The Economics of the Net Zero Transition: Policy Scenarios and the Role of Trade and Cooperation*

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Highlights: The Economics of the Net Zero Transition

Limiting the rise in global temperatures to 1.5°C above pre-industrial levels, as agreed by the signatories of the Paris Agreement, likely requires eliminating global net carbon emissions by 2050, as well as other steps. Meeting the net zero goal poses unprecedented policy challenges and opportunities. The Asia and the Pacific region, the largest emitter of CO_2 and the region most vulnerable to climate change, will have to be at the core of this effort.

This study offers policymakers, and especially those in Asia and the Pacific, a quantitative roadmap to alternative decarbonization initiatives and their economic impact. The implications of the net zero transition are daunting: the strategy will require large investments and shifts in economic activities ranging from energy production to consumption and trade.

A comprehensive Global Trade-Environment Model (GTEM) is used to simulate the economic effects of net zero and four other environmentally focused scenarios. Three scenarios represent general decarbonization strategies with different ambitions and two examine trade-related approaches, including carbon-leakage-mitigation and environmentally focused cooperation. For each scenario we project the energy transition required over the 2025-2050 period and assess macroeconomic results, such as output, employment and investment, as well as microeconomic results ranging from energy production and industrial structure to prices, wages, and trade, all by region and year.

The current Nationally Determined Contributions (NDCs) proposed by governments under the Paris Agreement are not enough to reach net zero emissions by 2050; they would reduce global carbon emissions only by two-thirds from their 2025 levels instead of eliminating them altogether. Instead, the "to do" list for net zero needs to include further advances in climate-efficient technologies, in the rollout of taxes and green regulations to incentivize their adoption and, most importantly, public acceptance of substantial preference shifts toward low-carbon production and demand.

Scenarios for achieving net zero typically focus on transforming energy use patterns and energy efficiency, the rapid electrification of energy demand, and increasing the role of renewables in electricity generation. These changes will affect trade and trade shares, with the proportion of service trade rising, the shares of agriculture, mining and energy falling, and manufacturing following trajectories in between to accommodate new product requirements. Large shifts in investment will be required from fossil fuels and products that depend on them to low-carbon energy sources and related manufactures, although overall investment levels will have to rise only modestly. Meanwhile, the implications for GDP are manageable: they appear to be far below the costs of continued climate change.

Trade is sometimes blamed for aggravating emissions, but this study finds that instead it is an important element in the solution. Trade will help to make new products and technologies that reduce carbon emissions more widely available worldwide. Trade can also help to control global carbon emissions directly, through policy initiatives such as the Carbon Border Adjustment Mechanism (CBAM) now being introduced by the European Union. By applying border taxes to imports from low carbon-tax countries, this system stimulates the adoption of low-emissions technologies. Its costs appear to be low, although initially adverse effects on the global income distribution will need to be managed with support for low-income countries.

Emphasizing regional trade policy cooperation also appears productive. We examine strategies that reduce impediments to trade in environmental goods and services, improve global trade regulations, expand the availability of green trade finance, and adjust trade-oriented government regulations (e.g. improve green government procurement, reduce fossil fuel subsidies, and promote the regeneration of forests). With such policies, net CO_2 emissions could fall by almost 3% while also increasing real GDP and trade modestly.

Whether net zero will indeed be achieved by 2050 will ultimately depend on international and national support for climate action. The economic cost of a zero-carbon economy appears to be manageable—indeed, the path will create new jobs, innovations, and investment opportunities. To be sure, the transition will affect major economies and economic sectors unequally, generating opposition. If the resulting divisions prevent or delay vigorous climate action, the accumulation of CO_2 in the atmosphere will lead to costlier and more dangerous consequences. The losses would fall heavily on Asia and the Pacific, including its most vulnerable citizens.

The Asian Development Bank (ADB) is already committed to an ambitious environmental program in its *Climate Change Action Plan 2023-2030.* In partnership with other development banks, the ADB can offer critical support for net zero. Its contributions should range widely: financing green investments and climate adaptation, leveraging private-sector finance, helping small- and medium-sized green enterprises gain better access to trade finance, promoting and facilitating green trade and investment, and using its convening power to mobilize related efforts by other organizations such as ASEAN and the Regional Comprehensive Economic Partnership (RCEP).

I. Introduction

To prevent potentially catastrophic changes in the earth's climate and related environmental systems, nearly 200 countries have now adopted legally binding commitments to keep global temperatures from rising more than 2ºC above pre-industrial levels, and preferably limiting those increases to under 1.5°C.[1] In turn, the International Energy Agency (IEA, 2021) has proposed a simple milestone toward the Paris goals: eliminating net industrial CO_2 emissions across the world by 2050. By 2024 more than one hundred countries and thousands of local governments and companies had launched or began developing net zero plans of their own (Energy & Climate Intelligence Unit | Net zero Scorecard).

Although the net zero effort has quickly gained momentum, many of its implications remain unclear. This study addresses one critical dimension: the global economic adjustments needed to eliminate CO_2 emissions by 2050. Clearly, achieving this goal will require rapid changes in the global supply and demand of energy and other products, improvements in energy technology, shifts in international trade, and investments in capital and human resources. These efforts suggest a global economic undertaking with no historical peer.

The benefits of decarbonization are difficult to assess precisely. It is reasonable to expect, as some research finds, that permitting global temperatures to cross the Paris threshold will eventually cost millions of lives and trillions of dollars in lost economic activity in the intermediate future. One estimate reported in Figure 1 shows that a 3.2º C rise in global temperatures[2] above pre-industrial levels by 2048 would reduce world GDP by 18.1 percent, Asian GDP by 26.5 percent, and ASEAN GDP by 37.4 percent.[3] Along the way, climate change would sharply increase poverty and amplify global income inequality[4].

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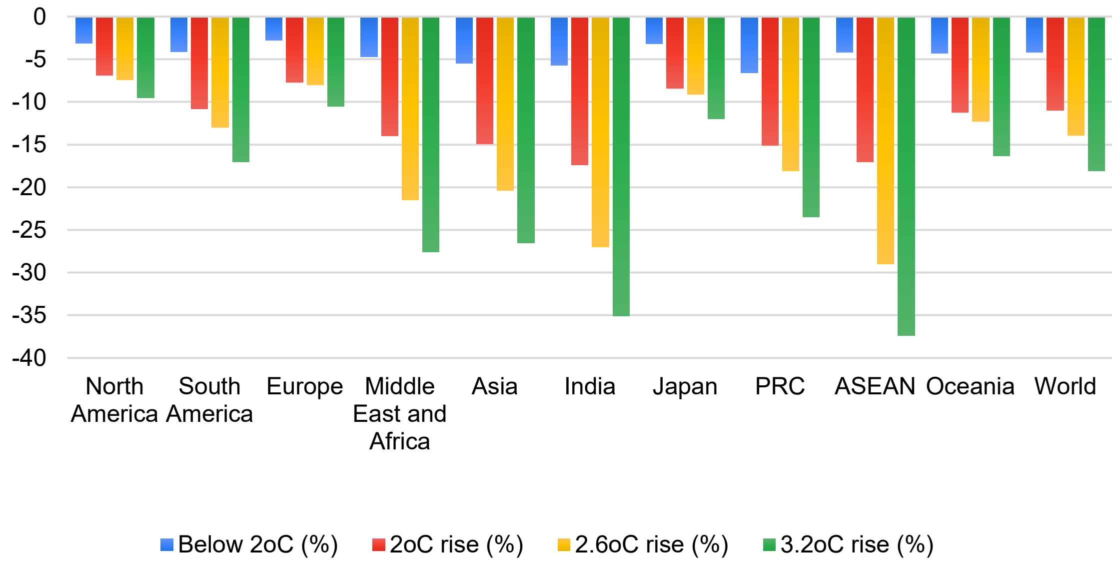
[1] This commitment, enshrined in the Paris Agreement of the 2015 United Nations Conference on Climate Change (UNFCCC), reflects the findings of the Intergovernmental Panel on Climate Change (IPCC), the leading international body established for assessing climate science.
[2] This is the largest temperature increase the study cites, but even a 2ºC increase would yield results about half as large as those in the text. Today's global temperatures represent a 1.4ºC increase, just slightly below the Paris limit.
[3] Studies of economy-wide costs of climate change vary but tend to be very high. For example, the Potsdam Institute for Climate Impact Research (Kotz, et. al. 2024) estimates a negative effect of unchecked climate change equivalent to 19 percent of global incomes by 2050, or six times the cost of mitigation, similar to the Guo study cited above.
[4] The World Bank (2020) predicts that higher temperatures will drive 68-135 million people into poverty already by 2030, and Dang, et al. (2023) find that each 1ºC rise in global temperatures will increase the world's Gini index by 0.8 percent.

Figure 1: Effects of Rising Temperatures on GDP by 2048
(Guo, et. al. 2021)



Source: Guo, Jessie, Daniel Kubli, and Patrick Saner (2021).

This study analyzes the economics of decarbonization and documents the implications of the net zero strategy for economic change, investments and international cooperation. It shows, on one hand, that feasible paths for implementing net zero exist, with costs that pale in comparison to those of inaction. But it also shows that immense challenges lie ahead on this path, requiring rapid, collective action. Meanwhile, weather anomalies are becoming more extreme, climate-related disasters more frequent, and displacements more widespread.[5] Research shows that the costs of mitigation will be lower—and the potential benefits higher—the sooner we act.

a. The challenge facing Asia and the Pacific

Asia and the Pacific countries are especially exposed to the impact of climate change and will have to play a central role in combating global warming. Dabla-Norris, et al. (2021) find that temperatures in Asia are rising at twice the global average rate and more than one-third of the world's weather-related disasters in 2020 occurred in this region, far more than anywhere else. ADB (2023a) calculates that failure to tackle the climate challenge would cost the Asia and the

[5] According to the International Displacement Monitoring Centre, in 2022 climate-related disasters caused a record number of internal displacements of 32.6 million. https://www.unhcr.org/news/stories/climate-change-and-displacement-myths-and-facts

Pacific $210 trillion in economic losses over 2020–2100,[6] with developing Asia losing 24% of its GDP by 2100.[7] The region's losses exceed those in other regions.

At the same time, Asia and the Pacific's global greenhouse gas (GHG) emissions are the highest in the world. The region accounted for one-third of global emissions in 1995 and for one-half in 2018 (Kim, et al. 2023), substantially more than its share in the world economy in both years. Since the region is expected to continue growing relatively fast, these shares will likely rise.

CO_2 emissions are also intertwined with a signature feature of development in Asia and the Pacific: successful participation in global trade and value chains. Throughout the region, countries have turned trade opportunities into engines of development and weapons against poverty. Trade raised the region's productivity, helped it tap into wealthy markets, provided access to new technologies, and attracted foreign investment. Wacziarg and Welch (2003) shows that trade liberalization from 1950 to 1998 enabled developing economies to grow 1.0 to 1.5 percentage points faster than they would have otherwise. Trade especially benefited the poorest two-fifths of the region's population.[8] The Asia and the Pacific region will be understandably reluctant to sacrifice its trade successes on the path to net zero.

Yet, Asia's industrial structure is carbon-intensive in part due to its success in building competitive but energy-intensive supply chains. To boost the region's export competitiveness and attract foreign direct investment (FDI), industrial policies had the effect of keeping energy prices low and environmental regulations light, with the effect of developing carbon-intensive industrial clusters across regional economies.

Nevertheless, trade can support growth and decarbonization. Trade provides access to markets, products and technologies that are instrumental in the net zero transition. But trade also has pitfalls. If environmental externalities—specifically the costs of mitigating carbon emissions—are not fully reflected in the prices of imported goods, then consumers of emissions-intensive products will purchase excessive amounts of them. This process, usually termed "carbon leakage," gradually transfers emissions-intensive production from countries with strict carbon

[6] On a purchasing power parity (PPP) basis at net present value, not including the Republic of Korea and the Pacific. ADB (2023a, 8).
[7] ADB (2023a, 10).
[8] https://www.worldbank.org/en/topic/trade/overview, accessed 20 July, 2024.

regulations to those with lax ones (WTO 2022). It increases global emissions by locating production in areas with lax regulations and by encouraging the consumption of emissions-intensive products with prices that fail to account for the negative externality. It also disadvantages carbon-intensive production in markets with stricter regulations, undermining investments and domestic political commitments to decarbonization.

As exporters of emissions-intensive products, Asia and the Pacific countries could face barriers against these exports unless they ensure that they are sold at prices that cover mitigation costs. This issue will become increasingly important as global emissions obligations become more binding and penalize imports from countries with weaker regulatory environments. This is already apparent in the European Commission's Carbon Border Adjustment Mechanism (CBAM), which aims to reduce carbon leakage by imposing tariffs on imports produced under lax regulations. In principle, CBAM encourages exporting countries to impose adequate carbon taxes, since that exempts them from CBAM tariffs. In practice, however, CBAM is difficult to administer because few countries or firms can accurately measure the emissions content of exports, thus making the implementation of CBAM expensive and potentially biased against imports. CBAM is often criticized for targeting low- and middle-income exporters, given their less advanced regulatory environments.

The carbon intensive industrial structure in Asia and the Pacific threatens its long-run economic security. The region's policy makers need to participate actively in global decisions and ensure that they recognize both the urgency of global warming and the value of trade in development.

b. Approach and contributions of this study

This paper offers a roadmap for understanding the economic implications of net zero, including projections of industrial composition, trade patterns, and technological progress. It also assesses the scale and pattern of investments and policy changes needed for a low-carbon economy. These estimates are developed with a large model that represents the energy, emissions, and conventional sectors of several major world regions. This Global Trade and Environment Model (GTEM) is ultimately used to analyze policy options for the 2025-2050 period.

The GTEM model and its applications build on decades of experience by international research and policy institutes in similar policy analyses. The model itself is based on a large international data collection effort, the Global Trade Analysis Project (GTAP), and includes special features developed at the World Trade Organization (WTO) and other international research institutes. The environmental and trade policy goals draw on work at the International Energy Agency (IEA), the United Nations Framework Convention on Climate Change (UNFCCC), the Asian Development Bank (ADB) and the WTO. Many other sources will be also referenced below.

The starting point of scenario construction is the model's *baseline scenario.* This scenario defines a "most likely" projection of the model's key economic and environmental variables and serves as a point of comparison for other scenarios with different policy assumptions. As further explained below, the baseline scenario is based on exogenous projections of several key drivers of economic and environmental change. In turn, the four major policy scenarios replace some parameters with values that reflect different policy objectives. Solutions based on these adjustments are then compared to the baseline to answer a host of questions about how the policy will perform, including how it will affect carbon emissions, investment requirements, trade and employment, wages and incomes, and other variables, all in regional and sectoral detail.

The study's five policy scenarios span a wide range of environmental ambitions and economic strategies for reaching them. Each scenario produces a database of results, covering hundreds of economic and environmental variables, 17 world regions, 28 economic sectors, and 25 projection years. Essentially, it builds "what if" snapshots of the global economy on the baseline and the five policy alternatives examined. We report selections from these results, prioritizing variables of greatest policy interest.

c. Major findings

Four major themes emerge from this report. First, the results underline the vast geographical and economic scale of the net zero project and its challenges. Rapid progress will be needed on three difficult transitions: increasing energy efficiency, electrification, and replacing fossil fuels with renewable power sources. As Figure 3 will show, these transitions imply dramatic shifts in the use and production of energy and require massive investments. These transitions will create jobs and investment opportunities in new technologies and likely accelerate innovation and cost reductions. But they will also reduce jobs in brown industries and require reallocation of workers and capital from across sectors. In most political settings these shifts will trigger vigorous resistance from those adversely affected. This is already evident in many sectors and countries.

Second, the results point to significant changes in trade levels and trade patterns. These changes are not dramatic overall—we expect that under net zero global real trade flows will grow by 2.2 percent relative to the baseline by 2050, somewhat more slowly than in recent years and only 0.3 percent more slowly than under the baseline scenario. But these aggregates hide significant divergences across sectors. For example, the sectoral projections show that trade in services will expand much more rapidly than total trade, and trade in energy products will *decline* sharply. This last result reflects a falloff in fossil fuel trade as demand shifts to low-carbon sources that are more widely available across the world.

Third, the results demonstrate that decarbonization requires international cooperation. All decarbonization scenarios examined in the study assume parallel efforts across the world, and payoffs to these loosely coordinated policies would fall sharply if important countries or groups of countries abandoned—in effect exploited as "free riders"—the global strategy. Moreover, an explicit Cooperation scenario examined below would both reduce emissions and increase incomes—but only if most countries are willing to adopt parallel policies to reduce critical trade barriers, eliminate fossil fuel subsidies, pursue reforestation, and join other green efforts.

Fourth, the results strongly suggest that powerful leadership will be essential for the success of the net zero project, given its political and economic complexity. Regional institutions, including the ADB, are well placed to provide critical expertise: they have financial resources to leverage private investment, knowhow to support new policy initiatives, experience in capacity building, and regional networks of national officials to foster collaborative decision making. The ADB has already embarked on becoming a "climate bank" and on growing climate finance to at least 50 percent of its lending portfolio by 2030 (ADB News Release 12, November 2024). These resources and expertise can be leveraged through joint initiatives with other regional and multilateral banks, knowledge pooling in fields like private-sector finance and large-scale infrastructure, policy collaborations with organizations like ASEAN and the Regional

Comprehensive Economic Partnership (RCEP), and research collaboration with non-profit organizations.

d. Caveats on results

As already noted, this study estimates the *costs* of limiting climate change but does not assess the benefits of preventing the deterioration of the climate, that is, the study does not calculate *losses avoided* by keeping temperatures within 1.5ºC of pre-industrial levels.[9] Research by Guo et al. (2021) fills this gap and offers estimates for benefit-cost comparisons. This and other sources suggest that benefits from avoiding global warming far exceed the costs of decarbonization. Given disproportionate benefits, the decision to fight climate change is not a close call—as the title of Swiss Re report puts it, decarbonization is "not an option."

An example for five ASEAN countries (the model's ASEAN5 region) illustrates this point. The simulation of the Net Zero scenario shows that its implementation would depress their GDP by 4.3 percent ($305 billion) relative to the baseline scenario in 2050, suggesting that rapid decarbonization will involve a significant sacrifice. Yet if temperatures were to grow from around 1.5ºC to 2.6ºC (above pre-industrial levels) in 2048, a reasonable expectation without the net zero strategy, Guo et al. (2021) estimates that ASEAN's GDP would fall by 29 percent ($1,949 billion). Since net zero would prevent this loss, its $305 billion annual cost would return $1,949 billion in annual benefits, a gain 6.4 times as large as the underlying investment.

