Asia Pacific's Energy Transition Outlook

Commissioned by

GenZero

October 16, 2024

BloombergNEF

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$88.7 trillion

Energy sector investment and spending in Asia Pacific over 2024 to 2050 in BNEF's Net Zero Scenario

50%

Cumulative emissions abatement from clean power in Asia Pacific by 2050 in the Net Zero Scenario versus a 'no transition' pathway

17.5 terawatts

Wind and solar capacity deployment in Asia Pacific by 2050 in the Net Zero Scenario

Asia Pacific is central to global energy sector decarbonization and the world's transition to net zero. The region saw energy-related emissions grow 151% between 2000 and 2023, driven by strong economic development, population growth and industrialization. However, emissions will need to peak and rapidly reduce if the world is to achieve the goals of the Paris Agreement.

Countries must act immediately to decarbonize along a Paris-aligned emissions trajectory

- **The window to reach net-zero emissions by 2050 is rapidly closing, although immediate and accelerated action could still put Asia Pacific on track.** In BloombergNEF's Net Zero Scenario, global warming is limited to 1.75C by the end of the century, in line with the goals of the Paris Agreement of well below 2C of global warming. Governments need to double down and accelerate decarbonization efforts in the next decade, starting immediately, or risk missing their climate goals.
- **Achieving net zero by 2050 requires India, Indonesia and Vietnam to reach peak emissions 12 to 18 years earlier than under BNEF's Economic Transition Scenario.** These three see the largest decarbonization challenges on a country level. Whether it's an economic-led pathway or a Paris Agreement-aligned transition, energy-related emissions in key Asia Pacific markets[1] peaked in 2023 and are now on a sustained decline out to 2050.

There are actions that countries can, and must, take today

- There is no cookie cutter approach for the decarbonization of Asia Pacific energy systems. Each market's optimal portfolio of decarbonization technologies will be influenced by local policies, access to resources, and geographical constraints. However, there are commonalities. **Today, mature, commercially scalable technologies with proven business models exist.** These include electric vehicles, renewable power, energy storage, and power grids, all of which require a significant acceleration to get on track for net zero, but bear little to no technology risk and economic premiums are generally small or non-existent.
- **Reducing emissions from the region's power sectors need to be of utmost priority and can be implemented immediately** with an accelerated scaling of low-carbon technologies and a swift end to financing of new unabated fossil fuel plants. A low-carbon power system will be the foundation of a net-zero energy sector, comprising 75% of the region's energy consumption by 2050. Clean power alone could abate 50% of Asia Pacific's cumulative emissions between 2024 and 2050. However, some markets may still face regulatory and infrastructure barriers as well as bottlenecks that can impede clean power deployment. Policymakers will need to address these challenges.

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[1] In this report, the key Asia Pacific markets discussed are China, India, Japan, South Korea, Indonesia and Vietnam.

Table 1: Opportunities to accelerate deployment of mature climate solutions

Technology (units)	Economic Transition Scenario, 2050 *(Multiplier versus 2023)*	Net Zero Scenario, 2050 *(Multiplier versus 2023)*	Key challenge to keeping on track for net zero	Possible solutions
Solar (gigawatts)	6,781 *(x6.9)*	11,676 *(x11.8)*	Rapid scaling	• Binding phase-out targets for unabated fossil fuel power plants • Regulatory and market reforms to unlock renewable opportunities • Easing potential grid bottlenecks • Minimizing site acquisition hurdles through land allocation for renewable project development • Clear, long-term procurement programs
Wind (GW)	2,970 *(x5.5)*	5,847 *(x10.9)*	Rapid scaling	
Battery storage capacity (GW)	1,761 *(x48.5)*	2,227 *(x61.3)*	Rapid scaling	• Standalone or hybrid auctions • Power market reforms to allow for participation of batteries in ancillary service, energy, and capacity markets
Passenger electric vehicle fleet (million vehicles)	515 *(x22.2)*	671 *(x28.9)*	Rapid scaling	• Stringent fuel-economy or tailpipe emissions standards • Mandate electrification of business fleets • Subsidies and/or tax incentives to ease purchase barriers • Developing sufficient charging infrastructure • Introduce and legislate a complete phase-out date for sales of new internal combustion engines
Power grid (thousand kilometers)	44,036 *(x1.4)*	53,101 *(x1.7)*	Socio-political acceptance	• Minimizing site acquisition hurdles by facilitating easement rights • Regulatory reforms to spur greater private investments and open access to larger pool of capital

Source: BloombergNEF

- The urgency of global decarbonization means **governments and corporates need to intensify efforts to commercialize emerging decarbonization technologies for deployment at scale within the next 10 years.** These include nuclear, carbon capture and storage (CCS), hydrogen, sustainable aviation fuels, and heat pumps, all of which are under various stages of development but require more support and partnerships between all stakeholders to reach the stage of mass deployment necessary under a net-zero pathway.

