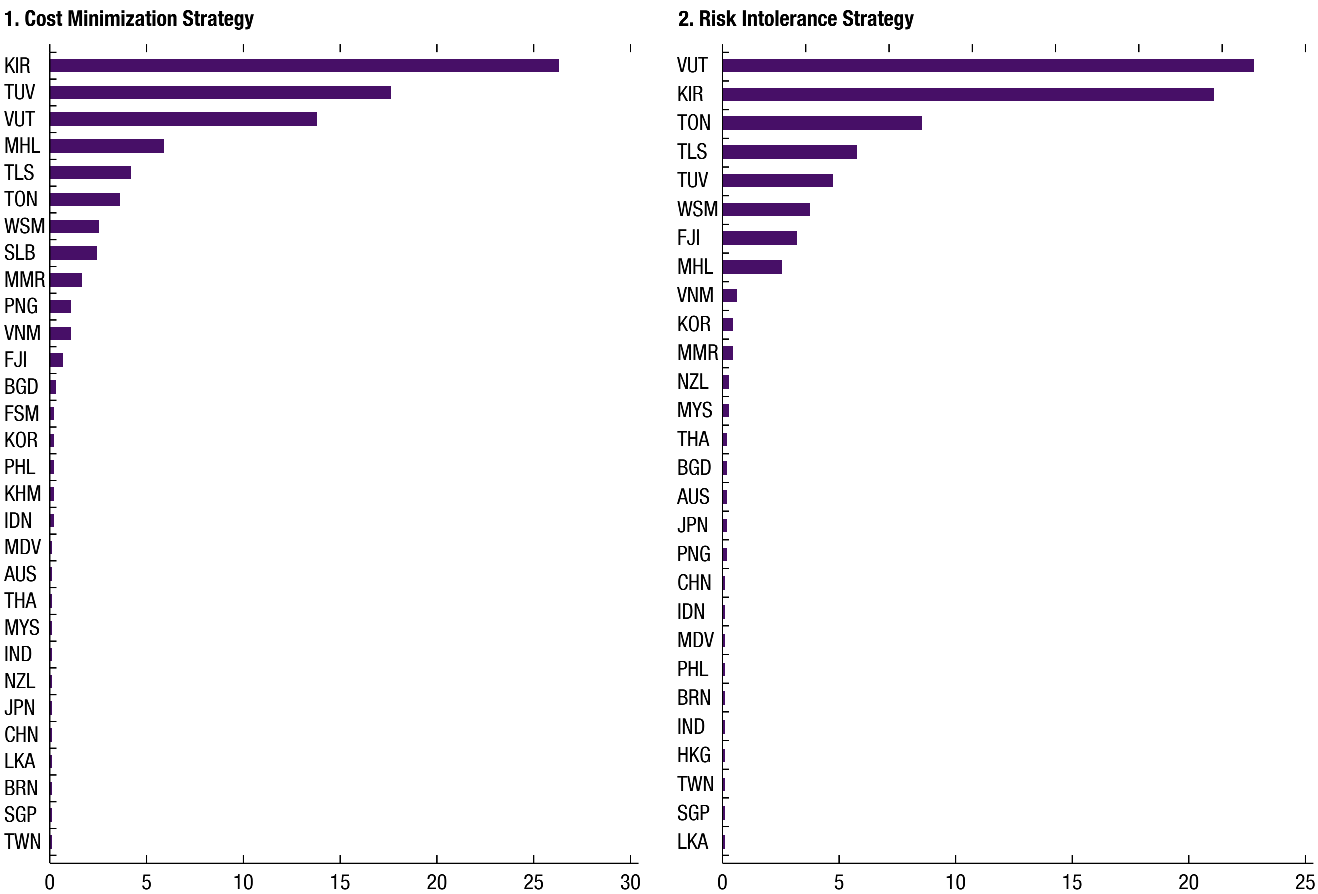
Figure 38. Annual Adaptation Costs of Retrofitting Existing Physical Assets by 2030
(Percent of GDP)



Sources: Hallegatte, Rentschler, and Rozenberg (2019); Nicholls and others (2019); Rozenberg and Fay (2019); IMF Capital Stock 2019 Dataset; IMF, World Economic Outlook database; and IMF staff calculations.
Note: All estimates are at the country level. Upgrading cost estimates are constructed using projected investment spending, the likely exposure of investment projects, and upgrading unit costs. Retrofitting costs are constructed using capital stock estimates, estimates of the average exposure of physical assets, and retrofitting unit costs. Coastal protection estimates were obtained with the methodology of Rozenberg and Fay (2019). Data labels in the figure use International Organization for Standardization (ISO) country codes.

GDP annually for the region. Pacific island countries have the highest public investment needs for adaptation due to their expensive coastal protection infrastructure needs. Other countries, such as China, Indonesia, Japan, Lao P.D.R., and the Philippines also face high public investment needs owing to their high stock of exposed assets. Country-specific adaptation challenges will require separate and sector-specific analyses. For Tonga, for example, a recent Climate Change Policy Assessment conducted by the IMF and the World Bank reported climate-related investment needs (of which adaptation invest-

Figure 39. Annual Investment and Maintenance Costs to Protect Coasts by 2030
(Percent of GDP)

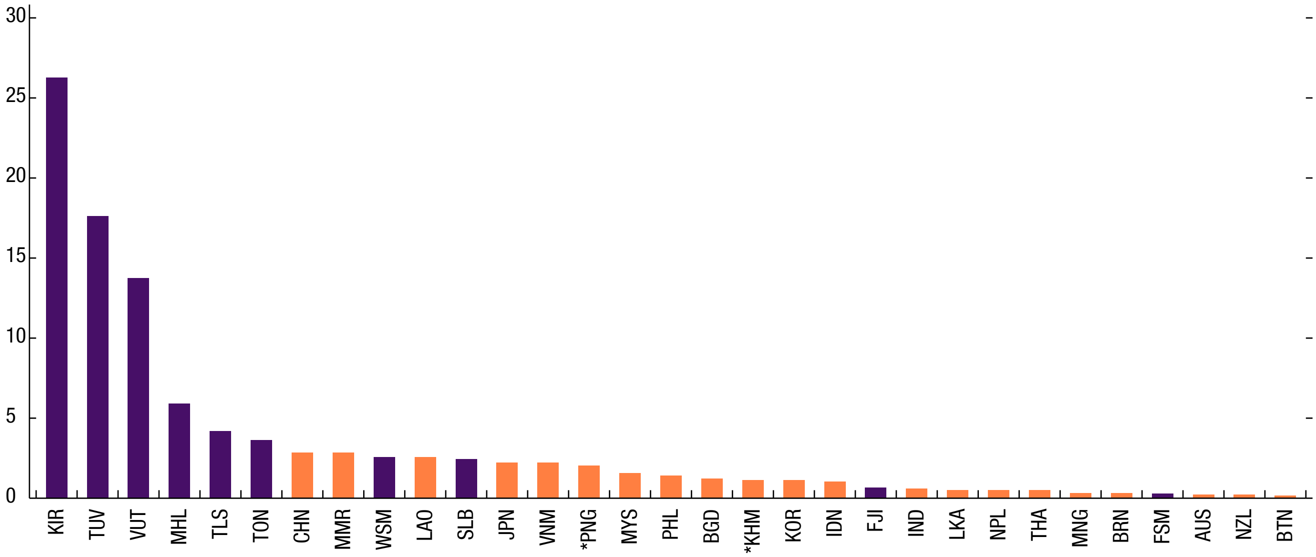


Sources: Hallegatte, Rentschler, and Rozenberg (2019); Nicholls and others (2019); Rozenberg and Fay (2019); IMF Capital Stock 2019 Dataset; IMF, World Economic Outlook database; and IMF staff calculations.
Note: All estimates are at the country level. Upgrading cost estimates are constructed using projected investment spending, the likely exposure of investment projects and upgrading unit costs. Retrofitting costs are constructed using capital stock estimates, estimates of the average exposure of physical assets, and retrofitting unit costs. Coastal protection estimates were obtained with the methodology of Rozenberg and Fay (2019). In panel 1, the level of protection corresponds to the protection that minimizes the sum of protection costs and residual flood damage to assets. In panel 2, the level of protection corresponds to the protection that keeps average annual losses below 0.01 percent of local GDP for protected areas. See Annex 8 for methodological details. Data labels in the figure use International Organization for Standardization (ISO) country codes.

ment accounts for a major part) at 14 percent of GDP annually for 10 years (IMF 2020c). According to the United Nations Development Programme, common challenges related to adaptation needs in the East and Southeast Asia region include improving water resources management; agriculture productivity; and flood, cyclone, and coastal protection.[9]

[9]https://web.archive.org/web/20191204165901, https://www.adaptation-undp.org/explore/south-eastern-asia.

Figure 40. Public Annual Adaptation Costs
(Percent of GDP)



Source: IMF staff calculations.
Note: The purple bars represent Pacific island countries, and the orange bars represent all other Asia-Pacific countries. Bars correspond to the sum of upgrading and retrofitting costs in the public sector and coastal protection costs. The level of protection being costed corresponds to the protection that keeps average annual losses below 0.01 percent of local GDP for protected areas. Data labels in the figure use International Organization for Standardization (ISO) country codes.
*Missing values in the risk intolerance case for Cambodia and for the private sector for Papua New Guinea.

To keep adaptation investment affordable, it is crucial to ensure efficient selection, execution, and maintenance of investment projects. Although damage risks from climate hazards can never be eliminated, there is scope to reduce them by designing and spending infrastructure investment wisely. For example, physical assets that face small climate risks or that are less essential to the rest of the economy may not need strengthening. Assets in areas that face overwhelming climate risks can be relocated, possibly rebuilt, when cost effective. Substitution with cheaper design or lower quality material at the construction stage and skimping on maintenance can undermine the benefits of adaptation investment. Although adaptation investment is costly, when countries are evaluating these projects they need to consider their broader benefits beyond climate resilience. For example, effective coastal management in Fiji could raise fisheries productivity (Fiji 2017).

What Are the Implications of Scaling Up Adaptation Investment for Growth and Debt Sustainability?

Investing in adaptation infrastructure can yield high returns but is fiscally costly. By increasing economic resilience, adaptation investment is crucial to

Table 6. Adaptation Costs and Pre-COVID Fiscal Space

	At least some fiscal space or moderate/low risk of debt distress	At-risk fiscal space or high risk of debt distress
Public adaptation costs above 1 percent of GDP	China, Bangladesh, Cambodia, Indonesia, Japan, Korea, Myanmar, Papua New Guinea, Philippines, Solomon Islands, Timor-Leste, Vanuatu, Vietnam	Fiji, Kiribati, Lao P.D.R., Malaysia, Maldives, Marshall Islands, Micronesia, Tonga, Tuvalu, Samoa
Public adaptation costs below 1 percent of GDP	Australia, Bhutan, Nepal, New Zealand, Singapore, Thailand	India

Sources: Hallegatte, Rentschler, and Rozenberg (2019); Nicholls and others (2019); Rozenberg and Fay (2019); and IMF staff reports and staff calculations.
Note: Fiscal space assessments are estimated for advanced and emerging market economies and are based on the last published IMF Article IV debt sustainability assessment; risks of debt distress estimated for low-income countries and are taken from the last published debt-sustainability assessment. These assessments were performed pre-COVID and do not reflect the developments since the outset of the pandemic.

mitigate natural disaster damage and disruption and to save on post-disaster recovery costs (IMF 2020a).[10] Studies report that returns to climate adaptation investment can exceed 100 percent (Hallegatte, Rentschler, and Rozenberg 2019; GCA 2018a). In the post COVID-19 era, public investment in adaptation can support economic recovery by boosting demand. On the other hand, financing large adaptation investment will challenge fiscal space in many countries, which has deteriorated due to the COVID-19. Table 6 highlights countries with high adaptation costs and limited fiscal space even before the COVID-19, which include Pacific island countries with high debt levels. For many countries, the pandemic has further reduced fiscal space. With such worsening of the growth-debt trade-off, financing adaptation costs in these countries may require strengthening domestic revenue mobilization, expenditure rationalization, a prioritization of adaptation investment, or grant financing. Part of additional revenues from carbon taxes, net of compensation costs for those affected, could be channeled to finance adaptation investment.

We explore the growth-debt trade-off of boosting adaptation investment through illustrative model simulations. We use a dynamic general equilibrium model outlined in Marto, Papageorgiou, and Klyuev (2018) to illustrate macroeconomic implications of a natural disaster for a typical low-income country or emerging market economy.[11] The model distinguishes between public investment in cheaper standard infrastructure and costlier adaptation infrastructure. Although investing in adaptation infrastructure results initially in higher public debt, it improves resilience of the economy by reducing: (1) the adverse impact of natural disasters on output, (2) damages to physical

[10]While unrelated to climate change adaptation, case studies of the 2011 earthquake in New Zealand show that the US$6 million spent to strengthen infrastructure reduced asset replacement costs by between US$30 and US$50 million (Hallegatte, Rentschler, and Rozenberg 2019).

[11]See Annex 9 for details on the methodology. Agarwal and others (forthcoming) use this model to study the impact of natural disasters in Maldives finding similar takeaways.

assets, and (3) post-disaster fiscal costs for rebuilding and lifeline support. To analyze this trade-off, we compare scenarios of no (additional) investment, investment in standard infrastructure, and investment in adaptation infrastructure, and examine paths of growth and public debt after a large natural disaster hit the economy. Investment is financed by commercial debt and takes place over five years before the disaster strikes (in year 6), as reaping benefits from disaster resilience would require substantial accumulation of adaptation investment.

