Getting Asia to Net Zero

Building a Powerful and Coherent Vision

A DISCUSSION PAPER OF THE HIGH-LEVEL POLICY COMMISSION ON GETTING ASIA TO NET ZERO

CONVENED BY THE ASIA SOCIETY POLICY INSTITUTE AS SECRETARIAT

Appendix & modelling prepared by Cambridge Econometrics

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GETTING ASIA TO NET ZERO

The High-level Policy Commission on Getting Asia to Net Zero aims to urgently accelerate Asia's transition to net zero emissions while ensuring that the region thrives and prospers through this transition. Through research, analysis and engagement, the commission's diverse set of recognized Asian leaders seek to advance a powerful, coherent, and Paris-aligned regional vision for net zero emissions in Asia. The Asia Society Policy Institute serves as the Commission's secretariat. For more information and a list of commissioners, visit: AsiaSociety.org/NetZero

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APPENDIX: RESEARCH & MODELLING

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ACRONYMS

ASEAN	Association of Southeast Asian Nations
ASPI	Asia Society Policy Institute
BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CE	Cambridge Econometrics
CGE	Computable General Equilibrium
COP26	26th United Nations Climate Change Conference
EU27	Current member states of the European Union
EV	Electric Vehicle
FTT	Future Technology Transformation
G20	Group of Twenty
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
ILO	International Labor Organization
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LTS	Long-term Strategies
LULUCF	Land Use, Land-Use Change and Forestry
NDC	Nationally Determined Contributions
OECD STAN	Organization for Economic Co-operation and Development – Structural Analysis Database
PLN	Perusahaan Listrik Negara (Indonesia State Electricity Company)
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

DELIVERING THE ASIA-PACIFIC'S COP26 POLICIES AND COMMITMENTS IN FIGURES	
2056	Year in which the region reaches net zero carbon emissions
21%	Reduction in CO_2 emissions by 2030 compared to 2010 levels
5.4%	Increase in GDP at the peak of investment in the 2030s compared to baseline
2.0%	Increase in GDP by 2060 compared to baseline
$53.5trn	Cumulative economy-wide investment required from now until 2060
$500bn	Improvement to the Asia-Pacific's trade balance by 2060
34 million	Number of additional jobs created by 2060
$700bn	Reduction in household spending by 2060
$200bn	Household energy cost savings by 2060
$1.4trn	Net costs of policy implementation by 2060
1.6°C	Global temperature change by 2100 if all other countries also deliver their COP26 policies and commitments

>> **The Asia-Pacific region includes some of the world's largest economies and greenhouse gas emitters.** Through the region's rapid economic growth in recent decades, and its strong recovery from COVID-19, the Asia-Pacific has become a key driver of global emissions. In 2020, it accounted for about half of global CO_2 and GHG emissions.

>> **Power generation systems that are heavily dependent upon fossil fuels (especially coal) are the main reason behind high current emissions in the region.** While the share of fossil fuels in global power generation is 63 percent, China and India have a 68 percent and 77 percent share, respectively. Slow electrification of transport and a high share of energy-intensive industries in economic output also contribute to high emissions. However, the faster than expected uptake of renewables, especially solar PV in the power sector, has slowed down the pace of emissions growth in recent years.

>> Limiting global warming and preventing climate damage are especially important for protecting the vulnerable populations of the Asia-Pacific. Most of the region is highly exposed to climate-related disasters and costly health impacts from pollution and extreme weather events. Action by Asia-Pacific nations to decarbonize their own economies will help reduce the climate damages they face given the region's significant and increasing share of global emissions.

>> All Asia-Pacific economies have submitted Nationally Determined Contributions (NDCs) and around half have also submitted Long-Term Strategies (LTSs) to the UNFCCC summarizing their climate action commitments since the Paris Agreement was adopted in 2015.[1] Fourteen countries, including China, India, Japan,

1 Taiwan cannot sign onto the UNFCCC so it has not submitted a formal NDC, but it has announced an Intended Nationally Determined Contribution. All other countries analyzed in this report have submitted NDCs.

South Korea, Australia, New Zealand, and Indonesia, have also announced net zero targets, aiming to reach emissions neutrality by dates that range from 2050 to 2070. However, some of these targets have been criticized by the scientific research community for lacking implementation plans and/or not aligning with the Paris Agreement's target of limiting global temperature increases to 1.5°C above preindustrial levels by 2100.

>> This report provides economic analysis to assess costs and benefits of increasing climate ambition compared to policies currently in place. **Five core scenarios with different levels of decarbonization (including the current net zero commitments and more ambitious net zero 2050 targets for Asia-Pacific economies) were modelled**, complemented by sensitivities on the policies implemented to achieve these targets. Results in this report are shown for a subset of these scenarios focusing on commitments made up through COP26, while the extended report will expand this to also include more ambitious scenarios and discuss policy recommendations in greater detail.

>> The modelling shows that **the status quo of pre-COP26 policies in the *baseline* scenario will lead to a higher than 3°C global temperature** by the end of the century (compared to preindustrial temperatures). It is possible to limit this warming to less than 2°C if current commitments are also implemented as planned. For full alignment with a 1.5°C pathway, which is expressed as the preferential goal in the Paris Agreement, **more ambitious targets and policies beyond those currently committed will be needed**.

>> Our modelling shows that **decarbonization comes with substantial economic benefits for the Asia-Pacific**. Achieving current commitments, including COP26 goals, can lead to **5.4 percent greater GDP by 2030** than the trajectory implied by currently enacted pre-COP26 policies. Impacts are smaller in the long run but still equate to **2.0 percent of additional output in 2060**.

>> The short- and medium-term growth impacts of climate action are largely driven by the substantial stimulus provided by the investment needed to decarbonize the economy. In the power sector, phasing out unabated coal and fossil-based generation and replacing it with renewable capacities requires large investments. This investment generates jobs and outputs in other sectors of the economy throughout production, installation, and operation supply chains.

>> **Reducing the dependence on, and therefore the import of, fossil fuels also improves the trade balance of the Asia-Pacific.** This higher trade balance is responsible for slightly less than one-third of the long-term growth. Electrification of transport, energy efficiency, and falling energy intensity of production also bring productivity improvements and savings on household energy costs.

>> However, these benefits come with trade-offs. **When the transition is funded entirely domestically, Asia-Pacific households are on average worse off as a result of the transition**, faced with higher prices and higher taxes to help finance additional investments. **Employment impacts are positive overall, but there will be winners and losers**, with many jobs lost in fossil fuel supply sectors. The transition away from coal mining and impacts on wider coal networks pose a challenge for local communities.

>> To deliver a just transition in the Asia-Pacific, social policies (such as reskilling schemes to allow workers to take advantage of employment opportunities created in the transition) and additional sources of financing are the most critical supporting policies needed to complement climate policies especially in the poorest regions, as implied by the modelling. For example, while less developed economies can use carbon revenues or other tax-raising mechanisms to fund green investments, **international financial support would free up domestic finance for development, poverty reduction, and management of social impacts**.

INTRODUCTION

BACKGROUND

The Asia-Pacific[2] makes up about half of the global population and a relatively high birthrate is the key driver of its population growth. The largest economies in the Asia-Pacific — Japan, China, and India — are among the largest economies in the world as well, in terms of their aggregate output (GDP). However, China's and India's per capita income remains below or at the global average. This shows that while the regional production capacity is vast, poverty rates and inequality are still high in parts of the region.

TABLE 1.1: THE SIZE OF ASIAN ECONOMIES ANALYZED IN THE REPORT, 2021

	POPULATION	GDP	GDP PER CAPITA	GDP GROWTH
	MILLIONS	BN USD	USD	%
	2021	2021	2021	2005–2020
Australia	26	1633	63529	5.2%
China	1413	14863	12359	13.8%
India	1392	3042	2185	8.9%
Indonesia	272	1060	4357	9.2%
Japan	126	4937	39340	0.5%
Korea	52	1799	34801	5.0%
Malaysia	33	373	11399	6.4%
New Zealand	5	248	41428	5.1%
Taiwan	24	790	33775	4.3%
Rest of ASEAN*	361	1800	4984	8.5%
Asia-Pacific	3702	33265	8986	6.9%
World	7693	96293	12517	4.4%
Asia-Pacific / World (%)	48.1%	34.5%	71.8%	

Note(s): For the Asia-Pacific, weighted average GDP per capita and growth rates are presented.
* Brunei, Cambodia, Laos, Myanmar, Philippines, Singapore, Vietnam and Thailand are modelled as a group that is referred to as "Rest of ASEAN."
Source(s): IMF (2022).

Energy and electricity demands are on the rise in the Asia-Pacific. Table 1.2 shows renewable shares in the power sector are close to the global average for the Asia-Pacific region, but the share of fossil fuels used in power generation is about 10 percentage points higher due to lower nuclear shares than in the rest of the world. High coal shares are especially responsible for high power sector and overall emissions.