Table 2: Opportunities to supporting emerging climate solutions

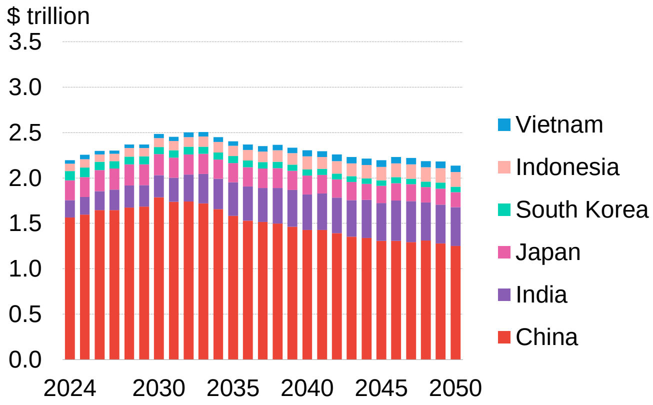
Technology (units)	**Economic Transition Scenario** ***(Multiplier versus 2023)***	**Net Zero Scenario** ***(Multiplier versus 2023)***	**Key challenge to keeping on track for net zero**	**Possible solutions**
Nuclear capacity (gigawatts)	240 *(x2.2)*	620 *(x5.8)*	Socio-political acceptance and technology commercialization	• Increased research and development on new-generation nuclear technologies • Safety framework and policies to address concerns • International technology and financing collaborations
Carbon dioxide emissions captured by CCS (million metric tons of CO2 per year)	-*	5,367*	Technology commercialization	• Research and development and pilot projects in critical sectors • Tax incentives and/or contract for differences to lower upfront development costs • Establish shared facilities and infrastructure among users
Hydrogen demand (million tons of hydrogen (140 megajoules per kilogram))	73 *(x1.8)*	211 *(x5.3)*	Technology commercialization	• Pushing existing hydrogen uses (for instance fertilizer production) to clean hydrogen • Tax incentives and/or contract for differences to support production and demand • Enforceable quotas for clean hydrogen use • Establish shared facilities and infrastructure among producers, users and exporters
Heat pumps (million units)	66.7 *(x3.2)*	214.3 *(x10.3)*	Rapid scaling	• Policies to reduce upfront cost, and improve accessibility of heat pumps • Support adoption in multi-family buildings and retrofit market
Sustainable aviation fuels demand (million gallons)	1,844 *(x66.7)*	33,775 *(x1,221.9)*	Technology commercialization	• In the short term, provide incentives – both supply-side and demand-side – to scale up the infrastructure for sustainable aviation fuels (SAFs) • Phase out usage of biofuels for road transport to ensure availability of feedstocks for SAF production • Set targets for replacement of jet fuel with SAF

*Source: BloombergNEF. Note: Hydrogen demand today is largely served by fossil fuel-derived hydrogen, so the multiplier for low-carbon hydrogen is many orders of magnitude larger. *There is no multiplier for carbon capture and storage due to absence of operational capacity outside of the upstream extractive sectors.*

Financing the energy transition requires strong mandates from governments and collaboration between all stakeholders

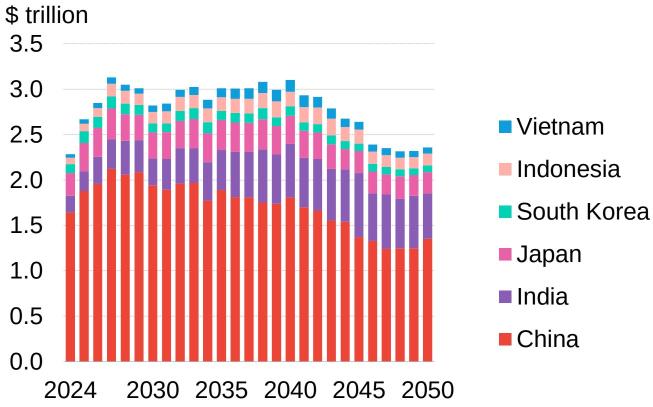
- **The energy transition requires a substantial scale-up of capital directed toward low-carbon assets and infrastructure.** Under BloombergNEF's Economic Transition Scenario and Net Zero Scenario, the energy investment opportunity between 2024 and 2050 totals $74 trillion and $89 trillion respectively. The falling costs of some low-carbon solutions, such as electric vehicles and clean power, and new policy commitments are closing the spending gap between the two scenarios. However, vastly different investment choices need to be made if net zero by mid-century is to be achieved.

Figure 1: Annual investment in selected Asia Pacific markets, Economic Transition Scenario



Source: BloombergNEF

Figure 2: Annual investment in selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF

- **It is critical to accelerate access to low-cost finance for mature low-carbon technologies**, as these tend to be associated with high capital expenditure. The cost to access this capital remains a limiting factor especially in the current high interest rate environment. The higher the perceived risks of a project, the greater the unwillingness to finance or more unfavorable the terms will be. Key concerns such as regulatory risks, off-take and curtailment risks and a lack of or weak market price signals for decarbonization need to be managed.
- **Emerging technologies may require greater support from governments and multilateral institutions to catalyze deployment. They may face higher barriers to financing due to the uncertainties around technology performance, supply chains and profitability.** Collaboration with development institutions and international banks can help mobilize greater capital flow at more financially viable costs for emerging technology projects.
- **Carbon markets can be a funding source for decarbonization activities** by transferring financial resources from other markets into Asia Pacific countries and provide financial incentives for emissions reductions in multiple sectors. As mature low-carbon technologies such as wind and solar power are increasingly competitive without further financial support, there is an opportunity to redirect funding from carbon markets to finance earlier-stage technologies and into managing phase-outs of fossil fuel plants with long-remaining lifespan that have greater funding needs.
- **Subsidies and carbon pricing mechanisms need to be well designed to achieve intended outcomes. They are some of the most direct interventions to support an emerging technology but need to be deployed strategically.** Subsidies need to be

targeted into sectors that need them in the short term, and need to be phased out when financial support for the technology is no longer required to avoid over-reliance on government support in the long run. A market’s carbon pricing mechanism also needs to be sufficiently high and cover a significant share of emissions, without too generous a concession that could negate the incentive for companies to abate emissions.

Section 2. Asia Pacific's energy transition outlook

Home to some of the fastest-growing economies, Asia Pacific faces a colossal but not insurmountable challenge to decarbonize, while ensuring sufficient, affordable and secure energy supply to meet growing needs. Cost-competitive low-carbon solutions already exist, such as solar, wind and passenger electric vehicles, and they represent a significant economic opportunity. Getting to net zero by 2050, however, requires accelerated deployment momentum that needs to be supported by strong government commitment and an enabling regulatory environment for project financing and investment.

2.1. Scenarios

This report builds and expands on the results of the New Energy Outlook 2024, BNEF's proprietary energy and climate scenarios publication, with a focus on six key markets – China, India, Japan, South Korea, Indonesia and Vietnam. The New Energy Outlook models the power, transport, industry, and buildings sectors to 2050 using bottom-up sub-sector models for 12 countries and seven regions, with additional power sector analysis for 19 markets. It covers 16 sub-sectors and more than 75 decarbonization technologies.