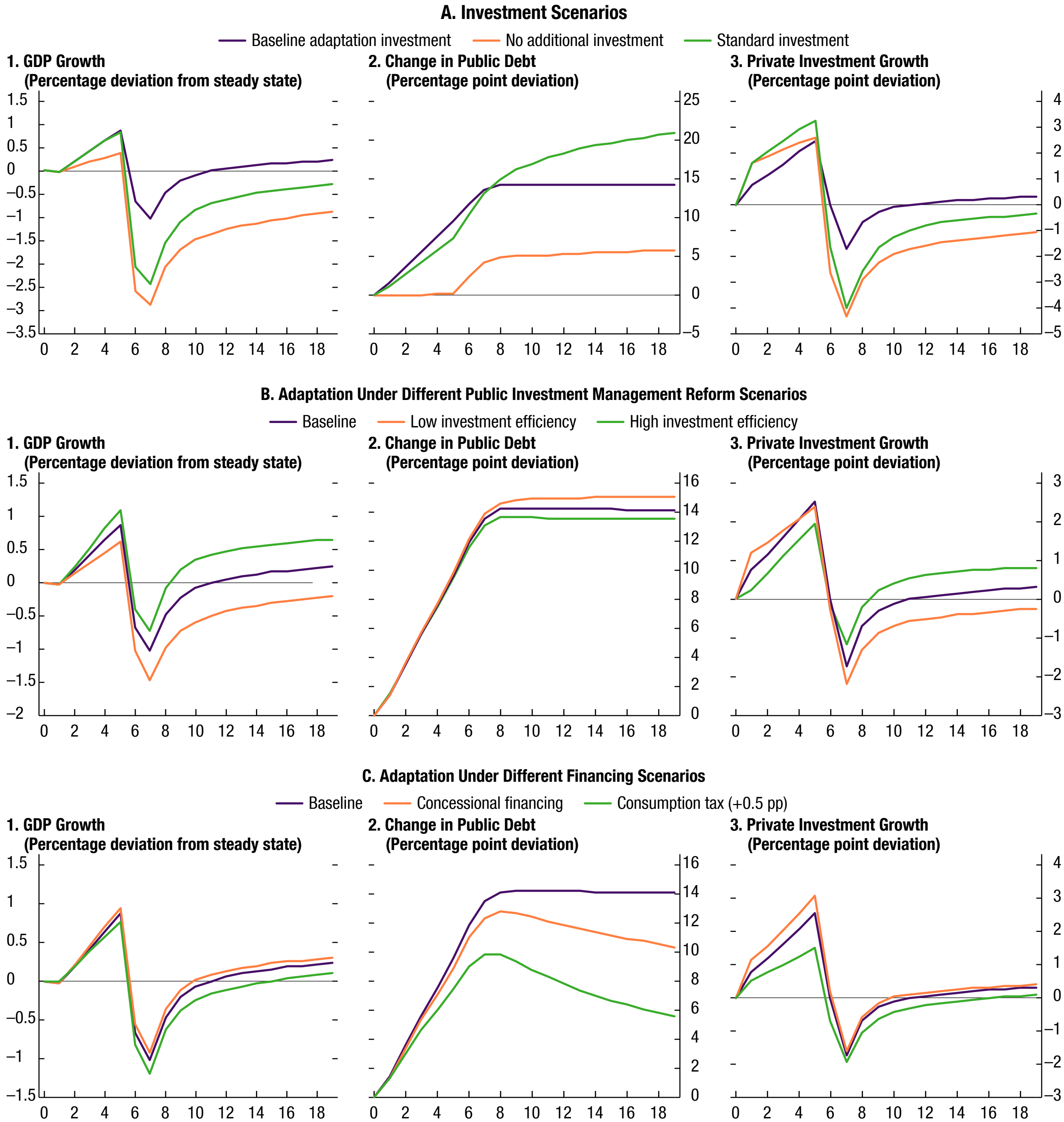
Adaptation investment, albeit costly, can make the economy resilient against natural disasters, limiting a post-disaster rise in public debt. The growth and public debt paths for the three investment scenarios are shown in Figure 41, panel A. Post-disaster output losses are softened in the adaptation investment scenario, by more than half compared to the scenarios of no additional investment and standard investment. Private investment is also more resilient under the adaptation investment scenario because adaptation infrastructure provides protection to private assets and mitigates productivity losses, raising returns to private investment and spurring output growth. Embarking on more expensive adaptation investment implies higher public debt in initial years. Unlike the standard investment scenario, however, the debt level stabilizes over the long term due to smaller and less-persistent output losses and smaller reconstruction needs.

Better public investment management can lessen the growth-debt trade-off for adaptation investment. Weak management can lead to poor maintenance and wasteful investment in low-exposure areas or in assets that should be relocated because of overwhelming risks.[12] The benefits of improved public investment management (PIM) efficiency are illustrated in Figure 41, panel B. If PIM efficiency improves from the lowest levels observed in the region ("low investment efficiency" scenario in panel B) to those of best performers ("high investment efficiency" scenario), output resilience against natural disasters further improves and public debt paths are brought down. The results echo those for the Solomon Islands (IMF 2018), which show that PIM reforms amplify the benefits of adaptation investment.

Financing adaptation investment with concessional external financing or revenue mobilization can also alleviate the growth-debt trade-off. Alternative financing options for adaptation investment are examined in Figure 41, panel C. Financing adaptation investment with foreign concessional loans can put public debt on a decreasing path after the disaster by freeing up resources to repay debt faster. Foreign concessional financing also reduces domestic

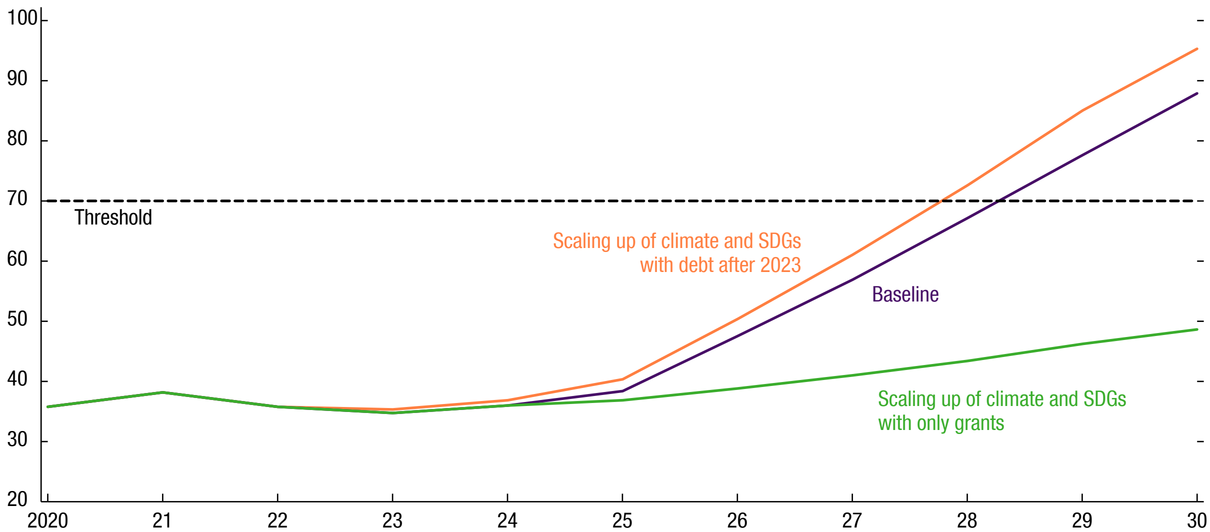
[12]For all types of public infrastructure, the literature estimates that more than one-third of the funds spent on creating and maintaining them are lost because of inefficiencies in their infrastructure governance (IMF forthcoming).

Figure 41. Simulated Impacts by Year of a Natural Disaster under Different Scenarios



Source: IMF staff calculations.
Note: Simulations are produced with the model outlined in Marto, Papageorgiou, and Klyuev (2018). The model is matched with an economy whose macroeconomic indicators are averages for developing economies in Asia and the Pacific. A natural disaster occurs in year 6 and is calibrated to yield a 3 percentage point decline in GDP growth in the scenario with no additional investment (baseline). In panel A, we assume an additional public investment of 2 percent of GDP relative to the no additional investment scenario in years 1–5 in standard infrastructure and in adaptation infrastructure. In panel B, the efficiency of public investment is calibrated at 60 percent in the baseline, at 30 percent in the low efficiency scenario, and at 90 percent in the high-efficiency scenario, based on Ghazanchyan and others (2017). In panel C, three options are considered for financing additional adaptation investment commercial debt (as in panel A), external concessional financing, and an increase in consumption tax.

Figure 42. Tonga's Public Debt to GDP Sustainability Analysis in a Natural Disaster Scenario
(Present value, 2019–29)



Source: Kingdom of Tonga: Climate Change Policy Assessment (IMF 2020c).
Note: A natural disaster shock is assumed to hit in 2021 and reduce economic growth by more than 3 percentage points, with exports contracting by 7 percentage points of GDP. SDGs = UN Sustainable Development Goals.

financing needs by the government and avoids crowding out private investment. Alternatively, countries can mobilize domestic revenues to finance adaptation investment. A consumption tax increase can put public debt on a faster declining path than under the concessional financing scenario, even though the tax burden negatively affects output by depressing private demand. While not included in the simulations in panel C, rationalizing government spending can also put public debt on a declining path.

For the most vulnerable countries, adaptation investment and post-disaster reconstruction costs would be difficult to accommodate without donor funding. Without additional resources, natural disasters could push vulnerable countries like Vanuatu (IMF 2018) or Tonga (IMF 2020c) into debt distress. Because of climate change, more intense natural disasters are likely to provide larger shocks to economic activity, lead to substantial and unanticipated fiscal financing gaps, and further jeopardize already weak growth and high debt vulnerabilities, as illustrated in the Climate Change Policy Assessment for Tonga (Figure 42). The donor community can provide critical support for enhancing the economic resilience and debt sustainability of such vulnerable countries by providing grants for financing adaptation spending.[13]

[13]Cantelmo, Melina, and Papageorgiou (2019) find that, for a given improvement in welfare derived from international aid, it is more cost-effective for donors to contribute to the financing of resilience *before* the realization of disasters, rather than disbursing aid for reconstruction *after* disasters' realizations.

Box 2. Indices for Climate Change Adaptation

Adaptation indices typically aim at assessing a country's vulnerabilities to climate change by combining information about the country's exposure to adverse climate events and the country's capacity to reduce and cope with these events.

There have been a flurry of adaptation indices from a range of institutions, such as the European Commission Index for Risk Management (INFORM), the United Nations University Institute for Environment and Human Security World Risk Index (WRI), the Notre Dame Global Adaptation Index (ND-GAIN), and the Fuzzy Assessment of Climate Security (FACS) by Phillis and others (2018). Yet there is no consensus on the best approach to measure adaptation capacity.

Adaptation indices are usually broken down into three components: (1) exposure to natural hazards; (2) vulnerability, sensitivity, and susceptibility to these hazards; and (3) the lack of coping or adaptive capacity. Each of these components is constructed by aggregating geographic, climate, socioeconomic, and institutional indicators.

Although adaptation indices and their components are usually well correlated across sources, they can differ substantially for some countries. For example, Vanuatu is ranked as one of the lowest among 30 countries in Asia and the Pacific for some indices (30th for ND-GAIN, 24th for WRI) but average for others (17th for FACS and INFORM).

Overall, differences among sources come from (1) inconsistent definitions, (2) imperfectly overlapping coverage of the types of vulnerabilities, and (3) differences in aggregation methods.

Box Table 2.1. Correlations of Adaptation Indices from Different Sources

	INFORM	WRI	ND-GAIN	FACS	GDP per Capita
INFORM	1				
WRI	0.32	1			
ND-GAIN	0.83	0.44	1		
FACS	0.72	0.34	0.86	1	
GDP per capita	−0.64	−0.35	−0.77	−0.64	1

Source: IMF staff calculations based on 2015–18 data from the European Commission, the United Nations University Institute for Environment and Human Security, the University of Notre Dame, Phillis and others (2018), and the IMF World Economic Outlook database.

Note: FACS = Fuzzy Assessment of Climate Security; INFORM = European Commission, Index for Risk Management; ND-GAIN = Notre Dame Global Adaptation Index; WRI = United Nations University Institute for Environment and Human Security, World Risk Index.

Box 2. Indices for Climate Change Adaptation *(continued)*

We construct country-by-country composite indices on adaptive capacity and exposure to climate change risks, using INFORM, WRI, and ND-GAIN, for which we were able to obtain disaggregated information. The composite index on adaptive capacity measures the vulnerabilities coming from socioeconomic, infrastructure, and institutional characteristics, and the index on exposure to climate change risks measures essentially exogenous vulnerabilities based on the physical characteristics of natural disasters.

We use the average of the standardized values of the three sources. This approach is robust against alternative approaches: results from a principal component analysis do not meaningfully change the result, and narrowing the definition of adaptive capacity to include only characteristics that can be directly affected by policy yields very similar results.

Box 3. What Are National Adaptation Plans?

As the adverse effects of climate change become clear, it has become increasingly important for countries to draft plans to adapt to new climate expectations. These plans are distinct to a country's circumstances and have been formed independently over the last few decades starting with many advanced economies.

The national adaption plan (NAP) process was established under the Cancun Adaptation Framework agreed in 2010, with two objectives in mind: 1) to reduce vulnerability to climate change by increasing adaptive capacity and resilience and 2) to facilitate the integration of adaptation into new and existing policies, programs, and activities within all relevant sectors (Figure 3.1).[1] To address those principles effectively, four guidelines were created:[2]

- **Lay the groundwork and identify information and administration gaps.** This includes taking stock of available information on climate change impacts, identifying capacity gaps and weaknesses in terms of planning for adaptation, and finding synergies between development and adaptation goals.
- **Strategic orientation and preparation.** This involves analyzing current and future climate scenarios; assessing climate vulnerabilities and identifying potential solutions that coincide with national development plans, including their costs; and communicating these plans to the public.
- **Implementation strategies.** This involves mainstreaming climate adaptation into national planning, enhancing the capacity for adaptation planning and implementation across all levels of governments and sectors of the economy, and developing a long-term NAP that includes potential financing measures. For example, Australia's National Adaptation Strategy for Coasts (CoastAdapt) lays out alternative mechanisms of financing[3] such as tradeable development rights and infrastructure charges.[4] Many Nationally Determined Contributions (NDCs) also include some estimates of adaptation costs (GCA 2018b).
- **Report, monitor, and review.** Continually monitoring progress made, reevaluating the adaptation plan, and regularly updating it are essential elements of creating an effective NAP. An example of this is the Korean government's establishment of the Korea Adaptation Center for Climate Change that ensures effective progress in implementation as part of its NAP in 2009.

This box was prepared by Joey Kilpatrick.

[1]Report of the Conference of Parties on its Seventeenth Session, Addendum 1 (2012).

[2]LDC Expert Group. 2012. National Adaptation Plans: Technical Guidelines for the National Adaptation Plan Process.

[3]Ware (2016).

[4]"Infrastructure charges (sometimes called 'developer charges' or 'developer contributions') are fees levied on developers to compensate governments for providing facilities necessary for land development." (Henry 2009).