In addition, this study does not cover non-industrial emissions of greenhouse gases, particularly from agriculture. These contribute significantly to the global climate threat but are weakly linked to the energy systems addressed by this study.

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[9] Our long-term GDP projections use the Shared Socioeconomic Pathways Database coordinated by International Institute for Applied Systems Analysis (IASA) (https://iiasa.ac.at/models-tools-data/ssp), which does not explicitly account for climate change. We assume that these projections underestimate changes in the climate and its negative effects on GDP and assuming moderate global warming of about 1ºC over the next 25 years.

II. Modelling Environmental Policy

The “engine room” of this study is a global CGE model extended with environmental variables and focused on the Asia and the Pacific region. This section describes the model and how it is used to develop a baseline scenario and four policy alternatives.

a. Modelling strategy

The study draws from several research areas: (a) climate policy objectives, specifically the speed and scale of necessary reductions in CO_2 emissions; (b) technologies to support transition from fossil fuels to low-carbon energy sources, and (c) simulation methodologies that can connect economic and environmental modeling.

First, it relies mainly on the UNFCCC process to define climate policy objectives, including country-level Nationally Determined Contributions (NDCs) drafted in its deliberations. Second, it uses IEA information to set technological parameters for the technology transition, drawing on their extensive knowledgebase on energy balances and national policy proposals. Third, it analyzes these goals and data using a model built on the latest (2023) release of the GTAP11-POWER-E(missions) database which includes environmental externalities such as CO_2 emissions and detailed energy production and utilization relationships.[10] The model adopts innovations from recent work by the WTO on economic and environmental models, along with further improvements tailored to the objectives of this study.[11]

The model serves as a laboratory for exploring the global economic implications of medium-term climate policy. It produces simulated paths for economic and environmental variables for the 2025-2050 period, covering 17 world regions (eight in Asia and the Pacific), and for 28 economic sectors (including 13 energy industries). The model’s GTAP dataset is based on 2017 observations, which are updated to establish a 2025 base year for simulations. The model also includes a variety of estimated parameters that describe how variables interact and react to

[10] The 13 energy sectors are coal, oil, gas, products of oil and other fuels, transmission and distribution of electricity, and electric power generated with coal, oil, and gas, and with nuclear, hydro, wind, solar, and all other technologies.
[11] WTO studies have introduced more detailed representations of firm and consumer decisions on energy use and emissions than have been applied in the past. Our model builds on the Bekkers-Cariola model (Bekkers and Cariola, 2022), which was used, in somewhat modified form, in the WTO report on the environment.

changes in prices, income, and other drivers. Base year data are adjusted to be internally consistent with all model equations, ensuring, for example, that the global sum of exports equals the global sum of imports for every product.[12]

As already noted, we begin by building a baseline scenario for 2025-2050. This path is designed to portray likely outcomes; it is based on external projections of major economic drivers such as population, technological progress, and investment rates, obtained from leading research agencies. These projections are then used as exogenous variables to calculate the baseline trajectory of the world economy. For example, population and growth projections we used come from the International Monetary Fund (IMF) and the International Institute for Applied Systems Analysis (IIASA), while the environmental assumptions are from the IEA's Stated Economic Policy scenario ("STEPS"). Table 1 shows how these external assumptions are translated into values for the model's exogenous variables and parameters.

We then consruct four *policy scenarios* to explore the effects of alternative assumption about environmental and related economic policies (see Table 1). For example, the IEA "Pledges" scenario revises the STEPS assumptions for commitments to future policies that countries have been made in the Paris process, and the IEA "Net Zero" scenario assumes the full elimination of net CO_2 emissions in every model region by 2050. The study's two final scenarios represent environmentally oriented *trade policies*: one models *leakage mitigation*, based on applying tariffs to carbon-intensive trade; the other represents broad *international cooperation* by combining recent global policy proposals to reduce emissions.

b. Overview of the Global Trade-Environment Model

CGE models are widely used in international trade and, more recently, environmental analysis. A global CGE model includes multiple regional economies connected by trade. Each consists of multiple industries and final consumers that are linked through input-output structures. Economic activity in each region is driven by the purchasing decisions of four groups of economic agents (consumers, investors, governments and firms) whose incomes depend on market demands and

[12] This is not observed in raw trade data and is imposed through data adjustments. Goods imported in any finite period are not necessarily equal to those exported in that period, since they were exported in earlier periods.

Table 1: Scenario Assumptions

	Baseline (STEPS)	Pledges	Net Zero	Leakage Mitigation	Cooperation
Objectives	• Assess current policy commitments via the IEA STEPS scenario	• Implement pledged policies according to IEA Scheduled Pledges scenario	• Achieve net zero emissions worldwide in IEA Net Zero scenario	• Expand carbon tariffs to reduce leakage of emissions to low-carbon-cost economies	• Use WTO policy tools to reduce emissions through coordinated global environmental trade and tax policies
Technological developments	• Reduce energy use in production sectors • Improve power generation	• Accelerate advances in technologies in baseline	• Further advances in technologies in Pledges scenario		
Environmental policy actions	• Increase electrification • Set growth targets for coal wind and solar power • Establish Incentives for energy transition	• New household efforts to minimize emissions • New corporate efforts to minimize emissions • Increased support for baseline policies	• Further efforts in areas addressed by Pledges scenario		• New reforestation agreement
Trade policy actions				• CBAM-style tariffs encompassing more regions and products • Tariffs applied by US, Europe, North America, and Advanced Asia on others	• Eliminate impediments to EGS trade: tariff regulations, trade finance • Liberalize food and agriculture trade • Align trade regulations with environmental goals
Tax policy actions	• Add carbon taxes to meet IEA STEPS outcomes	• Add carbon taxes to meet IEA Pledges outcomes	• Add carbon taxes to meet IEA Net Zero outcomes		• Remove fossil fuel subsidies • Intensify government procurement of EGS

Source: authors

factor prices. The income of each agent is allocated to purchases of different products (domestic and imported) according to their prices and the agent's consumer or technical preferences.

The heart of a CGE model is a set of simultaneous market-clearing equations. These require total supply to equal total demand for every product and factor of production in every region. Regional supply adds up products sold by local as well as foreign firms in the local market; regional demand includes purchases by all domestic and foreign agents active in that market. Similar market clearing equations apply to capital, labor, land and other primary factors of production. An equilibrium solution of the model requires prices that bring all demands and supplies into balance.

To solve a CGE model, researchers first specify a "closure" by choosing which variables will be fixed (exogenous) and assign values to them, and which variables will be computed by the model (endogenous).[13] For example, a scenario might fix carbon taxes at $100/ton of CO_2 emissions in each region and allow regional emissions to be determined endogenously. Alternatively, emissions might be set exogenously, letting the model compute carbon taxes endogenously to meet the emissions target.

Policy decisions can be introduced using instruments such as taxes, production quotas, or investments. Taxes may apply to supply, demand, imports, exports and other variables. These interventions could target production outputs or inputs, or the use of primary factors such as labor, capital, and land. The closures used in our scenarios will be explained below.

GTEM is a dynamic, recursive model producing annual simulations from 2025 to 2050. Adjoining annual solutions are linked through investment and other variables; investment in year t becomes part of the model's capital stock in year $t+1$. Taxes and other parameters established in year t remain in effect until they are explicitly changed in a later year.

c. How GTEM calculates CO_2 emissions and represents environmental policy

GTEM calculates CO_2 emissions based on the use of four fossil fuels (coal, oil, gas, and the refined products of these fuels, whether domestically used or imported) in combustion. Although fossil fuel combustion takes place in only a few economic sectors, input-output linkages imply

[13] The number of endogenous variables must equal the number of independent equations in the model. Equations are independent if they cannot be derived as a linear combination of other equations.

that emissions ultimately depend on the full range of an economy's production and consumption activities.[14] As expected, electricity generation, transportation, consumption, and a handful of large industrial sectors are the key direct users of fossil fuels and largest proximate contributors to emissions. However, outputs produced by these sectors (for example, electric power) are widely used by other sectors, so fossil fuel combustion and related emissions indirectly depend on every activity in the economy.

Energy demand systems play a central role in determining emissions. GTEM uses detailed energy sub-models to represent the energy-related decisions of consumers and firms in various industries. These sub-models consist of 9-layered decision trees (see Figure 2) that determine a production sector's (identified at the top) energy expenditures, approximately 1/3 down the tree, and then distribute this to 12 energy sources (identified in bold italic font).[15] Each layer allows substitution among multiple products, including eventually energy sources. These are typically specified with CES demand functions. Energy and other prices, as well as demand and regulatory parameters, determine how demand is split up at each branch of the tree. System parameters are calibrated to base year data on prices and demand in each sector and region.[16]

Taxes and regulatory constraints influence energy demand allocations at every layer. Alternative policy scenarios are implemented by setting values for these instruments. A detailed list of such instruments—including taxes, subsidies, regulations and interventions like advertising—can be introduced in each layer of the model to induce changes in allocations. For example, taxes may apply to energy in general, energy based on direct combustion, or coal-derived electric power.

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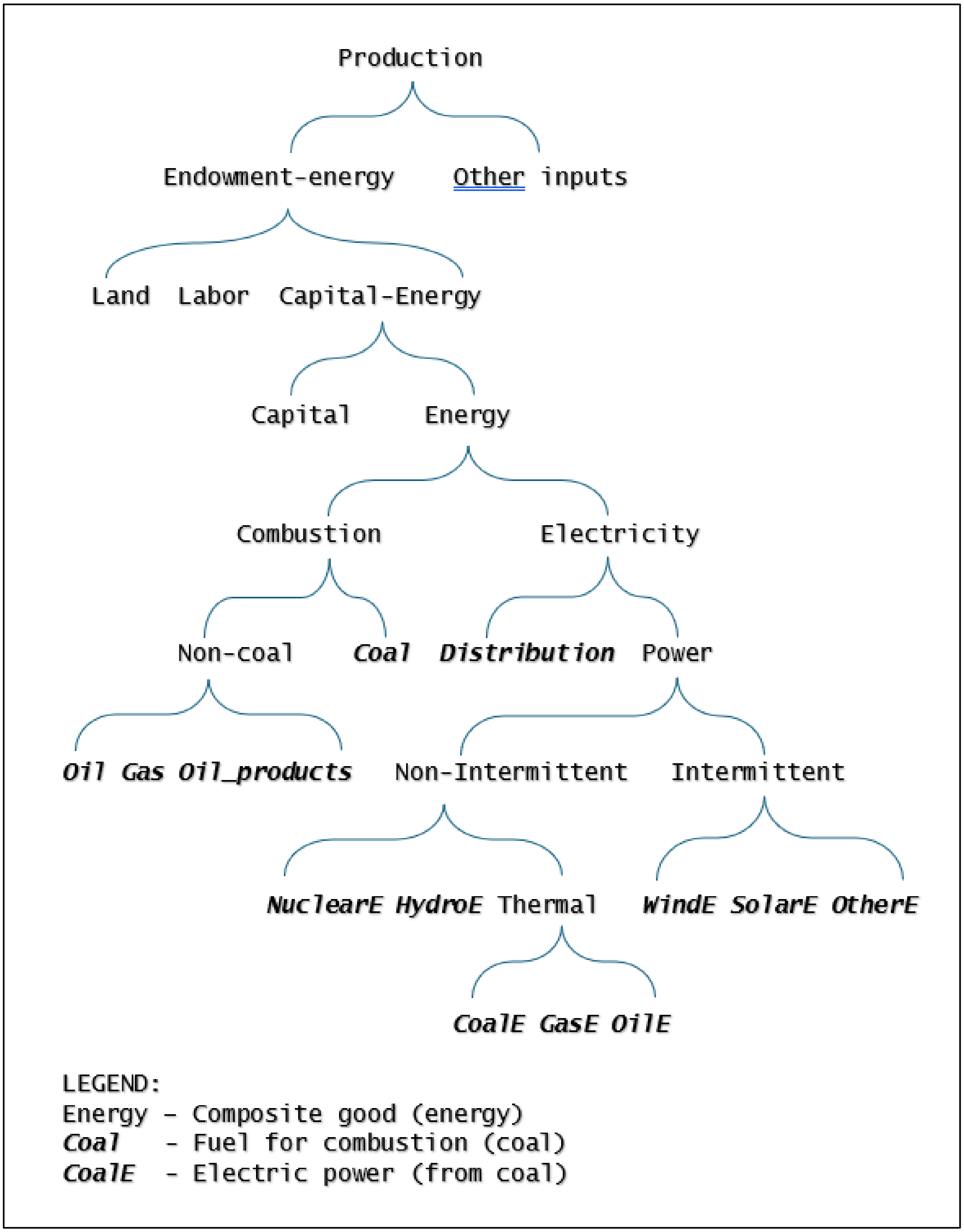
[14] Combustion and emissions may occur in fuel production itself. For example, the natural gas byproducts of oil extraction may be "flared," or directly burned, because they are too costly to use at the site.

[15] Firms in specific industries and individual consumers will have simpler decisions to make, because not all substitution possibilities will be relevant to their objectives. The more complete decision tree discussed above represent choices facing "representative" national firms and consumers, which can be viewed as averaging the characteristics of many types of firm and consumers.

[16] The decision tree representing firms' choices includes steps for allocating energy budgets through a sequence of choices. This sequence includes allocations: (1) between capital equipment and energy, (2) between electric energy and other direct energy sources, (3) between intermittent and non-intermittent electricity sources, (4) among three different sources of intermittent power (wind, solar, and other), and (5) among three different sources of non-intermittent power (nuclear, hydro, thermal). Such multi-layered demand systems can respond flexibly to different combinations of energy price changes and provide more ways to fit differences across industries and regions.

Figure 2: GTEM Energy Demand Sub-Model



Source: authors, based on similar work in Bekkers and Cariola (2022).

Policy instruments differ in how they influence demand. Table 2 summarizes three approaches:

1. *Technological advances*. Policies can support research and investment for improving efficiency in energy production or use. Supply-side progress reduces input requirements in energy production. Demand-side progress affects the energy required to operate energy-using devices, such as motors or batteries. Each can be modelled by changing the inputs of energy required to achieve specific outcomes at constant prices.

2. *Financial and regulatory interventions.* Market prices often fail to capture externalities, requiring interventions to correct prices, which may include taxes and subsidies, regulations, financial disclosures about externality generation, and policy directives to phase out fuels or distribution systems.

3. *Preference shifts*. The energy demand patterns of firms, households, and governments often reflect inertia in decision-making, perhaps due to lack of information or the costs of changing behavior. In either case, shifts to low-carbon energy sources may be cost-neutral or even cost-reducing (at least in the ordinary sense of costs). In some circumstances, "socializing" new energy choices may be more cost-efficient in changing behavior through direct financial incentives.

A powerful environmental tax instrument—a general carbon-tax on fossil fuels proportional to the CO_2 emissions they generate in combustion—is also operationalized in GTEM. In some simulations the carbon tax is used as a tool of "last resort" to assess the scale of additional interventions needed to meet emissions targets *beyond* other policies explicitly included in a scenario. When the carbon tax is computed endogenously, as in our decarbonization simulations, a high carbon tax indicates that the scenario's emissions target cannot be met with the policy shocks introduced explicitly by the scenario. A low value suggests that the target is roughly in line with specified policies, and a negative value indicates that the policies are more than sufficient to meet emissions targets. The computed value is typically positive, indicating the need for additional policy measures. A policy mix consisting of multiple instruments—targeting different decision points or mechanisms—may be more effective than a mix that relies on narrower policies. Mixed strategies can affect more agents, potentially inflicting smaller costs on each. They also allow instruments to be targeted for their maximum effectiveness, reducing overall costs and undesirable side effects.

Table 2: Policy Instruments Included in the Model and How Applied

Lever	How the lever affects energy use	How these are modeled
Technological advances	Demand-side innovations can augment the value of energy sources in meeting households or firm needs. Examples include efficiency improvements in devices such as motors, light sources or boilers and coolers.	Innovations are represented by changes (usually reductions) in the energy input requirements of companies and households.
	Supply-side innovations improve the efficiency of energy-related activities ranging from mining and capital goods required in energy production to the generation activity itself and finally energy distribution.	Innovations are represented by changes (usually reductions) in the input requirements of energy sectors.
Financial and regulatory interventions	Taxes on carbon-intensive sources reduce demand while subsidies encourage the use of green power. They are widely used to discourage carbon-intensive energy sources and to encourage low carbon alternatives.	Taxes or subsidies are modeled by imposing costs on the production or utilization of goods and services.
	Regulations impose costs on harmful energy sources or reduce costs on green alternatives. Regulatory interventions act similarly to technological changes and make some sources cheaper and others more expensive to use.	Regulations are modeled by imposing (or reducing) costs on the production or use of targeted products.
	Import duties increase the cost of products that result in carbon emissions both lowering demand at home and lowering production abroad in the exporting economy.	Duties are charges imposed on the imports of targeted goods and services.
	Carbon taxes are specifically designed to internalize the carbon externality, that is, to increase the prices of goods made with emissions-intensive processes.	Carbon taxes may be imposed on primary emissions sources or on commodities produced using them.
Preference shifts	This lever describes changes in the demand patterns of firms, households and governments that are cost-neutral but favor low-carbon alternatives. These shifts may reflect growing awareness of climate change or public pressure from consumers producers or governments. They may be also stimulated by educational and political initiatives.	Cost-neutral changes are modeled by changing the parameters of production functions and household and government demand functions.

Source: authors.

III. Results from Decarbonization Scenarios

Following the Paris process, parties are developing independently determined pathways toward decarbonization. Their action plans, known as Nationally Determined Contributions (NDCs), were first committed in 2020 and are expected to be updated every five years. Some countries or groupings, like the European Union (EU) through its Green New Deal, have articulated clear goals and policies, in part codified into law. But many have not. A global stocktake of progress at Conference of the Parties (COP) 28 in December 2023 found that most countries were not on track to achieve the Paris Agreement goals. Much uncertainty remains about individual plans and the likelihood of achieving the aggregate goals of the Paris process.

a. Decarbonization Scenarios Defined

The three decarbonization scenarios of this study include common assumptions about economic parameters but differ in environmental policy assumptions, which are based on three similarly named decarbonization scenarios developed by the IEA (IEA 2021). The IEA develops its scenarios on detailed analyses, including studies of country-level documents submitted to the UNFCCC and other available announcements and reports. While the IEA publishes precise estimates of the *CO_2 emissions* generated by its scenarios, it does not provide corresponding detail on the arrays of policies incorporated into those scenarios. To fill this gap, we develop plausible policy mixes that generate emissions equal to those reported by the IEA, partly based on published details of the IEA scenarios. However, in the end, the policy assumptions used in our scenarios do not necessarily correspond to those used in IEA analyses.