Table 3: Two scenarios in the New Energy Outlook

<table>
<tr><th>Economic Transition Scenario (ETS)</th><th>Net Zero Scenario (NZS)</th></tr>
<tr><td>• Exploratory base case which describes how the power, industry, transport, and buildings sectors might evolve as a result of cost-based technology changes.
• Consistent with a 2.6C warming outcome.
• Assumes no further policy support for energy transition beyond existing measures.
• Low-carbon transition is largely limited to the power and transport sectors.</td><td>• Normative climate scenario which describes a tough but achievable stretch to get on track for net zero by 2050 by meeting sectoral carbon budgets.
• Consistent with a 1.75C warming outcome.
• No overshoot or reliance on net-negative emissions post-2050.
• Fully decarbonizes power, transport, industry, and buildings by 2050.</td></tr>
<tr><td colspan="2">• Uses bottom-up sub-sector models, instead of top-down general equilibrium model or integrated assessment models.
• Uses consistent macro-economic inputs across both scenarios.
• Leverages proprietary data and expertise of 200 analysts.
• Models at yearly granularity for transport, industry, and buildings sectors and hourly granularity in the power sector to 2050.</td></tr>
</table>

Source: BloombergNEF

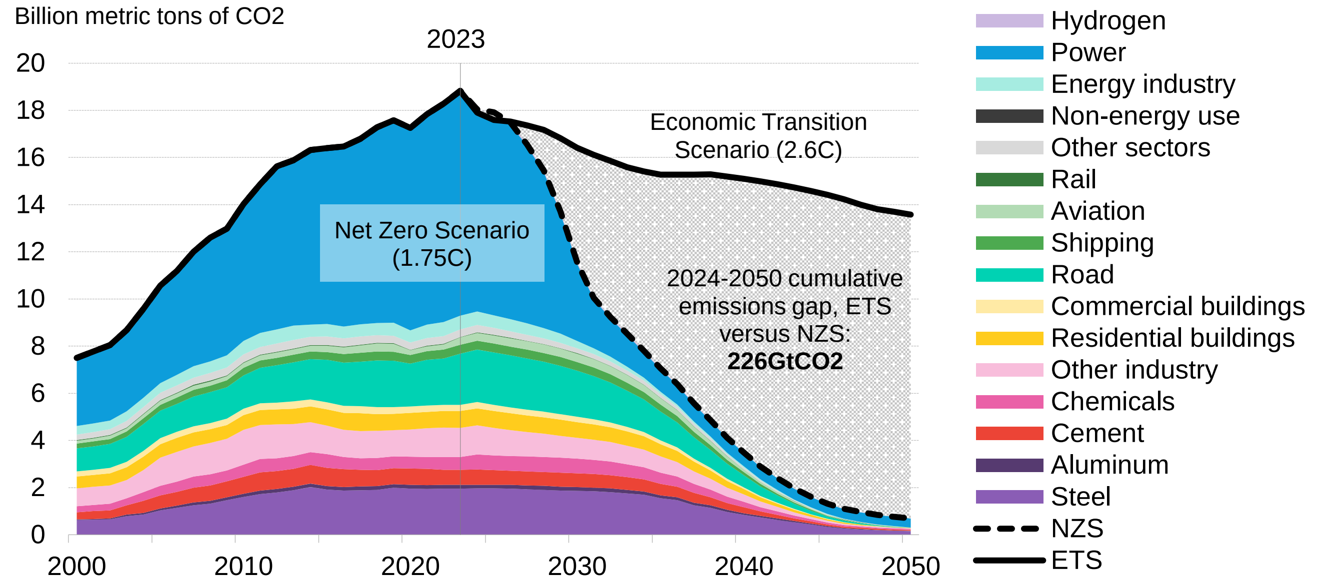
The base-case scenario used in BNEF research is our **Economic Transition Scenario (ETS)**. This scenario employs a combination of near-term market analysis, least-cost modeling, consumer uptake, and trend-based analysis to describe the deployment and diffusion of commercially available technologies in the absence of new policy regimes. It reveals the underlying economic fundamentals driving the energy transition. The **Net Zero Scenario (NZS)** uses similar least-cost optimization but shows a plausible pathway to achieve the main goals of the Paris Agreement and stay well below 2C of global warming, reaching net zero by 2050.

2.2. Emissions

Under both the ETS and NZS, energy-related emissions in Asia Pacific peaked in 2023 and are on a sustained decline to 2050. Achieving net zero by mid-century requires emissions to decline sharply, starting immediately, with the power sector leading decarbonization efforts.

The cumulative emissions gap over 2024-2050 between BNEF's ETS and NZS for Asia Pacific is 226GtCO2. Bridging this gap is no small task. Regional governments will need to bolster policy measures to further drive decarbonization efforts, particularly in hard-to-abate sectors. New and existing decarbonizing technologies will need to scale up, requiring a shift in investment paradigms, and regulatory and market designs.