2 The Asia-Pacific grouping used in this analysis covers India, Indonesia, China, Japan, South Korea, Malaysia, Taiwan, Brunei, Cambodia, Laos, Myanmar, the Philippines, Singapore, Vietnam, Thailand, Australia, and New Zealand.

TABLE 1.2: POWER GENERATION SHARES AND CO_2 EMISSIONS, 2020

	FOSSILS	NUCLEAR	RENEWABLES	CO_2 EMISSIONS
	SHARE IN POWER GENERATION			MT OF CO_2
Australia	77%	0%	23%	376
China*	68%	5%	27%	9919
India	77%	3%	20%	2310
Indonesia	83%	0%	17%	627
Japan	73%	4%	19%	1024
Korea	66%	27%	6%	571
Malaysia*	83%	0%	17%	237
New Zealand	19%	0%	81%	33
Taiwan	82%	11%	5%	248
Rest of ASEAN*	77%	0%	22%	788
Asia-Pacific*	73%	2%	25%	16133
World without Asia-Pacific*	55%	17%	28%	17489
World*	63%	10%	26%	33622

Note(s): The asterisk indicates that due to data availability, the shares are only valid for 2019. Brunei, Cambodia, Laos, Myanmar, Philippines, Singapore, Vietnam, and Thailand are modelled as a group that is referred to as "Rest of ASEAN."
Source(s): IEA (2022a).

The latest report of the Intergovernmental Panel on Climate Change (IPCC), the mitigation-focused installment of the Sixth Assessment Report (AR6), warns that the window to peak global emissions is closing (global emissions need to peak by 2025) and that strong and immediate action is needed to overturn it and keep emissions below 1.5°C or even below 2°C by the end of the century (IPCC 2022).

All economies analyzed in the report have submitted a Nationally Determined Contribution (NDC) to the UNFCCC, and some have strengthened their commitments based on the Paris Agreement's ratchet mechanism through which countries revise and recommunicate their NDCs every five years.[3] These NDCs summarize the climate action commitments of each country to ensure that the Paris Agreement's temperature goals are met. Fourteen economies analyzed in the report (including those of China, India, Japan, South Korea, Australia, New Zealand, and Indonesia) currently responsible for almost half of global carbon emissions have also announced net zero targets, aiming to reach emissions neutrality by dates that range from 2050 to 2070.[4]

3 Taiwan cannot sign onto the UNFCCC so it has not submitted a formal NDC, but it has announced an Intended Nationally Determined Contribution.

4 Note that these net zero commitments may differ in form and content. Net zero targets are set largely in response to the Paris Agreement's call that "all Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies." Some countries have committed to net zero targets in their long-term strategies, while others announced targets in other strategies. Targets differ in the coverage of emissions as well, whether the commitments refer to all greenhouse gases, only CO_2 emissions, or are unspecified.

While the region has seen strong uptake of renewables (particularly wind and solar in power generation) and committed policies have the potential to reduce emissions substantially by 2030, there is still support for the use and expansion of fossil fuels and coal. This is particularly visible in COVID-19 recovery packages that mixed green elements with support for energy-intense industries as well as fossil fuel extraction (Climate Action Tracker 2020).

Despite the announced NDCs and net zero targets, detailed policies need to be developed and enacted; in addition, greater ambition is needed to achieve the Paris Agreement's temperature goals (Climate Action Tracker 2022; Global Energy Monitor 2021; Jong 2021; Xinhua 2021).

OBJECTIVES

This report provides economic analysis to support the High-level Policy Commission of the Asia Society Policy Institute (ASPI) in providing guidance and advice to countries in Asia on the region's net zero transition. The analysis also considers the potential synergies and/or trade-offs between decarbonization and development goals.

This report focuses on the Asia-Pacific economy as a whole, providing a pan-regional context to complement two detailed country studies on India and Indonesia. The commission will expand this analysis to other areas of Asia and their relevant characteristics in future research.

The current analysis focuses on a group of Asian economies (henceforth the Asia-Pacific),[5] including India, Indonesia, China, Japan, South Korea, Malaysia, Taiwan, Brunei, Cambodia, Laos, Myanmar, Philippines, Singapore, Vietnam, Thailand,[6] Australia, and New Zealand.

REPORT STRUCTURE

The rest of the report consists of three chapters describing the approach and findings, supplemented by technical appendices.

Chapter 2 describes the approach of the analysis, including the narratives of the modelled scenarios.

Chapter 3 shows the findings of the modelling for the baseline of enacted policies and one of the scenarios where all current commitments are also met. It intends to provide a comparative framework for more ambitious decarbonization scenarios that will be discussed in the forthcoming extended report.

Chapter 4 concludes by describing the socioeconomic and climate impacts of those results and analyzing the policy implications that follow to answer the key research questions.

5 Note that the selected countries cover all economies that could reasonably be considered part of the Asia-Pacific region and are represented in the E3ME. We recognize that there are gaps due to the coverage of the E3ME model, which is limited by data availability.

6 Note that Brunei, Cambodia, Laos, Myanmar, Philippines, Singapore, Vietnam, and Thailand are modelled as a country group in this analysis that is referred to as "Rest of ASEAN" economies.

SCENARIO FRAMEWORK

MODELLING FRAMEWORK

The report presents a set of scenarios describing alternative decarbonization pathways for the Asia-Pacific using E3ME, a global macro-econometric model, developed and maintained by Cambridge Econometrics. ASPI and local experts with strong country-specific knowledge were involved in designing the scenarios and reviewing the results to ensure their robustness and relevance.

E3ME is a simulation-based model that contains many policy instruments including taxes, subsidies, regulations, energy efficiency, and support for new technologies. The model solves annually and has detailed sectoral coverage including bottom-up technologies in key sectors (power, road transport, steelmaking, and heating). It shows where each alternative pathway will get to in terms of economic growth, jobs, emissions, and other key indicators. More details can be found in the technical appendices accompanying this report.

The modelling covers the period 2023–2060, the end of which is determined by the model setup (the model does not extend beyond 2060). The results outline impacts across this time frame, acknowledging that additional impacts will take place beyond this point that are not included. Where there are targets for specific years before 2060, results for these years are also presented.

SCENARIO NARRATIVES

The scenarios were designed to provide answers for the following key research questions:

- **Identify impacts and benefits** — What would be the short- and long-term economic, social, and climate impacts of different levels of decarbonization effort/ambition?
- **Accelerate ambition** — How strong do current policies and commitments need to be to deliver net zero targets? How must this ambition level shift if the date of the net zero target is brought forward to align with a 1.5°C pathway?
- **Support implementation** — Which policies should be prioritized to further accelerate climate action without significantly compromising economic and social outcomes? Which policy package is expected to deliver the most economic, social, and climate benefits? What are the associated policy costs? What are potential barriers or trade-offs (and how can they be addressed)?

Therefore, the key narratives explored as part of this study include the following:

- **Pre-COP26 policies *(baseline)*:** This scenario is our reference case for the Asia-Pacific to benchmark other scenarios against. It represents the least ambitious pathway, taking into account impacts of policies implemented before COP26 with no additional policies thereafter.
- **Baseline + 2030 targets *(2030 targets)*:** This scenario represents a pathway in which countries' 2030 commitments announced up until January 2022[7] are met but no new policies are

7 Since the analysis started new policy and political developments have taken place that are acknowledged in the report but not included in the modelling — in particular, Australia's updated NDC with more ambitious 2030 targets.

implemented thereafter. This scenario treats short-term pledges to 2030 as credible and enforced, but it does not assume an increase in ambition beyond those policies.[8]

- **All COP26 commitments:** This scenario represents a pathway beyond the 2030 commitments that includes additional policies to deliver countries' announced net zero and other commitments made up through COP26.
- **Accelerated coal phaseout:** This scenario represents a pathway in which the Asia-Pacific not only meets its current targets but in which there is an additional effort to phase out unabated coal power generation from the economy by 2040, more rapidly than current policies imply and in line with calls from the scientific community (UNFCCC 2022a).
- **2050 net zero:** In this scenario, the climate action of the Asia-Pacific economies is increased well beyond committed targets to reach net zero emissions by 2050. The rest of the world along with other Asian economies are assumed to act in line with a 1.5°C global pathway.

In all scenarios, it is assumed that governments are responsible for financing investment in energy efficiency measures, financial support for low-carbon technologies, and compensation to power companies for stranded assets caused by coal regulations. It is also assumed that any carbon revenues received by governments will be specifically earmarked for these transition-related policy costs. The evolution of different technologies is determined within the model, based on historical cost and market shares data and subject to technical potential constraints (particularly for relatively new solutions such as carbon capture and storage and green hydrogen).