Baseline Scenario. This scenario incorporates current policy commitments, including environmental policies derived from the IEA (2021) STEP policy scenario which includes policies already enacted but excludes commitments that are still provisional. Instruments used to reflect STEPS policies include improvements in energy efficiency, productivity advances in power generation, preference changes that favor electrification, and tax and regulatory measures to reduce coal power generation and to increase renewable power generation. These assumptions lead the model to project modest decreases in CO_2 emissions over the 2025-2050 period.

Pledges Scenario. This scenario aligns with the IEA (2021) Scheduled Pledges Scenario. The IEA adds governments' announced commitments to improve policies over time. We implement this scenario objective by specifying accelerating advances in energy conservation, technological improvements in renewable energy production, shifts in household and industry preferences toward green power sources, and more aggressive policy incentives, including regulatory penalties on fossil fuels and subsidies for renewable energy. Under these assumptions, CO_2 emissions will decline to about 50 percent of their 2025 levels by 2050.

Net Zero Scenario. This scenario aligns with IEA's Net Zero scenario and eliminates net emissions in all regions by 2050. Our policy specification envisions further technological improvements in energy production and use, along with stronger incentives for decarbonization and preference shifts. The scenario also intensifies efforts to remove CO_2 from the atmosphere and to prevent its release during power generation, using direct carbon capture and storage, and a shift to biomass fuels that absorb CO_2 production.

b. Results of the Decarbonization Scenarios

The results of the three decarbonization scenarios were calculated for the 2025-2050 period using sequences of annual simulations of the GTEM model. The 2025 starting year of these simulations is itself a projection, since 2017 is the latest year available in the GTAP system.[17]

Each year of these solution time series generates values for hundreds of variables, often in detail for 17 regions and 28 production sectors. Key results are reported in the tables, figures, and discussions that follow, but naturally not all detail could be reported. Additional results are available on request. Results are primarily reported for four benchmark years: 2025, 2030, 2040, and 2050.

The baseline scenario, unlike the policy scenarios, is solved using a "calibration" closure. Among other assumptions, this closure makes GDP and CO_2 emissions exogenous, with values obtained from outside projections. At the same time, several key parameters are treated endogenously, to find values consistent with the exogenous drivers of the baseline path. For example, the model

[17] This is the year of the full global dataset behind the current GTAP model, derived by imposing international accounting constraints, like the requirement that global exports equal global imports.

uses the GDP projections to calibrate labor productivity growth parameters, and emissions projections to calibrate coefficients defined as CO_2 emissions per unit of fossil fuel burned.

The policy scenarios are then run with a "projection" closure. In this mode the parameters obtained in calibration (such as labor productivity levels and emissions/fuel ratios) are treated exogenously, while GDP and emissions levels, which were exogenous drivers in calibration, are determined endogenously. As a result, policy solutions can diverge from their baseline scenario values to new values associated with policy shocks applied in different scenarios. The effects of policy shocks on model variables can be the determined by comparing policy solutions with the baseline solution.

Ten broad conclusions to highlight the results of the decarbonization scenarios. Each is connected to simulation results reported in tables and figures below.

1. *National environmental policies implemented or pledged fall well short of meeting the goals of the Paris Agreement.* From 2025 to 2050, under the baseline scenario, carbon emissions (Table 3) are projected to fall by about 20 percent for both Asia and the Pacific region and the world, leaving net emissions well above zero in both groupings at 15,878 Mt CO_2 and 29,660 Mt CO_2, respectively. The Pledges scenario reduces net emissions by an additional one-third, but that still leaves emissions levels well above net zero. The Paris goals will require significantly more aggressive policy policies than those envisioned in current or pledged national commitments.

2. *Designing policies to yield Net Zero emissions is a challenge.* In developing the model, we anticipated cases where the policy shocks used to represent a scenario would fail to yield the required emissions results (obtained from IEA solutions). For these cases, we equipped the model with a backup policy—adding a general carbon tax that would force emissions to match targets. For the baseline and Pledges scenarios, only moderate additional carbon taxes were necessary—\$55/ton of CO_2 and \$41/ton of CO_2, respectively—because our assumed policy mix came close to delivering the IEA results.

Table 3: Net CO2 Emissions, Decarbonization Scenarios

		Baseline (STEPS)			Pledges			Net Zero		
	2025	2030	2040	2050	2030	2040	2050	2030	2040	2050
Asia and Oceania	**19,728**	**19,768**	**17,653**	**15,878**	**17,509**	**10,509**	**5,889**	**13,689**	**3,544**	**0**
PR China	11,733	11,261	8,836	6,897	9,949	4,888	1,946	7,779	1,648	0
ASEAN5	1,518	1,687	1,928	2,091	1,515	1,226	824	1,185	413	0
Southeast Asia nec	407	453	518	562	407	330	222	318	111	0
India	2,813	3,252	3,394	3,363	2,875	2,070	1,481	2,248	698	0
South Asia nec	393	388	388	394	340	261	196	265	88	0
Caucasus and Central Asia	532	571	633	705	519	488	468	406	164	0
Advanced Asia	1,887	1,718	1,518	1,423	1,522	953	532	1,190	321	0
Oceania and Pacific	444	438	438	443	383	294	221	299	99	0
High Income	**8,866**	**7,740**	**5,910**	**5,014**	**6,267**	**2,503**	**768**	**4,900**	**844**	**0**
United States	4,198	3,608	2,513	1,982	2,900	859	10	2,268	290	0
North America nec	1,000	1,008	983	972	826	525	299	646	177	0
Europe	3,668	3,124	2,414	2,061	2,541	1,120	459	1,987	378	0
Middle and Low Income	**5,625**	**5,767**	**6,088**	**6,620**	**5,287**	**4,589**	**3,959**	**4,133**	**1,548**	**0**
Latin America and Caribbean	1,251	1,275	1,372	1,425	1,109	859	590	867	290	0
Middle East and North Africa nec	1,287	1,366	1,503	1,740	1,248	1,163	1,071	976	392	0
Sub-Saharan Africa	72	810	903	1,097	734	672	641	574	227	0
Russia	1,757	1,645	1,551	1,470	1,569	1,358	1,192	1,227	458	0
Rest of World	558	672	759	888	626	536	465	490	181	0
Middle East Oil Producers	**1,689**	**1,819**	**1,973**	**2,148**	**1,678**	**1,593**	**1,408**	**1,312**	**537**	**0**
World	**35,908**	**35,094**	**31,624**	**29,660**	**30,741**	**19,194**	**12,023**	**24,035**	**6,473**	**0**

Source: authors' simulations (MacroTables/Pres).
Note: CO2 Net Emissions equal CO2 Gross Emissions less CO2 Removals.

However, the error was large for Net Zero: an additional $181/ton of CO_2 tax was required to achieve net zero emissions. In effect, the policy instruments we identified did not meet Net Zero ambitions More generally, since we selected plausible yet aggressive policies, the gap suggests that ambitious targets will also require innovations in policy design. Importantly, policy choices are constrained by political or social feasibility, and the levers we currently use (summarized in Table 2) may be inadequate for meeting ambitious decarbonization goals. Expanding the global inventory of environmental policy options is therefore a high priority.

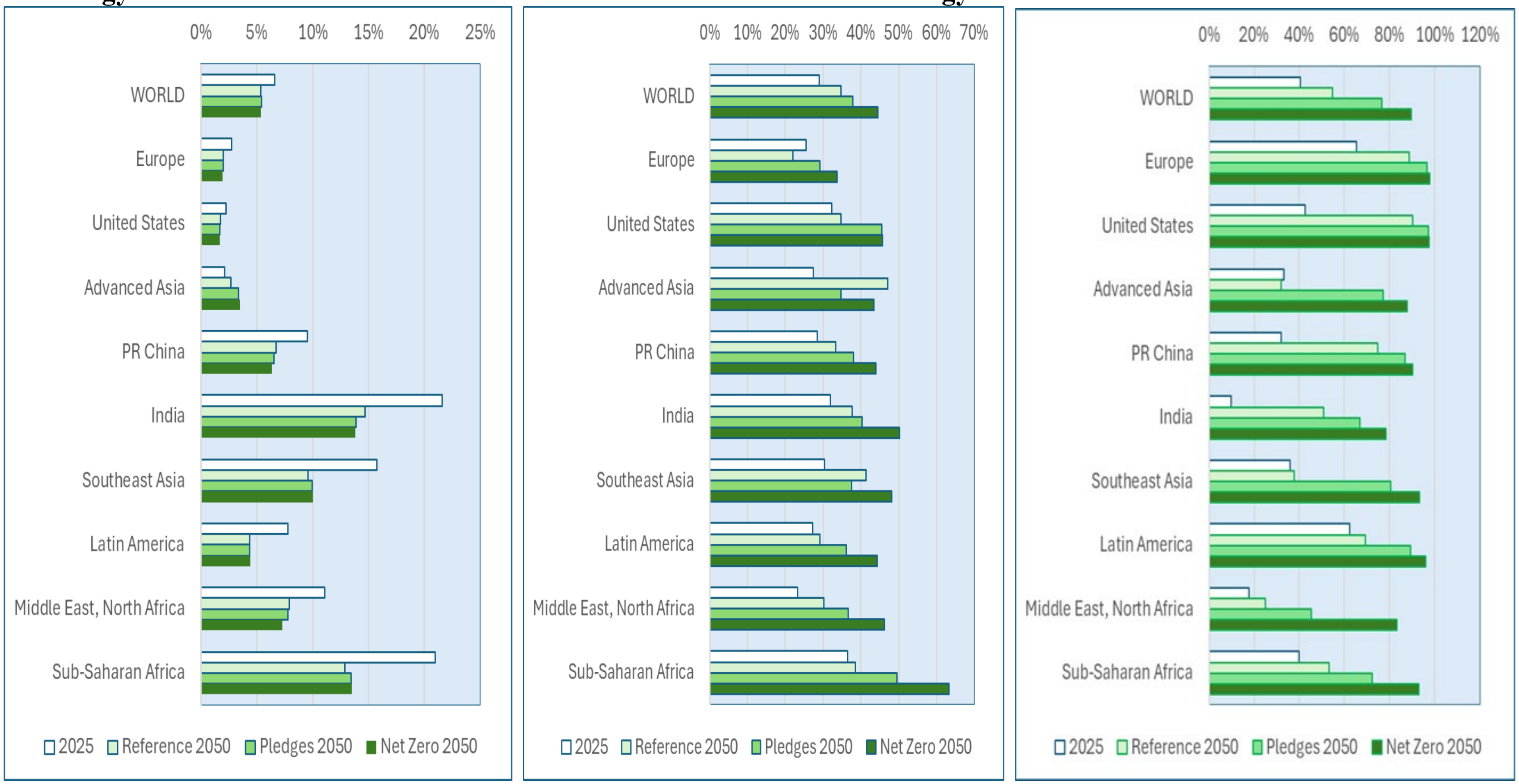
3. *The Net Zero strategy dramatically changes the structures of all regional economies.* Three broad indicators of the energy sector, collected in Figure 3, illustrate the

transformation. Figure 3a shows that the energy intensity of GDP—the energy/GDP ratio—will fall by about 25 percent globally, with significant variations across regions. It will fall by one-third in the PRC and a bit less in Southeast Asia, and will rise by one-third in India. Figure 3b addresses electrification—the share of electric power in energy use—which will rise in all regions and especially in Africa and the Middle East. Finally, Figure 3c tracks the role of renewables—the share of renewables in total electric power—and shows their sharp rise across the world, reaching nearly 100% in Europe and several other regions, and exceeding 79% throughout the world.

4. *Capital stocks will grow and change rapidly to support the energy transition.* Table 4 reports total capital stocks in the energy sector for 2025 and 2050, for three decarbonization scenarios by region. Table 5 disaggregates this same information by sector. Globally, energy capital stocks are projected to increase from $29.5 trillion in 2025 to $44.1 trillion, $44.7 trillion, and $37.6 trillion in 2050 under the baseline, Pledges, and Net Zero scenarios, respectively. The Net Zero scenario calls for the least increase in capital stocks—its policy assumptions call for a larger jump in energy efficiency. More importantly, the sectoral structure of capital changes sharply; for example, in the Net Zero case, the capital stock in low-carbon sectors will expand from $5.3 trillion to $22.1 trillion, while in fossil fuel sectors it will contract from $21.4 trillion to $9.6 trillion. The transition will also call for significant increases in power transmission and distribution.

Figure 3: Energy Sector Implications of Decarbonization Scenarios

a. Energy Share of GDP **b. Electric Power Share of Energy** **c. Renewables' Share of Electric Power**



Source: authors simulations (StrucCharts/EGYD)
Note: in current value terms.

Table 4: Energy Sector Capital Stocks, Decarbonization Scenarios ($Bill.)

	2025	Capital stocks, 2050		
		Baseline	Pledges	Net Zero
WORLD	29,453	44,130	41,731	37,645
Asia	10,454	19,683	18,830	17,668
PR China	6,715	12,492	11,144	10,219
India	662	2,518	2,698	2,670
Southeast Asia	959	1,640	1,923	1,948
Advanced Asia	736	1,200	1,432	1,466
High Income nec	7,018	9,880	9,471	9,583
Europe	3,072	4,143	4,219	4,172
United States	2,488	4,085	3,876	4,152
Lower income nec	11,981	14,567	13,431	10,394
Latin America	1,808	2,430	2,513	2,313
Middle East, North Afr	5,022	6,194	5,431	3,683
Sub-Saharan Africa	2,664	3,252	3,109	2,695

Source: authors' simulations.

Table 5: Energy Capital Stocks by Subsector ($Bill.)

a. Baseline 2025

	Total Energy	Fossil Fuels All	Coal	Oil	Gas	Power	Low-Carbon sources All	Wind	Solar	Other	Distribution
WORLD	**29,453**	**21,361**	**4,234**	**9,698**	**5,489**	**1,940**	**5,289**	**1,145**	**782**	**3,362**	**2,803**
Asia	**10,454**	**6,973**	**3,571**	**1,702**	**819**	**881**	**2,000**	**393**	**320**	**1,287**	**1,481**
PR China	6,715	4,367	3,038	816	4	509	1,411	344	207	860	936
India	662	573	177	304	43	48	33	5	5	23	57
Southeast Asia	959	646	111	283	145	107	188	9	13	165	125
Advanced Asia	736	231	0	79	2	150	282	23	87	172	223
High Income nec	**7,018**	**3,866**	**256**	**2,144**	**905**	**561**	**2,282**	**632**	**389**	**1,261**	**869**
Europe	3,072	1,100	24	525	353	198	1,365	433	242	689	608
United States	2,488	1,637	79	823	410	324	679	182	143	354	172
Lower income nec	**11,981**	**10,522**	**407**	**5,852**	**3,765**	**497**	**1,007**	**120**	**72**	**815**	**452**
Latin America	1,808	1,185	68	905	157	55	490	61	28	401	133
Middle East, North Afr	5,022	4,648	5	3,345	1,157	141	156	42	22	93	218
Sub-Saharan Africa	2,664	2,542	143	593	1,747	59	99	13	20	67	23

b. Net Zero 2050

	Total Energy	Fossil Fuels All	Coal	Oil	Gas	Power	Low-Carbon sources All	Wind	Solar	Other	Distribution
WORLD	**37,645**	**9,636**	**1,342**	**4,856**	**2,417**	**1,020**	**22,109**	**7,946**	**10,002**	**4,161**	**5,900**
Asia	**17,668**	**3,489**	**1,168**	**1,440**	**378**	**503**	**10,975**	**3,616**	**5,205**	**2,154**	**3,205**
PR China	10,219	2,036	**1,136**	**630**	**1**	**269**	6,142	**1,645**	**3,251**	**1,245**	**2,041**
India	2,670	617	**13**	**512**	**16**	**76**	1,837	**552**	**1,165**	**120**	**216**
Southeast Asia	1,948	166	**1**	**119**	**13**	**33**	1,446	**626**	**285**	**535**	**337**
Advanced Asia	1,466	121	**0**	**69**	**1**	**51**	1,053	**605**	**372**	**76**	**292**
High Income nec	**9,583**	**1,374**	**83**	**1,093**	**104**	**94**	**6,569**	**3,018**	**2,870**	**680**	**1,639**
Europe	4,172	179	**1**	**138**	**8**	**33**	2,849	**1,750**	**777**	**321**	**1,145**
United States	4,152	640	**3**	**541**	**66**	**29**	3,167	**1,100**	**1,913**	**154**	**346**
Lower income nec	**10,394**	**4,773**	**91**	**2,323**	**1,935**	**423**	**4,565**	**1,312**	**1,926**	**1,327**	**1,056**
Latin America	2,313	308	**6**	**265**	**7**	**30**	1,708	**559**	**761**	**388**	**297**
Middle East, North Af	3,683	1,753	**0**	**1,447**	**127**	**178**	1,345	**313**	**751**	**281**	**584**
Sub-Saharan Africa	2,695	2,017	**27**	**268**	**1,701**	**21**	606	**147**	**332**	**128**	**71**

Source: authors' simulations (StrucTables/IZ3P)

5. *Large changes in capital stocks require vigorous, nimble capital markets.* The scale of the energy transition will create excellent opportunities for investors. Table 6 shows cumulated gross energy investments for all three decarbonization scenarios. Table 7 shows annual results by period, for the Net Zero scenario only, disaggregated by energy sector. It indicates that substantial annual energy investments will be needed initially, about one-tenth of the baseline energy capital stock. However, the investments requirements will subside over the simulation timeframe as the new energy structure

stabilizes, from $2.1 trillion per year in the initial 2026-2030 period to $2.0 trillion per year in the 2031-2040 period, and then to $1.6 trillion in the 2041-2050 period. Meanwhile the structure of investments will change sharply. Already in the first 5-year time frame, low-carbon energy investments ($1,4 trillion) will be more than three times as large as fossil fuel investments ($433 billion). Moreover, fossil fuel investments will fall steadily over the simulation period. Investments in low-carbon sources grow initially but also begin to decline in the last decade of the transition. Only distribution investments will continue to grow throughout the period. Meanwhile, significant uncertainties surround these estimates due to estimating the power requirements for artificial intelligence (AI). AI will play a critical role in the future, and as its adoption widens, it will generate a rapid burst of demand for power. Its longer-term effects are harder to predict, since the application of AI in other economic activities will also likely improve the economy's general energy intensity.