Figure 3: Asia Pacific's energy-related emissions and net-zero carbon budget

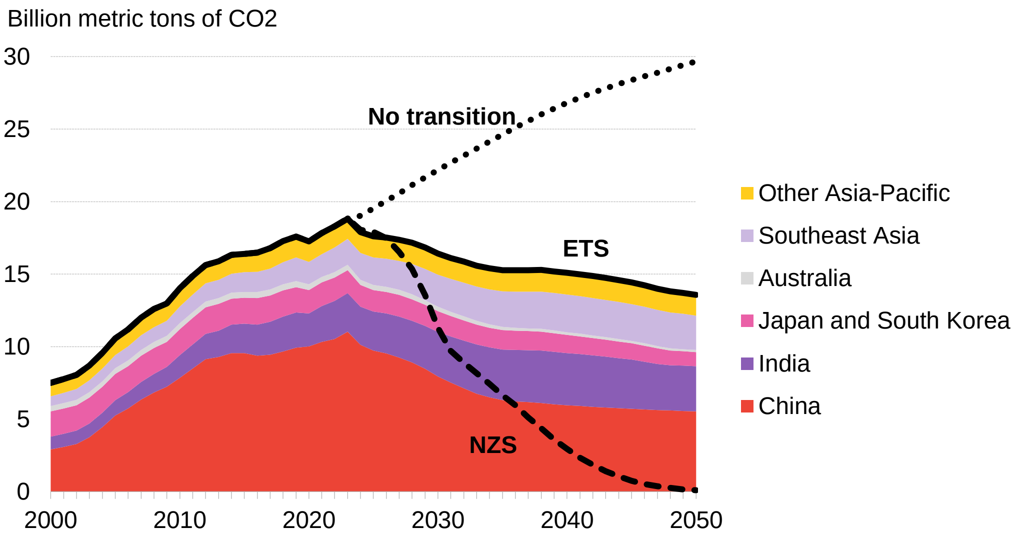


Source: BloombergNEF. Note: NZS is Net Zero Scenario, ETS is Economic Transition Scenario. 'Non-energy use' is non-combusted fuel consumption; consumed mostly in industry (chemicals). GtCO2 is billion metric tons of carbon dioxide.

Even the ETS sees a substantial transition toward low-carbon energy. In this scenario, Asia Pacific's energy transition is driven primarily by the impact of current policies and economically competitive, commercially-at-scale clean technologies. These measures alone see the region's emissions fall by 24% from current levels to 13.6 billion metric tons of CO2 (GtCO2) by 2050 (consistent with a 2.6C warming trajectory), less than half of the 29.6GtCO2 by 2050 under a counterfactual 'no transition' scenario in which there is no further progress on decarbonization (Figure 4).

The ETS assumes no further support for clean technologies beyond existing measures, although it hinges on a level playing field that allows these solutions to access markets and compete with incumbent technologies. This sets the stage for the region's renewables capacity to more than double by 2030 and then quadruple by 2050, from current levels. With that growth, fossil fuels are toppled as the dominant source of electricity generation as renewables cross a 50% share of supply at the end of this decade.

Figure 4: Energy-related CO2 emissions in Asia Pacific by market



Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NZS is Net Zero Scenario. The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. Refer to Appendix A for full list of geographies included.

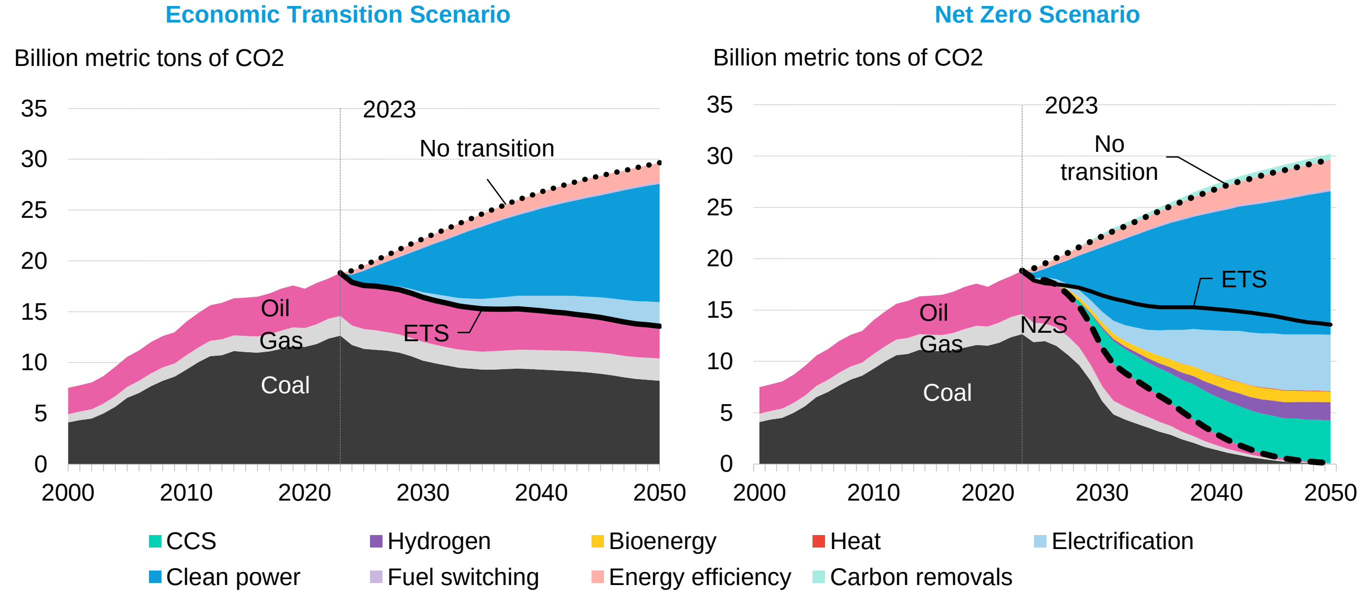
The NZS shows that while the more ambitious target of 1.5C looks increasingly out of reach, there are still plausible pathways to stay within 1.75C of warming. Still, significant effort is needed to achieve the pace of emissions reductions required.

Under the NZS, aggregate emissions across Asia Pacific decline 37% by 2030 and 84% by 2040 against 2023 levels, and hit net zero by 2050, consistent with Paris Agreement goals to keep temperatures below 2C above pre-industrial levels. The power sector undergoes a radical transformation as the region's renewables capacity increases over sevenfold by mid-century from current levels. The use of unabated fossil fuels is effectively phased out of power systems by 2040, while renewables' share of supply surpasses 80% by 2050 from 28% today.