Announced targets and commitments taken into account are provided in Appendix B and detailed policy assumptions are described in Appendix C. Extended narratives can be found in the technical appendices.

STRENGTHS AND LIMITATIONS

Following are E3ME's key strengths for supporting this analysis:

- The close integration of the economy, energy systems, and the environment, with two-way linkages between each component
- The econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to Computable General Equilibrium (CGE) models
- The econometric specification of the model, making it suitable for short- and medium-term assessment, as well as longer-term trends
- A high level of disaggregation, enabling detailed analysis of sectoral effects across a wide range of scenarios; the model captures individual country dynamics as well as interactions with other regions of the global economy
- The availability of a wide range of climate policy options including regulations, taxes, tariffs, and subsidies, especially for the largest emitters in the economy (power, steel, road transport,

8 Note that announcements that are not made into policies are only included in the *All COP26 commitments* scenario and *2050 net zero* scenario. Policy updates announced after December 2021 are not included.

- and residential buildings), which also feature a detailed representation of technology diffusion
- The shift of focus away from determining a least-cost policy implementation toward potential trade-offs and opportunities arising from decarbonization

However, this analysis has a number of limitations:

>> The modelled scenarios incorporate only information available in the public domain up until December 2021. Recent major events including the Ukraine war, fossil fuel price spikes, and high rates of inflation are not included, but all are likely to impact the results to some extent. In particular, our own previous research (Cambridge Econometrics 2022) suggests that high prices and fossil fuel supply disruptions as a result of the war would encourage more investment in low-carbon alternatives; however, it still leads to long-term economic scarring (in terms of GDP and household consumption) in some of the largest economic blocs. As these effects spread to the rest of the world through supply chain impacts, the Asia-Pacific would also see greater incentives to adopt a more rapid transition (including economic benefits from investment, improved energy security, and avoided climate and policy costs of delayed action), while facing new challenges in managing the social impacts on local communities.

>> As with any modelling tool, E3ME is an imperfect representation of reality, constrained by data availability and quality. Both gaps in the data (particularly for developing countries) and inability to predict the future contribute to uncertainty in the model results. Given the diverse characteristics of the economy and energy systems, it is not technically possible to account precisely for every available energy source and technology in each sector. Macroeconomic models like E3ME often involve a balancing act between breadth and depth, requiring simplified assumptions. For example, the model does not fully capture detailed power grid balancing requirements (which can only be accounted for using real-time hourly data) but rather accounts for seasonal variations. Grid stability and the implied demand for backup generation and storage during downtimes are incorporated to determine the technology mix. In addition, assumptions about technological constraints (based on literature and announcements) are applied to ensure a realistic level of uptake of different technologies.

>> The analysis focuses on evaluating the socioeconomic impacts of increased climate action with some consideration for costs, savings, and trade-offs. It does not quantify avoided climate-related physical damages (the cost of inaction) and co-benefits (from improved environmental outcomes), both of which would add more incentives to accelerate the low-carbon transition.

>> The modelling considers costs of policies aimed specifically at encouraging take-up of low-carbon technology options and assumes they are financed domestically by a combination of carbon revenues and other taxation. It does not quantify the costs of other policies to manage the transition (such as social and labor market interventions) and the role of alternative financing mechanisms (such as international support), which do not have a significant impact on emissions but do influence socioeconomic outcomes. The impact of these policies depends directly on their implementation and can be better explored in follow-up analysis.

FINDINGS

IMPACTS OF IDENTIFIED PATHWAYS

Emissions and Emission Intensity

In the *baseline* scenario, the Asia-Pacific region[9] is projected to experience strong GDP growth of above 4.2 percent per annum (pa) over 2020–2040. Rapid economic growth is supported by household consumption, investment, and exports, while employment grows modestly in line with population.

Emissions are projected to continue to increase in the Asia-Pacific, although the rate of growth will slow through the 2030s and 2040s. The power sector drives the pattern of overall emissions where fossil fuels continue to make up a high share of the capacity mix, especially in China and India. Most countries have growing or constant emissions in the modelled period. Therefore, the NDCs of Asia-Pacific economies, apart from India's NDCs, that are on track to be overachieved by current policies but have not been updated since 2015 (Climate Action Tracker 2022) are not met in this scenario as countries lack the required policies to achieve them.

In the *2030 targets* and *All COP26 commitments* scenarios, policies are added where they would have the most impact to ensure that NDC and other targets are met. The 2030 targets with the greatest impact on the Asia-Pacific's emissions pathway are China's emissions peaking before 2030, and India reaching cumulative emissions reductions of 1bn tonnes this decade and reducing the carbon intensity of GDP carbon by 45 percent by 2030 compared to 2005 levels.[10] The policy packages modelled lead to CO_2 emissions declining rapidly between now and 2030, and continuing to fall thereafter at a slightly slower pace. In the *All COP26 commitments* scenario, the Asia-Pacific's CO_2 emissions reach net zero by 2056, with ambitious commitments and a large LULUCF impact as the main contributors.

Table 3.1 shows the energy and technology shares for aggregate sectors in 2060, in the *All COP26 commitments* and the *baseline* scenarios. A noticeable share of fossil fuel use remains in the industry and transport sectors, despite other sectors being largely decarbonized. For net zero emissions to be achieved by 2056 in the Asia Pacific, there must be a greater role for carbon sequestration (from forests as well as carbon capture and storage solutions, particularly in the power generation and industry sectors) to offset remaining emissions from fossil fuel use.

9 Asia-Pacific in this modelling includes India, Indonesia, China, Japan, South Korea, Malaysia, Taiwan, Australia, New Zealand, Brunei*, Cambodia*, Laos*, Myanmar*, Philippines*, Singapore*, Vietnam*, Thailand*. Countries marked with an asterisks are modelled as part of the "Rest of ASEAN" regional aggregate.

10 Although India has not submitted an updated NDC, these 2030 targets were announced by the prime minister and therefore are considered to be equivalent to official submissions.

TABLE 3.1: ENERGY AND TECHNOLOGY SHARES FOR AGGREGATE SECTORS IN 2060

		ELECTRICITY	FOSSIL FUELS (COAL, OIL & GAS) INCLUDING CCS APPLICATIONS	BIOMASS	NON-BIO-MASS RENEWABLES	OTHER FUELS (HYDROGEN, WASTE, & HEAT)
Baseline	**Energy production**	-	38%	2%	46%	14%
	Industry	26%	69%	3%	-	-
	Transport	19%	79%	2%	-	-
	Buildings	70%	19%	10%	-	-
All COP26 commitments	**Energy production**	-	2%	3%	85%	11%
	Industry	52%	38%	6%	-	-
	Transport	45%	23%	30%	-	-
	Buildings	85%	6%	8%	-	-

Source: Cambridge Econometrics, E3ME modelling result.

In the *All COP26 commitments* scenario, electricity demand is around 20 percent higher than in the baseline by 2060 due to the electrification of the economy, and 98 percent of all electricity generation is from nonfossil fuel sources (compared to 64 percent in the baseline). This high share of nonfossil fuels in the power mix is supported by short-term battery storage and long-term hydrogen storage, the cost of which is reflected in the cost of generation and electricity prices. However, additional investments to develop storage, grid integration, and management technologies are not included. The power generation mix is dominated by solar, replacing unabated coal generation. The disappearance of the use of fossil fuels from power generation is the key driver behind lowering emissions, brought about primarily by incentives for renewables and coal phase-down regulations.

In transport, by 2060 most passenger vehicles are electric (driven by electric vehicle subsidies and petrol/diesel regulation), whereas rail transport is significantly electrified and a share of fuel demand for road freight and air and marine transport is replaced by alternative fuels such as hydrogen and biofuels.

On the other hand, industry, agriculture, and buildings decarbonize more slowly. There is a shift away from fossil fuels to electricity and biofuels in agriculture, and electricity becomes the dominant form of energy used in industries and buildings. Biofuel mandates and carbon pricing are key policy drivers in these sectors, with energy efficiency programs also facilitating the transition in the buildings sector. Industry sectors are particularly difficult to decarbonize because low-carbon technology alternatives are not as widely deployed as in other sectors and are less cost competitive than conventional fossil fuel–based methods. As a result, carbon capture technologies play a visible role in decarbonizing industrial emissions.