Box 3. What Are National Adaptation Plans? *(continued)*

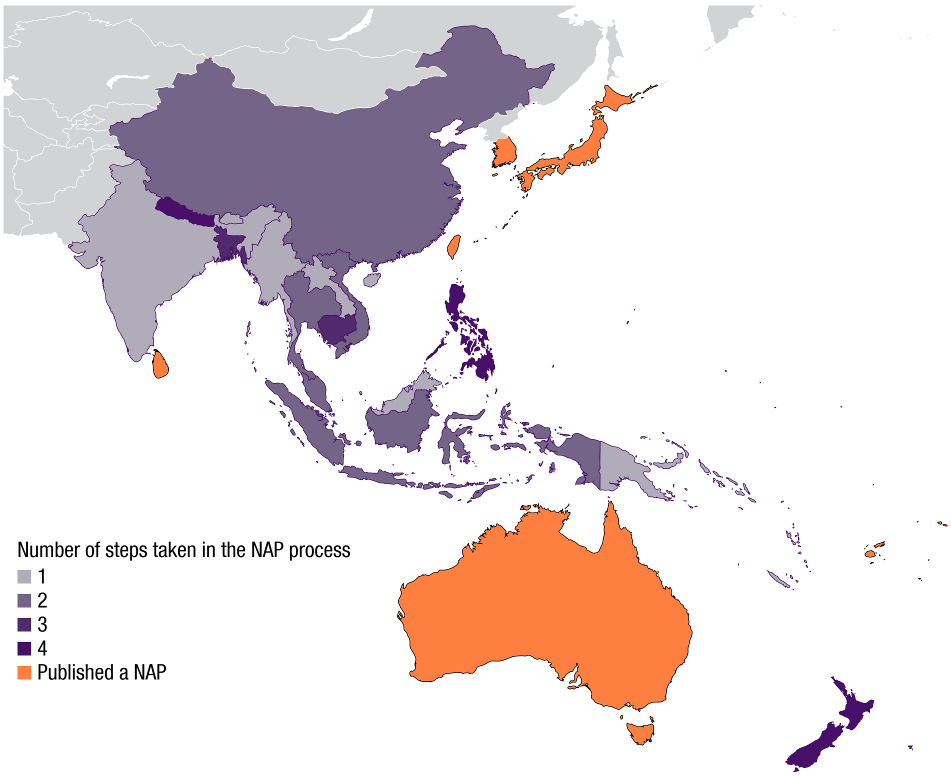
These guidelines are purposefully broad, as NAPs will vary widely based on a country's specific national processes in implementation, national goals, the relevance of sectors in the economy, and the heterogeneous effects of climate change. Kiribati's NAP, for example, places emphasis on gender-inclusivity, requiring relevant programs to release gender-disaggregated data as an effort to ensure equitable access.[5]

As of today, nine countries in Asia and the Pacific have published a NAP; all others have made progress toward at least one part of the process (Figure 3.1). Using the step scoring described in Figure 3.1, the region's score for NAP preparation is above average compared to the rest of the world (a score of 1.97 compared to 1.68).

[5]Kiribati Joint Implementation Plan for Climate Change and Disaster Risk Management, 2019–28.

Box 3. What Are National Adaptation Plans? *(continued)*

Box Figure 3.1. Progress Toward NAPs in Asia and the Pacific



Sources: Summary on Progress on NAPs (https://unfccc.int/topics/adaptation-and-resilience/workstreams/national-adaptation-plans); UNFCCC (2019); and IMF staff analysis.
Note: The figure is created from the UNFCCC table of progress on national adaptation plans (NAPs) as follows. The technical guidelines by the United Nations consists of four elements: (1) laying the groundwork and addressing gaps; (2) strategic orientation and preparation; (3) implementation strategies; and (4) reporting, monitoring, and review. The number of steps taken in the NAP process represents the number of the elements a country has completed (at least one measure in each element is taken; the country is deemed to complete that element). Four countries (Malaysia, Marshall Islands, Micronesia, and Palau) were not in the UNFCC database, but considered to have taken one step because documents were found that showed progress had been made in creating an adaptation plan. For advanced economies, independent research verified the status of their respective NAPs.

Chapter

5 Supporting Green Investment and Promoting a Green Recovery

The COVID-19 crisis provides a unique opportunity to support green investment. Fiscal stimulus packages can play an important role in "greening" the recovery from the COVID-19 by promoting innovations and investment in climate-smart technologies. An initial green investment push would strengthen the macroeconomy in the near term while lowering the costs of adjusting to higher carbon prices. Some countries in Asia and the Pacific have introduced policy packages with green measures, but more can be done.

Green investments can complement efforts to tackle climate change in Asia and the Pacific. While carbon pricing and other complementary non-tax mitigation measures should be at the heart of the mitigation strategy for the region, its effectiveness to phase out carbon-intensive activities will be further enhanced by investments in climate-smart technology and infrastructure. In fact, early use of green research and development subsidies can lower the carbon tax rate required to achieve the lower-emissions targets. Green investments also ameliorate the negative economic impact of mitigation measures—IMF (2020d) finds that an initial green investment push, combined with steadily rising carbon prices, deliver the goal of net zero emissions by about 2050 at reasonable transitional global output costs. The transition to a green economy will also diminish climate hazards and reduce adaptation costs in the long term.

Promoting green sectors, such as renewable energy and electric car production, can boost employment in the short and long term. Green sectors are typically more labor-intensive than the shrinking carbon-intensive sectors (such as fossil fuel energy, transportation, heavy manufacturing). For example, renewable energy sources have a larger employment multiplier than dirty energy (IMF 2020d). In addition, while these green jobs require more specialized skills, they have lower educational requirements and better pay than the national averages (Muro and others 2019).

Facilitating the shift to a green economy requires complementary fiscal policies.[1] Robust carbon pricing can provide across-the-board incentives for green innovation (Farid and others 2016). However, in the absence of direct policy support, the market may be slow to deliver green investments at the needed scale. This is particularly the case for network infrastructure which requires coordination and has public good properties (for example, electricity grids). Private sector R&D in green technologies undertaken by one firm may increase productivity in other firms through knowledge spillovers.[2] These positive externalities imply that market forces will lead to an under-investment in R&D in green technologies compared to the level that is socially efficient. Firms developing or pioneering the use of green technologies cannot capture spillover benefits to rival firms that can imitate these technologies or benefit from "learning-by-doing" experiences with the technology.

Fiscal policy can play an important role in promoting R&D and innovation in new energy-efficient technologies and incentivizing green investment. Fiscal incentives such as direct subsidies, price guarantees, and tax incentives can lower the private cost of R&D so that firms are inclined to invest more (IMF 2016a). Given the potential for large spillovers, there may also be scope for direct public investment in low-carbon technologies and infrastructure that are far from ready for market but may ultimately be critical for a low-carbon transition. Incentives for applied R&D may also be needed, for example through patents and technology prizes. Once new technologies are ready for the market, their adoption by households (for example, low-emission cars) and firms (for example, wind energy) is often heavily subsidized—even though spillovers at this stage are generally weaker than for basic and applied research (IMF 2016a). Such deployment incentives should be phased out as technologies mature to avoid a misallocation of resources.

Multilateral institutions and green bonds can play a pivotal role in financing green investment. Global efforts for promoting and financing the transfer of environmentally sound technologies to developing countries—a mandate of developed countries under the UNFCCC—should be stepped up. Many small states and low-income developing countries (LIDCs) in Asia and the Pacific rely on multilateral climate funds such as Green Climate Fund, Global Environment Facility, and Climate Investment Funds for their mitigation and adaptation needs. Expanding these funds and improving their accessibility would drive growth in green sectors. For example, the Asian Development Bank and the Green Climate Fund have agreed to partner toward a green recovery from the COVID-19 pandemic. Many large economies are also

[1]The term "green" often refers to all types of environmental and ecological issues, but this paper focuses solely on climate.

[2]Evidence suggests that clean-energy R&D, especially in early-stage technologies, tends to generate large knowledge spillovers, with applications outside the energy sector as well (Popp 2002).

tapping into green bonds to promote R&D and green investment in private sector. In fact, China was the leading green bond issuer in the world in 2019 at $22.9 billion (McGrath 2020). Green bond markets expanded rapidly in the Philippines to about $2.6 billion in 2020 (Climate Bonds Initiative 2020). An aggressive investment policy would be affordable and desirable in the next decade for governments as interest rates for many large emitters are likely to stay low for long.

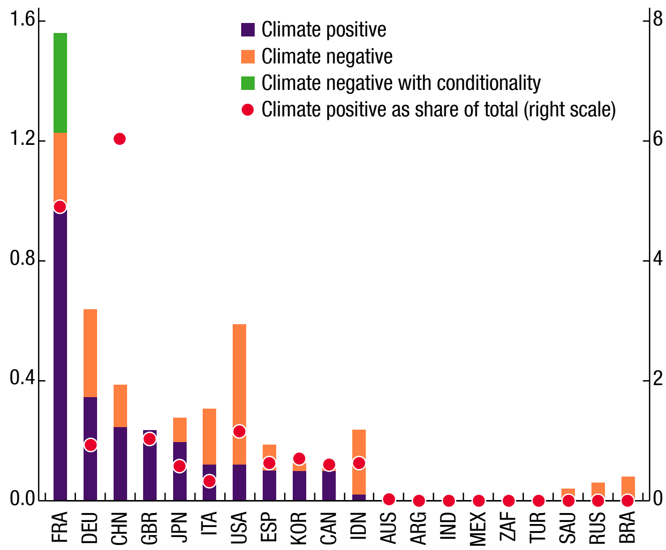
As many countries in the region implement fiscal stimulus measures toward a post COVID-19 recovery, support for green investment should be prioritized. Providing fiscal support for green R&D and investment would stimulate aggregate demand in the short term while helping the gradual phase-in of higher carbon prices once the recovery is entrenched. Government support for deployment of green technologies would also have the added benefit of boosting productivity and employment (IMF 2020b, Hepburn and others 2020). Prioritizing climate-smart infrastructure (for example, renewable energy, modernizing the electric grid, public transport, improving digital infrastructure), and developing and adopting climate-smart technologies (for example, carbon storage and capture) could also be considered. Importantly, policy support packages should avoid locking in excessive investment in carbon-intensive capital that might become stranded.

Policy packages announced by countries in Asia and the Pacific include some green measures for the transport, industry, and energy sectors, but more can be done. For example, China provided subsidies or incentives for more energy-efficient vehicles, while Korea provided tax rebates for more energy-efficient home appliances and Indonesia offered subsidies for palm oil biodiesel fuels (IMF 2020a). Other measures include loans and grants for green investments, such as building climate-resilient infrastructure in Japan. Some countries have made explicit climate commitments as part of their recovery response. For example, Korea plans to invest an additional 0.6 percent of GDP by 2022 in its new green deal. Since the onset of COVID-19, governments across the world have provided policy support totaling about US$12 trillion. So far, however, little of the global COVID response has been "green" (IMF 2020b; Figure 43). There is much scope to make policy packages greener, especially as the response moves from the emergency/containment phase (with a heavy health focus) to the stimulus/recovery phase (with a greater investment focus).

Good communication and the efficient and transparent use of public funds are paramount to building support for greening the recovery. Green investments need to adhere to the best practices in public investment management (IMF 2015, Dabla-Norris and others 2012). They need to be appraised, vetted, selected, and procured following transparent criteria and credible

Figure 43. Climate Relevance of Fiscal Measures in the G20 Related to the COVID-19 Crisis

(Percent of GDP, left scale; percent of total, right scale)



Source: IMF, October 2020 *Fiscal Monitor*.

Note: Measures are categorized into positive and negative policy archetypes, based on the climate relevance of specific activities. A similar methodology is applied in the Greenness of Stimulus Index (https://www.vivideconomics.com/casestudy/greenness-for-stimulus-index). Data labels use International Organization for Standardization (ISO) country codes.

estimates of benefits and costs. Strong project management and regular and timely progress reports are critical to avoid delays and cost overruns. Accountability needs to be guaranteed by public oversight, effective audits, and an independent judiciary. Along the process, decisions and their rationale need to be communicated to the public and support mechanisms need to be implemented for any groups negatively affected by the projects.

Annex 1. Paris Agreement Pledge by Countries in Asia and the Pacific

Annex Table 1.1. Paris Mitigation Contributions and Emissions Data, Selected Countries

		2030 BAU		
Country	**Paris Mitigation Contribution**[1]	**Share of Global CO_2**	**Tons CO_2/$ 1000 Real GDP**	**Tons CO_2 per Capita**
Australia	26–28% below 2005 levels by 2030	1.0	0.23	13.8
Bangladesh	5% (15%) reduction below BAU by 2030	0.3	0.23	0.7
Brunei Darussalam	20% below BAU by 2030	0.0	0.49	14.3
Cambodia	(64.6%) below BAU by 2030	0.0	0.32	0.7
China	60–65% of CO_2 intensity below 2005 by 2030	31.9	0.49	8.7
Hong Kong SAR	65–70% of CO_2 intensity below 2005 by 2030[2]	0.1	0.09	4.9
India	33–35% below 2005 by 2030	7.3	0.63	1.9
Indonesia	29% (41%) below BAU in 2030	1.5	0.36	2.0
Japan	25.4% below 2005 by 2030	2.7	0.19	8.7
Kiribati	12.8% by 2030 below BAU	0.0	0.24	0.4
Korea	24.4% below 2017 levels by 2030	1.5	0.31	11.5
Lao P.D.R.	Sectoral measures	0.0	0.61	2.0
Malaysia	35% below 2005 by 2030	0.7	0.47	7.0
Mongolia	22.7% (27.5%) below BAU by 2030	0.1	1.23	6.7
Myanmar	Sectoral measures, conditional	0.1	0.34	0.8
Nepal	Sectoral measures, conditional	0.0	0.26	0.4
New Zealand	30% below 2005 by 2030	0.1	0.13	5.6
Philippines	(70%) below BAU by 2030	0.4	0.25	1.2
Singapore	36% below 2005 carbon intensity and GHG no more than 65 MtCO2e by 2030	0.1	0.12	7.4
Sri Lanka	4% (20%) below BAU in energy sector, 3% (10%) other sectors	0.1	0.25	1.3
Thailand	20% (25%) below BAU by 2030	0.7	0.39	3.7
Vietnam	9% (27%) below BAU in 2030, sectoral measures	0.7	0.43	2.5

Sources: UNFCCC; and IMF staff calculations.