2.3. Abatement

There is no cookie-cutter approach for the decarbonization of Asia Pacific energy systems. Each market's optimal portfolio of decarbonization technologies will be influenced by local policies, access to resources, and geographical constraints. Scaling up of mature, commercially ready technologies, such as renewable energy and electrification, is critical under both scenarios. To stay on track for net zero, efforts to bring emerging technologies such as hydrogen and carbon capture and storage to commercial readiness is vital, in addition to accelerating and intensifying renewable deployment and electrification efforts.

Figure 5: Energy-related carbon dioxide emissions reductions from fuel combustion by measure in Asia Pacific by scenario



Source: BloombergNEF. Note: The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 in the shipping sector). For all other sectors, the counterfactual to the Net Zero Scenario is the Economic Transition Scenario. 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage (CCS), hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry. Includes 'Carbon removals' needed to offset incomplete capture from point-source carbon capture processes, which are up to 90% complete.

In the ETS, clean power accounts for over 70% of the emissions avoided across Asia Pacific between today and 2050, compared with a 'no transition' scenario (Figure 5). The electrification of end-use sectors, including road transport, buildings and industry, accounts for another 11%. Improved energy efficiency also lowers overall energy demand and helps avoid 13% of abated emissions between now and 2050. Despite the significant decrease in carbon emissions under the ETS, efforts fall short of delivering an emissions reduction consistent with the Paris Agreement goals. Instead, its emissions profile is consistent with a carbon budget corresponding to a 2.6C temperature rise.

Getting to net zero by mid-century requires an almost complete phase-out of unabated fossil fuel use in the entire energy system across Asia Pacific. A much wider suite of decarbonization technologies will be required to achieve this across clean power, electrification, fuels, and industrial processes.

In the NZS, clean power is still the single biggest contributor of emissions reductions across Asia Pacific, responsible for half (249GtCO2) of the region's emissions reductions over 2024-2050, compared with 73% (190GtCO2) in the ETS. To be on track for net zero, Asia Pacific needs to see deeper electrification of end-use applications compared to the ETS, and faster. Electrification is the second-largest driver of emissions abatement under the NZS, accounting for 17% of total emissions reductions during this period, compared with 11% in the ETS. Energy efficiency accounts for a sizable 9% of emissions abatement.

Emerging technologies such as hydrogen and carbon capture and storage play a larger role under the NZS, accounting for 4% and 14% of abatement over 2024-2050, respectively. These technologies are particularly crucial in addressing emissions from hard-to-abate industries in the NZS, but fail to scale up to any meaningful level in the base-case ETS due to a combination of insufficient policy support and economic competitiveness.

Carbon removals in the New Energy Outlook

The New Energy Outlook scenarios are focused on technology pathways addressing emissions associated with fossil fuel combustion using primarily technologies that are already commercially available. The use of carbon removals under the Net Zero Scenario is limited to addressing residual emissions from carbon capture and storage. Carbon removals may well play a role in the decarbonization of the wider economy, particularly to deal with non-fossil fuel combustion emissions associated with land use, land-use change and forestry (LULUCF). Scaling up carbon removal technologies such as direct air capture will be critical for addressing LULUCF emissions.

For more information on emission constraints used in New Energy Outlook modeling, see Appendix B.

Economic Transition Scenario

The makeup of technologies used to abate emissions can vary significantly across markets in Asia Pacific, due to differences in relative technology costs, impact of current policies, and available resources. Figure 6 illustrates the differences between the technology drivers that bring about emissions abatement across four selected markets in Asia Pacific in the ETS.

- In **China**, the combination of near-term policies and an economics-led pathway in the ETS sees carbon emissions decline 45% from 10,126 million metric tons of carbon dioxide (MtCO2) to 5,527MtCO2 over 2024-2050. Against the 'no transition' counterfactual, switching power generation from fossil fuels to clean power is by far the biggest contributor to its emissions reductions, accounting for 80% of abatement during this period. Electrification emerges as the second-most important decarbonization vector, responsible for 12% of emissions reductions.
- **India's** energy-related emissions increase in our base-case scenario, from 2,621MtCO2 in 2024 to 3,117MtCO2 by 2050, peaking at 3,626MtCO2 in 2038, driven by a rapidly growing population and economic output. Substituting clean power for fossil fuel generation accounts for the largest share (63%) of abated emissions over 2024-2050, followed by energy efficiency (27%) and electrification (7%).
- **Southeast Asia's** emissions also increase in the ETS from 1,853MtCO2 to 2,376MtCO2 during this period, peaking at 2,594MtCO2 in 2040. Clean power is responsible for half of total emissions abated, followed by energy efficiency, which accounts for another 31% of emissions abatement during this period. Electrification accounts for 13% of abatement.
- **Japan and South Korea's** energy-related emissions peaked in 2013 and decline 35% from 1,498MtCO2 to 970MtCO2 over 2024-2050 in our ETS. Clean power abates 41% of emissions against the 'no transition' counterfactual during this time, followed by energy efficiency (26%) and electrification (23%).