Macroeconomic Indicators

GDP expenditure components

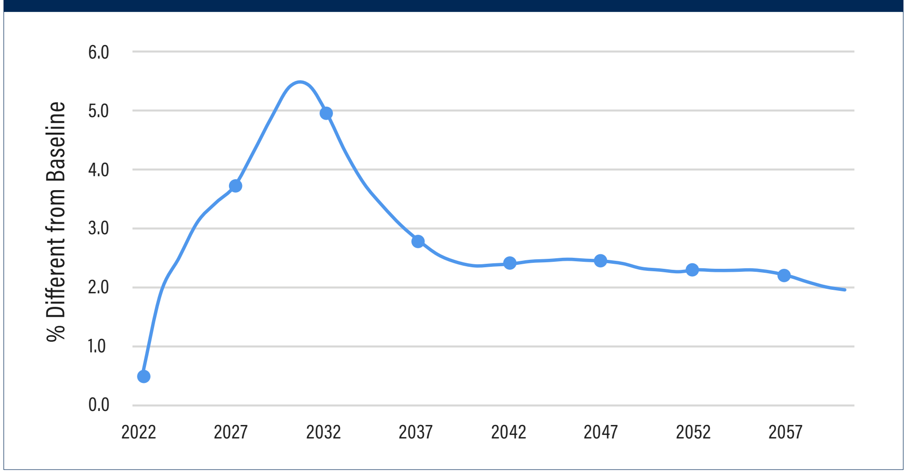
In the *All COP26 commitments* scenario, decarbonization has a positive impact on both GDP and employment.

GDP is projected to be 5.4 percent higher than baseline in the *All COP26 commitments* scenario at its peak in 2030–2031 before settling at around 2.0 percent above baseline from around 2050 onward (see Figure 3.1).

The GDP impacts are driven mainly by higher levels of investment in the power sector, energy efficiency, and carbon sinks. In the power sector in particular, the assumption is that large amounts of investment will be frontloaded to facilitate the construction of critical infrastructure in time to achieve the 2030 targets. Given the assumption that many new implementing policies are introduced in 2023 to achieve 2030 targets, the modelling suggests that the majority of additional investment is expected in the years between now and 2030. The profile of positive GDP impacts follows that of investment requirements (relative to GDP) over time. Cumulative investment requirements for meeting announced net zero targets are estimated at $53.5trn from now until 2060,[11] with most investment in China and India. The peak of low-carbon investment is expected around 2031 (reflecting different peak years across different countries), when investment is 14.1 percent higher than in the *baseline* scenario. This investment requirement excludes investment in grid management systems, charging infrastructure and production capacity for new energy sources, which would increase the short-term stimulus but likely lead to higher long-term costs.

Reduced dependence on imported fossil fuels as part of the transition leads to a long-term improvement in the Asia-Pacific's trade balance with the rest of the world, estimated at $533bn by 2060 (equating to just under a third of the total GDP impact). This gain mostly comes from a reduction in fossil fuel imports. Imports of manufactured fuels, oil and gas, and coal are 71 percent, 58 percent, and 27 percent, respectively, below the baseline levels in 2060. Improved energy security through lower import dependence helps maintain a reliable and affordable supply to the domestic population, especially households at risk of financial and fuel poverty.

FIGURE 3.1: GDP IMPACTS (RELATIVE DIFFERENCES FROM BASELINE) IN THE ASIA PACIFIC IN THE *ALL COP26 COMMITMENTS* SCENARIO



Source(s): Cambridge Econometrics, E3ME modelling result.

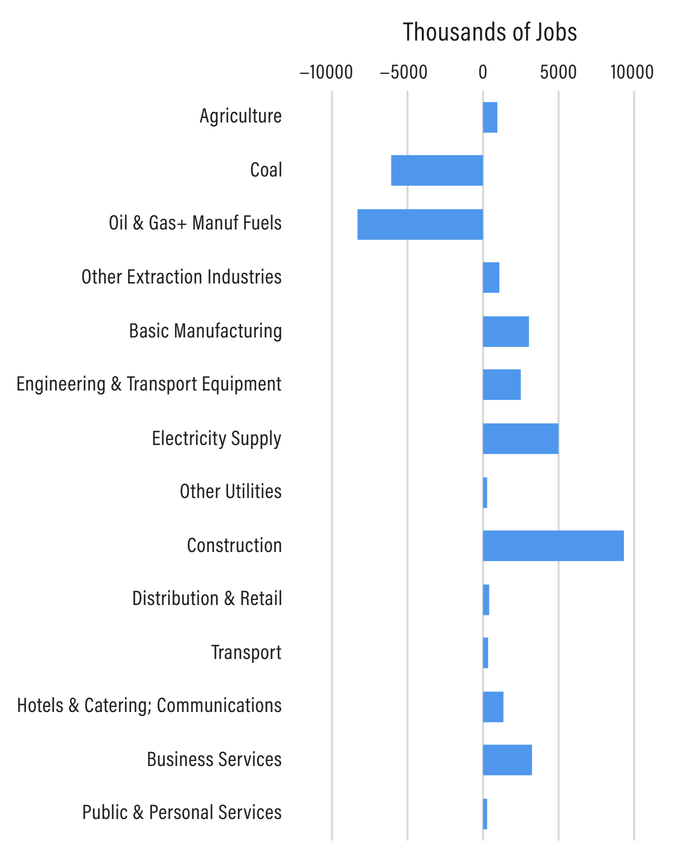
11 The modelled period ends in 2060, beyond which point further investment will be required to fully achieve net zero targets that have been set at a later date (e.g. 2070 for India).

Employment impacts by sector

Employment is estimated to be 1.5 percent higher than baseline in 2031 (when the impact peaks), and 0.7 percent higher than baseline in 2060. The sharp peak is consistent with the investment and GDP impacts that lead to substantial increases in demand for labor to support the construction of critical infrastructure needed to deliver 2030 targets. It is also driven by Chinese labor market patterns, in particular that the use of fossil fuels (coal especially) in power generation is phased out quickly due to greater incentives for renewables (which are on average more labor intensive per unit of electricity produced). The 2060 impact is relatively small in percentage terms but is equivalent to 34 million additional jobs in the Asia-Pacific's economy. The employment impacts are smaller in percentage terms than the GDP impacts, due to improved efficiency and associated average wage gains linked to additional investments.

Figure 3.2 shows the sectoral breakdown of the employment impacts in 2060. Job losses occur in fossil fuel supply sectors (coal and oil and gas) due to the transition to renewables. All other sectors, however, show new job opportunities. Most notable are substantial gains in sectors that form the supply chains of the technology transition, including construction (responsible for infrastructure developments), other extraction industries (suppliers of minerals), and manufacturing sectors (suppliers of machinery, equipment, and manufactured materials).

FIGURE 3.2: EMPLOYMENT IMPACT IN THE ASIA-PACIFIC IN THE *ALL COP26 COMMITMENTS* SCENARIO, 2060



Source(s): Cambridge Econometrics, E3ME modelling result.

Employment also increases in the electricity supply sector, for a number of reasons: (1) the demand for electricity is greater; (2) renewable energy generation technologies are more labor intensive per unit of capacity than conventional generation; and (3) the load factor of renewables is (mostly) lower than conventional generation, so the labor intensity per unit of generation increases more than per unit of capacity. Services sectors also benefit from increased investment, as they form the critical supply chain to the sectors that benefit directly.

Country-Level Impacts

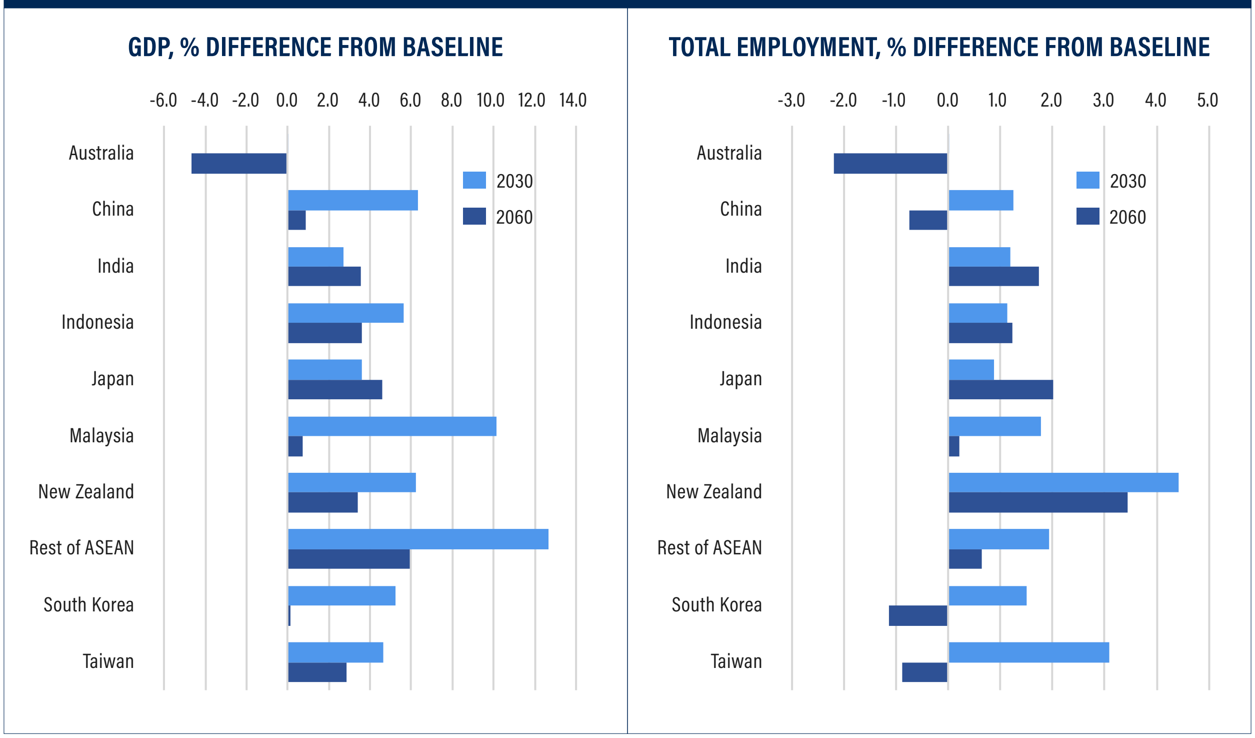
The regional results, described above, are unpacked at the country level in Figure 3.3. The countries can be grouped as follows:

- *Indonesia, Malaysia, Rest of ASEAN, Taiwan, India, and South Korea* all experience relatively strong and positive short-term GDP and employment impacts and milder long-term impacts. These countries are similar to the Asia-Pacific aggregate. Investments in energy efficiency and renewables are initially at high levels (as a result of coal phase down and phaseout). However, consumers bear the cost in the long run because carbon revenues are lower than the costs of policy implementation. In the case of South Korea and Taiwan, the impact of inflation on consumers (due to carbon pricing and investment cost pass-through) is more sustained, leading to slightly negative employment impacts by 2060.
- *China* sees similar impacts on GDP as the countries just discussed, but its overall job losses in the long term are driven by the decline of fossil fuel extraction industries, which is primarily influenced by reduced domestic demand. These losses outweigh the benefit to manufacturing industries (from increased domestic and international demand for machinery, equipment, and vehicles to support the construction of low-carbon infrastructure). Under a more rapid transition in which other countries raise their targets significantly, the gains may exceed the losses, given China's prominent role in global low-carbon value chains.
- *New Zealand and Japan* have sustained positive GDP and employment impacts over the period to 2060. The long-term employment impacts, relative to the size of their workforces, are the largest in the region. Along with the initial investment, an improved trade balance (due to a reduction in fossil fuel imports) and low costs to households help maintain the positive impact in the long term. In both countries and in particular in New Zealand, job gains are strong in business services (including rental and leasing, employment services, and travel agencies and administrative services) that support households and most other sectors, as a result of consumers' increased real incomes. New Zealand currently has the lowest share of fossil fuels in its energy system among all countries in the Asia-Pacific, while the energy sector in Japan is relatively small, so positive impacts from renewables energy supply dominate over job losses in the existing fossil fuel sectors.
- *Australia* is the only country that experiences a negative long-term impact on both GDP and employment, following a limited short-term stimulus. Losing fossil fuel exports and low levels of potential carbon revenues (due to its carbon intensity of GDP already being lower than the Asia-Pacific average), the country is likely to require higher taxes to fund the transition, which lowers real household incomes and consumption. The modelling does not assume the creation of a large-scale, low-carbon industry to replace the existing fossil

fuel supply (implying that demand is met by current domestic capacity and an increase in imports). If this potential were realized, the negative impacts would be alleviated.

The aggregate Asia-Pacific GDP impacts are driven by the largest economies in the region: China, India, and Japan. These countries share the substantial positive short-run stimulus and have sustained positive impacts in the long run, which shows up in the aggregate Asia-Pacific results. Excluding Australia and New Zealand improves the positive regional GDP impact slightly because of the negative impact in Australia, whereas the regional employment impact is reduced slightly, albeit still positive, because New Zealand has the strongest relative increase in employment among all Asia-Pacific countries.

FIGURE 3.3: COUNTRY-LEVEL IMPACTS IN THE *ALL COP26 COMMITMENTS* SCENARIO



Source(s): Cambridge Econometrics, E3ME modelling result.

Social Impacts

The impact on households of increasing climate ambition is twofold:

- A higher level of aggregate employment in the *All COP26 commitments* scenario relative to baseline results in a higher level of income from employment for households.
- In all scenarios, decarbonization is assumed to be financed by private investments or domestic government revenues, as preferred to via government borrowing or international financial support. On the one hand, privately funded investments and higher industry costs

> due to carbon pricing are passed on to consumers in the form of higher product prices, which reduces purchasing power. On the other hand, investments and policy costs funded by governments that are not covered by carbon and ETS revenues are assumed to be funded via additional taxes, directly increasing the tax burden on households and reducing disposable income.

The impacts of both lower purchasing power and higher tax burden outweigh the positive impact on nominal income described above. As a result, there is a net negative impact on household income and consumption, implying that consumers directly bear some of the cost burden of the transition. In addition to the impact of carbon pricing (which affects the price of non-energy consumption items indirectly and fossil fuel use by households directly), households also face a higher electricity price. This increase is due to the cost of power sector investment and renewable electricity generation, which would require market reforms and price caps to protect low-income groups from fuel poverty.

This reduction in household consumption is equivalent to $700bn (about 1.6 percent below baseline) in 2060 and lowers demand for all consumer goods (although GDP impacts remain positive due to large and positive contributions from investment and net trade). The consumption loss in percentage terms is largest in Australia, Korea, and Taiwan, at 6 percent–11 percent below baseline, so excluding Australia and New Zealand from the regional aggregate reduces the consumption effect to 1.3 percent below baseline.

If the modelling assumed that the Asia-Pacific's decarbonization investment were instead funded by international support, domestic consumption impacts would be less negative (mitigating the risk of pushing vulnerable households into poverty) and overall macroeconomic impacts would be boosted further.

DELIVERING SHORT-TERM TARGETS

The Asia-Pacific economies analyzed in this report have set out targets for emissions reductions and renewable energy supply by 2030 in their NDCs and additional pledges before or at COP26. Acknowledging that the Asia-Pacific does not have targets as a region, Table 3.2 shows the regional overview for key indicators typically included as country-level targets in the *baseline* and the *All COP26 commitments* scenarios. The main result to highlight is the high share of nonfossil fuel capacity, double the share in 2022 and more than 60 percent higher than that in the baseline, which makes the most contribution to emissisons reductions by 2030. This is driven by a reduced role for coal accompanied by a rapid uptake of solar in China in particular and followed by similar trends in other countries.

Although achieving All COP26 commitments (including NDC targets) represents a major step-up in climate action in the Asia-Pacific and comes with noticeable environmental and economic benefits (as discussed earlier in this chapter), this action will still not be enough to limit temperature rise to 1.5°C. The *Accelerated coal phaseout* and *2050 net zero* scenarios are designed to illustrate ways in which the region can further its actions to better align with this vision. The results of these scenarios will be discussed as part of the extended report.

TABLE 3.2: THE ASIA-PACIFIC'S DELIVERY OF CURRENT 2030 TARGETS

THE ASIA-PACIFIC, 2030	BASELINE	ALL COP26 COMMITMENTS
CO_2 emissions reduction by 2030 compared to baseline	-	–51%
Change in CO_2 emissions by 2030 compared to 2010 levels	56%	–21%
Reduction in carbon intensity of production by 2030 compared to baseline	-	–55%
Reduction in carbon intensity of production by 2030 compared to 2022 levels	–19%	–61%
Nonfossil share in power capacity by 2030	50%	81%
EV fleet share in road transport by 2030	20%	46%
Net zero year	-	2056

Source(s): Cambridge Econometrics, E3ME modelling result.

POLICY COSTS, SAVINGS, AND WIDER BENEFITS

Policy Costs and Savings

It is evident from the modelling results that more ambitious decarbonization goals are beneficial to the Asia-Pacific economy in terms of GDP and employment. However, costs and savings from ambitious policies underlie those macro-level benefits.

Costs

The decarbonization investment requirements (which include capital investment but exclude operating expenses) discussed in section 3.1 reflect costs of decarbonizing to the whole economy.

In addition, governments directly incur costs of policy implementation that significantly affect the macroeconomic results. "Net policy costs" are defined as the difference between governments' revenues from policies (carbon pricing and fuel duties) and costs of policy implementation (consisting of subsidies for renewables and low-carbon technologies, investments in energy efficiency, and compensation to investors for stranded assets due to coal regulation in the power sector[12]). Positive net policy costs indicate an increase in government deficits that is passed on to households in the form of higher taxes (this effect is responsible for the lower household consumption described in section 3.1), and vice versa.

Net costs are volatile over time, reflecting sector readiness and evolving climate goals. In particular, spikes in net costs through the projected period correspond to government compensation to investors for early closures of coal power plants due to regulations. This makes the combination of accelerated coal phase down in the medium term and complete phaseout of unabated capacity in the long term an effective yet costly policy.