Table 6: Energy Sector Investments 2026-2050, Decarbonization Scenarios ($Bill.)

	Investments, 2026-2050		
	Baseline	Pledges	Net Zero
WORLD	51,074	50,322	47,254
Asia	23,817	24,167	23,642
PR China	15,244	14,263	13,650
India	3,158	3,687	3,791
Southeast Asia	1,925	2,443	2,564
Advanced Asia	1,456	1,912	2,025
High Income nec	11,477	11,797	12,497
Europe	4,824	5,255	5,565
United States	4,919	5,125	5,703
Lower income nec	15,780	14,358	11,114
Latin America	2,679	2,904	2,831
Middle East, North Af	6,783	5,695	3,685
Sub-Saharan Africa	3,521	3,338	2,795

Source: authors' simulations (StrucTables/compare)

Tables 7: Annual Energy Investments by Subsector, Net Zero ($Bill.)

a. Average, 2026-2030

	Total Energy	Fossil Fuels					Low-Carbon sources				Distribut'n
		All	Coal	Oil	Gas	Power	All	Wind	Solar	Other	
WORLD	**2102**	**433**	**4**	**243**	**118**	**67**	**1461**	**461**	**812**	**187**	**208**
Asia	**1042**	**138**	**1**	**83**	**22**	**32**	**789**	**220**	**460**	**108**	**115**
PR China	688	55	0	37	0	18	555	148	332	75	79
India	112	29	0	25	2	2	78	17	57	4	5
Southeast Asia	73	15	0	10	2	4	50	17	15	17	9
Advanced Asia	100	9	0	4	0	5	79	30	43	6	12
High Income nec	**593**	**46**	**0**	**34**	**3**	**8**	**485**	**196**	**252**	**37**	**61**
Europe	272	7	0	4	0	3	221	117	92	12	44
United States	270	20	0	16	0	4	238	66	153	18	12
Lower income nec	**468**	**248**	**3**	**125**	**94**	**26**	**187**	**45**	**100**	**42**	**32**
Latin America	110	13	0	12	0	1	88	25	53	9	9
Middle East, North Afr.	166	105	0	84	10	11	42	3	27	12	19
Sub-Saharan Africa	107	84	1	12	69	1	22	6	13	3	2

b. Average, 2031-2040

	Total Energy	Fossil Fuels					Low-Carbon sources				Distribut'n
		All	Coal	Oil	Gas	Power	All	Wind	Solar	Other	
WORLD	**2043**	**256**	**6**	**117**	**85**	**49**	**1502**	**517**	**737**	**248**	**285**
Asia	**1036**	**107**	**3**	**58**	**14**	**31**	**774**	**226**	**391**	**157**	**155**
PR China	629	45	3	21	0	21	478	118	256	104	107
India	168	34	0	28	2	4	125	35	83	7	9
Southeast Asia	97	6	0	4	0	2	76	25	21	31	14
Advanced Asia	80	3	0	2	0	1	66	38	23	5	12
High Income nec	**564**	**19**	**1**	**17**	**0**	**1**	**461**	**217**	**222**	**22**	**83**
Europe	263	1	0	1	0	0	201	134	61	6	61
United States	251	11	0	11	0	0	224	72	148	5	16
Lower income nec	**442**	**130**	**1**	**42**	**71**	**17**	**266**	**73**	**124**	**68**	**46**
Latin America	115	2	0	2	0	0	99	30	49	20	13
Middle East, North Afr.	145	40	0	32	0	8	79	16	46	16	27
Sub-Saharan Africa	112	73	0	5	68	1	35	9	23	4	3

c. Average, 2041-2050

	Total Energy	Fossil Fuels					Low-Carbon sources				Distribut'n
		All	Coal	Oil	Gas	Power	All	Wind	Solar	Other	
WORLD	**1632**	**257**	**35**	**95**	**78**	**48**	**1038**	**428**	**452**	**158**	**337**
Asia	**807**	**118**	**33**	**51**	**10**	**24**	**504**	**203**	**225**	**76**	**185**
PR China	391	65	33	22	0	11	214	65	122	27	112
India	156	29	0	24	0	5	110	37	66	8	16
Southeast Asia	123	2	0	1	0	1	98	51	15	32	23
Advanced Asia	72	5	0	3	0	2	52	37	15	0	14
High Income nec	**390**	**41**	**2**	**33**	**2**	**4**	**263**	**137**	**112**	**14**	**86**
Europe	158	5	0	3	0	2	95	71	18	6	58
United States	184	21	0	19	1	0	144	58	83	3	20
Lower income nec	**435**	**98**	**0**	**11**	**67**	**20**	**271**	**88**	**115**	**67**	**67**
Latin America	114	2	0	1	0	2	93	37	42	14	19
Middle East, North Afr.	141	15	0	7	0	9	88	23	49	16	37
Sub-Saharan Africa	114	72	0	4	67	1	38	9	20	9	5

Source: authors' simulations. (StrucTables/IZ3P)

6. *Regions and sectors will nevertheless absorb sizeable "stranded assets."* These are productive assets, such as coal mines, rendered obsolete by unanticipated declines in demand, such as changes in regulations or profitability under decarbonization policies. Table 8 calculates stranded assets for each region and sector as the annual decline in the capital stock that exceeds standard depreciation. (This method likely produces a lower-bound estimate, given the coarse aggregation of the GTEM model.) The results are significant: $440 billion worth of assets will be stranded globally even under the baseline scenario, and the estimate rises by tenfold to $4.4 trillion under the more aggressive New Zero scenario. Additional results (not shown in the table) suggest that stranded assets will become especially significant in the middle of the transition period (2031-2040), with the fossil fuel sector disproportionately affected.

Table 8: Accumulated Stranded Capital ($Bill.)

	Stranded Capital, 2026-2050		
	Baseline	Pledges	Net Zero
WORLD	**440**	**1,702**	**4,424**
Asia	**106**	**679**	**1,631**
PR China	29	244	790
India	0	54	139
Southeast Asia	9	152	269
Advanced Asia	66	110	129
High Income nec	**280**	**828**	**1,244**
Europe	100	338	605
United States	176	430	550
Lower income nec	**54**	**195**	**1,549**
Latin America	5	69	293
Middle East, North Af	9	17	662
Sub-Saharan Africa	7	34	118

Source: authors' simulations (StrucTables/compare)

7. *Direct carbon removal from the atmosphere is critical for Net Zero.* In addition to exploring ways to limit emissions, this study also tracks two approaches to removing carbon already present in the atmosphere: carbon capture and storage (CCS) and reforestation. Table 9 presents the quantity of carbon that we assume will be removed through these channels under each decarbonization scenario, while Table 10 shows the

related costs. Note that carbon removal is much more actively used in the Net Zero scenario than in other simulations, especially in the late years of the simulation horizon. Carbon removal allows regions to run higher *gross* CO_2 emissions, presumably in activities where eliminating emissions is especially difficult, while still meeting *net* zero targets. Table 11 shows, for example, gross emissions for the World and for Asia and the Pacific economies under Net Zero in 2050 are still around 20 percent of 2025 emissions due to carbon removal strategies. The marginal cost of eliminating emissions rises as emissions decline, while the marginal cost of removal activities will most likely fall with increased scale. Thus, carbon removal is likely to play an increasingly important role along the "last mile" of decarbonization.

8. *The distributional impacts of Net Zero are mixed.* Tables 12, 13 and 14 show changes in factor returns for unskilled labor, skilled labor, and capital, respectively. Over the 2025-2050 baseline, unskilled wages tend to rise most rapidly among the three, followed by skilled wages and returns to capital. This ranking reflects inverse changes in the abundance of the three factors: over time, unskilled labor tends to grow least rapidly and capital most rapidly, with skilled labor falling in between. Although skilled workers have higher wages than unskilled workers, their advantage erodes as their numbers grow. The effects of accelerating decarbonization are mixed. Energy production, whether using fossil fuels or low-carbon technologies, tends to be capital- and skill-intensive. Thus, a shift to Net Zero will likely *reduce* skilled wages and returns to capital in currently fossil fuel exporting regions (Caucasus, Russia, Middle East Oil Exporters) and *increase* these returns in countries like India, which will substitute domestic energy for imports. Paradoxically, while Net Zero may raise India's income, it will also widen the gap between its skilled and unskilled workers.

Table 9: CO2 Removed from Atmosphere (Mill. tons) Decarbonization Scenarios

	2025	2030	2040	2050	2030	2040	2050	2030	2040	2050
Asia and Oceania	**11**	**20**	**53**	**99**	**92**	**1,142**	**2,410**	**204**	**2,091**	**4,105**
PR China	5	10	32	45	51	766	1,498	114	1,403	2,539
ASEAN5	2	3	3	2	12	54	140	27	99	237
Southeast Asia nec	0	1	1	1	3	14	37	7	26	63
India	0	0	0	0	5	142	387	10	259	656
South Asia nec	1	1	1	2	4	14	31	9	26	53
Caucasus and Central Asia	0	0	0	0	0	3	7	0	5	33
Advanced Asia	3	3	14	47	12	132	275	26	241	466
Oceania and Pacific	1	1	2	2	5	16	35	11	30	60
High Income	**56**	**96**	**221**	**335**	**412**	**1,167**	**1,591**	**913**	**2,139**	**2,697**
United States	44	75	180	270	290	876	1,118	642	1,606	1,894
North America nec	6	9	13	15	41	80	156	90	147	265
Europe	6	12	29	50	82	211	317	181	386	538
Middle and Low Income	**11**	**14**	**24**	**26**	**40**	**153**	**339**	**90**	**280**	**680**
Latin America and Caribbean	9	10	14	15	22	59	117	48	109	197
Middle East and North Africa	2	4	10	11	12	63	143	26	116	242
Sub-Saharan Africa	0	0	0	0	4	25	67	9	46	113
Russia	0	0	0	0	3	5	13	7	10	92
Rest of World	0	0	0	0	0	0	0	0	0	36
Middle East Oil Producers	**6**	**11**	**29**	**30**	**24**	**115**	**234**	**52**	**211**	**397**
World	**86**	**140**	**327**	**490**	**569**	**2,577**	**4,575**	**1,259**	**4,721**	**7,879**

Source: authors' simulations (MacroTables/Pres)
Note: CO2 removals include carbon capture, utilization and storage (CCUS) and CO2 emissions avoided through forest additions and renewal Source: authors' simulations

Table 10: Costs of CO2 Removal, Decarbonization Scenarios ($Bill.)

	Baseline (STEPS)				Pledges			Net Zero		
	2025	2030	2040	2050	2030	2040	2050	2030	2040	2050
Asia and Oceania	**3**	**6**	**16**	**30**	**28**	**342**	**723**	**61**	**627**	**1,232**
PR China	1	3	10	14	15	230	449	34	421	762
ASEAN5	0	1	1	1	4	16	42	8	30	71
Southeast Asia nec	0	0	0	0	1	4	11	2	8	19
India	0	0	0	0	1	42	116	3	78	197
South Asia nec	0	0	0	0	1	4	9	3	8	16
Caucasus and Central Asia	0	0	0	0	0	1	2	0	2	10
Advanced Asia	1	1	4	14	4	39	82	8	72	140
Oceania and Pacific	0	0	1	1	1	5	11	3	9	18
High Income	**17**	**29**	**66**	**100**	**124**	**350**	**477**	**274**	**642**	**809**
United States	13	22	54	81	87	263	335	193	482	568
North America nec	2	3	4	5	12	24	47	27	44	80
Europe	2	3	9	15	25	63	95	54	116	161
Middle and Low Income	**3**	**4**	**7**	**8**	**12**	**46**	**102**	**27**	**84**	**204**
Latin America and Caribbean	3	3	4	5	6	18	35	14	33	59
Middle East and North Africa	1	1	3	3	4	19	43	8	35	73
Sub-Saharan Africa	0	0	0	0	1	8	20	3	14	34
Russia	0	0	0	0	1	2	4	2	3	27
Rest of World	0	0	0	0	0	0	0	0	0	11
Middle East Oil Producers	**2**	**3**	**9**	**9**	**7**	**34**	**70**	**16**	**63**	**119**
World	**26**	**42**	**98**	**147**	**171**	**773**	**1,372**	**378**	**1,416**	**2,364**

Source: authors' simulations (MacroTables/Pres)
Note: CO2 removals include carbon capture, utilization and storage (CCUS) and CO2 emissions avoided through forest additions and renewal.

Table 11: Gross CO2 Emissions, Decarbonization Scenarios (Mill. tons)

	Baseline (STEPS)				Pledges			Net Zero		
	2025	2030	2040	2050	2030	2040	2050	2030	2040	2050
Asia and Oceania	**19,739**	**19,788**	**17,706**	**15,976**	**17,601**	**11,650**	**8,299**	**13,893**	**5,635**	**4,105**
PR China	11,737	11,271	8,868	6,942	10,000	5,654	3,444	7,892	3,052	2,539
ASEAN5	1,520	1,690	1,931	2,093	1,527	1,280	964	1,211	513	237
Southeast Asia nec	408	454	519	563	410	344	259	325	138	63
India	2,813	3,252	3,394	3,363	2,879	2,212	1,868	2,258	958	656
South Asia nec	394	390	390	395	344	275	227	275	114	53
Caucasus and Central Asia	532	571	633	705	519	490	475	406	170	33
Advanced Asia	1,890	1,721	1,532	1,470	1,533	1,084	806	1,216	562	466
Oceania and Pacific	445	440	440	445	388	310	256	310	129	60
High Income	**8,922**	**7,835**	**6,131**	**5,349**	**6,680**	**3,671**	**2,359**	**5,813**	**2,983**	**2,697**
United States	4,241	3,683	2,693	2,251	3,190	1,735	1,127	2,909	1,895	1,894
North America nec	1,007	1,017	996	987	867	605	455	736	324	265
Europe	3,674	3,135	2,442	2,110	2,623	1,330	776	2,168	764	538
Middle and Low Income	**5,636**	**5,781**	**6,112**	**6,646**	**5,327**	**4,742**	**4,297**	**4,223**	**1,828**	**680**
Latin America and Caribbean	1,260	1,284	1,386	1,440	1,131	919	706	915	398	197
Middle East and North Africa	1,289	1,370	1,513	1,750	1,260	1,226	1,213	1,002	508	242
Sub-Saharan Africa	772	810	903	1,097	738	697	708	582	273	113
Russia	1,757	1,645	1,551	1,470	1,572	1,364	1,205	1,234	468	92
Rest of World	558	672	759	888	626	536	465	490	181	36
Middle East Oil Producers	**1,696**	**1,830**	**2,002**	**2,179**	**1,702**	**1,708**	**1,642**	**1,365**	**748**	**397**
World	**35,993**	**35,234**	**31,951**	**30,149**	**31,310**	**21,770**	**16,598**	**25,294**	**11,194**	**7,879**

Source: authors' simulations (MacroTables/Pres).

Table 12: Wage Index for Unskilled Workers

	2025	2050			% chg from Baseline	
		Baseline	Pledges	Net Zero	Pledges	Net Zero
Asia and Oceania						
PR China	100	171	167	171	-2.2	-0.3
ASEAN5	100	207	207	206	-0.1	-0.5
Southeast Asia nec	100	155	156	155	0.4	-0.2
India	100	221	229	229	3.9	3.9
South Asia nec	100	169	171	170	0.8	0.7
Caucasus and Central Asia	100	139	136	129	-2.2	-7.5
Advanced Asia	100	201	202	203	0.4	0.9
Oceania and Pacific	100	130	129	127	-0.8	-2.5
High Income						
United States	100	136	135	136	-1.0	-0.1
North America nec	100	154	152	152	-1.3	-1.1
Europe	100	165	165	166	0.0	0.8
Middle and Low Income						
Latin America and Caribbean	100	174	175	173	0.6	-0.9
Middle East and North Africa nec	100	155	164	158	5.4	2.1
Sub-Saharan Africa	100	142	143	141	0.9	-0.8
Russia	100	177	172	161	-2.7	-9.1
Rest of World	100	216	234	235	8.1	8.7
Middle East Oil Producers	100	220	215	205	-2.2	-6.9
World						

Source: authors' simulations (MacroTables/Pres)

Table 13: Wage Index for Skilled Workers

	2025	2050			% chg from Baseline	
		Baseline	Pledges	Net Zero	Pledges	Net Zero
Asia and Oceania						
PR China	100	118	115	118	-2.0	0.2
ASEAN5	100	153	153	153	0.1	-0.4
Southeast Asia nec	100	121	122	123	1.2	1.5
India	100	170	178	178	5.1	5.1
South Asia nec	100	139	141	141	1.3	1.5
Caucasus and Central Asia	100	105	103	98	-1.8	-7.1
Advanced Asia	100	142	143	144	0.5	1.1
Oceania and Pacific	100	108	107	105	-0.8	-2.4
High Income						
United States	100	113	112	114	-1.2	0.2
North America nec	100	121	119	119	-1.5	-1.3
Europe	100	126	126	127	0.0	0.7
Middle and Low Income						
Latin America and Caribbean	100	133	133	131	0.4	-1.2
Middle East and North Africa nec	100	114	121	117	5.5	2.6
Sub-Saharan Africa	100	107	108	106	0.6	-1.1
Russia	100	145	140	128	-3.4	-11.7
Rest of World	100	170	179	179	5.2	5.4
Middle East Oil Producers	100	145	140	133	-2.9	-7.9
World						

Source: authors' simulations (MacroTables/Pres)

Table 14: Index for Returns to Capital

	2025	2050			% chg from Baseline	
		Baseline	Pledges	Net Zero	Pledges	Net Zero
Asia and Oceania						
PR China	100	88	87	89	-1.4	1.0
ASEAN5	100	117	119	120	1.9	2.7
Southeast Asia nec	100	88	91	93	3.2	5.7
India	100	111	116	118	5.2	6.4
South Asia nec	100	107	110	111	2.5	3.7
Caucasus and Central Asia	100	84	84	82	0.8	-2.5
Advanced Asia	100	110	111	113	1.2	2.9
Oceania and Pacific	100	104	104	104	0.2	0.2
High Income						
United States	100	107	107	109	-0.2	1.9
North America nec	100	118	118	119	-0.3	1.1
Europe	100	115	117	118	1.2	2.6
Middle and Low Income						
Latin America and Caribbean	100	128	130	130	1.8	1.6
Middle East and North Africa nec	100	113	121	120	7.1	6.2
Sub-Saharan Africa	100	115	117	116	2.3	1.4
Russia	100	111	109	103	-2.1	-7.4
Rest of World	100	117	124	126	6.3	7.6
Middle East Oil Producers	100	116	113	108	-2.5	-7.0
World						

Source: authors' simulations (MacroTables/Pres)

9. *Decarbonization will reduce trade volumes and reorient trade patterns.* The effects of decarbonization on trade are dominated by the decline of fossil fuels trade, with exports concentrated in a few regions, and a sharp, but ultimately small, increase in the trade of low-carbon fuels that are much more widely distributed. In general, less trade will be needed to meet regional energy demand, and more regions will be available to fill the remaining requirements. Table 16 shows changes in exports for selected regions focused on Asia. It confirms that decarbonization reduces exports by current fossil fuel exporters like the Caucasus, Russia, and Middle East Oil regions. Table 17 reports the product composition of these changes. Primary commodities expand relatively slowly, except for extraction. Manufacturing is large and expands relatively fast under the Net Zero scenario, but its composition remains relatively stable. Services trade grows relatively quickly as well, with the expansion focused on business services, although services for energy-related activities, like power distribution, expand rapidly while still remaining small. Energy exports fall quite sharply, to about one-third their size from $2.1 trillion in 2025 to $0.7 trillion in 2050. Coal drops most (91%) but oil absorbs the greatest loss by value (from $968 billion to $335 billion). Exports of wind, hydro and solar power exports grow, but remain small in absolute terms.