Note: BAU = business as usual.

[1] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses.

[2] China's nationally determined contribution applies to Hong Kong SAR.

Annex Table 1.2. Paris Pledge for Asia Pacific Countries

Country	Summary of the Paris Pledge
Australia	A 26 to 28% reduction in emissions by 2030 on 2005 levels. These are mainly implemented through Australia's Emissions Reduction Fund and a range of other policies. The government is developing a Long-Term Greenhouse Gas Emissions Reduction Strategy to be submitted ahead of the 26th Conference of the Parties (COP26).
Bangladesh	An unconditional 5% reduction in GHG emissions by 2030, compared to business-as-usual levels, equivalent to 12 mtCO_2e, in the power, transport, and industry sectors. To be accompanied by a further 10% reduction, conditional upon international support. Includes section on adaptation.
Brunei	Pledges to reduce GHG emission by 20% relative to business-as-usual levels by 2030, with 2015 as reference. Includes adaptation actions.
Bhutan	Remain carbon neutral, so that emissions of greenhouse gases do not exceed carbon sequestration by forests. Also pledges to maintain current levels of forest cover. Includes a selection of low-emissions policies. Includes section on adaptation. Successful implementation will depend on level of support received.
Cambodia	A reduction of 41.7% in GHG emissions below a business-as-usual scenario by 2030, with contributions of 59.1 percent from Forestry and Land Use sector, 21.3 percent from energy, 9.6 percent from agriculture, 9.1 percent from industry, and 0.9 percent from waste.This is conditional upon international support. Includes section on adaptation.
China	A peak in carbon dioxide emissions by 2030, with best efforts to peak earlier. China has also pledged to source 20% of its energy from low-carbon sources by 2030 and to cut emissions per unit of GDP by 60–65% of 2005 levels by 2030, potentially putting it on course to peak by 2027.
Fiji	An unconditional 10% emissions cut by 2030, compared to business-as-usual levels, or a conditional 30% reduction with international support. Applies to energy emissions only. As part of the target, reduce domestic maritime shipping emissions by 40% by 2030 and aim for carbon neutrality by 2050. Includes adaptation policies.
India	A 33–35% reduction in emissions intensity by 2030, compared to 2005 levels. Also pledges to achieve 40% of cumulative electricity installed capacity from non-fossil fuel-based resources by 2030. Will also increase tree cover, creating an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent by 2030. India intends to cover the $2.5 trillion cost of its pledge with both domestic and international funds. Includes information on adaptation.
Indonesia	A 29% reduction in emissions by 2030, compared to business as usual. Indonesia says it will increase its reduction goal to 41%, conditional on support from international cooperation. Includes a section on adaptation.
Japan	A 26% reduction in emissions on 2013 levels by 2030 and carbon neutrality by 2050. Includes precise information on how it will generate its power by 2030.
Kiribati	A conditional 13.7% by 2025 and 12.8% by 2030 reduction, compared to business-as-usual levels. Includes fossil fuels and marine sequestration. Kiribati offers a more ambitious 61.8% reduction in emissions by 2030 compared to business as usual, conditional on international finance, and technical support. Includes specific proposed projects for mitigation and adaptation.
Korea	Reduce 24.4% from the total national GHG emissions in 2017, which is 709.1 MtCO_2eq, by 2030. This is an absolute emissions reduction target. Korea also pledged carbon neutrality by 2050, and will update its nationally determined contributions again before 2025. Korea has increased its share of domestic reduction including LULUCF to achieve its target. Includes adaption actions.
Lao P.D.R.	Commits to a number of policies and actions designed to reduce emissions, which it will need financial support to implement. Includes adaptation policies.
Malaysia	Malaysia intends to reduce its GHG emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005. This consists of 35% on an unconditional basis and a further 10% is conditional upon receipt of climate finance, technology transfer, and capacity building from developed countries.
Maldives	26% reduction of emissions in 2030 as compared to business-as-usual, conditional on availability of financial resources, technology transfer, and capacity building. Net-zero emission by 2030 conditional on international support. Includes adaptation policies.

Marshall Islands	At least 32% reduction in emissions below 2010 by 2025, 45% by 2030, including a 40% reduction in domestic shipping and a 27% reduction in transport, with a view to achieving net-zero GHG emissions by 2050. Includes adaption policies.
Micronesia	An unconditional reduction in GHGs by 28% on 2000 levels by 2025. An additional pledge to reduce emissions up to 35% by 2025, conditional upon financial, technical, and capacity-building support. Does not intend to use market mechanisms.
Mongolia	22.7% reduction in total national GHG emissions by 2030 compared to the projected emissions under a business-as-usual scenario for 2010. Could achieve a 27.2% reduction if conditional mitigation measures such as the carbon capture and storage and waste-to-energy technology are implemented. Conditional upon international funding. Contains adaptation actions.
Myanmar	Presents a series of sectoral goals including to increase hydropower capacity to 9.4 gigawatts by 2030, to achieve rural electrification based on at least 30% renewable sources and to increase the forested area to 30% by 2030. Efforts to calculate and present a reliable estimate of current emissions are part of the pledge. Includes section on adaptation.
Nauru	A conditional commitment to spend $50 million on a solar power system and demand management to reduce emissions. An additional unconditional commitment to spent $5 million on a smaller 0.6MW solar system. Also includes sections on adaptation and loss and damage.
New Zealand	A 30% reduction by 2030 on 2005 levels, which translates to an 11% reduction on 1990 levels. Pledged to reduce net emissions of GHGs (other than biogenic methane) to zero by 2050, and to reduce emissions of biogenic methane to 24 to 47% below 2017 levels by 2050, including to 10% below 2017 levels by 2030.
Palau	Pledges to reduce energy sector emissions by 22% below 2005 levels by 2025, and has a renewable energy target of 45% and an energy-efficiency target of 35% by 2025. If implemented, these would reduce emissions by 22% by 2025 on 2005 levels
Philippines	A reduction in emissions of about 70% by 2030, relative to a business-as-usual scenario, on the condition of international support. Includes adaptation policies.
Singapore	Peak GHG emission at 65 $MtCO_2e$ around 2030, consistent with a 36% reduction in emission intensity compared to 2005 levels. Contains information on adaptation actions.
Thailand	An unconditional 20% reduction in GHG emissions by 2030, compared to business-as-usual projections. This could increase to 25%, conditional upon adequate and enhanced access to technology development and transfer, financial resources, and capacity-building support. Includes section on adaptation.
Timor-Leste	Sets out a series of mitigation options, including use of renewables to electrify rural areas and energy efficiency to reduce fossil fuel use for cookstoves. Requires international support.
Tuvalu	Pledges to reduce GHG emissions from the electricity sector by 100% by 2025 and to reduce emissions from the energy sector overall by 60%. Emissions from other sectors, such as agriculture and waste, will also be reduced dependent on the necessary finance and technology.
Vietnam	A 9% reduction in emissions by 2030 compared to a business-as-usual scenario, using itsown domestic resources. This could be increased to 27% conditional upon international support. Includes section on adaptation.

Source: UNFCCC.
Note: GHG = greenhouse gas.

Annex 2. Emission Trading Schemes in Selected Countries in Asia and the Pacific

The *Beijing Pilot Emission Trading Scheme* was launched in November 2013 in Beijing. It covers about 45 percent of the city's total emissions, including companies with more than 5,000 tons of annual CO2 emissions from electricity, heating, cement, petrochemicals, manufacturing, services, and public transport. Free allocations are provided based on historical emissions or carbon intensity for existing firms and on benchmarks for electricity generators and new entrants. The scheme has a cap of 50 million tons and bilateral transactions are allowed. Auctions of up to 5 percent of the allowances are possible for market stabilization purposes.

The *Korean Emission Trading Scheme (KETS)* started in January 2015 and is now in its second phase (2018–20). It covers more than 600 companies in six sectors (heat and power, industry, building, transportation, waste sector, and public) and about 70 percent of the total GHG emissions from six types of direct emissions—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrogen fluorocarbon (HFCS), perfluorocarbon (PFCS), and sulfur hexafluoride (SF_6) —as well as indirect consumption of electricity. The current phase has a total ceiling of 1,796 million tons between 2018 and 2020, with 97 percent free allocation and 3 percent for auction, which started in 2019 and amounted to 7.95 million tons. Sector-specific benchmarking is aimed to reach 50 percent by end of the phase. Only companies that did not receive free allowances and are on the list of the Ministry of Environment could bid, and no participant could bid for more than 30 percent of the allowances at one time. In the third phase from 2021–25, free allocation will drop to below 90 percent and auction will be more than 10 percent. Financial investment companies and private investors will be allowed to participate in the market, and carbon emission derivatives will be introduced.

The New Zealand Emission Trading Scheme (NZ ETS) was launched in 2008 to provide financial incentives for businesses to reduce emissions and land-owners to plant forests to absorb emissions. The government gives eligible foresters emission units that the foresters can sell on the NZ ETS market to businesses who must purchase units to cover their emissions and surrender to the government. All sectors including agriculture, forestry, stationary energy, industrial processing, liquid fossil fuels, and synthetic gases must report their GHG emissions. Except for agriculture, all sectors are subject to surrender obligations, making the coverage of the ETS to more than 50 percent of the GHGs. From 2025, agricultural emissions will also be covered. Free allocation is provided for 26 eligible activities based on emissions-intensive, trade-exposed (EITE) criteria: 90 percent for high EITE (above 1,600 ton per 1 million NZD revenue) activities, and 60 percent for moderate (above 800 ton per NZD 1 million revenue) activities. From 2021, the government will phase down the free allocation with a minimum of 1 percent across all activities between 2021–30, 2 percent between 2031–40, and 3 percent between 2041–50. Further phase-down will be implemented for activities that are considered lower risk for carbon leakage. The government also plans to introduce a cap for the supply of units to the market in the future and an auction system in late 2020.

Annex 3. Pre-Tax and Post-Tax Energy Subsidy, 2017

Annex Table 3.1. Pre-Tax and Post-Tax Energy Subsidy, 2017
(Percent of GDP)

Country	Pre-Tax	Petroleum	Coal	Natural Gas	Electricity
Australia	0.0	0.8	0.7	0.3	—
Bangladesh	0.4	1.1	0.6	1.4	0.3
Bhutan	—	—	1.2	0.3	—
Brunei Darussalam	0.6	3.5	5.0	3.6	0.2
Cambodia	—	—	1.4	0.6	—
China	0.2	3.5	10.6	0.3	0.4
Fiji	—	1.6	5.6	2.8	—
Hong Kong SAR	—	0.3	1.1	0.2	—
India	0.3	1.1	7.4	0.2	0.4
Indonesia	2.6	8.8	2.3	0.5	1.4
Japan	0.0	2.5	0.7	0.4	—
Kiribati	—	—	1.5	0.5	—
Korea	0.0	1.4	1.8	0.5	0.2
Lao P.D.R.	—	0.5	0.9	0.3	—
Macao SAR	—	—	0.5	0.1	—
Malaysia	1.3	10.5	1.7	1.6	0.4
Maldives	0.2	8.9	2.7	1.2	—
Marshall Islands	—	—	16.5	4.2	—
Micronesia	—	—	21.9	5.6	—
Mongolia	0.1	11.5	16.3	4.5	—
Myanmar	—	2.7	0.2	0.5	—
Nauru	—	—	7.9	1.9	—
Nepal	—	0.9	0.7	1.0	—
New Zealand	—	0.5	0.2	0.2	—
Palau	—	—	3.9	1.0	—
Papua New Guinea	—	—	1.3	0.1	—
Philippines	—	2.5	1.1	0.1	—
Samoa	—	0.2	7.0	3.8	—
Singapore	—	2.3	0.3	0.5	—
Solomon Islands	—	—	1.2	0.4	—
Sri Lanka	0.1	0.5	1.4	4.2	0.1
Taiwan Province of China	0.1	2.0	3.6	0.4	0.2
Thailand	0.1	4.5	3.8	1.2	0.3
Timor-Leste	—	—	1.6	0.3	—
Tonga	—	—	6.9	3.8	—
Tuvalu	—	—	18.9	4.8	—
Vanuatu	—	—	8.9	4.9	—
Vietnam	0.5	4.4	4.8	0.7	0.6
Average	**0.2**	**2.0**	**4.6**	**1.6**	**0.1**

Sources: IMF Global Subsidy Database (2019).