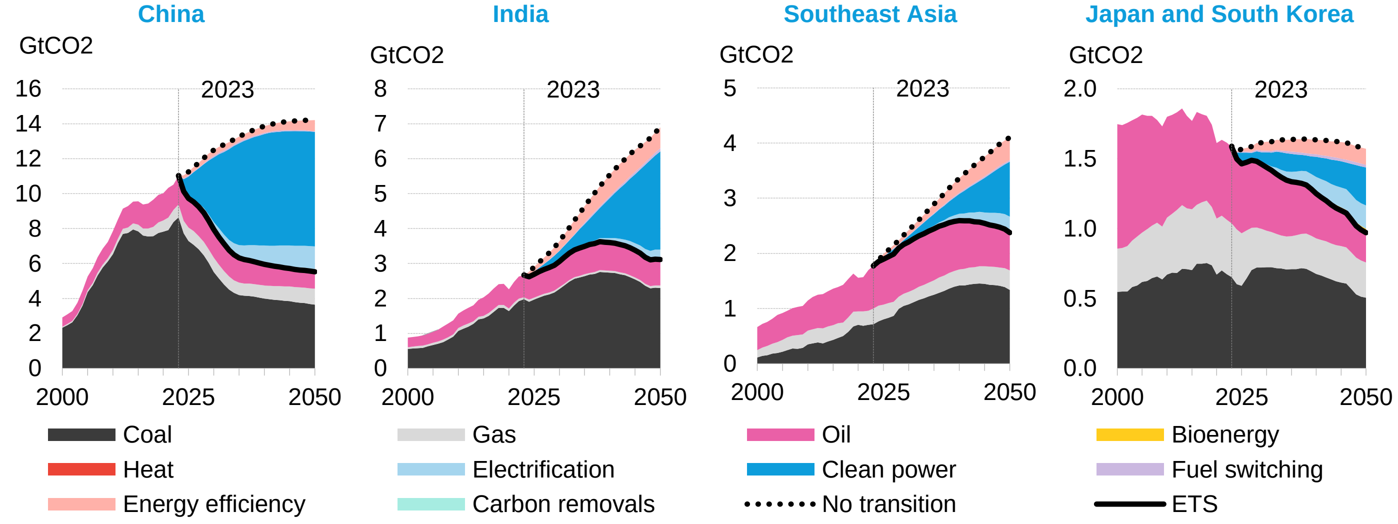
Energy efficiency in the New Energy Outlook

Emissions avoided through energy efficiency measures are hard to isolate or quantify. Energy efficiency captures a range of demand-side reduction in energy intensity to deliver the same 'useful' energy, ranging from more efficient electrical household appliances to improved industrial processes. BNEF accounts for these in its general electricity demand forecast models.

Underlying our projections of country electricity-demand growth are two fundamental drivers: population and economic output. Electricity consumption tends to increase with an expansion of these two, most notably in economies with low to medium GDP per capita. Economies at advanced stages of development tend to experience much slower demand growth or even a decline in electricity consumption as their GDP continues to expand. The forecast is therefore already accounting for energy efficiency improvements.

For the *New Energy Outlook* 2024, we show emissions abated via energy efficiency as the delta between our general demand forecast and a 'no transition' scenario, in which demand for 'useful' energy continues to evolve but there is no improvement in energy intensity or decoupling between economic growth and electricity demand. The emissions that would have occurred without these improvements can be attributed to energy efficiency.

Figure 6: Carbon dioxide emissions reductions from fuel combustion in selected Asia Pacific markets, Economic Transition Scenario versus 'no transition' scenario



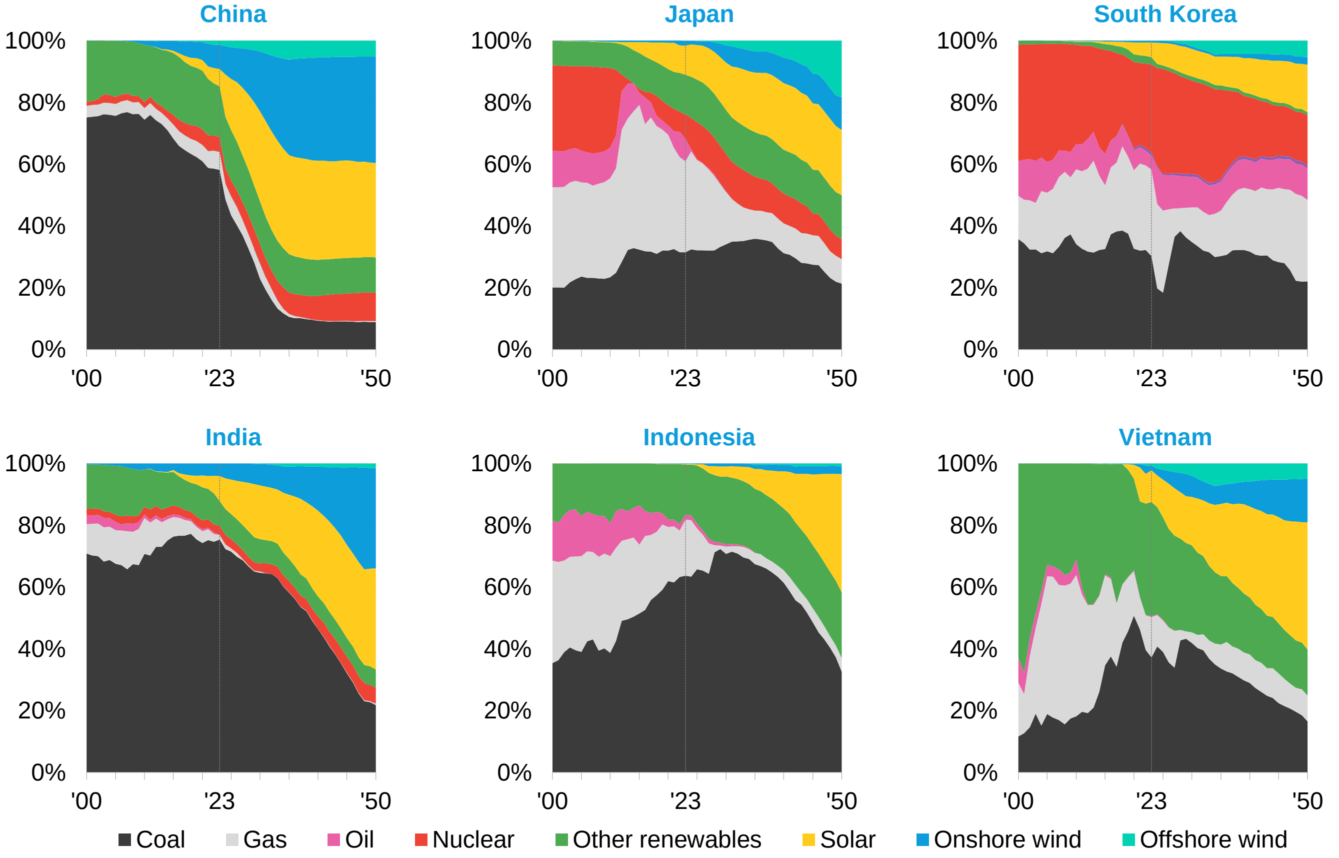
Source: BloombergNEF. Note: GtCO2 is billion metric tons of carbon dioxide. ETS is the Economic Transition Scenario. The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 for shipping). 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage (CCS), hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry. Includes 'Carbon removals' needed to offset incomplete capture from point-source carbon capture processes.