Table 15: Regional Exports, Decarbonization Scenarios ($Bill.)

		2050			% chg from Baseline	
	2025	Baseline	Pledges	Net Zero	Pledges	Net Zero
Asia and Oceania	**7,886**	**14,757**	**14,394**	**13,722**	-2.46	-7.01
PR China	2,708	5,606	5,844	5,455	4.24	-2.69
ASEAN5	984	2,174	2,042	2,001	-6.04	-7.93
Southeast Asia nec	405	889	839	794	-5.55	-10.65
India	550	1,045	855	777	-18.14	-25.62
South Asia nec	145	400	375	364	-6.23	-9.11
Caucasus and Central Asia	149	281	288	294	2.28	4.39
Advanced Asia	2,469	3,509	3,314	3,218	-5.56	-8.31
Oceania and Pacific	477	852	836	819	-1.93	-3.89
High Income	**11,623**	**17,154**	**16,627**	**16,460**	-3.07	-4.04
United States	2,413	4,209	4,145	4,085	-1.54	-2.96
North America nec	1,134	1,992	1,957	1,948	-1.75	-2.20
Europe	8,076	10,953	10,526	10,428	-3.90	-4.80
Middle and Low Income	**2,527**	**4,674**	**4,402**	**4,320**	-5.81	-7.58
Latin America and Caribb.	853	1,197	1,105	1,095	-7.71	-8.53
Middle East and North Africa	497	698	576	548	-17.50	-21.49
Sub-Saharan Africa	537	1,793	1,752	1,740	-2.24	-2.96
Russia	463	718	741	738	3.17	2.78
Rest of World	177	268	228	199	-14.75	-25.74
Middle East Oil Producers	**1,065**	**2,011**	**2,057**	**2,107**	2.28	4.78
World	**23,101**	**38,596**	**37,481**	**36,610**	-2.89	-5.15

Source: *authors' simulation (MacroTables/Pres)*

Table 16: Exports, Net Zero scenario, World and Asia ($Bill.)

	World		Asia Pacific		PR China		India		ASEAN*		Developed Asia	
	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050
Total Exports	**23,101**	**29,762**	**7,886**	**10,854**	**2,708**	**4,235**	**550**	**662**	**984**	**1,534**	**2,469**	**2,681**
Primary Commodities	**945**	**1,101**	**246**	**304**	**25**	**28**	**26**	**33**	**26**	**32**	**6**	**6**
Crops	434	354	86	72	16	14	13	11	13	12	2	1
Livestock	134	138	39	48	5	8	4	7	3	5	2	1
Extraction nec	377	609	120	184	4	6	9	14	10	15	3	4
Manufacturing	**14,904**	**19,261**	**5,955**	**7,912**	**2,203**	**3,221**	**327**	**374**	**750**	**1,233**	**2,036**	**2,102**
Chemicals	2,561	3,233	776	1,071	234	360	70	106	116	198	318	347
Light manufacturing	2,565	3,220	1,132	1,697	485	705	107	127	177	353	77	59
Energy-intensive mfg.	2,018	2,739	677	756	258	334	42	30	58	63	213	188
Electrical equipment	3,571	4,585	2,095	2,684	801	1,092	19	23	280	420	838	913
Machinery	2,076	2,666	749	1,014	325	558	64	54	63	96	255	232
Transport equipment	2,113	2,819	527	692	100	172	25	33	55	103	334	363
Services	**5,161**	**8,709**	**1,304**	**2,497**	**434**	**962**	**159**	**244**	**143**	**254**	**359**	**546**
Power distribution	20	36	3	10	1	1	0	1	0	0	0	0
Construction	116	235	50	118	24	69	3	5	4	7	16	28
Services	4,470	7,563	1,113	2,135	353	787	151	231	124	230	306	461
Dwellings	0	0	0	0	0	0	0	0	0	0	0	0
Road and rail transpt	105	166	20	36	9	17	1	2	3	4	4	7
Water transportation	113	174	41	67	19	36	2	3	3	3	13	19
Air transportation	337	534	78	131	29	51	1	2	9	10	19	31
Energy	**2,092**	**691**	**381**	**141**	**46**	**24**	**37**	**12**	**66**	**14**	**67**	**27**
Coal	145	13	75	4	2	1	0	0	23	0	0	0
Oil	968	335	66	26	1	0	0	0	13	3	0	0
Gas	317	66	66	22	0	0	0	0	15	1	0	0
Oil products	621	175	166	57	42	15	36	8	14	3	67	27
Nuclear power	4	3	0	0	0	0	0	0	0	0	0	0
Coal power	8	0	3	0	1	0	1	0	0	0	0	0
Gas power	7	6	1	2	0	1	0	0	0	0	0	0
Wind power	3	35	0	7	0	0	0	0	0	6	0	0
Hydro power	9	18	3	13	0	1	0	0	0	0	0	0
Oil power	1	2	0	2	0	0	0	0	0	0	0	0
Other power	6	11	0	2	0	1	0	1	0	0	0	0
Solar power	2	26	0	8	0	5	0	2	0	0	0	0

Source: Authors' simulations (StrucTables/compare)

Table 17: Export Shares, Net Zero scenario, World and Asia ($Bill.)

	World		Asia Pacific		PR China		India		ASEAN*		Developed Asia	
	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050	2025	2050
Total Exports	**100.0**	**100.0**	**34.1**	**36.5**	**11.7**	**14.2**	**2.4**	**2.2**	**4.3**	**5.2**	**10.7**	**9.0**
Primary Commodities	**100.0**	**100.0**	**26.0**	**27.6**	**2.6**	**2.5**	**2.8**	**3.0**	**2.7**	**2.9**	**0.7**	**0.6**
Crops	100.0	100.0	19.9	20.2	3.7	3.9	3.1	3.2	3.0	3.3	0.5	0.3
Livestock	100.0	100.0	29.3	34.7	3.6	5.7	3.3	5.3	1.9	3.9	1.4	0.8
Extraction nec	100.0	100.0	32.0	30.3	1.0	1.0	2.3	2.3	2.7	2.5	0.7	0.6
Manufacturing	**100.0**	**100.0**	**40.0**	**41.1**	**14.8**	**16.7**	**2.2**	**1.9**	**5.0**	**6.4**	**13.7**	**10.9**
Chemicals	100.0	100.0	30.3	33.1	9.1	11.1	2.7	3.3	4.5	6.1	12.4	10.7
Light manufacturing	100.0	100.0	44.1	52.7	18.9	21.9	4.2	3.9	6.9	11.0	3.0	1.8
Energy-intensive mfg	100.0	100.0	33.6	27.6	12.8	12.2	2.1	1.1	2.9	2.3	10.6	6.9
Electrical equipment	100.0	100.0	58.7	58.5	22.4	23.8	0.5	0.5	7.8	9.2	23.5	19.9
Machinery	100.0	100.0	36.1	38.0	15.6	20.9	3.1	2.0	3.0	3.6	12.3	8.7
Transport equipment	100.0	100.0	24.9	24.5	4.7	6.1	1.2	1.2	2.6	3.7	15.8	12.9
Services	**100.0**	**100.0**	**25.3**	**28.7**	**8.4**	**11.0**	**3.1**	**2.8**	**2.8**	**2.9**	**7.0**	**6.3**
Power distribution	100.0	100.0	14.8	26.7	3.3	4.2	1.9	2.5	0.3	0.2	0.0	0.0
Construction	100.0	100.0	43.1	50.0	20.4	29.3	2.5	2.3	3.2	2.9	14.2	11.9
Services	100.0	100.0	24.9	28.2	7.9	10.4	3.4	3.1	2.8	3.0	6.8	6.1
Dwellings	100.0	100.0	22.9	22.9	1.6	1.2	0.8	1.2	3.7	4.4	2.2	1.2
Road and transport	100.0	100.0	19.1	21.8	8.2	10.4	1.2	1.1	2.9	2.5	3.8	4.1
Water transportation	100.0	100.0	36.2	38.5	17.2	20.5	1.8	1.6	2.3	1.7	11.9	11.0
Air transportation	100.0	100.0	23.1	24.6	8.5	9.6	0.4	0.3	2.7	1.9	5.7	5.9
Energy	**100.0**	**100.0**	**18.2**	**20.4**	**2.2**	**3.5**	**1.8**	**1.7**	**3.1**	**2.1**	**3.2**	**3.9**
Coal	100.0	100.0	51.7	27.5	1.2	4.8	0.0	0.0	16.1	1.8	0.0	0.0
Oil	100.0	100.0	6.8	7.6	0.1	0.1	0.0	0.0	1.4	1.0	0.0	0.0
Gas	100.0	100.0	20.8	32.6	0.1	0.3	0.0	0.0	4.8	1.3	0.0	0.0
Oil products	100.0	100.0	26.8	32.3	6.7	8.7	5.8	4.8	2.2	1.9	10.7	15.2
Nuclear power	100.0	100.0	1.9	8.2	1.2	4.6	0.3	1.9	0.0	0.0	0.0	0.0
Coal power	100.0	100.0	35.1	56.6	11.8	26.8	8.7	15.6	1.0	0.3	0.0	0.0
Gas power	100.0	100.0	16.1	35.4	1.2	10.6	0.8	4.0	0.8	1.2	0.0	0.0
Wind power	100.0	100.0	6.0	19.3	1.9	1.0	0.1	0.8	3.5	16.3	0.0	0.0
Hydro power	100.0	100.0	28.1	72.4	1.6	3.4	0.4	0.4	0.1	0.1	0.0	0.0
Oil power	100.0	100.0	14.2	73.8	2.6	10.1	1.1	3.2	0.2	0.1	0.0	0.0
Other power	100.0	100.0	2.7	14.3	1.4	5.0	0.6	6.5	0.5	2.1	0.0	0.0
Solar power	100.0	100.0	7.0	30.0	5.4	20.0	1.0	7.6	0.6	1.0	0.0	0.0

Source: Authors' simulations (StrucTables/compare)

10. *Despite the scale and speed of the Net Zero transition, its economic costs are manageable, and indeed a bargain compared to the costs of inaction.* The aggregate burden of Net Zero is significant, but still comparable to what the world economy routinely absorbs under other large shocks. Decarbonization does not require exceptional resources, but it does require exceptional versatility and execution in directing resources to low-carbon activities. Specifically, Table 18 shows that the Net Zero pathway would reduce GDP by 1.8 percent by 2050 for the world, and by 1.6 percent for Asia and the Pacific relative to the baseline. These losses are an order of magnitude smaller than the damage expected from global temperature rises of 3.2ºC above pre-industrial levels.

Table 18: Real GDP, Decarbonization Scenarios ($Bill.)

		2050			% chg from Baseline	
	2025	Baseline	Pledges	Net Zero	Pledges	Net Zero
Asia and Oceania	**36,978**	**71,809**	**71,240**	**70,653**	-0.8	-1.6
PR China	18,215	33,609	33,182	33,359	-1.3	-0.7
ASEAN5	2,789	7,024	6,901	6,720	-1.8	-4.3
Southeast Asia nec	480	1,240	1,239	1,205	-0.1	-2.9
India	3,877	11,628	11,735	11,493	0.9	-1.2
South Asia nec	1,093	3,425	3,413	3,345	-0.3	-2.3
Caucasus and Central Asia	471	970	969	916	-0.1	-5.7
Advanced Asia	8,099	10,530	10,446	10,333	-0.8	-1.9
Oceania and Pacific	1,952	3,382	3,355	3,282	-0.8	-3.0
High Income	**46,819**	**68,679**	**67,776**	**68,083**	-1.3	-0.9
United States	22,844	32,651	32,191	32,489	-1.4	-0.5
North America nec	3,174	5,503	5,395	5,334	-2.0	-3.1
Europe	20,801	30,525	30,190	30,260	-1.1	-0.9
Middle and Low Income	**12,428**	**27,304**	**27,192**	**26,330**	-0.4	-3.6
Latin America and Caribbean	5,568	10,625	10,523	10,324	-1.0	-2.8
Middle East and North Africa nec	2,566	5,926	5,981	5,699	0.9	-3.8
Sub-Saharan Africa	2,143	7,294	7,273	7,143	-0.3	-2.1
Russia	1,731	2,680	2,650	2,431	-1.1	-9.3
Rest of World	421	779	765	733	-1.8	-5.9
Middle East Oil Producers	**2,566**	**4,803**	**4,718**	**4,412**	-1.8	-8.1
World	**98,791**	**172,595**	**170,927**	**169,477**	-1.0	-1.8

Source: authors' simulations (MacroTables/Pres)

Box 1. The Net Zero Challenge for ASEAN in 2050

ASEAN is arguably the most successful regional cooperation project in the global South, with notable successes including the ASEAN Economic Community, six bilateral free-trade areas, and the ASEAN-centric Regional Comprehensive Economic Partnership. It is also the most open region in the world, with trade to GDP reaching 106% in 2022, and the most vulnerable to climate change (see Figure 1). Accordingly, trade and climate change are central priorities for member-states.

NDCs vary considerably in the region (see ASEAN State of Climate Change Report, 2021) but are relatively ambitious for developing and emerging markets. Regional coordination is advancing through initiatives such as the ASEAN Strategy for Climate Neutrality, endorsed at the 43rd ASEAN leaders summit. This strategy includes eight priorities including boosting green and circular-economy supply chains, interoperable carbon markets, and green best-practices sharing. Most ASEAN member-states have adopted net zero strategies for 2050.

Estimates from GTEM suggest that while the transition to net zero requires extensive structural change, its long-term economic costs are manageable and the payoffs large. ASEAN5's GDP in 2050 would fall by $304 billion or 4.3% on the Net Zero pathways, but the anticipated losses from unchecked climate change are estimated to be far larger, ranging from 25% of GDP (with a rise of 2.6ºC) to 37 % of GDP (with a rise of 3.2ºC). Other Southeast Asian economies face smaller impacts of $35 billion (2.9% of GDP). The energy share of GDP under Net Zero remains stable through 2050, but the electric power share of energy rises from one-third in 2025 to one-half in 2050, driven by renewables, which will account for 90% of electric power in 2050. ASEAN's energy capital stock will double from 2025 to 2050 with major distributional changes in favor of renewables: capital stock in fossil fuels will fall by 75%, coal will be largely phased out, and renewables will rise by eight-fold, led by wind and solar whose stocks will rise by even greater percentages, albeit from a small base. Structural adjustment will be important as labor moves out of energy-intensive industries. Skilled and unskilled wages in ASEAN5 fall slightly relative to the baseline (-0.4% and -0.5%, respectively), whereas the effects on wages for the rest of the region are mixed, with skilled wages rising significantly (1.5%) and unskilled wages slightly falling (-0.2%). Returns to capital will climb for both ASEAN groups, suggesting a marginal worsening of income distribution during the transition.

The transition to net zero is projected to have modest effects on overall trade flows, but significantly alter the industry composition of trade. ASEAN energy exports will fall to $14 billion in 2050, with fossil-fuel exports becoming negligible and wind rising to almost half of the total. Exports of manufactures and services rise by two-thirds and three-fourths, respectively, and the share of these sectors in global trade rises. Electrical equipment continues to be the most valuable regional export, rising by 50% over 2025-2050. Exports of light manufacturing, livestock and wind experience the largest increases in global market shares, and coal and gas the largest drops. Preventing carbon leakage through the imposition of carbon border taxes by developed countries would have a modest positive effect on ASEAN exports and expanded green cooperation would increase them even more.

Under the GTEM Net Zero scenario, current policy levers—grouped under technological improvements, financial and regulatory change, and preference shifts—are insufficient to attain net zero emissions in 2050, as indicated by relatively high residual carbon prices. Additional technological deepening, green incentives, preference shifts, and investments in carbon renewal and carbon sinks will be necessary to meet regional net-zero goals. These shifts will have to be reasonably rapid (over 25 years) and will have asymmetric impacts across the economy, potentially creating political resistance and underscoring the need for active government policies to facilitate structural change in the most efficient and equitable manner possible. Mobilizing climate finance and investing in green technologies present difficult but necessary challenges, ones that multilateral development banks like ADB should support through their lending facilities, partnering with other regional and multilateral banks and the private sector, and helping to generate bankable projects through research and innovative ideas.