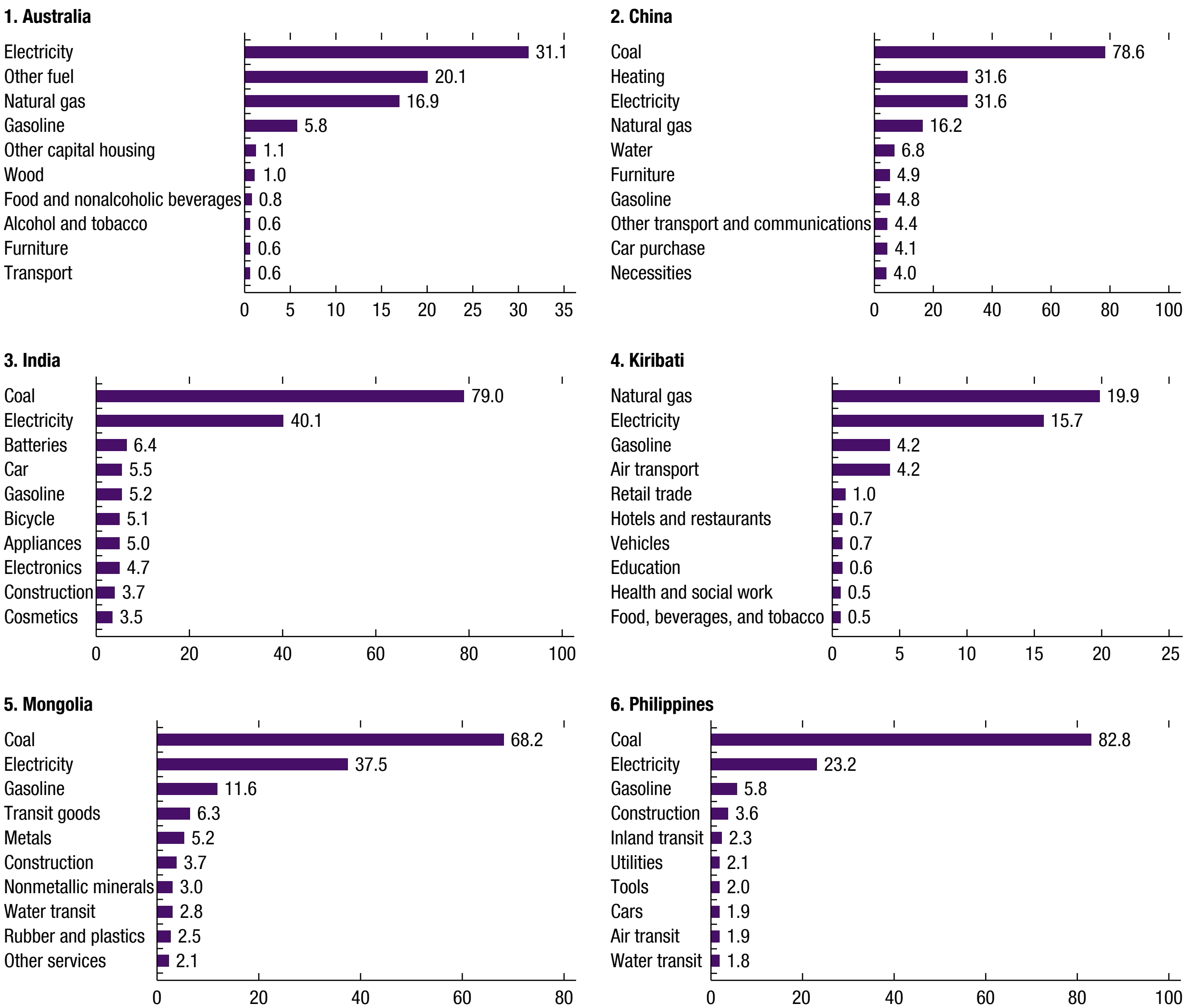
Annex 4. Methodology: Household's Incidence Analysis

We use household surveys for Australia, China, India, Kiribati, Mongolia, and the Philippines to trace the impact of a carbon tax on households through higher prices and lower labor income in the energy sector and evaluate country-specific compensatory policies, following five steps.

First, we use the energy prices induced by carbon taxes of $25 per ton from Chapter 2. The impact of a carbon tax on the prices of coal, electricity, gasoline, natural gas, and other fuel products is calculated using the IMF tool spreadsheet model from IMF (2019a). The tool uses country-specific energy use matrices and projections of GDP growth, and projections on technological change and global energy prices. The tool produces energy prices in 2030, by when the carbon price is assumed to be in place. For further details on the methodology, please see Parry, Mylonas, and Vernon (2018). Additional macro variables such as GDP, exchange rates, and inflation are retrieved from the World Economic Outlook database.

Second, we use input-output tables to track the impact of higher energy prices on the prices of other goods and services. We obtain input-output tables from national statistics agencies in the cases of Australia, China, India, and the Philippines. For Australia, we use the 2016–17 input-output table of 114 industries. For China, we use the 2012 input-output table, which provides a breakdown for 139 industries. For India, we use the 130-industry input-output table for 2007–08. For the Philippines, we use the 65-industry 2012 input-output table. For Mongolia, we use the 35-industry 2017 input-output table obtained from the Asian Development Bank. Unfortunately, there is no input-output table for Kiribati; instead, as a proxy, we use the Asian Development Bank's 35-industry 2017 input-output table for Fiji, the smallest island country in the region for which data are available. We identify the direct impact on energy prices through specific industries. From the input-output tables, we compute the total requirements matrix, which

Annex Figure 4.1. Impact of a $25 Carbon Tax on Prices of Consumption Goods
(Percent, top 10 goods with largest price increases)



Source: IMF staff calculations.

allow us to track the indirect effect of higher energy prices on the price of each industry's output. In this exercise, a full pass-through of higher input costs into the price of final goods is assumed.[1] Annex Figure 1 presents the

[1]When the industry breakdown is not detailed enough to map each energy good directly, we gathered sectoral data from other surveys (for example, mining surveys) in the country to produce a weighted average for the industry to be traced down the input-output table and yield the indirect price effect. However, we preserved the direct price effect if that good is included in the household survey.

Annex Table 4.1. Household Surveys' Summary Statistics

	China	India	Kiribati	Mongolia	Philippines
Number of Households	13,315	101,662	1,161	16,441	41,544
Number of Individuals	51,001	464,959	6,725	56,525	192,564
Average Family Size	3.7	4.4	6.2	3.5	4.6
Share of Urban Households	51.3	31.2	37.5	67.0	—
Consumption per Capita (2017 USD)	1,886	461	953	2,269	1,123
Survey	2012 China Family Panel Studies	2011–12 68th Round of the National Sample Survey	Household Income and Expenditure Survey 2006	2016 Household Socio Economic Survey	2015 Family Income and Expenditure Survey

Source: IMF staff calculations.

impact of the $25 per ton carbon tax on output prices (direct and indirect impacts combined) by country.

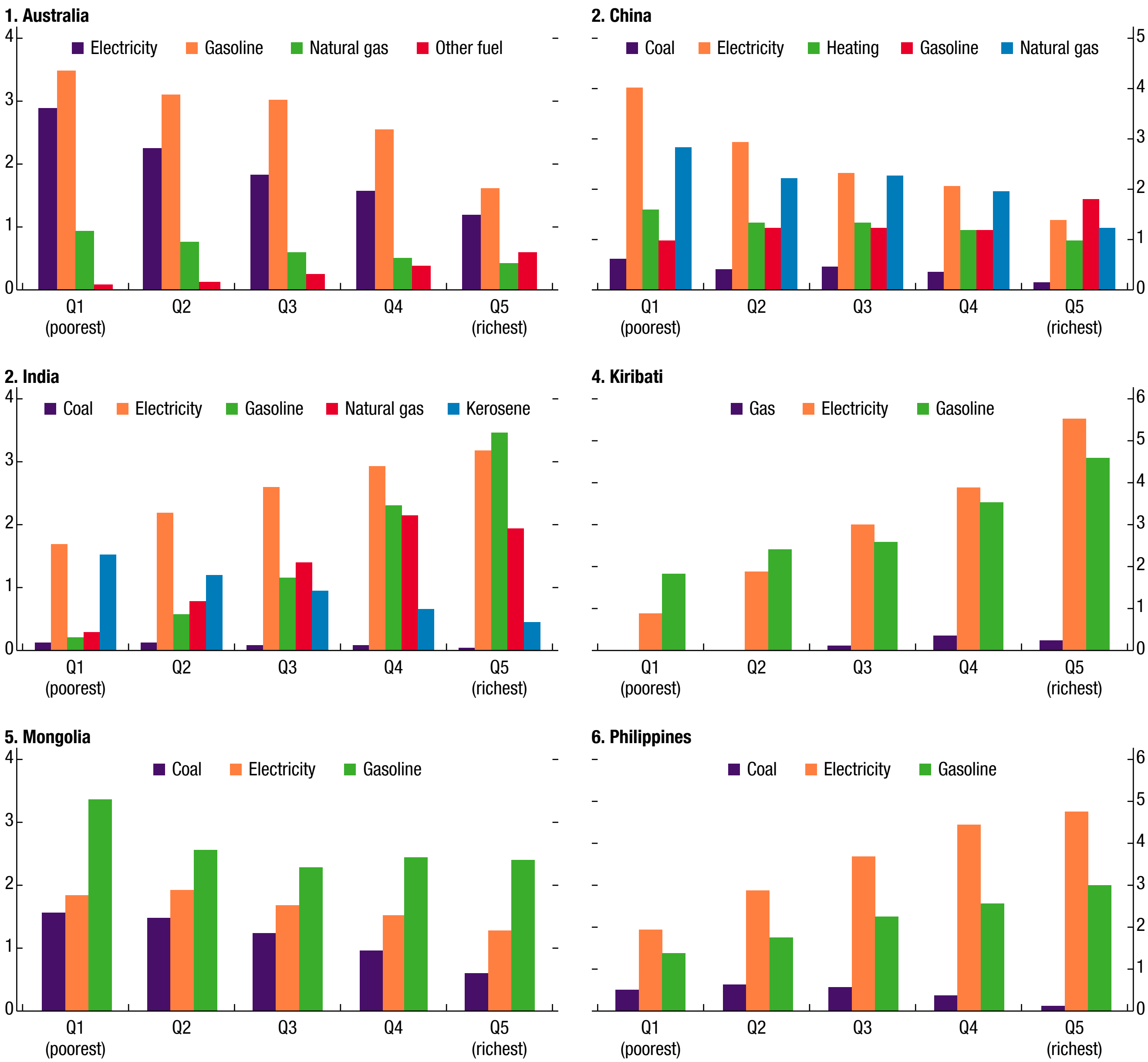
Third, we evaluate the impact of such higher prices on individual household's consumption using household surveys. We map the goods produced by input-output tables into those reported in household expenditure surveys. We are unable to access the microdata for Australia, but we use the average shares by income quintile for the 2015–16 Household Expenditure Survey. We use the 2012 China Family Panel Studies for China (Institute of Social Science Survey 2015), the 2011–12 68th Round of the National Sample Survey for India (National Sample Survey Office 2011), the Household Income and Expenditure Survey 2006 for Kiribati accessed through the Pacific Community's Data Hub (Kiribati National Statistics Office 2006), the 2016 Household Socio Economic Survey for Mongolia (National Statistics Office of Mongolia 2016), and the 2015 Family Income and Expenditure Survey for the Philippines (Philippine Statistics Authority 2015). We sort households in quintiles using consumption per capita (except for Australia, where we use income quintiles) because consumption tends to be better measured in surveys in low-income countries. All results are computed using sample weights. Annex Table 4.1 presents summary statistics of the household surveys, and Annex Figure 2 shows consumption on energy goods by quintiles of per capita consumption.

We follow the incidence analysis framework as outlined in IMF (2019a) and measure the loss of higher prices for consumers as:

$$\sum_i \rho_i \omega_i \left(1 - \frac{\rho_i \varepsilon_i}{2}\right)$$

in which i represents each consumer good, ρ_i is the percent increase in price induced by the carbon tax, ω_i is the weight of good i on the consumer budget, and ε_i is the price elasticity of good i. For energy goods, we assume a price elasticity of –0.25 in line with empirical estimates as noted in IMF (2019a), but results are robust to assuming a zero elasticity.

Annex Figure 4.2. Share of Energy Goods on Household Consumption
(Percent of total household consumption, average by quintile)



Source: IMF staff calculations.
Note: Quintiles are defined in terms of consumption per capita for all countries, except Australia, for which income is used.

Fourth, we use household surveys also to identify households most likely to be affected through a negative labor income channel. Given that we are assuming a negative price elasticity for energy goods, we would expect lower labor demand in those sectors. Specifically, we model a negative labor income shock for workers in energy sectors assuming constant labor productivity—in other words, a 10 percent drop in consumption of output of a given sector would yield a 10 percent reduction in labor income for workers in the sector. Because each household in the survey represents many more, we do not need to take a stand on whether the reduction in labor income takes place through lower employment or earnings.

We use employment and income variables on household surveys to identify energy workers. We use country-specific definitions of energy sectors to account for differences in the richness of workers' industry and occupation variables across surveys.

- In China, we identify workers employed by the mining industry and, among them, we assign coal mining jobs by using the province share on national coal production from Caldecott and others (2017). For non-coal workers, we compute their labor income shock through the average shock of oil and gas extraction and other mining weighted by their respective share on compensation of employees as per the input output tables. Similarly, we identify workers in the utilities sector and compute their income shock as the compensation-weighted shock for electricity, heat production and supply, gas production and supply, and water production and supply. We identify workers involved in the refining of gasoline keeping those working in the manufacturing industry in refining occupations.
- In India, we identify coal workers as those employed in industries 0510 and 0520, workers engaging with the extraction of crude petroleum and natural gas as those in industries 0610 and 0620, and workers involved in the refining of gasoline as those in industries 1920, 192x, and 19xx. Electricity workers are those employed in industry 3510. Natural gas workers are those employed in industries 3520 and 352x.
- In Kiribati, we identify electricity workers as those employed in industry 41 (Electricity supply). There are no other relevant energy sectors in the country.
- In Mongolia, we identify coal workers as those employed in industries 510, 510.1, and 520. We identify oil and gas workers as those in industries 610 and 620. Workers involved in the refining of gasoline would be identified as in industry 1920, but there were none at the time of the survey.[2] Electricity workers are identified by industry 3520 and natural gas workers by industry 3520.

[2]The construction of the country's first oil refinery was launched in 2018. See Reuters. 2018. "Mongolia Launches Construction of First Oil Refinery with Indian Aid." June 22.

- In the Philippines, coal workers are those employed in industries 510 and 520. Oil and gas workers are in industries 610 and 620. Industries 1920 and 1990 identifies workers in the refining of fuel products. Electricity workers are those employed by industry 3510. Natural gas workers are in industry 3520.

Finally, we study the impact of compensating measures. The list of measures considered in the analysis is shown in Annex Table 4.2. We assume that all tax revenues raised by the carbon tax are spent on compensating measures. We obtain carbon tax collections as percent of GDP from the IMF tool spreadsheet model in IMF (2019a) and apply them to GDP in local currency in 2017. We then deflate into local currency prices for the year of each survey using accumulated inflation from the IMF World Economic Outlook database. We divide those resources among the households or individuals eligible for each policy (and in the corresponding amounts) to ensure that all tax revenues are spent on every simulation. We do not assume any administrative costs on implementing the measures. For the simulation of a perfect expansion of the minimum income scheme in China (Dibao), we assume that a 40 percent differential between rural and urban minimum-income threshold is preserved.[3] We raise the threshold providing households below it with a transfer for the amount of the difference with respect to their consumption reported in the survey. The new threshold is chosen so that all carbon tax revenues are spent. For the poor expansion of Dibao, we assume that targeting fails, and we allocate randomly a transfer on the amount of the average transfer under the perfect expansion of the scheme.[4]

[3]Dibao's minimum-income threshold varies by province and by whether the household is in a rural or urban area. Beneficiary households in this scheme then receive a cash transfer so that their income reaches the minimum income threshold. As of 2017, the Dibao standard was on average 40 percent higher in urban than in rural areas.

[4]We abstract from changes in transfers received from existing schemes where eligibility and benefit amount could vary due to the carbon tax.