12 It excludes the cost of retraining, relocating, and redundancy compensation for workers of retired coal power plants.

Delivering COP26 commitments would cost Asia-Pacific governments around $1.4trn by 2060. The main costs are renewable subsidies and stranded asset compensation in the short to medium term and energy efficiency investments in the long term. These are areas where international support would be most constructive, although carbon pricing also plays an important role in lowering costs in the medium term when emissions levels are relatively high.

Savings

Despite the cost of capital investment to adapt to low-carbon technologies, a reduction in energy demand by households results from energy efficiency improvements and technological transformations. The *All COP26 commitments* scenario includes savings of almost 40 percent on household energy costs by 2050, and just under 30 percent by 2060 due to rebound effects and continued economic growth (equivalent to an absolute reduction of around $200bn across the Asia-Pacific region). This reduction coincides with lower demand for energy imports that helps protect the domestic energy supply from external fossil fuel price volatility, therefore ensuring the population has reliable and affordable access to clean domestic energy.

In contrast, the economy-wide energy spending increases with a higher level of decarbonization ambition, relative to baseline. The reason is that industries (where many of the region's countries currently have a comparative advantage) are likely limited to fewer and more costly decarbonization options than households because of the structure of their manufacturing plants and processes. For example, the cost of green hydrogen is higher than that of fossil fuels and hydrogen produced from fossil fuels and CCS due to high costs of electrolysers, whereas biofuels have a lower energy efficiency than petroleum-based products, meaning more biofuel is needed to produce the same output.

Wider Benefits

In addition to macroeconomic benefits, there are also wider benefits from climate actions (or costs of no action) that are not quantified as part of this modelling exercise but are noteworthy.

The Asia-Pacific region includes the biggest country emitters in the world. Therefore, its progress toward carbon neutrality also contributes to the global climate challenge. Table 3.3 shows the estimated global temperature change[13] by 2100 associated with the *baseline* and *All COP26 commitments* scenarios, assuming that the Asia-Pacific's climate action is matched by similar levels of ambition in the rest of the world. The main drivers of the notable reduction in temperature increase are the short-term and net zero commitments made by China and India, two of the world's largest emitters. However, the current levels of ambition are likely to fall short of the 1.5°C target, suggesting a need for more ambitious targets and policies in the region.

13 These estimates are based on cumulative emissions results from E3ME and an average warming coefficient of 1.84°C/TtC, based on Millar and Friedlingstein (2018).

TABLE 3.3: ESTIMATED GLOBAL TEMPERATURE CHANGE ACROSS SCENARIOS

SCENARIO	GLOBAL TEMPERATURE CHANGE BY 2100
Baseline	Above 3°C
All COP26 commitments	1.6°C –1.7°C

Source(s): Cambridge Econometrics, E3ME modelling result.

Delayed or inadequate climate action risks additional damage to economic growth, due to disruptions from global warming, causing extreme weather events and lost productivity and livelihoods. These physical risks are widely discussed in the literature, where application of Integrated Assessment Models (IAMs) and econometric analysis have previously been used to estimate the impact of climate change on future economic growth.

The literature contains a wide range of estimated GDP impacts associated with future temperature and climatic change. For example, Burke et al. (2019), using econometric analysis on national-level data, estimate that a 3°C temperature increase (in line with the *baseline* scenario) would reduce global GDP by 25 percent, whereas a 1.5°C pathway would lead to an 11 percent reduction in global GDP by 2100 (both compared to a global economy absent any climate change). The Asia-Pacific would bear a share of these damages.

Although not quantified as part of this study, additional co-benefits, such as better air quality, other health benefits, and improved biodiversity, are likely to result from enhanced climate protection and benefit the Asia-Pacific's population significantly.

CONCLUSIONS

SOCIOECONOMIC AND CLIMATE IMPACTS

Decarbonization of the Asia-Pacific region is key for avoiding devastating climate damages and can bring substantially higher economic growth.

The modelling shows that increasing climate ambition and action generates substantial macroeconomic benefits in GDP and employment terms for Asia-Pacific economies. This growth is driven by high levels of investment, particularly in the power sector, as well as energy efficiency and carbon sink investments. In addition, the net trade balance improves in the long term due to lower demand for imported fossil fuels.

However, households and their consumption levels could be negatively affected as a result of increased taxes and prices, indirectly bearing some of the costs of the transition. Despite an overall positive impact on employment, there is the potential for a significant number of job losses in fossil fuel supply industries as a result of the low-carbon transition, which presents a distributional and social challenge for local communities.

Current policies and COP26 commitments enacted in the Asia-Pacific region are insufficient to meet obligations under the Paris Agreement and could contribute to 3°C of global warming. Delivering on NDCs and 2030 targets can limit warming to less than 2°C and lead to net zero emissions for the region in the second half of the century. A lower degree of warming helps reduce climate-related disasters and damages, which in the absence of decarbonization will be devastating for vulnerable populations of the region.

POLICY IMPLICATIONS

The Asia-Pacific's tremendous growth potential but lower than global average per capita income means that aligning decarbonization targets with development goals should be a strong policy priority. The modelling shows that additional and more ambitious policies would allow the region to stay on course for limiting climate change impacts and reaping additional economic benefits in the process. However, strong trade-offs lie behind the aggregate impacts.

To deliver a just transition for vulnerable groups, policies aimed at protecting social welfare and international support for emerging Asian economies analyzed in the report are needed to complement and fund climate policies. While recycling carbon revenues or leveraging other tax-raising mechanisms play an important role as potential funding mechanisms for green investments, international support specifically aimed at assisting the low-carbon transition will free up domestic finance in low-income countries for development, poverty reduction, and management of social impacts. Policies to support reskilling and upskilling of the workforce will also allow workers to take full advantage of new employment opportunities that arise in a low-carbon economy.

ADDITIONAL APPENDICES

APPENDIX A: BIBLIOGRAPHY

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APPENDIX B: ANNOUNCED TARGETS AND COMMITMENTS

Table B.1 shows the key targets included in countries' official NDCs. These targets generally take the form of either a level of emissions reductions or an emissions intensity target. Some countries have included additional sectoral targets such as for increasing the usage of renewable energy sources and/or decreasing the usage of fossil fuels, mainly coal. These targets vary substantially in their level of ambition and in the detail of supporting policies for implementation.

Some countries have made additional pledges beyond those explicitly included in their official NDCs. For instance, China has announced that it will "strictly control coal-fired power generation projects and limit the increase in coal consumption" over the 14th Five-Year Plan period (2021–2025) and will phase it down over the 15th Five-Year Plan period (2026–2030) (Xinhua 2021). Indonesia is another example where the state-owned electricity utility, PLN, has announced that it would not build coal-fired power plants after 2023. However, both announcements allow the increase of coal capacity through already commissioned plants and non-state-funded investments (Global Energy Monitor 2021; Jong 2021).

Table B.1 shows that most Asian economies analyzed in the report have announced net zero targets either in long-term strategy documents submitted to the UNFCCC or in government announcements. These commitments vary in their coverage of emissions (i.e., all greenhouse gases or only CO_2), and their target years typically range from 2050 to 2070. Some countries also have more ambitious targets conditional on international support. Our scenarios capturing current commitments treat all of the above targets as credible; however, we recognize the substantial uncertainty in how these commitments will be realized.

TABLE B.1: KEY SHORT- AND LONG-TERM TARGETS IN THE ASIA-PACIFIC

	NDC & LTS UPDATE	KEY SHORT-TERM GOALS (2030)	NET ZERO TARGETS
Australia	2021	Investing in green technologies	Net zero, including LULUCF by 2050 (GHG)
		43% GHG emissions reduction as compared to 2005	
China	2021	Peaking CO_2 emissions before 2030	Net zero before 2060 (emissions scope not specified)
		Share of nonfossil fuels to ~25%	
		Increase forest stock	
India	2016	Reduce carbon intensity of GDP by more than 45% by 2030	Aiming for net zero by 2070 (emissions scope not specified)
		Reduce emissions by 1 bn tonnes	
		50% of energy requirement from RES	
Indonesia	2021	31.89% reduction in emissions (43.20% with international aid)	Exploring net zero by 2060 (emissions scope not specified)