IV. Results from Trade Policy Scenarios

Trade has played a central role in reducing poverty and improving global living standards (WTO 2023). Since the widespread adoption of trade liberalization and other reforms three decades ago, poverty levels have plummeted from 43% in 1981 to 9% in 2022.[18] Asia's development exemplifies this impact: as the region's trade share of GDP doubled from 31% in 1974 to 61% in 2023, its per capita income increased more than 20-fold from $612 to $12,928.[19]

The influence of trade on global emissions is more nuanced. On one hand, trade integration and FDI accelerate the diffusion of cleaner technologies and inputs that reduce the carbon intensity of production. ADB (2023a) finds that despite the rising share of Asia in global emissions, the region's carbon intensity has been declining since 2011 due to technological advances, tighter environmental regulation, and the rising priority of environmental issues. The emissions intensity for imports and exports have declined by roughly 50 percent since 2000 (Kim, et. al. 2023).

Trade can also increase emissions, including most directly through emissions related to the transport of goods. Institutional factors matter, since in the absence of price interventions, trade based on market prices does not account for the negative environmental effects of production. Firms in countries where carbon emissions are priced and/or regulated will be at a disadvantage compared to those in countries without such policies, leading to excessive emissions and the misallocation of global resources. Complaints about an "unfair carbon playing field" undermine the political case for reducing emissions. Furthermore, trade barriers tend to be lower in carbon-intensive products, including fossil fuels, further encouraging emissions worldwide (WTO 2022).

a. Trade policy scenarios

Trade policy is an essential instrument for climate policy, especially in the open economies of Asia and the Pacific. This study addresses connections between trade and the environmental objectives with two environmentally targeted trade scenarios: the first focused on tariffs to

[18] World Bank estimates, https://data.worldbank.org/topic/poverty .
[19] World Bank, https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS?locations=Z4 https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS?locations=Z4 and https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=Z4

discourage trade in emissions-intensive goods, and the second on collaborative efforts to *encourage* trade that leads to emissions reductions.

Carbon Leakage Mitigation. Without market interventions, countries with high carbon taxes are likely to experience "carbon leakage," that is, the migration of emissions-intensive industries to countries with low or nonexistent carbon taxes. The EU's Carbon Border Adjustment Mechanism (CBAM) was designed to prevent this mechanism from driving its emissions-intensive industries abroad by applying tariffs to imports from low carbon-tax countries. CBAM was launched in 2023 and is in a transitional phase until 2026, when carbon tariffs will be applied. Since the EU has high climate ambitions and internal carbon taxes, it designed CBAM to apply tariffs on emissions-intensive goods imported from countries with low or nonexistent carbon taxes. CBAM targets six emission-intensive sectors: iron and steel, cement, fertilizers, aluminum, electricity, and hydrogen, selected due to high carbon emissions and administrative feasibility (Simões 2023). Tariffs are designed to match the input costs foreign producers avoid by not paying carbon taxes at European rates. Imports from countries with carbon taxes equivalent to those in the EU will be exempted from the tariff.

Although the initial effects of CBAM are generally estimated to be small,[20] the program is likely to strengthen over time, as CBAM is expanded to cover all products in the European Trading System (ETS) by 2030.[21] The calculation of the carbon tariff may be also revised to include emissions generated by the *inputs* embedded in traded products. Meanwhile, other countries[22] are predicted to follow with carbon taxes and tariffs of their own. This study models the Carbon Leakage Mitigation scenario on CBAM, but assumes that the United States, the rest of North America (i.e., Canada and Mexico), and Advanced Asia also join the CBAM framework in 2030.[23] Carbon tariffs will be zero within this larger bloc.

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[20] For a survey of studies estimating the effects of CBAM, including by the European Commission itself, see Kim et. al. (2023).
[21] See, for example, European Parliament (2023).
[22] For a review and analysis of recent carbon-tax-related proposals in the United States, see Rasool, et. al. (2024).
[23] Note: since these groupings all apply equivalent carbon border taxes, they do not impose them on each other.

Table 19: WTO Environment-Related Trade Policies for Climate Action

Tool	Objective	Comments
#1 Trade Facilitation	Increase efficiency of customs clearance, expand use of electronic documentation, build on WTO Trade Facilitation Agreement (TFA)	• Could lead to reduction of 85% of emissions at border crossings • TFA is expected to reduce trade costs by 14.3 percent on average, developing countries gain most
#2 Government Procurement	Reduce emissions by adopting "Green Government Procurement," that is, reducing GHG content in government purchass	• Government procurement constitutes 13% of global GDP and is responsible for 15% of GHG • EU Green New Deal requires public sector to adopt target of reducing energy consumption by 1.9 percent annually.
#3 Regulations and certification	Create and adopt international standards to reduce regulatory costs and improve green regulations	• Increasingly important with energy efficiency requirements • IEA (2021) estimates that regulations reduced emissions already by 12% over 2000-17.
#4 Services	Improve mitigation and adaptation efforts through the facilitation provision of cross-border, climate-related services	• WTO suggests there is much scope to improve trade in this area • Increasing area of focus in Trade Policy Reviews
#5 Import Tariffs	Liberalize trade in EGS and rebalance tariff policies that benefit carbon-intensive sectors	• Oil and coal face average tariffs of 0.8% and 1.6% whereas renewable energy equipment faces tariffs in 3.2%-12% range. • 30 WTO members have already reduced tariffs for environmental purposes
#6 Subsidies	Reform subsidies that harm the environment, including to fossil fuel industries harmful agricultural subsidies	• Estimates suggest that governments spend annually $1.2 trillion on harmful subsidies • Reforming and repurposing fossil fuel subsidies by 2025 would reduce CO2 emissions by 6% by 2030, and repurposing to green investments would add another 3%
#7 Trade Finance	Improve support for green technologies and equipment through better trade finance, such as loans and guarantees, for developing regions, SMEs, and women-owned companies	• 60-80% of global trade is supported by trade finance but only up to 25% in developing regions • Financial institutions such as private banks and regional development banks should prioritize green trade finance in developing countries

#8 Food and agricultural trade	Enhance agricultural markets and climate action by facilitating food trade and repurposing subsidies	• Climate change will continue to negatively affect food trade, threatening food security. • Tariffs tend to be high—average of 6.2% in 2021 but can even exceed 1000% on individual products—and should be reduced to enhance trade • Subsidies—in OECD $630 billion in 2020-22-- can be repurposed to support adaptation and mitigation.
#9 Sanitary and Phytosanitary Measures (SPS)	Protect against spread of diseases and pests intensified by climate change	• Plant pests along cause losses of up to 40% of crop production • Governments should adopt strategies that enhance SPS systems to safeguard plant and animal health
#10 Internal taxation and carbon pricing	Reduce fragmentation and compliance costs through better coordination of climate-related policies, including carbon pricing	• Two-thirds of NDCs include carbon prices to meet Paris Agreement targets • Much proliferation, with 70 pricing systems globally and prices from less than $1 to $130 per a ton of CO2-equivalent • Internal taxes can be coordinated through international platforms

Source: WTO, 2023. Trade Policy Tools for Climate Action, Geneva, World Trade Organization.

Carbon Targeted Cooperation. The second trade policy simulated below is a carbon-targeted trade policy cooperative scenario, which encourages tax collaboration among countries with similar environmental objectives. The scenario builds on the list of ten “Trade Policy Tools for Climate Action” that WTO (2023) developed for COP 28. These tools are summarized in Table 19 (Table 2 explains how they were applied in the scenario).

Addressing climate change is inherently a global goal and will require international cooperation. Unilateral approaches to carbon pricing and other decarbonization initiatives risk creating market distortions and will raise implementation costs, making the Paris Agreement goals harder to achieve. In contrast, international cooperation ensures that free-rider problems are avoided, making it easier for countries to adopt stricter regulations. Modelling consistently shows that international cooperation improves the prospects of reaching net zero and lowers the cost of transition[24].

Our model of cooperation using the WTO trade-policy template, focusing on eight initiatives:

- Removing barriers to trade in environmental goods and services (EGS)
- Easing restrictions on services trade[25]
- Aligning trade facilitation policies and regulatory policies for EGS
- Reducing trade financing costs for EGS
- Liberalizing food and agricultural trade[26]
- Expanding government preferences for purchasing EGS goods and services
- Eliminating subsidies for fossil fuels by 2030
- Promoting international reforestation to build better carbon sinks[27]

These measures represent a strategic pathway for addressing trade and climate goals through multilateral cooperation.

b. Results of Leakage Mitigation and Cooperation

The results of the two trade policy scenarios are found in Tables 20-25. As expected, since neither of these scenarios affects broad environmental policy levers or targets, their effects are muted compared to the decarbonization scenarios discussed in the previous section.

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[24] Bekkers et al. (2022) use a WTO model to simulate pathways to net zero and find that international cooperation is critical to realizing the Paris Agreement goals. Their baseline scenario maintains mitigation policies at 2021 levels and leads temperatures to rise by 3°C by 2100. Their second scenario is a "divided world," with each country following NDC pledges until 2030 and thereafter imposing carbon taxes on imports from countries with lower carbon prices. This leads to a global temperature rise of 2.6°C in 2100. Their third scenario models "cooperation" with countries imposing a global carbon tax. This limits temperature increases to 1.7°C by 2050, in line with the Paris Agreement.

[25] Services trade is ameliorated by regulatory realignment, in which we assume that 10% of service trade is EGS, the tariff equivalent of regulatory barriers is 10%, and these are reduced by 50%.

[26] Tariffs are reduced by one percentage point on all agricultural trade.

[27] Additional forests are assumed to be established or restored globally in the following amounts: 100 Mha (million hectares) by 2030, 300 Mha by 2040, and 500 Mha by 2050. For reference, the Bonn Challenge agreement, initially undertaken in 2011, called for restoration of 20 Mha of forests annually over 2011-2030 and received pledges roughly meeting those objectives. Global goals are allocated to regions according to shares of global forests in 2020. The annualized costs of adding or restoring forests are assumed to be $100/ha and each hectare is assumed to remove 2 $MtCO_2$ annually. Data are from FAO (State of World Forests), Resource for the Future, and other sources.

Two key findings emerge from the results of the Carbon Leakage Mitigation strategy:

1. *The application of carbon border taxes reduces emissions modestly, with minimal negative effects on GDP.* The carbon tax scenario envisions the EU and other advanced economies imposing carbon taxes modeled on CBAM in 2027 and 2030, respectively. By harmonizing the external cost of emissions across borders, the strategy discourages the relocation of carbon-intensive production to regions with weaker regulations, thereby curbing global emissions. Table 20 shows that this scenario reduces net CO_2 emissions by 0.8% for the world and for Asia and the Pacific, resulting in emissions reductions of 25 $MtCO_2$ and 13 $MtCO_2$, respectively.

   Table 21 shows that these policies have minimal effects on overall economic growth. Real GDP declines by 0.01% ($21 billion) for the world, and by 0.01 ($11 billion) for Asia and the Pacific. In general, regions that contain ADB developing member countries tend to lose rather than gain from this policy, since these regions typically export emissions-intensive products and have limited emissions regulations. Nevertheless, these net losses are small, with none exceeding one-third of one percent of GDP.

2. *International trade is only marginally affected by carbon leakage mitigation, with modest adverse impacts in some developing economies.* Table 22 shows that a CBAM-like carbon tariff will cause trade in emissions-intensive goods to fall, affecting mainly exporters in emerging regions. Asia and the Pacific regions experience a decline of 0.22% in real exports, with India, Caucasus and Central Asia, Russia, and the Rest of the World affected by declines of 0.70%, 0.70%, 0.47% and 0.89%, respectively. Meanwhile, ASEAN countries benefit from these changes through a positive terms-of-trade effect. Overall, the Carbon Leakage Mitigation scenario suggests that carbon tariffs encourage the green transition, albeit with some adverse effects on economies with lower carbon taxes, such as the DMCs.

Table 20: Net CO2 Emissions, Trade Policy Scenarios

		2050			% chg from Baseline	
	2025	Baseline	Leakage	Cooperation	Leakage	Cooperation
Asia and Oceania	**19,728**	**15,878**	**15,865**	**15,682**	-0.08	-1.23
PR China	11,733	6,897	6,890	6,833	-0.11	-0.94
ASEAN5	1,518	2,091	2,096	2,060	0.26	-1.46
Southeast Asia nec	407	562	561	568	-0.11	1.10
India	2,813	3,363	3,352	3,264	-0.32	-2.93
South Asia nec	393	394	394	390	0.08	-0.83
Caucasus and Central Asia	532	705	700	707	-0.67	0.24
Advanced Asia	1,887	1,423	1,428	1,425	0.35	0.16
Oceania and Pacific	444	443	443	435	0.06	-1.94
High Income	**8,866**	**5,014**	**5,024**	**4,627**	0.19	-7.73
United States	4,198	1,982	1,985	1,793	0.15	-9.54
North America nec	1,000	972	974	767	0.24	-21.05
Europe	3,668	2,061	2,065	2,067	0.20	0.29
Middle and Low Income	**5,625**	**6,620**	**6,602**	**6,380**	-0.26	-3.62
Latin America and Caribbean	1,251	1,425	1,423	1,411	-0.17	-0.96
Middle East and North Africa nec	1,287	1,740	1,737	1,749	-0.16	0.52
Sub-Saharan Africa	772	1,097	1,095	1,093	-0.16	-0.32
Russia	1,757	1,470	1,463	1,240	-0.50	-15.66
Rest of World	558	888	885	887	-0.33	-0.16
Middle East Oil Producers	**1,689**	**2,148**	**2,144**	**2,148**	-0.19	-0.00
World	**35,908**	**29,660**	**29,635**	**28,837**	-0.08	-2.77

Source: authors' simulations
Note: CO2 Net Emissions equal CO2 Gross Emissions less Baseline CO2 Removals and CO2 Removals Beyond the Baseline under the Leakage and Cooperation scenarios.

Table 21: Real GDP, Trade Policy Scenarios ($Bill.)

	2025	2050			% chg from Baseline	
		Baseline	Leakage	Cooperation	Leakage	Cooperation
Asia and Oceania	**36,978**	**71,809**	**71,798**	**71,885**	-0.02	0.11
PR China	18,215	33,609	33,601	33,662	-0.02	0.16
ASEAN5	2,789	7,024	7,029	7,030	0.06	0.08
Southeast Asia nec	480	1,240	1,239	1,243	-0.05	0.27
India	3,877	11,628	11,622	11,635	-0.05	0.06
South Asia nec	1,093	3,425	3,427	3,435	0.06	0.29
Caucasus and Central Asia	471	970	967	972	-0.32	0.12
Advanced Asia	8,099	10,530	10,531	10,527	0.01	-0.03
Oceania and Pacific	1,952	3,382	3,382	3,381	-0.02	-0.02
High Income	**46,819**	**68,679**	**68,693**	**68,664**	0.02	-0.02
United States	22,844	32,651	32,657	32,650	0.02	-0.00
North America nec	3,174	5,503	5,505	5,496	0.03	-0.13
Europe	20,801	30,525	30,531	30,518	0.02	-0.02
Middle and Low Income	**12,428**	**27,304**	**27,287**	**27,345**	-0.06	0.15
Latin America and Caribbean	5,568	10,625	10,621	10,630	-0.04	0.04
Middle East and North Africa nec	2,566	5,926	5,921	5,930	-0.09	0.06
Sub-Saharan Africa	2,143	7,294	7,291	7,316	-0.04	0.30
Russia	1,731	2,680	2,677	2,690	-0.12	0.36
Rest of World	421	779	777	780	-0.29	0.06
Middle East Oil Producers	**2,566**	**4,803**	**4,796**	**4,801**	-0.13	-0.04
World	**98,791**	**172,595**	**172,574**	**172,694**	-0.01	0.06

Source: authors' simulations (MacroTables/Pres).

Table 22: Real Exports, Trade Policy Scenarios ($Bill.)

		2050			% chg from Baseline	
	2025	Baseline	Leakage	Cooperation	Leakage	Cooperation
Asia and Oceania	**7,886**	**14,757**	**14,724**	**14,839**	-0.22	0.56
PR China	2,708	5,606	5,595	5,653	-0.20	0.83
ASEAN5	984	2,174	2,176	2,176	0.09	0.12
Southeast Asia nec	405	889	889	891	0.02	0.28
India	550	1,045	1,038	1,058	-0.70	1.29
South Asia nec	145	400	400	405	0.00	1.29
Caucasus and Central Asia	149	281	279	283	-0.70	0.58
Advanced Asia	2,469	3,509	3,495	3,518	-0.41	0.24
Oceania and Pacific	477	852	852	854	-0.04	0.22
High Income	**11,623**	**17,154**	**17,131**	**17,202**	-0.13	0.28
United States	2,413	4,209	4,199	4,242	-0.23	0.78
North America nec	1,134	1,992	1,989	1,988	-0.12	-0.16
Europe	8,076	10,953	10,943	10,972	-0.09	0.17
Middle and Low Income	**2,527**	**4,674**	**4,658**	**4,713**	-0.33	0.84
Latin America and Caribbean	853	1,197	1,193	1,208	-0.36	0.90
Middle East and North Africa nec	497	698	695	702	-0.42	0.64
Sub-Saharan Africa	537	1,793	1,790	1,808	-0.13	0.88
Russia	463	718	715	725	-0.47	1.00
Rest of World	177	268	266	269	-0.89	0.36
Middle East Oil Producers	**1,065**	**2,011**	**1,999**	**2,026**	-0.61	0.71
World	**23,101**	**38,596**	**38,512**	**38,780**	-0.22	0.48

Source: authors' simulations (MacroTables/Pres)

Two additional key findings emerge from the results of the Cooperation strategy:

3. *International cooperation in applying green initiatives offers additional avenues for reducing emissions. Unlike other approaches, it appears to have positive effects on key environmental and economic variables.* Unlike the Carbon Leakage Mitigation scenario, the Cooperation scenario simultaneously reduces emissions and increases GDP and trade. To be sure, it will depend on alignment across a complex geopolitical landscape. Table 20 shows that the Cooperation scenario will reduce net emissions in 2050 by 2.77% globally, and by 1.23% in Asia and the Pacific. Meanwhile, Table 20 shows that real GDP will increase by 0.06% globally and 0.11% in Asia and the Pacific. Table 23 notes that real exports will also increase, by 0.4% for the world, 0.6% for Asia and the Pacific, and by relatively large margins for the PRC (1.0%) and India (1.1%). These changes are concentrated in manufacturing and services, while energy trade declines further.