Annex Table 4.2. Compensating Measures

China

Policy	Benefit (2017 USD)
Universal lump sum transfer per person	69
Child grant to all children younger than 14	455
Noncontributory old age pension to everyone older than 65	741
Dibao's minimum-income thresholds raised to 12,790 and 17,906 yuan (in 2017 prices) for rural and urban households, respectively[1]	—
Poorly targeted expansion of Dibao where a fixed amount is randomly granted to 110 million households	1,004
Subsidy to households who cook with firewood/straw or coal	737
Subsidy to households who own a car	2,069
Subsidy to households who own a tractor	3,276
Subsidy to households who live in urban communities	722
Subsidy to households who live in rural communities	395

India

Policy	Benefit (2017 USD)
Universal lump sum transfer per person	18
Child grant to all children younger than 14	61
Noncontributory old age pension to everyone older than 65	367
Lump sum to households with Antyodaya or BPL ration cards	226
Lump sum to all households receiving ration cards	100
Subsidy to urban households	256
Subsidy to rural households	116
Subsidy to households who cook with coke, coal, firewood and chips, dung cake, charcoal, or without cooking arrangement	128
Subsidy to households with electricity	100

Kiribati

Policy	Benefit (2017 USD)
Universal lump sum transfer per person	14
Child grant to all children younger than 14	46
Noncontributory old age pension to everyone older than 65	457
Subsidy to urban households	226
Subsidy to rural households	135
Subsidy to households with kitchen outside or no kitchen	123
Subsidy to households who cook with wood or sawdust stoves or open fires	138
Subsidy to households with electricity	180

Mongolia

Policy	Benefit (2017 USD)
Universal lump sum transfer per person	83
Raise noncontributory old age pension to everyone older than 65	266
Quadruple child money	—
Subsidy to households in the six most severely hit aimags (Khentii, Govisumber, Govi-Altai, Bayan-Ulgii, Khovd)	2,378
Subsidy to households who own a motorcycle	2,166
Subsidy to households who own a tractor	47,723
Subsidy to households who own a vehicle	784
Subsidy to urban households	428
Subsidy to rural households	869

Philippines

Policy	Benefit (2017 USD)
Universal lump sum transfer per person	15
Child grant to all children younger than 5	173
Child grant to all children aged 5–17	53
Subsidy to households who own a car	975
Subsidy to households who own a banca	6,327
Subsidy to households who own a motorcycle	282
Subsidy to households with electricity	76

Source: IMF staff calculations.

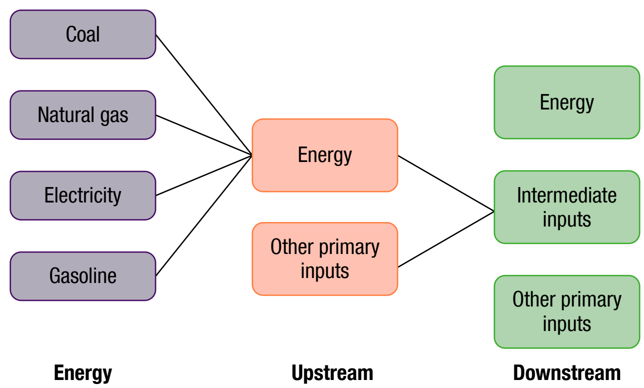
[1]For reference, in 2017 the average threshold was 4,893 and 6,861 for rural and urban households, respectively.

Annex 5. Methodology: Sectoral Analysis

We use national input-output (IO) tables to identify most impacted industries from carbon taxation. The IO tables describe the sale and purchase relationships between producers and consumers within an economy, and hence show the interlinkages between industries. We use IO tables to breakdown the impact of higher energy prices on the cost of production for each industry into direct and indirect cost increases. We identify the direct impact on production costs from higher prices of energy inputs such as electricity, coal, natural gas, and refined petroleum into production. From the IO tables, we also compute the total requirements matrix, which allows them to track the indirect effect of higher energy prices through higher intermediate input costs for downstream sectors. Annex Figure 5.1 illustrates how we perceive these effects to travel through the supply chain. An example of an upstream sector would be basic metal manufacturing such as aluminum sheets. A downstream sector is one that would use aluminum sheets in its production, like machinery manufacturing. Note that other primary inputs include labor and capital.

We obtain IO tables from national statistics agencies in the cases of Australia, China, India, and the Philippines. For Australia, we use the 2016–17 IO table with 114 industries. For China, we use the 2012 IO table with 139 industries. For India, we use the 2007–08 table with 130 industries. For the Philippines, we use the 2012 IO table with 65 industries. For the rest of the countries we study, we use the 2017 IO tables provided by the Asian Development Bank, which include 35 industries. The IO tables have data on total output and value added by industry. To determine overall impact by country or by a set of industries, we aggregate across industries using output weights. Our results are robust to using value-added weights. Because the IO tables also include data on exports by industry, we can determine the impact for export-oriented industries relative to industries that primarily cater to domestic markets.

Annex Figure 5.1. Sample Supply Chain for the Sectoral Analysis



Source: IMF staff.

We use the following input-weighted formula to compute cost increase for industry *j* in country *c*:

$$\textit{Industry cost increase from carbon taxation}_{jc} = \omega_{energy,jc}\,\rho_{energy,c} + \sum_{i=1}^{j-1}\omega_{ijc}\,\rho_{ic}$$

in which ρ is the percent increase in price induced by the carbon tax for industry *i* in country *c* and ω_{ijc} is the weight of industry *i* as a share of total input costs (excluding labor and capital) for industry *j* derived from the country-specific IO table. The first part is the impact from energy cost increase (direct cost increase) and the second part is the impact from the increase in intermediate input costs (indirect cost increase). For intermediate input industry *i,* we assume full pass-through of the cost increase from the carbon tax to estimate the percent increase in price of intermediate inputs for industry *j*.

We use the changes in the energy prices induced by a carbon tax from Chapter 2. The impact of a $25 per ton carbon tax on the prices of coal, electricity, gasoline, natural gas, and other fuel products, $\rho_{energy,c}$, is calculated using the IMF tool spreadsheet model from IMF (2019c). For further details on the methodology, please see Parry, Mylonas, and Vernon (2018). We assume a full pass-through in the energy sector in estimating the cost increase from carbon taxation. For countries with aggregated IO tables where some of the energy products are combined, we weight the price increase using information on their energy consumption shares.

To estimate jobs-at-risk from higher energy prices, we combine the above estimates on cost increases with the employment data from United Nations

Industrial Development Organization (UNIDO) industrial statistics. The UNIDO industrial statistics contains employment data for all manufacturing industries at the two-digit level of ISIC for a large set of countries in Asia and the Pacific.[1] We assume full pass-through of the cost increase to customers and unitary price elasticity of demand, that is, a given percentage increase in the output price leads to an equal percentage fall in the quantity demanded. We also assume that production requires a fixed a share of labor, capital, energy, and intermediate inputs: when demand falls by a given percentage, there is an equal percentage fall in labor inputs. Then, jobs-at-risk in industry *j* in country *c* is obtained by:

$$\textit{Jobs-at-Risk}_{jc} = \frac{\textit{Number of workers}_{jc}}{\textit{Total workers in manufacturing}_{c}} \times \textit{Cost increase from carbon taxation}_{jc}$$

Our estimates of cost increases and jobs-at-risk from carbon taxation involve some critical assumptions.

- Pass-through rates: a full pass-through for the direct cost increase from the energy sector is a reasonable assumption. However, for the indirect cost increase, this is likely an upper bound as upstream suppliers could absorb some of the cost increases and only partially pass-through the cost increase.
- Static production technology: we assume no dynamic response in production technology and no substitution in inputs in response to increase in costs. This is appropriate for the short-term but in the long-term, production is likely to become less energy-intensive as industries switch existing capital stock to green technology and become more productive to reduce the impact of carbon taxation.
- No recycling of revenue from carbon taxation and no complementary fiscal policies: unlike the household incidence analysis, we do not assume that tax revenues raised by the carbon tax are spent on compensatory measures to support affected workers or foster adoption of green technology.

[1] To create a concordance between the industry-level aggregation in the IO tables and the more disaggregated ISIC two-digit level, we aggregate all the variables in the UNIDO to correspond to the respective IO industry categories and use the estimated cost increases from carbon taxation.

Annex 6. Methodology: Firm-Level Analysis

To evaluate how vulnerability to carbon taxation varies by firm characteristics, we analyze firm-level data using the World Bank Enterprise Survey (WBES). The WBES is a standardized data set covering a representative sample (random stratified sampling) of 166,386 firms across 145 countries over the period from 2006 to 2016. The survey covers a broad range of firm-level characteristics including their performance measures, employment, investment, sales, and breakdown of operating costs. We define a firm's vulnerability to carbon taxation as the share of annual costs of electricity and fuel in its total sales. Because not all firms respond with details of their production costs, the sample is reduced to 50,242 firms. Because of concerns with selection bias, the results cannot be interpreted at the country level.

The firm characteristics of interest include firm size, productivity, profitability, trade exposure, and input intensity. Firm size is measured by the number of employees. The age of the firm is the difference between the year of the survey and the first year of its operation. Export orientation is captured by a dummy variable taking 1 if the share of sales exported is positive and 0 otherwise. The financial access is measured as a dummy variable that takes 1 if the firm has a credit line or an overdraft facility and 0 otherwise. For firm productivity, we use sales per worker, which is the commonly used measure of labor productivity. Profitability is the difference between revenue and operational expenses. Labor intensity is proxied by total employee costs divided by operating revenues. Skill intensity is proxied by the average wage a firm pays to its employees because, without distortions, a higher wage would indicate a higher marginal productivity of labor and a larger share of skilled labor. To reduce the influence of outliers, we drop firms at the 1st and 99th percentile for all outcome variables of interests and vulnerability measure. All the nominal values are adjusted for inflation. For all firm characteristics, we create dummies that equal 1 for firms above the median of a characteristic and 0 otherwise.

We run the following fixed effects regression to help minimize potential endogeneity concerns:

$$In(Vulnerability_{ijct}) = \alpha + \beta * \mathit{firm\ characteristic}_{ijct} + e_j + \lambda_c + \gamma_t + \delta_{ct} + \varepsilon_{jct}$$

in which *i* is the firm in industry *j* situated in country *c* on year *t.* β is the coefficient of interest, with significance indicating that a specific firm characteristic is correlated with energy intensity of its production processes. Country fixed effects λ_c control for the country-level macroeconomic conditions including institutional capacity, political economy, and other time-invariant country-specific factors. To account for time-variant country-specific factors such as energy prices, development in electricity infrastructure and carbon taxes, we include country-year fixed effects, δ_{ct}.Industry fixed effects e_j control for any variations in the impact of carbon taxes, productivity, labor intensity, export orientations, and other factors at the industry level. We also include year fixed effects as the survey for different countries is conducted in different years; this controls for any shocks that affect all countries at once like the global financial crisis. Errors are clustered at the firm-level.

The results are robust to alternative measures of firm characteristics. The results are consistent if we use the natural log of the continuous variable instead of dummies for firm characteristics. For firm productivity, we use value added per worker as a robustness check. For financial constraints, we also check if the response to access to financing in the part of the survey that asks about investment climate constraints yields the same results as the baseline measure of financial access. We find that firms that state access to financing as more of an obstacle have more energy-intensive production process. Our results also hold when we include other firm characteristics such as productivity as a control variable when testing the significance of different firm characteristics. Overall, the results are robust to alternative measures of firm characteristics and inclusion of additional control variables in the regression specification.

Annex 7. What Actions Should Governments Take to Adapt to Climate Change?

The IMF (2019b) three-pillar approach to large natural disasters can guide adaptation to all climate change effects, including permanent ones. The first pillar promotes investment in infrastructures, technologies, regulations, the diffusion of information, and early warning mechanisms to limit the adverse impact of climate hazards. The second pillar puts forward financial resilience, ensuring that adequate financing exists to preserve debt sustainability. The third pillar focuses on building systems to respond timely and effectively to the realization of residual risks.

Fiscal policy is instrumental for climate change adaptation and finance ministries should play a prominent role. Climate change adaptation should be embedded in public finance management systems, medium-term budgets, and fiscal reports. It should be reflected in macroeconomic forecasting, the costing of fiscal policies, and ex post evaluations.

Under the first pillar, fiscal policy can provide a wide array of tools to facilitate the adaptation of firms and people.

- Direct and targeted transfers in the form of subsidies or tax expenditures can support adaptation services or products, for example, the development of drought-resilient crops, the protection or expansion of forest coverage, and the preservation and allocation of scarce water resources. Tax schemes can also incentivize the upgrade and replacement of private physical assets to enhance their climate resiliency.
- Efficient public investment in climate-resilient public infrastructure and adequate maintenance protect assets and service delivery. For any new projects, careful planning is essential to make the most of limited resources: the development, appraisal, and selection of projects and their resilience characteristics should factor in climate risks under different scenarios. For

existing assets, a regular inventory assessing their conditions and how they relate to climate risks should be regularly undertaken and should inform maintenance and strengthening priorities. For example, Vietnam uses flood maps to assess risks to public health care facilities (World Bank 2020). Because of complementarity, more resilient public infrastructure contributes to attract more private investment.

Under the second pillar, building resilient infrastructure and planning an adequate response to natural disasters require tailored financing strategies. Long-term capital investment financing needs should be addressed by mobilizing domestic revenue. Over time, better climate-resilient infrastructure can pay off by lowering maintenance costs. In the short term, governments can consider domestic or external borrowing, possibly including green bonds, and, if needs are substantial, international grants. To cope with damages from natural disasters, different budgetary and financial instruments should be used depending on the frequency of the shocks (IMF 2016b, 2019b). Fiscal buffers are relatively inexpensive and flexible solutions to address small recurring shocks, although their political economy can be complicated. More expensive solutions such as contingent credit lines from development partners, regional risk-sharing facilities, private insurance, and catastrophe bonds can be considered for greater disasters. The same logic applies to the private sector, where insurance products can provide protection against rare shocks.[1]

Under the third pillar, robust social programs are essential to help the vulnerable withstand residual climate shocks. For example, the Chars Livelihood Program in Bangladesh protected 95 percent of recipients from losing their assets after the 2012 floods (Kenward, Cordier, and Islam 2012). Programs' design can further strengthen the efficacy of social policies. For example, making benefits portable across different states or regions help people migrate away from areas negatively hit by natural hazards. Social protection systems can be made "adaptive" and more responsive to shocks by either expanding the list of beneficiaries or increasing transfers to existing beneficiaries, as in Fiji. Raising financial inclusion can also help households withstand climate shocks.