TABLE B.1: KEY SHORT- AND LONG-TERM TARGETS IN THE ASIA-PACIFIC

Japan	2021	Reduce GHG emissions by 46% below 2013 levels	Net zero by 2050 (GHG)
		36%–38% of total power generation from renewables	
Korea	2021 & 2020	40% GHG emissions reduction as compared to 2018	Net zero by 2050 (GHG)
Malaysia*	2021	45% GHG intensity reduction as compared to 2005	Net zero by 2050 (GHG)
New Zealand	2021	50% GHG emissions reduction as compared to 2005	Net zero by 2050 (GHG)
		Coal phaseout	
Taiwan	-	50% GHG emissions reduction as compared to 2005	Net zero by 2050 (GHG)
Brunei**	2021	20% of GHG reduction to a pre-COP26 policies baseline by 2030	No net zero target
Cambodia**	2020	27% GHG emissions as compared to 2010 (with international support)	Carbon neutral by 2050 (GHG)
Laos**	2021	60% GHG emissions reduction to a pre-COP26 policies baseline scenario.	Conditional net zero by 2050 (GHG)
Myanmar**	2021	144 $MtCO_2e$ emissions reduction as compared to a pre-COP26 policies baseline scenario (297 $MtCO_2e$ with international support)	No net zero target
Philippines**	2021	75% reduction of GHG emissions as compared to a pre-COP26 policies baseline scenario, of which 72% is conditional on international support	No net zero target
Singapore**	2020	Peak emissions in 2030 to reach 65 $MtCO_2e$	Aiming toward net zero emissions "as soon as viable"
Vietnam*/**	2020	9% reduction of CO_2 emissions to a pre-COP26 policies baseline scenario, 903 $MtCO_2e$/year in absolute emissions	Net zero by 2050 (CO_2)
Thailand*/**	2020	20% reduction of GHG emissions to a pre-COP26 policies baseline scenario, 25% with international support	Net zero by 2065 (2050 with international support) (GHG)

Note(s): Taiwan cannot sign onto the UNFCCC so it has not submitted a formal NDC, but it has announced an Intended Nationally Determined Contribution.
* The asterisk indicates that the net zero targets are not in LTS documents but have been announced by the prime minister or ministries.
** These countries are all represented as a part of a "Rest of ASEAN" region in E3ME. Due to the wide range of variation between countries, the individual country targets cannot be explicitly modelled and instead are consulted to sense-check the "Rest of ASEAN" results, which are based on a Paris-aligned pathway.

Source(s): UN NDC Registry, national LTS documents, climateactiontracker.org.

APPENDIX C: MODELLING ASSUMPTIONS

Policy Assumptions

Table C.1 lists the policy assumptions modelled for all scenarios (including those whose results are not presented in this report).

TABLE C.1: POLICY ASSUMPTIONS

SECTOR	POLICIES	2030 TARGETS	ALL COP26 COMMITMENTS	ACCELERATED COAL PHASEOUT	NET ZERO 2050
Economy wide	Emissions reductions target	NDC targets	NDC and net zero emissions targets	Same as All COP26 commitments	All COP26 commitments or Paris-aligned emissions pathway for others (whichever is more ambitious)
	Carbon pricing	In most energy-intensive sectors	In all sectors and at a higher rate than 2030 targets	Same as All COP26 commitments	At a higher rate than Accelerated coal phaseout
	Revenue recycling to support low-carbon technologies	Yes	Yes	Yes	Yes
	Energy efficiency programs	Yes	Yes	Yes	Yes
Power sector	Coal phaseout	No new policy	Unabated phaseout in most countries: China — by 2060 Korea — by 2050 India — by 2070 Indonesia — by 2056 Japan, Australia, New Zealand, Taiwan, Malaysia, Rest of ASEAN — accelerated phase down	No new coal capacity beyond those under construction and more ambitious time lines for phaseout: OECD (Japan, Australia, New Zealand, Korea) — by 2030 India, Indonesia, and the Asia-Pacific — by 2040	Same as Accelerated coal phaseout
	Subsidies for renewables	Subsidies from 2023, phased out by 2046 China: bio-based technologies — 30%, CCS application — 25% India: hydro and wind — 20% Indonesia: bio-based technologies — 15%, CCS application — 13%, wind — 20% Korea: bio-based technologies — 15%, CCS application — 13%, wind — 10% Others: bio-based technologies — 30%, CCS application — 25%, wind — 20%	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
	Kick-start for CCS power generation	From 2023, for Australia, China, Korea, and Taiwan — CCS variants of power plants will be gradually built via government procurement for 5 years	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets

TABLE C.1: POLICY ASSUMPTIONS					
SECTOR	**POLICIES**	**2030 TARGETS**	**ALL COP26 COMMITMENTS**	**ACCELERATED COAL PHASEOUT**	**NET ZERO 2050**
Industries	Subsidies for EAF steelmaking	From 2023, at 25%, phased out over 2045–2055	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
	Subsidies for CCS steelmaking	From 2023, at 10%, phased out over 2045–2055	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
	Subsidies for hydrogen steelmaking	From 2023, at 50%, phased out over 2045–2055	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
	Kick-start for hydrogen-based steelmaking	From 2023, capacity will be gradually built for at least 5 years to allow the technology to participate in the market	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
Road transport	EV subsidies	From 2023, an additional vehicle subsidy is applied on EV purchases	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
	Fuel duties	From 2023, an increase of up to $0.02/liter compared to baseline is imposed, increasing linearly to $0.18/liter by 2045 and remaining in force thereafter	Same as 2030 targets	Same as 2030 targets	At a higher rate than Accelerated coal phaseout
	Phaseout of sales in combustion engine and ICE	Sales cap from 2023	Sales cap from 2023 and complete phase-out by the net zero target year	Same as All COP26 commitments	Same as All COP26 commitments but in line with a higher level of ambition
Other transport and agriculture	Biofuel mandate	Increasing to 100% by 2050–2060 depending on the level of ambition; mandate applies to remaining petrol and diesel use after accounting for electricity and hydrogen use	Same as 2030 targets	Same as 2030 targets	Increasing to 100% by 2050
Residential	Regulation of fossil fuel–based heating	Sales cap from 2023	Sales cap from 2023 and complete phase-out by the net zero target year	Same as All COP26 commitments	Same as All COP26 commitments but in line with a higher level of ambition
	Subsidies for renewable boilers	From 2023 onward, all renewable boilers receive a 50% subsidy on the upfront investment costs, which is linearly phased out between 2030 and 2050	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets
Land use	Regulation	Regulation is in place to deliver regional carbon sink potentials	Same as 2030 targets	Same as 2030 targets	Same as 2030 targets

LULUCF Assumptions

The LULUCF modelling assumptions are based on various sources including submitted NDCs, detailed assessments of decarbonization targets and efforts by region and country statistics. Table C.3 presents the assumptions along with the sources for each country in the regional aggregate.

TABLE C.3: LULUCF MODELLING ASSUMPTIONS BY COUNTRY

COUNTRY	ASSUMED YEARLY LULUCF SINK BASED ON NDCS AND HISTORICAL VALUES, $MTCO_2E$/YEAR	SOURCES
Japan	−10.61 to −47	Climate Action Tracker (2022)
China	700.0	IEA (2021a)
Korea	26.7	Climate Action Tracker (2022)
India	306.0–486.2 between 2022 and 2050	TERI (2021) and local experts
Indonesia	Reaching to 180, 200 $MtCO_2e$ sink by 2060	Government of Indonesia (Government of Indonesia 2021)
Malaysia	54	NDC (2020)
Taiwan	0.0	n.d.
Australia	5.0	Climate Action Tracker (2022)
New Zealand	10.6	Our World in Data (2022)
Rest of ASEAN	159.5	
Brunei Darussalam	1.2	Our World in Data (2022)
Cambodia	24.5	Our World in Data (2022)
Laos	1.1	National GHG Inventory (2019)
Myanmar	1.0	NDC (2021)
Philippines	9.0	UNFCCC (2000)
Singapore	0.0	Our World in Data (2022)
Vietnam	36.6	Our World in Data (2022)
Thailand	86.0	(Pradhan 2019)

Note(s): For Japan, linear growth of LULUCF is assumed to grow from −10.61 $MtCO_2e$ sinks to −46 $MtCO_2e$ linearly up to 2030, with stabilization at this level.
Source(s): Note that for regions committing to yearly LULUCF sinks in their NDCs, we used that data for the whole modelling period; otherwise, historical LULUCF sink levels have been used. See references in the table. For India and Indonesia, see the country reports.

If available, yearly LULUCF levels are consistent with announced policies and committed targets; otherwise, they reflect the latest historical data. For simplicity, the same LULUCF ambition has been used for all scenarios for each modelled Asian economy, with the exception of India and Indonesia for which assumptions are tailored to the policy ambition in each scenario. We assumed constant LULUCF levels over time for all countries except Japan. For Japan, yearly LULUCF sink levels grow linearly up to 2030 to achieve the targeted level (as data are available for both of those data points).

Note that for India and Indonesia, different ambition levels and growing LULUCF sinks are modelled in the pathways. The country reports provide the full detail on the modelled assumptions of the two regions.