4. *Reforestation will be a key driver of net emissions reductions under the Cooperation scenario.* As Table 24 shows, a substantial global reforestation effort plays a leading role in reducing net CO2 emissions under the Cooperation scenario. Reforestation is significant in virtually all regions but especially in Asia and the Pacific, where new or restored forests under scenario would increase from 6 Mha in 2025 to 150 Mha in 2050. Reforestation would account for two-thirds of the difference between gross and net emissions in the Cooperation scenario. Table 25 further indicates that the costs of carbon removal through reforestation would be relatively low, estimated to be $50 billion for the world and $15 billion for Asia and the Pacific.

The two trade-based scenarios support decarbonization and do so with few adverse side effects. The Carbon Leakage Mitigation scenario, despite modest negative effects on real GDP and trade, will reduce emissions and help to catalyze international cooperation on tax policies that accelerate decarbonization. The Cooperation scenario delivers rare win-win outcomes: it advances climate goals and also economic performance. In addition, DMCs that face export losses with Carbon Leakage Mitigation emerge as key beneficiaries under Cooperation. Together, these scenarios reinforce the decarbonization pathways examined in Section III, offering complementary strategies for internalizing environmental externalities and accelerating the green transition.

Table 23: Baseline Real Exports and Changes due to Cooperation Scenario in 2050, World and Asia ($Bill.)

	World		Asia Pacific		PR China		India		ASEAN*		Developed Asia	
	2050	% chg	2050	% chg	2050	% chg	2050	% chg	2050	% chg	2050	% chg
Total Exports	**31,871**	**0.4**	**11,667**	**0.6**	**4,347**	**1.0**	**856**	**1.1**	**1,661**	**0.1**	**2,905**	**0.3**
Primary Commodities	**1,135**	**1.0**	**315**	**0.9**	**29**	**1.1**	**37**	**1.4**	**34**	**1.1**	**6**	**0.8**
Crops	362	2.0	75	2.1	15	1.6	14	2.2	12	2.0	1	2.1
Livestock	141	2.2	49	2.1	8	1.2	9	2.1	6	2.4	1	2.0
Extraction nec	632	0.1	191	0.2	7	-0.1	15	0.2	16	0.0	4	0.0
Manufacturing	**19,707**	**0.5**	**8,351**	**0.8**	**3,281**	**1.4**	**488**	**1.6**	**1,311**	**-0.1**	**2,233**	**0.4**
Chemicals	3,335	0.1	1,136	-0.1	370	-0.6	135	0.8	216	0.2	354	-0.1
Light manufacturing	3,295	0.2	1,772	0.1	705	-0.6	160	0.7	367	0.1	63	0.2
Energy-intensive mfg.	2,770	0.4	840	0.6	362	0.9	46	2.1	74	-0.1	214	0.2
Electrical equipment	4,698	0.5	2,795	0.5	1,102	1.4	32	3.0	442	-0.6	964	0.2
Machinery	2,725	1.2	1,071	2.5	567	4.9	75	1.2	103	-0.6	249	-0.3
Transport equipment	2,886	0.9	736	2.3	176	2.9	41	6.4	110	0.9	389	2.1
Services	**8,820**	**0.0**	**2,563**	**-0.1**	**957**	**-0.3**	**283**	**0.4**	**267**	**0.0**	**567**	**-0.2**
Power distribution	31	0.1	8	0.3	1	0.0	1	-0.1	0	0.0	0	0.2
Construction	239	0.1	120	-0.1	69	-0.2	6	0.6	7	0.0	29	-0.1
Services	7,675	0.0	2,198	-0.1	790	-0.3	269	0.4	238	0.0	481	-0.2
Dwellings	0	0.1	0	0.0	0	0.4	0	-0.1	0	0.1	0	0.2
Road and rail transport	166	0.0	36	-0.1	16	-0.4	2	0.4	5	-0.1	7	-0.2
Water transportation	176	0.3	65	0.0	33	-0.1	3	1.1	4	0.2	19	-0.1
Air transportation	534	-0.1	136	-0.3	47	-0.7	2	0.1	13	-0.2	31	-0.4
Energy	**2,209**	**-0.2**	**438**	**-0.1**	**81**	**-0.9**	**48**	**-0.5**	**50**	**4.6**	**98**	**-0.5**
Coal	90	-0.4	39	-0.1	2	-3.3	0	-2.8	8	13.6	0	-6.0
Oil	1,034	-0.1	77	1.1	1	-2.7	0	-0.8	13	2.6	0	-3.5
Gas	260	0.1	59	0.3	1	-3.5	0	2.6	9	7.5	0	9.6
Oil products	757	-0.4	246	-0.5	73	-0.8	45	-0.5	18	0.8	98	-0.5
Nuclear power	4	-1.0	0	-1.0	0	-1.1	0	-0.9	0	0.0	0	-0.3
Coal power	3	-0.9	2	-0.7	1	-0.5	0	-0.8	0	3.3	0	0.7
Gas power	10	0.5	2	1.0	0	0.3	0	1.2	0	4.5	0	2.2
Wind power	15	0.0	2	1.3	0	-1.7	0	-0.6	2	2.0	0	0.4
Hydro power	13	-1.3	6	-2.1	0	-1.1	0	-0.5	0	-2.4	0	-0.6
Oil power	3	0.3	1	0.0	0	0.5	0	-0.4	0	-1.8	0	1.4
Other power	8	-0.7	1	-0.3	0	-0.7	0	0.3	0	-0.7	0	-0.1
Solar power	10	-0.3	3	-0.7	2	-1.4	1	-0.3	0	3.4	0	0.8

Source: authors' simulations (StrucTables/compare)
Note: ASEAN is sum of regions ASEAN5 and Southeast Asia, nes

Table 24: Forests Added or Restored, Cooperation Scenario (Mill. Ha.)

	2025	Leakage	Cooperation
Asia and Oceania	**6**	**0**	**150**
PR China	**2**	**0**	**46**
ASEAN5	**1**	**0**	**35**
Southeast Asia nec	**0**	**0**	**5**
India	**0**	**0**	**52**
South Asia nec	**1**	**0**	**3**
Caucasus and Central Asia	**0**	**0**	**1**
Advanced Asia	**1**	**0**	**3**
Oceania and Pacific	**1**	**0**	**5**
High Income	**28**	**0**	**201**
United States	**22**	**0**	**96**
North America nec	**3**	**0**	**101**
Europe	**3**	**0**	**5**
Middle and Low Income	**6**	**0**	**148**
Latin America and Caribbean	**5**	**0**	**10**
Middle East and North Africa nec	**1**	**0**	**1**
Sub-Saharan Africa	**0**	**0**	**6**
Russia	**0**	**0**	**125**
Rest of World	**0**	**0**	**6**
Middle East Oil Producers	**3**	**0**	**0**
World	**43**	**0**	**500**

Source: Authors' simulations.
Note: CO2 Removals are additional to amounts removed under Baseline policies, principally including forest additions and renewal under the Cooperation scenario.

Table 25: Cost of CO2 Removals (Beyond Baseline) 2050 ($Bill.)

	2025	Leakage	Cooperation
Asia and Oceania	**1**	**0**	**15**
PR China	**0**	**0**	**5**
ASEAN5	**0**	**0**	**4**
Southeast Asia nec	**0**	**0**	**1**
India	**0**	**0**	**5**
South Asia nec	**0**	**0**	**0**
Caucasus and Central Asia	**0**	**0**	**0**
Advanced Asia	**0**	**0**	**0**
Oceania and Pacific	**0**	**0**	**0**
High Income	**3**	**0**	**20**
United States	**2**	**0**	**10**
North America nec	**0**	**0**	**10**
Europe	**0**	**0**	**0**
Middle and Low Income	**1**	**0**	**15**
Latin America and Caribbean	**0**	**0**	**1**
Middle East and North Africa nec	**0**	**0**	**0**
Sub-Saharan Africa	**0**	**0**	**1**
Russia	**0**	**0**	**13**
Rest of World	**0**	**0**	**1**
Middle East Oil Producers	**0**	**0**	**0**
World	**4**	**0**	**50**

Source: authors' simulations

Note: CO2 Removals are additional to amounts removed under Baseline policies, principally including forest additions and renewal under the Cooperation scenario.

Box 2. Implications of Decarbonization and related Trade Policies for PRC and India: CBAM, Cooperation, and Beyond

India and the PRC are the most populous countries in the world and over the past three decades among the most dynamic. While their development paths have been different, they each registered impressive growth rates in the wake of pervasive economic reforms, starting with the "Four Modernizations" for the PRC and after economic crisis in India in the early 1990s. International trade has been a common variable in their respective success stories.

However, their growth paths have been carbon intensive. They are among the largest sources of production-based CO2 emissions in the world, together accounting for over one-third of the global total. In addition, they are responsible for one-fourth of embodied CO2 emissions in exports. Net emissions in 2025 are estimated to be 11.7 billion metric tons (PRC) and 2.8 billion metric tons (India), with carbon emissions per dollar of net GDP at 0.64 and 0.72, respectively. This compares to a global average of 0.36, placing them among the least carbon efficient in the world. Obviously dramatic changes will be needed in order to arrive at net zero.

Each has an NDC in place with stipulated net zero target dates, albeit later than the assumed 2050 in this study (i.e., 2060 for PRC, 2070 for India). Their progress will be critical to meeting the challenges of the Paris Agreement. A green future is clearly in their interests: with long, densely-populated coastlines and water scarcity and extreme-weather susceptibility in many areas, the two countries are among the most exposed to the costs of climate change.

The PRC has been at the forefront of developing and marketing green technologies and manufactures. For example, according to the IEA, in 2023 almost 20% of cars sold globally were electric, up from just 2% five years earlier. Almost two-thirds of these registrations were in the PRC. The Indian market for electric vehicles is small but growing rapidly; registrations were up 70% from 2022 to 2023. In 2024, the PRC's BYD became the largest producer of electric vehicles globally. The PRC is also by far the world's largest solar panel market and supplier.

But much remains to be done to reduce emissions toward net zero in both markets. Under the Pledges scenario in the GTEM model, relative to the baseline PRC and India net emissions will fall by 72% and 56%, respectively, by 2050, at which point they will account for 29% of global emissions compared to an estimated 41% in 2025. Electrification of the energy markets, especially in India, and supplied by renewable sources are key to progress in all scenarios. These changes will require major structural transformations, e.g., fossil-fuel capital stocks plummet in both countries, particularly coal, in favor of renewables.

In addition to general technological advances, green policy interventions, and changes in preferences of economic agents, carbon removal technologies play an increasingly important role along decarbonization pathways, especially for the PRC: under both Pledges and Net Zero its global share of carbon removal rises from less than one-tenth in 2030 to about one-third in 2050. In terms of aggregate effects on the economy, under the Pledges scenario by 2050 real GDP falls by 1.3% in the PRC, which is slightly more than the global average (-1%), but it rises (0.9%) for India, in part due to a favorable terms of trade effect with its shift out of fossil-fuels. Under Net

Zero by 2050 real GDP falls in India (-1.2%) and the PRC (-0.7%) but less than the global average (-1.8%).

Trade is of particular concern to the PRC and India in the context of policy headwinds in the global marketplace and the importance of trade to both economies as a source of, *inter alia*, external demand, cheaper and more diverse intermediate inputs, new technologies, and food security. Leakage mitigation programs such as the EU's Carbon Border Adjustment Mechanism (CBAM) have been a concern particularly to India as a potential form of protectionism, with small- and medium-sized enterprises most at risk. However, the World Bank CBAM Exposure Index would suggest that India and, especially, the PRC should not be significantly affected by the EU's CBAM, with the exception of Indian exports of iron and steel to the EU. The GTEM Carbon Leakage Mitigation scenario, which gauges the effects of CBAM applied by the EU and other developed countries, also suggests that these taxes would not have much of an effect on Indian and PRC real GDP and exports but would lead to a (slight) reduction in emissions for both economies, with the effect being greater than the global average. It would also ensure that the salutary effect of the greening of industries in developed economies would not be offset by the offshoring of brown industries.

Importantly, the GTEM Cooperation scenario shows that liberalization of trade in green goods and services, combined with other concerted approaches to reducing emissions, is able to not only help decarbonize the PRC and Indian economies but also promote growth and trade. Under Cooperation, net emissions fall significantly in both the PRC (-0.94%) and India (-2.93%), while at the same time increasing real GDP and exports. Manufactured exports grow the most in both economies led by machinery exports from PRC (4.9%) and transport equipment from India (6.4%).

Hence, economic and climate-related cooperation is in the interest of the PRC and India as well as the global community. There are many fora at which these giants can work together with other countries to advance the goals of the Paris Agreement, from the COP meetings to the G-20. The Regional Comprehensive Economic Partnership (RCEP), a trade grouping of 15 Asian economies in which the PRC is a founding member, is a "living agreement" and environmental issues will no doubt play an increasingly prominent role as they have in other trade agreements. It would benefit the PRC to promote the greening of RCEP. India was part of the original negotiations, and the agreement underscores that its future candidacy would be welcome. Given the proven role of trade in generating economic prosperity and its potential to serve as a weapon against climate change, the importance of PRC and Indian leadership in promoting cooperation has never been greater.

V. Conclusions and Policy Opportunities

Climate change is shifting from a looming threat to the defining risk to global well-being. Increasingly powerful storms, floods, draughts, heat, famines and displacement are affecting people around the planet, including especially the world's most vulnerable populations. The Asia and the Pacific region is among the most exposed.

While most governments have agreed to mitigate climate change, CO_2 emissions continue to rise in most countries and in the world. Despite the optimistic initial days of the 2015 Paris Agreement, global carbon emissions and temperatures set new records in 2024. This report finds that emissions may finally peak[28] in the next five years but reaching net zero emissions by 2050—a critical milestone for the 1.5°C goal—requires a 33 percent drop in emissions already by 2030. This intermediate goal will not be reached without immediate, coordinated, massive global efforts.

Using a comprehensive economic-environmental CGE model, this study evaluated five scenarios for implementing decarbonization strategies proposed by the IEA, the WTO and other international sources. Its four principal conclusions are summarized below.

a. Reaching Net Zero Emissions in 2050 Is Still Possible, but…

Although current trends are not on track, this analysis suggests that narrow paths to net zero emissions by 2050 continue to exist. Success hinges on the rapid, large-scale transformation of the global economy, particularly in energy sectors. Existing technologies and resources are largely sufficient, but current market prices will not drive change at the necessary scale and speed. For example, although wind and solar power prices have fallen sharply, incentives are insufficient to justify large, high-risk investments without public support. The gap between private prices and the social value of new energy sources remains to be addressed by policy,

[28] The potential peaking of emissions has received positive public attention recently (e.g., *The Economist*), and is indeed an important milestone on the road to decarbonization. But this discussion tends to overlook the even larger declines in emissions that will have to be sustained for decades to *decelerate* the rate at which temperatures are rising and eventually to stop them from rising any further.

through price incentives, regulations, investments, and guidance for business and consumer decisions.

Crucially, the transition depends on an unusually scarce resource: trust and political cooperation within and among countries. There is no alternative to public sector leadership in the energy transition. Private resources cannot overcome externalities and distorted market prices, and they cannot, by themselves, generate the necessary levels of investment and research. Meanwhile, the politics of intervention remain notoriously difficult. A diverse toolkit of policy options is needed to distribute adjustment burdens and to overcome diminishing returns. Ultimately, the climate challenge cannot be addressed without a working partnership of governments, markets and citizens.

b. The Costs of Net Zero are Manageable

We estimate the economic costs of achieving net zero by 2050 as approximately 3% of global GDP, comparable to losing one year of average growth. This includes the diversion of investment from conventional uses to new ways of producing and using energy, the direct costs of mitigating or removing carbon emissions from the atmosphere, and losses from abandoning formerly valuable assets. (Our analysis does not, however, estimate climate-related damages.) It also incorporates the cost of shifting world production and trade away from fossil fuels. These are large costs, but losses from unchecked climate change are likely to reach around 20 percent of global GDP.

Why then is the outlook for decarbonization so clouded? The uncertainty does not appear to stem from macroeconomic feasibility, but from microeconomic disruption. Reaching net zero will require new investment patterns, regulatory frameworks, and shifts in organizing the energy and fuel consumption of households, businesses and government. Even if the new systems will cost no more than the systems they replace, there will be winners and losers. Those harmed, even if only in transition, will resist change.

While countervailing coalitions exist, they will be hard to organize. They need to include those *not harmed* by storms and famines that are *not happening*—in short, they will be difficult to identify or mobilize. More realistically, support will come from those who will build green infrastructure and create goods and services that run on green energy.

As this study shows, the transition will involve massive shifts in investment and expenditures. The IEA (2021) estimates that the green investment required to reach net zero by 2050 will more than triple to $4 trillion by 2030. Some of these funds will come from declining fossil fuel investments and the reorganization of public and private expenditures. Black, et al. (2023) reports that fossil fuel subsidies amounted to $7.1 trillion in 2022, rising by over $2 trillion over the previous two years. For comparison, the WTO (2023) and OECD (2023) estimate that over 2020-2022 $630 billion annually was spent by OECD countries to support agricultural producers.

c. Cooperation is the critical resource

Cooperation within countries and among them will have to play the lead role in driving decarbonization. Powerful domestic political coalitions are indispensable for climate action, since market signals are unlikely to change at the necessary pace. International cooperation among countries is equally essential. Climate change is a global-commons challenge and requires global solutions. Unilateral efforts will be insufficient—they will be riddled by free-rider concerns and countries' inability to justify benefits to foreigners.

Regional institutions are already providing leadership for decarbonization:

- European Union: The EU's Green New Deal includes the "Fit for 55" goal, which commits members to reduce emissions by at least 55% before 2030, along the way to net zero in 2050.
- ASEAN: The ASEAN Economic Community has prioritized the green transition, coordinating Ministerial Meetings on the Environment and other high-level working groups. Other Asian fora, including the Regional Comprehensive Economic Partnership, could follow suit. ASEAN also launched its Strategy for Carbon Neutrality in August 2023, seeking to "accelerate an inclusive transition towards a green economy … as part

of a regional collective effort"[29]. It is planning an interoperable regional carbon market, exploring the harmonizations of emissions measurement, and considering joint approaches for tapping global liquidity for green investments.

- CPTPP: The Comprehensive and Progressive Agreement on Transpacific Partnership (CPTPP) is undergoing a General Review with a priority on strengthening its environmental chapter, as noted in its November 2024 interim report.