[1]A study of the Christchurch, New Zealand, earthquake in 2011 shows that insurance helps firms bounce back after a shock (Poontirakul and others 2017).

Annex 8. Estimating the Adaptation Costs of Investing in the Resilience of Physical Assets

While many important and necessary adaptation policies are needed (strengthening early warning systems, agriculture systems, and water resources management), investing in infrastructure resilience is by far the costliest (GCA 2018a). We focus on two natural hazards, floods and cyclones, and three types of adaptation costs: (1) upgrading new investment projects in all sectors to improve their resilience to natural hazards, (2) retrofitting existing economic assets exposed to natural hazards to improve their resilience, and (3) developing coastal protection infrastructure.

Costs *for upgrading new projects and retrofitting existing assets* are estimated with a bottom-up approach based on country exposure to natural hazards and the additional costs that would be incurred to make exposed assets more resilient. We use a new database where the shares of exposed assets by country are inferred from crossing two detailed global maps, one of natural hazards and another of a road and railway asset data (Koks and others 2019). The degree of asset exposure is adjusted to reflect higher protection standards in upper middle-income and high-income countries.[1]

The incremental costs of making exposed assets more resilient are estimated using the average values corresponding to the set of technical options from Miyamoto International (2019). Even as they are economically sensible, the technical solutions do not guarantee that assets cannot be damaged by natural hazards and do not include all possible options to reduce risks, including more cost-effective alternatives or more expensive options to reduce risks

[1]The protection standards in upper middle-income and high-income countries come from Table 5.2 in Rozenberg and Fay (2019).

further.[2] Based on the exposure and incremental costs measures, we estimate the following:

- *Costs for upgrading new projects* are computed as the annual investment projections on average over 2021–25, multiplied by the estimated share of exposed assets, and by a unit cost of 15 percent. Hence, the average exposure of future projects is assumed to be the same as the exposure of existing assets.[3] Public and private investment projections are from the *World Economic Outlook* (April 2020). When projections are unavailable, we assume that future investment to GDP ratios remain constant at the last observed level in the IMF Investment and Capital Stock Dataset (IMF 2019e).
- *Costs for retrofitting existing assets* are computed as the capital stock, multiplied by the estimated share of exposed assets and by a unit cost of 50 percent. The total costs are annualized by assuming constant investment in percent of GDP over the next 10 years. We use the 2017 levels of public and private capital stock from the IMF Investment and Capital Stock Dataset, 2019. It may be more cost-effective to abandon some exposed assets or tear down and rebuild them in a climate-resilient way. The unit cost of 50 percent would also correspond to an average view between these cases.

Costs *for developing coastal protection infrastructure* are the yet unreported country-level estimates corresponding to the global levels presented in Rozenberg and Fay (2019). We report the annual investment and maintenance costs for two levels of protection: (1) the economically optimal level of protection defined as the level that minimizes the sum of protection costs (capital and maintenance) and residual flood damage to assets to 2100 and (2) the level of protection under a risk intolerance strategy keeping average annual losses below 0.01 percent of local GDP for protected areas.[4] In both cases, the levels of protection are assumed to be reached by 2030 with disbursements spread equally over the years. The estimation uses the state-of-the-art Dynamic Interactive Vulnerability Assessment climate model and new estimates of coastal protection construction costs (Nicholls and others 2019).[5] When considering the different assumptions regarding socioeconomic projections, unit costs, and GHG concentration pathways, we chose to use average specifications.

[2]Many high-income countries such as Japan sometimes implement technical solutions that go beyond—and are more expensive than—the set of solutions considered in Miyamoto International (2019).

[3]This assumption is supported by historical evidence of the extreme persistence of human activity geographic distribution, even amid catastrophic shocks (Davis and Weinstein 2002).

[4]The GDP threshold of 0.01 percent is based on the residual risk implied by the protection infrastructure of Amsterdam and Rotterdam in 2005, as calculated by Hallegatte and others (2013).

[5]The DIVA (Dynamic Interactive Vulnerability Assessment) model is a global model of coastal systems that assesses biophysical and socioeconomic consequences of sea-level rise and socioeconomic development taking into account the following key impacts: coastal erosion (both direct and indirect), coastal flooding (including rivers), wetland change, and salinity intrusion into deltas and estuaries.

Annex 9. Illustrating Adaptation Investment Trade-Offs with Model-Based Simulations

Investing in resilient infrastructure benefits long-term growth but is costly. We illustrate this trade-off and the benefits of complementary reforms with simulations, based on the dynamic general equilibrium model of Marto, Papageorgiou, and Klyuev (2018) and Buffie and others (2012). The model was initially developed to study the macroeconomic effects on a small-open economy of public investment surges, making explicit: (1) the investment-growth linkages, (2) public external and domestic debt accumulation, and (3) the fiscal policy reactions that can restore debt-sustainability and external balance. Marto, Papageorgiou, and Klyuev (2018) extended the framework by introducing natural disasters and allowing the government to invest in both standard infrastructure and adaptation capital.

In the model, natural disasters impact the economy through the following channels: (1) permanent damages to public infrastructure, (2) permanent damages to private capital, (3) temporary losses of productivity, and (4) increased inefficiencies in public investment during the reconstruction process.

The model distinguishes between public investment in standard infrastructure and adaptation infrastructure. Investment in adaptation infrastructure is costlier than investment in standard infrastructure. However, adaptation infrastructure mitigates productivity losses during a natural disaster episode by allowing standard infrastructure to function better (for example, resilient roads allow users to access other infrastructure even in difficult conditions). It reduces the damages inflicted by a natural disaster (for example, seawalls) and depreciates at a lower rate. Investing in adaptation infrastructure is useful as a complement to conventional infrastructure as it raises the marginal product of other capital by helping withstand the impact of natural disasters, and crowds in private investment.

We examine the implications of a natural disaster on a typical low-income or emerging market economy in Asia and the Pacific. The key features of simulations are as follows:

- The model is matched with an economy whose macroeconomic indicators are averages for developing economies in Asia and the Pacific. The calibration of initial values and parameters is reported in Annex Table 9.1.
- A natural disaster shock is assumed to occur in year 6. The magnitude of the shock is calibrated to cause a 3 percentage point decline in GDP growth. The government aims to fully rebuild the damaged infrastructure in a horizon of about six to eight years.
- To assess implications of adaptation investment and standard investment, we consider scaling-up public investment by 2 percent of GDP in years 1–5 either in adaptation investment or standard investment, and compare with the baseline scenario of no additional investment. The additional investment is assumed to be financed with commercial debt.
- We analyze the effect of public investment efficiency. Based on Ghazanchyan and others (2017), the efficiency of public investment is calibrated at 60 percent in the baseline, and 30 and 90 percent in low- and high-investment efficiency scenarios, respectively.
- We also analyze the implication of two alternative financing options for additional investment: foreign concessional financing and a consumption tax increase.

Annex Table 9.1. Initial Values and Parameters for Model Calibration

Initial Value/Parameter Definitions	Values
Macroeconomic Aggregates	
GDP growth rate	3%
Imports to GDP ratio	70%
Government	
Public domestic debt to GDP	5%
Public concessional debt to GDP	20%
Public external (commercial) debt to GDP	15%
Real interest rate on public domestic debt	3%
Real interest rate on public concessional debt	0%
Real interest rate on public external debt	3%
Share of public debt adjustment between external and domestic debt	12.5%
Grants to GDP	20%
Consumption tax (VAT) rate	10%
Initial public standard investment to GDP	8%
Initial public adaptation investment to GDP	0%
Return on public standard infrastructure investment	15%
Return on public adaptation infrastructure investment	15%
Depreciation rate of standard infrastructure	15%
Depreciation rate of adaptation infrastructure	3%
Intratemporal elasticity of substitution across public capital inputs	50
User fees fraction of recurring spending	5%
Efficiency of public investment	60%
Firms	
Capital share in value added in the nontraded goods sector (%)	55%
Capital share in value added in the traded goods sector (%)	40%
Share of value-added in the nontraded goods sector	43.1%
Cost share of nontraded inputs in the production of private and public capital (%)	50%
Households	
Intertemporal elasticity of substitution of consumption	0.34
Intratemporal elasticity of substitution across consumption goods	0.5
Share of liquidity-constrained households (%)	17%
Private external debt to GDP	10%
Risk-free foreign real interest rate	4%
Depreciation rate of private capital	10%
Natural Disaster Damages	
Concavity parameter in ability of adaptation capital to withstand natural disaster	1
Scaling parameter in ability of adaptation capital to withstand natural disaster	0.2
Severity of damages to public capital	0.7
Severity of damages to private capital	0.3

Sources: Marto, Papageorgiou, and Klyuev (2018); and IMF staff estimates.

References

ACP-EU Natural Disaster Risk Reduction Program. 2017. "Climate Vulnerability Assessment: Making Fiji Climate Resilient." https://www.gfdrr.org/en/fiji-climate-vulnerability-assessment

Agarwal, Ruchir. Vybhavi Balasundharam, Patrick Blagrave, Eugenio Cerutti, Ragnar Gudmundsson, and Racha Mousa. Forthcoming. "Climate Change in South Asia: Further Need for Mitigation and Adaptation." International Monetary Fund, Washington, DC.

Bernard, Andrew B., J. Bradford Jensen, Stephen J. Redding, and Peter K. Schott. 2007. "Firms in International Trade." *Journal of Economic Perspectives* 21 (3): 105–30.

Bovenberg, A. Lans. 1999. "Green Tax Reforms and the Double Dividend: An Updated Reader's Guide." *International Tax and Public Finance* 6: 421–43.

Branger, Frédéric, Philippe Quirion, and Julien Chevallier. 2016. "Carbon Leakage and Competitiveness of Cement and Steel Industries under the EU ETS: Much Ado about Nothing." *The Energy Journal* 37 (3).

British Columbia. 2020. "Carbon Tax Guarantees Tax Cuts for British Columbians." https://archive.news.gov.bc.ca/releases/news_releases_2005-2009/2008FIN0009-000645.htm

Buffie, Edward E., Andrew Berg, Catherine Pattillo, Rafael Portillo, and Luis-Felipe Zanna. 2012. "Public Investment, Growth and Debt Sustainability: Putting Together the Pieces." IMF Working Paper 12/144, International Monetary Fund, Washington, DC.

Bumpus, Adam G. 2015. "Firm Responses to a Carbon Price: Corporate Decision Making under British Columbia's Carbon Tax." *Climate Policy* 15 (4): 475–93.

Burke, Marshall. 2020. "COVID-19 Reduces Economic Activity, which Reduces Pollution, which Saves Lives." Global Food, Environment and Economic Dynamics. http://www.g-feed.com/2020/03/covid-19-reduces-economic-activity.html

Caldecott, Ben, Geraldine Bouveret, Gerard Dericks, Lucas Kruitwagen, Daniel J. Tulloch, and Xiawei Liao. 2017. "Managing the Political Economy Frictions of Closing Coal in China." Discussion Paper, Sustainable Finance Programme, Smith School of Enterprise and the Environment, University of Oxford.

Cantelmo, Alessandro, Giovanni Melina, and Chris Papageorgiou. 2019. "Macroeconomic Outcomes in Disaster-Prone Countries." IMF Working Paper 19/217, International Monetary Fund, Washington, DC.

Carattini, S. and S. Kallbekken. 2019. "Carbon Pricing Is Finally Enjoying some Momentum, Despite Setbacks." LSE Business Review, London.

Chen, Jiaqian, Maksym Chepeliev, Daniel Garcia-Macia, Dora M. Iakova, James Roaf, Anna Shabunina, Dominique van der Mensbrugghe, and Philippe Wingender. 2020. "EU Climate Mitigation Policy." IMF Departmental Paper 20/13, International Monetary Fund, Washington, DC.

Climate Bonds Initiative. 2020. "Green Infrastructure Investment Opportunities: Philippines 2020 Report." http://dx.doi.org/10.22617/TCS200335-2

Climate Central. 2019. "Flooded Future: Global Vulnerability to Sea Level Rise Worse than Previously Understood." https://www.climatecentral.org/news/report-flooded-future-global-vulnerability-to-sea-level-rise-worse-than-previously-understood

Climate Change Secretariat of Sri Lanka. 2016. "National Adaptation Plan for Climate Change Impacts in Sri Lanka 2016–2025." Ministry of Mahaweli Development and Environment, Ethul Kotte, Sri Lanka.

Commonwealth of Australia. 2009. "Australia's Future Tax System: Report to the Treasurer, Part Two, Detailed Analysis." Canberra, Australia.

Dabla-Norris, Era, Jim Brumby, Annette Kyobe, Zac Mills, and Chris Papageorgiou. 2012. "Investing in Public Investment: An Index of Public Investment Efficiency." *Journal of Economic Growth* 17: 235–66.

Davis, Donald, R., and David E. Weinstein. 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." American Economic Review, 92 (5): 1269–1289.

Donald, Donald R., and David E. Weinstein. 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." American Economic Review 92 (5): 1269–89.

Douenne, Thomas, and Adrien Fabre. 2020. "French Attitudes on Climate Change, Carbon Taxation and Other Climate Policies." *Ecological Economics* 169: 106496.

El Congreso de Colombia. 2016. "Ley 1819 de 2016." https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=79140

EM-DAT. 2020. "The International Disaster Database." Center for Research on the Epidemiology of Disasters. https://www.emdat.be/

European Bank for Reconstruction and Development (EBRD). 2019. "Firm Dynamics and Productivity." In *Transition Report 2017–18: Sustaining Growth*. London: European Bank for Reconstruction and Development.

Farid, Mai, Michael Keen, Michael Papaioannou, Ian Parry, Catherine Pattillo, Anna Ter-Martirosyan, and other IMF staff. 2016. "After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change." IMF Staff Discussion Note 16/01, International Monetary Fund, Washington, DC.

Fiji (Government of Republic of Fiji). 2017. Climate Vulnerability Assessment. Making Fiji Climate Resilient. https://www.gfdrr.org/en/fiji-climate-vulnerability-assessment.

Flues, Florens, and Alastair Thomas. 2015. "The Distributional Effects of Energy Taxes." OECD Taxation Working Paper 23, Organisation for Economic Co-operation and Development, Paris.