Clean power does the heavy lifting in an economics-led decarbonization pathway

Despite the differences in each market's decarbonization pathway, clean power's role as the single biggest contributor to emissions abatement is a common theme across all Asia Pacific markets in both scenarios. The substitution of clean power for fossil fuel generation in the ETS sees solar and wind account for an increasingly larger share of supply across Asia Pacific (Figure 7). The degree of renewable penetration, however, varies between markets based on relative technology costs, impact of current policies and available resources.

- **China** experiences a rapid switch to clean power this side of 2030 as the share of generation from solar and wind more than doubles from 25% today to 52% by the end of the decade. After 2030, their share of supply grows further, but slower, to reach 70% by 2050. Hydro also accounts for 11% of supply for renewables to make up over 80% of power by mid-century. Clean power also includes nuclear, which sees its share of supply rise from 5% to 9% over 2024-2050. Fossil fuel generation makes up 9% of supply in 2050, down from 54% today.
- **Japan's** share of supply from renewables reaches 64% by 2050, the majority of which comes from solar and wind which increases from 12% today to 22% by 2030. Further cost declines see this figure more than quadruple from current levels to 50% by 2050. Hydro and bioenergy are responsible for the additional 14%. Nuclear sees a declining share, at 6% of supply, down from 10% today. The share of output from fossil fuels declines from 65% to 29% over 2024-2050.
- In **South Korea**, solar and wind penetration grows from 7% today, to 12% by 2030 and 23% by 2050. It relies on nuclear as a source of clean power generation. In 2024, generation from nuclear accounts for 32% of demand. By 2050, the influx of cheaper solar and wind sees nuclear's share halve to 16%.

Figure 7: Share of electricity generation by technology in selected Asia Pacific markets, Economic Transition Scenario



Source: BloombergNEF. Note: 'Other renewables' comprise all other non-combustible renewable energy, including hydro, bioenergy, geothermal and solar thermal.

- In **Indonesia**, solar and wind penetration grows from a negligible level today to 4% by 2030. During this decade, Indonesia relies more on other renewables like geothermal, which sees its share of supply double from 5% to 10% over 2024-2030. Solar and wind's influence increases after 2030, growing more than 10-fold, to 42%, over 2030-2050, while the share from other renewables remains largely flat. Indonesia's relatively young coal fleet mean over one-third of its power still comes from coal-fired capacity in 2050, down from 63% in 2024.

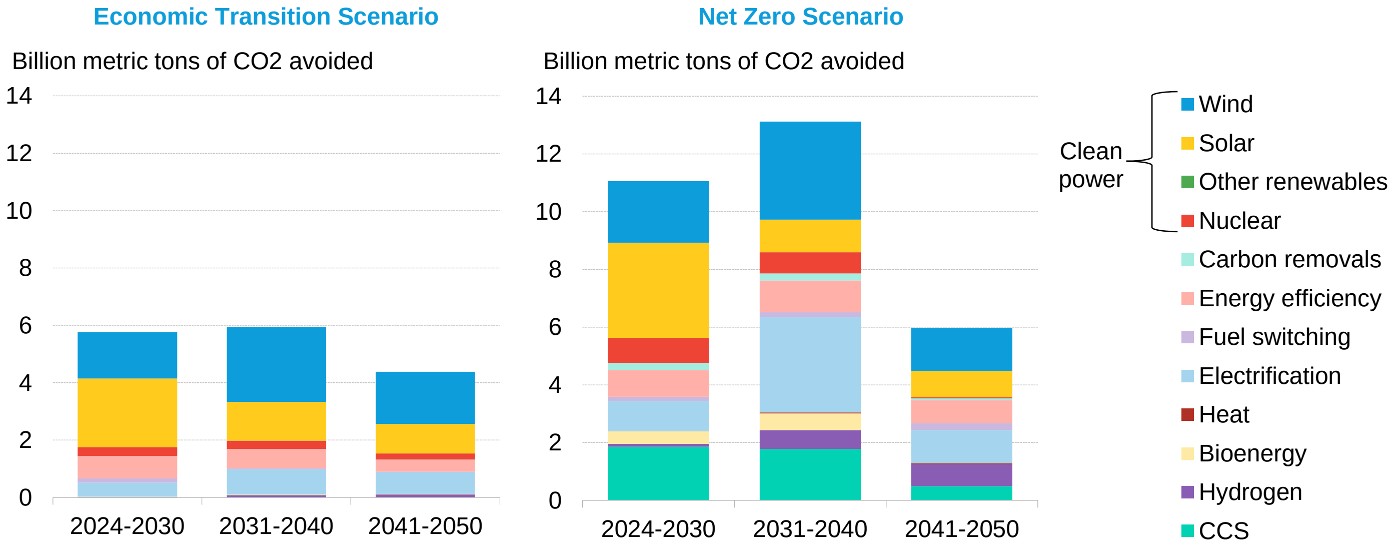
- In **Vietnam**, solar and wind already account for 14% of supply – a comparably higher share than many of its peers in Southeast Asia, driven by generous feed-in tariffs to incentivize uptake a few years ago. Overall, renewables already make up nearly half of Vietnam's generation with hydro supplying 36% of power in 2024. By 2050, renewables make up three-quarters of generation as solar and wind penetration more than quadruples to 60% compared to today. Hydro's share of supply falls to 13% by 2050 due to limited untapped potential and in favor of cheaper wind and solar. Like Indonesia, Vietnam also has a relatively young coal fleet. Hence, fossil fuels still make up a quarter of generation by mid-century, with coal accounting for 17%, down from 41% today.