Other Assumptions

In addition to the policy assumptions, the following assumptions were made:

- Changes to policies start in 2023 in all scenarios.
- In the sensitivities, only existing/announced policies are scaled up and down; no new policy is introduced.
- There is no crowding out of existing investment (but there are endogenous constraints for product, finance, and labor markets).
- The analysis excludes climate risks and co-benefits.
- Outside of target countries and regions with explicit targets, similar policies that align with the target country's level of ambition are set up across all regions (e.g., in the net zero 2050 scenarios); all other countries also decarbonize rapidly in line with the Paris Agreement.

APPENDIX D: E3ME DESCRIPTION

Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programs and is now widely used in Europe and beyond for policy assessment and research purposes. A technical model manual of E3ME and more information on the model are available online at www.e3me.com.

Policy decisions that can be informed by the models

E3ME is often used to assess the impacts of climate mitigation policy on the economy and the labor market. The basic model structure links the economy to the energy system to ensure consistency across each area.

Possible policies to assess include the following:

- Carbon and energy taxes
- Emission trading systems
- Environmental tax reforms
- Energy efficiency programs
- Subsidies for particular technologies in the power, transport, and residential sectors

Policy changes that have been influenced by the findings/application of the models include the following:

- Phaseouts of particular fuels and other direct regulation
- Resource efficiency programs

E3ME has been extensively applied for low-carbon analysis around the world, for example, for IRENA, the World Bank, GIZ, ILO, and UN-PAGE and in the 2018 New Climate Economy report.

A summary appraisal of the range of results the model can offer

As a global E3 (energy-environment-economy) model, E3ME can provide comprehensive analysis of policies:

- Direct impacts, for example, reduction in energy demand and emissions, fuel switching. and renewable energy
- Secondary effects, for example, on fuel suppliers, energy price, and competitiveness impacts
- Rebound effects of energy and materials consumption from lower price, spending on energy, or higher economic activities
- Overall macroeconomic impacts on jobs and the economy including income distribution at macro and sectoral levels.

Theoretical Underpinnings

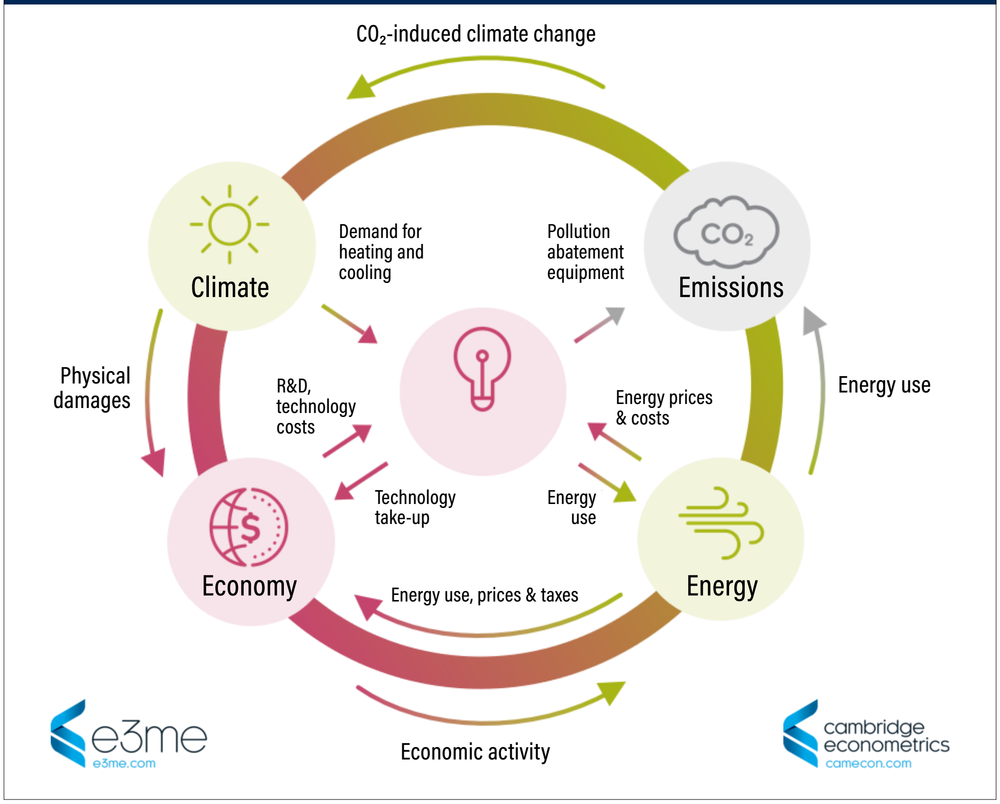
Economic activity undertaken by persons, households, firms, and other groups in society has effects on additional groups (possibly after a time lag), and the effects may persist into future generations. However, there are many actors and the effects, both beneficial and damaging, accumulate in economic and physical stocks.

The effects are transmitted through the environment, through the economy and the price and money system (via the markets for labor and commodities), and through global transport and information networks. The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels, and labor; through wages and prices affecting incomes; and through incomes leading in turn to further demands for goods and services. These interdependencies suggest that an E3 model should be comprehensive and include many linkages between different parts of the economic and energy systems.

Figure 1 provides a schematic of an idealized model. The current version of the model includes only limited treatment of physical damages (which are often instead calculated off-model) and of pollution-abatement equipment (which is specified exogenously by the model user). These issues remain areas for future development.

E3ME is often compared to Computable General Equilibrium (CGE) models. The modelling approaches are similar in many ways: they are used to answer similar questions and use similar inputs and outputs. However, underlying this are important theoretical differences between the modelling approaches.

FIGURE 1: OVERVIEW OF CAMBRIDGE ECONOMETRICS' E3ME MODEL



Source(s): Cambridge Econometrics.

In a typical CGE framework, optimizing behavior is assumed, output is determined by supply-side constraints, and prices adjust fully so that all the available capacity is used. In E3ME, the determination of output comes from a post-Keynesian, demand-driven accounting framework, and it is possible to have spare capacity in the economy. It is not assumed that prices always adjust to market-clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policies may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving toward a long-term trend. The dynamic specification is important when considering short- and medium-term analysis (e.g., up to 2030) and rebound effects, which are included as standard in the model's results.

Basic Structure and Data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labor market is also covered in detail, including both voluntary and involuntary unemployment. In total, there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand, and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970–2019, and the model projects forward annually to 2060. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for data include the UN, OECD, World Bank, IMF, ILO, and national statistical agencies. Gaps in the data are estimated using customized software algorithms.

The main dimensions of E3ME are as follows:

- 70 countries — all G20 and major world economies, the EU27, and candidate countries plus other countries' economies grouped
- 44 (or 70 in Europe) industry sectors, based on standard international classifications
- 28 (or 43 in Europe) categories of household expenditure
- 22 individual users of 12 fuel types
- 14 types of air-borne emissions (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

Key Outputs

As a general model of the economy, based on the full structure of the national accounts, E3ME can produce a broad range of economic indicators. In addition, there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure, and international trade)
- Sectoral output and gross value added (GVA), prices, trade, and competitiveness effects
- International trade by sector, origin, and destination
- Consumer prices and expenditures
- Sectoral employment, unemployment, sectoral wage rates, and labor supply
- Income distribution
- Energy demand, by sector and by fuel, energy prices
- Raw material demand by sector and by material types
- Power generation mix
- Passenger cars and heating technologies
- CO_2 emissions by sector and by fuel
- Other air-borne emissions

This list is by no means exhaustive, and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional levels and annually over the period up to 2060.

Linking E3ME to Bottom-Up Technology Submodules (FTTS)

Since 2012, the power sector in E3ME has been represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure,[14] called FTT:Power (Future Technology Transformations for the Power Sector). This is the first member of the FTT family of technology diffusion models. The current E3ME model version is also linked up to FTT:Transport, FTT: Steel, and FTT:Heat.

Drawing on an evolutionary approach, the FTT models use a decision-making core for investors or households facing several options in their purchasing decisions. The model is based on theories of technology diffusion, with rates of diffusion affected by relative market shares and technology prices. The detailed technology representation allows for a range of policy options.

Many of the policies are characterized by long lag times due to the lifetimes of the technologies that are built. However, the model can show rapid transitions as technologies gain market penetration, reinforced by cost reductions that result from learning rates.

The resulting diffusion of competing technologies is constrained by a global database of renewable and non-renewable resources (Mercure & Salas 2012, 2013).[15]

14 Mercure, J.-F. (2012), "FTT:Power A global model of the power sector with induced technological change and natural resource " Energy Policy, 48, 799–811.

15 Mercure, J.-F., and Salas, P. (2012), "An assessment of global energy resource economic potentials." Energy, 46(1), 322–336; Mercure, J.-F., and Salas, P. (2013), "On the global economic potentials and marginal costs of non-renewable resources and the price of energy commodities," Energy Policy, (63), 469–483.