Food and Agriculture Organization. 2020. "FAOSTAT Emissions Database." http://www.fao.org/faostat/en/#data

Ghani, Ejaz, William Kerr, and Stephen O'Connell. 2011. "Who Creates Jobs?" *World Bank – Economic Premise* 70.

Ghazanchyan, Manuk, Ricardo Marto, Jiri Jonas, and Kaitlyn Douglass. 2017. "Collect More, Spend Better: Public Investment in Asian Frontier Markets." IMF Working Paper 17/10, International Monetary Fund, Washington, DC.

Global Alliance of Health and Pollution (GAHP). 2019. "Pollution and Health Metrics: Global, Regional, and Country Analysis December 2019." https://gahp.net/wp-content/uploads/2019/12/PollutionandHealthMetrics-final-12_18_2019.pdf

Global Commission on Adaptation (GCA). 2018a. *Adapt Now: A Global Call for Leadership on Climate Resilience*. Washington, DC: World Resources Institute.

Global Commission on Adaptation (GCA). 2018b. "The Economics of (and Obstacles of) Aligning Development and Climate Change Adaptation." Discussion Paper, World Resources Institute, Washington, DC.

Global Facility for Disaster Reduction and Recovery (GFDRR). 2017. "A Decade of Progress in Disaster Risk Management." https://www.gfdrr.org/sites/default/files/10%20Years%20DRM%20Development%20DRAFT.pdf

Golder, Bishwanath. 2011. "Energy Intensity of Indian Manufacturing Firms: Effect of Energy Prices, Technology and Firm Characteristics." Science, Technology and Society 16 (3): 351–72.

Hallegatte, Stephane, Colin Green, Robert J. Nicholls, and Jan Corfee-Morlot. 2013. "Future Flood Losses in Major Coastal Cities." *Nature Climate Change* 3 (9): 802–06.

Hallegatte, Stephane, Jun Rentschler, and Julie Rozenberg. 2019. *Lifelines: The Resilient Infrastructure Opportunity*. Washington, DC: World Bank.

Henry, K., 2009. Australia' s future tax system: Report to the Treasurer, Part Two, Detailed analysis, Canberra ACT.

Hepburn, Cameron, Brian O'Callaghan, Nicholas Stern, Joseph Stiglitz, and Dimitri Zenghelis. 2020. "Will COVID-19 Fiscal Recovery Packages Accelerate or Retard Progress on Climate Change?" *Oxford Review of Economic Policy* 36 (1): S359–S381.

Institute of Social Science Survey. 2015. "China Family Panel Studies (CFPS)." Peking University, Peking University Open Research Data Platform, V39.

Intergovernmental Panel on Climate Change (IPCC). 2013. "Climate Change 2013, The Physical Science Basis." https://www.ipcc.ch/site/assets/uploads/2017/09/WG1AR5_Frontmatter_FINAL.pdf

Intergovernmental Panel on Climate Change (IPCC). 2014. "AR5 Synthesis Report: Climate Change 2014." https://www.ipcc.ch/report/ar5/syr/

Internal Revenue Service (IRS). 2020. "EITC Participation Rate by States." https://www.eitc.irs.gov/eitc-central/participation-rate/eitc-participation-rate-by-states

International Energy Agency (IEA). 2017. *Energy Policies of IEA Countries: Norway 2017*. Paris: OECD Publishing.

International Energy Agency (IEA). 2020. "Electricity Information Database." https://www.iea.org/subscribe-to-data-services/electricity-statistics

International Monetary Fund (IMF). 2015. "Making Public Investment More Efficient." IMF Policy Paper, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2016a. "Fiscal Policies for Innovation and Growth." *Fiscal Monitor*. Washington, DC, April.

International Monetary Fund (IMF). 2016b. "Small States' Resilience to Natural Disasters and Climate Change—Role for the IMF." IMF Policy Paper, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2017. "The Effects of Weather Shocks on Economic Activity." *World Economic Outlook*. Washington, DC, October.

International Monetary Fund (IMF). 2018. "Solomon Islands: Public Investment in the Face of Natural Disasters: A Model Application to Solomon Islands." IMF Country Report 18/73, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2019a. "Bangladesh Selected Issues: Climate Change Mitigation and Adaptation in Bangladesh." International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2019b. "Building Resilience in Developing Countries Vulnerable to Large Natural Disasters." IMF Policy Paper, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2019c. "Fiscal Policies for Paris Climate Strategies—from Principle to Practice." IMF Policy Paper 19/010, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2019d. "How to Mitigate Climate Change?" *Fiscal Monitor*. Washington, DC, October.

International Monetary Fund (IMF). 2019e. "Investment and Capital Stock Dataset." International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2020a. "Adapting to Climate Change in Sub-Saharan Africa." *Sub-Saharan Africa: Regional Economic Outlook*. Washington, DC, April.

International Monetary Fund (IMF). 2020b. "Fiscal Policies to Address the Pandemic." *Fiscal Monitor*. Washington, DC, October.

International Monetary Fund (IMF). 2020c. "Kingdom of Tonga: Climate Change Policy Assessment." International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). 2020d. "Mitigating Climate Change." *World Economic Outlook*. Washington, DC, October.

International Monetary Fund (IMF). 2020e. "Reaching Households in Emerging and Developing Economies: Citizen ID, Socioeconomic Data, and Digital Delivery." Special Series on Fiscal Policies to Respond to COVID-1, International Monetary Fund, Washington, DC.

International Monetary Fund (IMF). Forthcoming. "Infrastructure Governance: From Aspiration to Action." International Monetary Fund, Washington, DC.

Kemp-Benedict, Eric. 2014 "Shifting to a Green Economy: Lock-in, Path Dependence, and Policy Options." Stockholm Environment Institute.

Kenward, S., L. Cordier, and R. Islam. 2012. "Chars Livelihoods Programme: A Study to Assess the Performance of CLP Raised Plinths, Low Cost Latrines and Access to Clean Water during the July 2012 Flood." Chars Livelihoods Programme and Maxwell Stamp PLC, Dhaka, Bangladesh.

Kiribati National Statistics Office. 2006. "Household Income and Expenditure Survey 2006." https://microdata.pacificdata.org/index.php/home

Klenert, David, Linus Mattauch, Emmanuel Combet, Ottmar Edenhofer, Cameron Hepburn, Ryan Rafaty, and Nicholas Stern. 2018. "Making Carbon Pricing Work for Citizens." Nature Climate Change 8: 669–77.

Koch, Nicolas, and Houdou Basse Mama. 2019. "Does the EU Emissions Trading System Induce Investment Leakage? Evidence from German Multinational Firms." *Energy Economics* 81 (June): 479–92.

Koks, Elco E., Julie Rozenberg, Conrad Zorn, Mersedeh Tariverdi. 2019. "A Global Multi-hazard Risk Analysis of Road and Railway Infrastructure Assets." *Nature Commununications* 10 (1): 2677.

Lee, Jaeseok, and Jongmin Yu. 2019. "Heterogenous Energy Consumption Behavior by Firm Size: Evidence from Korean Environmental Regulations." *Sustainability* 11 (11): 3226.

Le Quéré, Corinne, Robert B. Jackson Matthew W. Jones, Adam J. P. Smith, Sam Abernethy, Robbie M. Andrew, Anthony J. De-Gol, David R. Willis, Yuli Shan, Josep G. Canadell, Pierre Friedlingstein, Felix Creutzig, and Glen P. Peters. 2020. "Temporary Reduction in Daily Global CO_2 Emissions during the COVID-19 Forced Confinement." Nature Climate Change 10: 647–53.

Ley, Marius, Tobias Stucki, and Martin Woerter. 2016. "The Impact of Energy Prices on Green Innovation." *The Energy Journal* 37 (1): 42–76.

Liu, Antung Anthony. 2013. "Tax Evasion and Optimal Environmental Taxes." *Journal of Environmental Economics and Management* 66 (3): 656–70.

Martin, Ralf, Laure B. de Preux, and Ulrich J. Wagner. 2014. "The Impact of a Carbon Tax on Manufacturing: Evidence from Microdata." *Journal of Public Economics* 117: 1–14.

Marto, Ricardo, Chris Papageorgiou, and Vladimir Klyuev. 2018. "Building Resilience to Natural Disasters: An Application to Small Developing States." *Journal of Development Economics* 135: 574–86.

McGrath, Charles. 2020. "China Leads in Green Bonds, Others Catching Up." https://www.pionline.com/interactive/

Melitz, Marc, J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica* 71 (6): 1695–725.

Miyamoto International. 2019. "Overview of Engineering Options for Increasing Infrastructure Resilience." World Bank, Washington, DC.

Muro, Mark, Adie Tomer, Ranjitha Shivaram, and Joseph Kane. 2019. "Advancing Inclusion through Clean Energy Jobs." Metropolitan Policy Program, Brookings Institution, Washington, DC.

NASA. 2020. "NASA, NOAA Analyses Reveal 2019 Second Warmest Year on Record." https://www.nasa.gov/press-release/nasa-noaa-analyses-reveal-2019-second-warmest-year-on-record

National Adaptation Plan Global Support Programme (NAP-GSP). 2016. "Regional Briefing on National Adaptation Plans: ASIA-PACIFIC in Focus." https://www.globalsupportprogramme.org/sites/default/files/resources/regional_briefing_on_naps_asia-pacific_1.pdf

National Climate Change Secretariat (NCCS). 2020. "Carbon Tax." https://www.nccs.gov.sg/faqs/carbon-tax/

National Sample Survey Office. 2011. "Household Consumer Expenditure: NSS 68th Round, July 2011 - June 2012." Ministry of Statistics and Programme Implementation, Government of India.

National Statistics Office of Mongolia. 2016. "Household Socio-Economic Survey 2016." http://web.nso.mn/nada

Neumann, Barbara, Athanasios T. Vafeidis, Juliane Zimmermann, and Robert J. Nicholls. 2015. "Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding- A Global Assessment." *PLoS ONE* 10 (6): e0131375.

Nicholls, Robert, Jochen Hinkel, Daniel Lincke, and Thomas van der Pol. 2019. "Global Investment Costs for Coastal Defense through the 21st Century." World Bank Policy Research Working Paper 8745, World Bank, Washington, DC.

National Oceanic and Atmospheric Administration. (NOAA). 2020. "Assessing the Global Climate in 2019." https://www.ncei.noaa.gov/news/global-climate-201912

Organisation for Economic Co-operation and Development (OECD). 2019. "Taxing Energy Use 2019: Country Note – Norway." Paris.

Parry, Ian, Victor Mylonas, and Nate Vernon. 2018. "Mitigation Policies for the Paris Agreement: An Assessment for G-20 Countries." IMF Working Paper 18/193, International Monetary Fund, Washington, DC.

Parry, Ian, Baoping Shang, Philippe Wingender, Nate Vernon, and Tarun Narasimhan. 2016. "Climate Mitigation in China: Which Policies Are Most Effective?" IMF Working Paper 16/148, International Monetary Fund, Washington, DC.

Philippine Statistics Authority. 2015. "2015 Family Income and Expenditure Survey." http://202.78.94.78/index.php/request-data

Phillis, Yannis A., Nektarios Chairetis, Evangelos Grigoroudis, Fotis D. Kanellos, and Vassilis S. Kouikoglou. 2018. "Climate Security Assessment of Countries." *Climatic Change* 148 (1–2): 25–43.

Poontirakul, Porntida, Charlotte Brown, Erica Seville, John Vargo, and Ilan Noy. 2017. "Insurance as a Double-edged Sword? Quantitative Evidence from the 2011 Christchurch Earthquake." *Geneva Papers on Risk and Insurance* 42: 609–32.

Popp, David. 2002. "Induced Innovation and Energy Prices." *American Economic Review* 92 (1): 160–80.

Rosegrant, Mark W., Gary Yohe, Mandy Ewing, Rowena Valmonte-Santos, Tingju Zhu, Ian Burton, and Saleemul Huq. 2010. "Climate Change and Asian Agriculture." *Asian Journal of Agriculture and Development* 7 (1): 41–81.

Rozenberg, Julie, and Marianne Fay. 2019. *Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet*. Washington, DC: World Bank.

Sahu, Santosh Kumar, and K. Narayanan. 2011. "Total Factor Productivity and Energy Intensity in Indian Manufacturing: A Cross-sectional Study." *International Journal of Energy Economics and Policy* 1 (2): 47–58.

Sawhney, Puja, and Mary AnnPerkins. 2015. *Emerging Climate Change Adaptation Issues in the Asia-Pacific Region*. Bangkok: Asian and Pacific Adaptation Network.

Singh, Kartikeya. 2020. "India's Coal Tax Is Key to Stabilizing Its Energy Transition." Center for Strategic and International Studies. https://www.csis.org/analysis/indias-coal-tax-key-stabilizing-its-energy-transition

UN Environment Programme. 2019. *Emissions Gap Report 2019*. Nairobi, Kenya: UN Environment Programme.

Venmans, Frank, Jane Ellis, and Daniel Nachtigall. 2020. "Carbon Pricing and Competitiveness: Are They at Odds?" *Climate Policy* 20 (9): 1070–91.

Ware, D. 2016. "Financial and Funding Mechanisms for Adaptation to Climate Change." CoastAdapt, National Climate Change Adaptation Research Facility, Gold Coast, Queensland, Australia.

World Bank. 2013. "Cyclone Phailin in Odisha: Rapid Damage and Needs Assessment Report (English)." World Bank, Washington, DC.

World Bank. 2015. "3 Steps to Decarbonizing Development for a Zero-Carbon Future." World Bank, Washington, DC.

World Bank. 2016a. "Bangladesh: Building Resilience to Climate Change." World Bank, Washington, DC.

World Bank. 2016b. "The Cost of Air Pollution. Strengthening the Economic Case for Action." The World Bank and Institute for Health Metrics and Evaluation University of Washington, Seattle.

World Bank. 2019. "Maldives First Fiscal Sustainability and Budget Credibility Development Policy Financing Operation." World Bank, Washington, DC.

World Bank. 2020. "Adaptation Principles Designing Strategies for Resilience and Climate Change Adaptation," World Bank guidance note (forthcoming), Washington, DC.

Wu, Xiao, Rachel C. Nethery, M. Benjamin Sabath, Danielle Braun, and Francesa Dominici. 2020. "Exposure to Air Pollution and COVID-19 Mortality in the United States: A Nationwide Cross-sectional Study." *Science Advances*.