These and further initiatives in Asia and elsewhere can help build a powerful framework for action within countries and among them.

d. Green trade is part of the solution

While trade has been criticized for contributing to CO_2 emissions—through transport and by facilitating emissions-intensive production—this study has shown that it can also play a pivotal role in decarbonization. There is no alternative to trade for making green energy technologies and products more widely and efficiently available. There is also further potential for reducing barriers to trade in environmental goods, services, and technologies. Finally, trade policies can minimize carbon leakage and encourage regulatory cooperation. These are the clear messages of this study and other research (e.g., Bacchetta, et. al. 2023).

Despite geopolitical headwinds, the long-standing negotiations on trade in green goods, services and technologies offer low-hanging fruit in the green transition. WTO (2022) and this paper underscore the benefits that trade offers in decarbonization. In addition, internationally consistent carbon taxes would go a long way toward preventing carbon leakage and minimizing compliance costs. Given its trade policy expertise (see ADB 2023a and ADB 2023b), the ADB has strong capabilities to contribute. As previously noted, the ADB *Climate Change Action Plan 2023-2030* envisions an ambitious program of climate-related activities, which could benefit from engaging the region's exceptional trading system.

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[29] ASEAN Secretariat, https://asean.org/wp-content/uploads/2023/08/Brochure-ASEAN-Strategy-for-Carbon-Neutrality-Public-Summary-1.pdf

Is Net Zero by 2050 feasible? Our study suggests a clear and economically viable path for eliminating net global CO2 emissions by 2050. The costs are manageable, and the technologies and constraints are well understood. Indeed, achieving net zero will be far less costly than the consequences of failure. Moreover, the transition should gain momentum with time, aided by technological breakthroughs, emerging business opportunities, and attractive new jobs in the green economy. But the path is nevertheless uncertain; it will face considerable political resistance and require visionary leadership.

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Annex Table 1: Regional Correspondence

GTEM Regions (17)			GTAP Regions (160)		
No.	**Code**	**Region Name**	**No.**	**Code**	**Country Name**
1	Chn	PR China	5	hkg	Hong Kong, China
1	Chn	PR China	4	chn	PRC
2	as5	ASEAN5	11	brn	Brunei Darussalem
2	as5	ASEAN5	13	idn	Indonesia
2	as5	ASEAN5	15	mys	Malaysia
2	as5	ASEAN5	16	phl	Philippines
2	as5	ASEAN5	18	tha	Thailand
3	Sel	Southeast Asia nec	12	khm	Cambodia
3	Sel	Southeast Asia nec	14	lao	Lao
3	Sel	Southeast Asia nec	20	xse	R SE Asia
3	Sel	Southeast Asia nec	19	vnm	Viet Nam
4	Ind	India	23	ind	India
5	Xsa	South Asia nec	21	afg	Afghanistan
5	Xsa	South Asia nec	22	bgd	Bangladesh
5	Xsa	South Asia nec	24	npl	Nepal
5	Xsa	South Asia nec	25	pak	Pakistan
5	Xsa	South Asia nec	27	xsa	R S Asia
5	Xsa	South Asia nec	26	lka	Sri Lanka
6	Cca	Caucasus and Central Asia	99	arm	Armenia
6	Cca	Caucasus and Central Asia	100	aze	Azerbaijan
6	Cca	Caucasus and Central Asia	101	geo	Georgia
6	Cca	Caucasus and Central Asia	94	kaz	Kazakhstan
6	Cca	Caucasus and Central Asia	95	kgz	Kyrgyztan
6	Cca	Caucasus and Central Asia	8	mng	Mongolia
6	Cca	Caucasus and Central Asia	98	xsu	R USSR
6	Cca	Caucasus and Central Asia	96	tjk	Tajikistan
6	Cca	Caucasus and Central Asia	97	uzb	Uzbekistan
7	Dea	Advanced Asia	6	jpn	Japan
7	Dea	Advanced Asia	7	kor	Korea
7	Dea	Advanced Asia	17	sgp	Singapore
7	Dea	Advanced Asia	9	twn	Taiwan
8	Ocn	Oceania and Pacific	1	aus	Australia
8	Ocn	Oceania and Pacific	2	nzl	New Zealand
8	Ocn	Oceania and Pacific	3	xoc	R Oceania
9	Usa	United States	29	usa	United States
10	Xna	North America nec	28	can	Canada
10	Xna	North America nec	30	mex	Mexico
10	Xna	North America nec	31	xna	R N America

11	Lac	Latin America and Caribbean	32	arg	Argentina
11	Lac	Latin America and Caribbean	33	bol	Bolivia
11	Lac	Latin America and Caribbean	34	bra	Brazil
11	Lac	Latin America and Caribbean	55	xcb	Caribbean
11	Lac	Latin America and Caribbean	35	chl	Chile
11	Lac	Latin America and Caribbean	36	col	Colombia
11	Lac	Latin America and Caribbean	43	cri	Costa Rica
11	Lac	Latin America and Caribbean	50	dom	Dominican Republic
11	Lac	Latin America and Caribbean	37	ecu	Ecuador
11	Lac	Latin America and Caribbean	48	slv	El Salvador
11	Lac	Latin America and Caribbean	44	gtm	Guatemala
11	Lac	Latin America and Caribbean	51	hti	Haiti
11	Lac	Latin America and Caribbean	45	hnd	Honduras
11	Lac	Latin America and Caribbean	52	jam	Jamaica
11	Lac	Latin America and Caribbean	46	nic	Nicaragua
11	Lac	Latin America and Caribbean	47	pan	Panama
11	Lac	Latin America and Caribbean	38	pry	Paraguay
11	Lac	Latin America and Caribbean	39	per	Peru
11	Lac	Latin America and Caribbean	53	pri	Puerto Rico
11	Lac	Latin America and Caribbean	49	xca	R C America
11	Lac	Latin America and Caribbean	42	xsm	R South America
11	Lac	Latin America and Caribbean	54	tto	Trinidad Tobago
11	Lac	Latin America and Caribbean	40	ury	Uruguay
11	Lac	Latin America and Caribbean	41	ven	Venezuela
12	Eur	Europe	87	alb	Albania
12	Eur	Europe	56	aut	Austria
12	Eur	Europe	89	blr	Belarus
12	Eur	Europe	57	bel	Belgium
12	Eur	Europe	58	bgr	Bulgaria
12	Eur	Europe	59	hrv	Croatia
12	Eur	Europe	60	cyp	Cyprus
12	Eur	Europe	61	cze	Czech Republic
12	Eur	Europe	62	dnk	Denmark
12	Eur	Europe	63	est	Estonia
12	Eur	Europe	64	fin	Finland
12	Eur	Europe	65	fra	France
12	Eur	Europe	66	deu	Germany
12	Eur	Europe	67	grc	Greece
12	Eur	Europe	68	hun	Hungary
12	Eur	Europe	69	irl	Ireland
12	Eur	Europe	70	ita	Italy
12	Eur	Europe	71	lva	Latvia
12	Eur	Europe	72	ltu	Lithuania

12	Eur	Europe	73	lux	Luxembourg
12	Eur	Europe	74	mlt	Malta
12	Eur	Europe	75	nld	Netherlands
12	Eur	Europe	85	nor	Norway
12	Eur	Europe	76	pol	Poland
12	Eur	Europe	77	prt	Portugal
12	Eur	Europe	92	xee	R E Europe
12	Eur	Europe	86	xef	R EFTA
12	Eur	Europe	93	xer	R Europe
12	Eur	Europe	78	rou	Romania
12	Eur	Europe	88	srb	Serbia
12	Eur	Europe	79	svk	Slovakia
12	Eur	Europe	80	svn	Slovenia
12	Eur	Europe	81	esp	Spain
12	Eur	Europe	82	swe	Sweden
12	Eur	Europe	84	che	Switzerland
12	Eur	Europe	91	ukr	Ukraine
12	Eur	Europe	83	gbr	United Kingdom
13	Meo	Middle East Oil Producers	102	bhr	Bahrain
13	Meo	Middle East Oil Producers	103	irn	Iran
13	Meo	Middle East Oil Producers	104	irq	Iraq
13	Meo	Middle East Oil Producers	107	kwt	Kuwait
13	Meo	Middle East Oil Producers	109	omn	Oman
13	Meo	Middle East Oil Producers	111	qat	Qatar
13	Meo	Middle East Oil Producers	112	sau	Saudi
13	Meo	Middle East Oil Producers	115	are	UAE
14	Mna	Middle East and North Africa nec	117	dza	Algeria
14	Mna	Middle East and North Africa nec	118	egy	Egypt
14	Mna	Middle East and North Africa nec	105	isr	Israel
14	Mna	Middle East and North Africa nec	106	jor	Jordan
14	Mna	Middle East and North Africa nec	108	lbn	Lebanon
14	Mna	Middle East and North Africa nec	119	mar	Morocco
14	Mna	Middle East and North Africa nec	110	pse	Palestine
14	Mna	Middle East and North Africa nec	121	xnf	R N Africa
14	Mna	Middle East and North Africa nec	116	xws	R W Asia
14	Mna	Middle East and North Africa nec	113	syr	Syria
14	Mna	Middle East and North Africa nec	120	tun	Tunisia
14	Mna	Middle East and North Africa nec	114	tur	Turkiye
15	Afr	Sub-Saharan Africa	122	ben	Benin
15	Afr	Sub-Saharan Africa	155	bwa	Botswana
15	Afr	Sub-Saharan Africa	123	bfa	Burkina Faso
15	Afr	Sub-Saharan Africa	124	cmr	Cameroon
15	Afr	Sub-Saharan Africa	134	caf	Central African Rep.

15	Afr	Sub-Saharan Africa	135	tcd	Chad
15	Afr	Sub-Saharan Africa	141	com	Comoros
15	Afr	Sub-Saharan Africa	136	cog	Congo
15	Afr	Sub-Saharan Africa	125	civ	Cote d'Ivoire
15	Afr	Sub-Saharan Africa	137	cod	DR Congo
15	Afr	Sub-Saharan Africa	138	gnq	Equatorial Guinea
15	Afr	Sub-Saharan Africa	156	swz	Eswatini
15	Afr	Sub-Saharan Africa	142	eth	Ethiopia
15	Afr	Sub-Saharan Africa	139	gab	Gabon
15	Afr	Sub-Saharan Africa	126	gha	Ghana
15	Afr	Sub-Saharan Africa	127	gin	Guinea
15	Afr	Sub-Saharan Africa	143	ken	Kenya
15	Afr	Sub-Saharan Africa	144	mdg	Madagascar
15	Afr	Sub-Saharan Africa	145	mwi	Malawi
15	Afr	Sub-Saharan Africa	128	mli	Mali
15	Afr	Sub-Saharan Africa	146	mus	Mauritius
15	Afr	Sub-Saharan Africa	147	moz	Mozambique
15	Afr	Sub-Saharan Africa	157	nam	Namibia
15	Afr	Sub-Saharan Africa	129	ner	Niger
15	Afr	Sub-Saharan Africa	130	nga	Nigeria
15	Afr	Sub-Saharan Africa	154	xec	R E Africa
15	Afr	Sub-Saharan Africa	159	xsc	R S Africa CU
15	Afr	Sub-Saharan Africa	140	xac	R S&C Africa
15	Afr	Sub-Saharan Africa	133	xwf	R W Africa
15	Afr	Sub-Saharan Africa	148	rwa	Rwanda
15	Afr	Sub-Saharan Africa	131	sen	Senegal
15	Afr	Sub-Saharan Africa	158	zaf	South Africa
15	Afr	Sub-Saharan Africa	149	sdn	Sudan
15	Afr	Sub-Saharan Africa	150	tza	Tanzania
15	Afr	Sub-Saharan Africa	132	tgo	Togo
15	Afr	Sub-Saharan Africa	151	uga	Uganda
15	Afr	Sub-Saharan Africa	152	zmb	Zambia
15	Afr	Sub-Saharan Africa	153	zwe	Zimbabwe
16	Rus	Russia	90	rus	Russia
17	Row	Rest of World	10	xea	R E Asia
17	Row	Rest of World	160	xtw	ROW

Annex Table 2: Sectoral Correspondence

GTEM Sectors (28)			GTAP Sectors (75)		
No	Code	Name	No	Code	Name
1	Crops	Crops	1	pdr	Paddy
1	Crops	Crops	2	wht	Wheat
1	Crops	Crops	3	gro	Cereal grains nec
1	Crops	Crops	4	v_f	Vegetables, fruit, buts
1	Crops	Crops	5	osd	Oil seeds
1	Crops	Crops	6	c_b	Sugar cane, sugar beet
1	Crops	Crops	7	pfb	Plant-based products
1	Crops	Crops	8	ocr	Crops nec
1	Crops	Crops	13	frs	Forestry
2	Livestock	Livestock	9	ctl	Cattle, sheep, goats, horses
2	Livestock	Livestock	10	oap	Animal products nec
2	Livestock	Livestock	11	rmk	Raw milk
2	Livestock	Livestock	12	wol	Wool
2	Livestock	Livestock	14	fsh	Fishing
2	Livestock	Livestock	19	cmt	Meat: cattle, sheep, goats, horses
3	Extraction	Extraction	18	oxt	Other extraction
4	Chemicals	Chemicals	33	chm	Chemical products
4	Chemicals	Chemicals	34	bph	Basic pharmaceutical products
4	Chemicals	Chemicals	35	rpp	Rubber and plastic products
5	Light_mfg	Light Manufacturing	20	omt	Meat products nec
5	Light_mfg	Light Manufacturing	21	vol	Vegetable oils and fats
5	Light_mfg	Light Manufacturing	22	mil	Dairy products
5	Light_mfg	Light Manufacturing	23	pcr	Processed rice
5	Light_mfg	Light Manufacturing	24	sgr	Sugar
5	Light_mfg	Light Manufacturing	25	ofd	Food products nec
5	Light_mfg	Light Manufacturing	26	b_t	Beverages and tobacco
5	Light_mfg	Light Manufacturing	27	tex	Textiles
5	Light_mfg	Light Manufacturing	28	wap	Wearing apparel
5	Light_mfg	Light Manufacturing	29	lea	Leather products
5	Light_mfg	Light Manufacturing	30	lum	Wood products
5	Light_mfg	Light Manufacturing	31	ppp	Paper products, publishing
6	En_int_mfg	Energy Intensive Manufacturing	36	nmm	Mineral products
6	En_int_mfg	Energy Intensive Manufacturing	37	i_s	Ferrous metals
6	En_int_mfg	Energy Intensive Manufacturing	38	nfm	Metals nec
6	En_int_mfg	Energy Intensive Manufacturing	39	fmp	Metal products

7	Electrical	Electrical Equipment	40	ele	Computer, electronic, optical
7	Electrical	Electrical Equipment	41	eeq	Electrical equipment
8	Machinery	Machinery	42	ome	Machinery and equipment nec
8	Machinery	Machinery	45	omf	Other manufactures nec
9	Trans_eq	Transport Equipment	43	mvh	Motor vehicles and parts
9	Trans_eq	Transport Equipment	44	otn	Transport equipment
10	TnD	Transmission, Distribution	46	TnD	Transmission and distribution
11	Construction	Construction	60	cns	Construction
12	Dwellings	Dwellings	76	dwe	Dwellings
13	Services	Services	59	wtr	Water
13	Services	Services	61	trd	Trade
13	Services	Services	62	afs	Accommodation, food, services
13	Services	Services	66	whs	Wearing apparel
13	Services	Services	67	cmn	Communication
13	Services	Services	68	ofi	Financial services
13	Services	Services	69	ins	Insurance
13	Services	Services	70	rsa	Real estate
13	Services	Services	71	obs	Business services
13	Services	Services	72	ros	Recreation and services
13	Services	Services	73	osg	Public administration, defense
13	Services	Services	74	edu	Education
13	Services	Services	75	hht	Human health and social work
14	Oth_tp	Ground Transportation	63	otp	Transport nec
15	Wat_tp	Water Transportation	64	wtp	Water transport
16	Air_tp	Air Transportation	65	atp	Air transport
17	Coal	Coal	15	coa	Coal
18	Oil	Oil	16	oil	Oil
19	Gas	Gas	17	gas	Gas
19	Gas	Gas	58	gdt	Gas manufactures, distribution
20	Oil_Pcts	Petroleum products	32	p_c	Petroleum, coal products
21	NuclearE	Nuclear Power	47	NuclearBL	Nuclear Baseload
22	CoalE	Coal Power	48	CoalBL	Coal Baseload
23	GasE	Gas Power	49	GasBL	Gas Baseload
23	GasE	Gas Power	54	GasP	Gas Intermittent
24	WindE	Wind Power	50	WindBL	Wind Baseload
25	HydroE	Hydroelectric Power	51	HydroBL	Hydro Baseload
25	HydroE	Hydroelectric Power	55	HydroP	Hydro Intermittent
26	OilE	Oil Power	52	OilBL	Oil Baseload
26	OilE	Oil Power	56	OilP	Oil Intermittent
27	OthE	Other Power	53	OtherBL	Other Baseload
28	SolarE	Solar Power	57	SolarP	Solar Intermittent

Annex Table 3: Policy Instruments Used in Model Scenarios

Policy levers applied	Baseline (IEA STEPS)	IEA Pledges	IEA Net Zero	Leakage Mitigation	Cooperative Policies
Technology					
Energy augmenting innovation	2	1	2		d
Electricity augmenting innovation					
Coal electricity innovation	-1	-1	-2		
Wind electricity innovation	1	1	2		
Solar electricity innovation	1	1	2		
Export augmenting innovation					e
Incentives					
Carbon tax	a	a	a		
Taxes/subsidies on coal electricity	b	b	b		
Taxes/subsidies on wind electricity	b	b	b		
Taxes/subsidies on solar electricity	b	b	b		
Taxes/subsidies on fossil fuels					
Import duties				c	f
Preference changes					
Energy vs. capital preference, firms		-0.5	-1		
Energy use preference, households		-1	-2		
Energy use preference, government					g
Electricity preference, firms		1	1.5		
Electricity preference, households		1	1.5		
Coal electricity preference	-2	-1.5	-2		
Coal electricity preference	-2	-1.5	-2		
Renewables preference, firms		1	1.5		
Renewables preference, households		1	1.5		

Notes. Values reflect annual percent changes in targeted productivity or variable.
a - endogenous carbon tax to meet emissions quota
b - endogenous tax or subsidy to meet output growth target
c - implementation of carbon border taxes
d - productivity effects of government environmental procurement policy
e - reduced trade costs due to trade facilitation, regulatory alignment, expanded finance
f - elimination of tariffs on environmentally preferred goods
g - reductions in government energy use due to environmental procurement