Net Zero Scenario

Accelerated progress over the next 10 years is critical

Early emissions reductions are crucial for Asia Pacific in the NZS. The 2024-2030 period is dominated by rapid power-sector decarbonization, energy efficiency gains, and rapid acceleration of carbon capture and storage deployment. Wind and solar alone are responsible for half of net emissions abatement during this seven-year period, contributing 5.4GtCO2 of net reductions in the NZS – 35% more than in the ETS.

Figure 8: Net carbon dioxide emissions reductions by period and measure/technology in Asia Pacific, Economic Transition Scenario and Net Zero Scenario versus 'no transition' scenario



Source: BloombergNEF. Note: Data shows the net contribution of each technology to carbon emissions abatement by time period compared to a counterfactual 'no transition' scenario in which there is no further action toward decarbonization. Time period lengths differ. CCS is carbon capture and storage. 'Other renewables' comprise all other non-combustible renewable energy in electricity generation, including hydro, geothermal and solar thermal. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry.

While the deployment of renewables continues across 2031-2040, the importance of electrification grows. Electrifying end uses in industry, transport, and buildings accounts for 25%

of the emissions avoided during this period in the NZS. This equates to 3.3GtCO2 of net abated emissions – almost quadruple that in the ETS. Abatement from hydrogen and bioenergy also rises in importance as carbon budgets for hard-to-abate sectors tighten.

The third period from 2041-2050 relies on a mix of different technologies aimed at hard-to-abate sectors, with hydrogen accounting for 14%, or 0.77GtCO2 of net emissions abated – almost eight times that in the ETS.

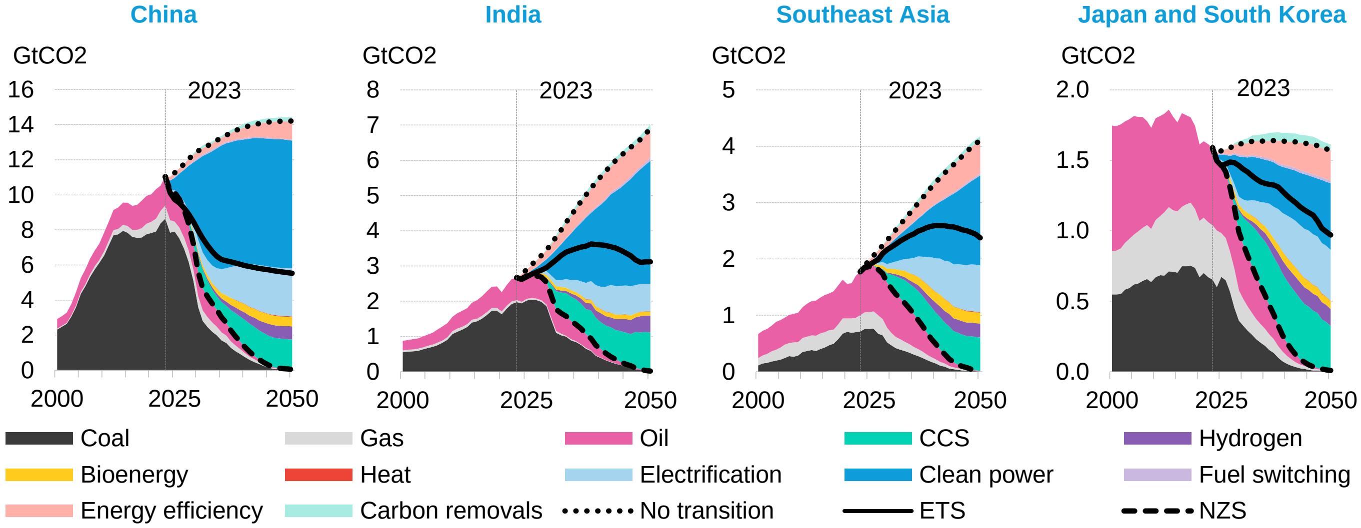
Tough choices await beyond clean power and electrification

To understand the scale of change needed to reach net zero, we quantify the contribution of emissions-saving technologies and other measures, and compare this with a 'no transition' pathway, which charts a route whereby we make no further efforts to decarbonize (Figure 9).

Getting to net zero requires an almost complete phase-out of unabated fossil fuel use in Asia Pacific's energy sector. Like in the ETS, switching power generation from fossil fuels to clean power sources is the single biggest contributor to the region's emissions reduction in the NZS. However, a more diverse set of technologies will be required to achieve net zero – some of which may currently not be economically competitive or commercially available at scale, like CCS and hydrogen, which are too costly under the ETS. The level to which these emerging technologies must scale to aid efforts to reach net zero varies across markets.

- In **China**, the need to decarbonize on a net-zero trajectory compliant with Paris Agreement goals sees its emissions decline 45% from 10,245MtCO2 to 5,588MtCO2 between 2024 and 2030. Over the next decade, emissions decline a further 72% before reaching net zero by 2050. Clean power accounts for 59% of emissions reductions over 2024-2050 in the NZS. Deeper and more rapid electrification of China's end use applications makes it the second-largest driver of its emissions reductions in the NZS, making up 17% of abatement during this period. CCS and hydrogen make up 11% and 3% of China's emissions reductions in the NZS over 2024-2050, respectively. China accounts for nearly 60% of all emissions abated in Asia Pacific over 2024-2050 – underscoring the importance of its decarbonization journey to the overall region's net zero transition.
- **India's** emissions decline 18% from 2,638MtCO2 today to 2,156MtCO2 by 2030 in the NZS. Over 2031-2040, emissions fall a further 64% to 638MtCO2 before reaching net zero by 2050. Clean power makes up nearly half of its emissions abatement by 2050, followed by CCS (17%), energy efficiency (14%), and electrification of end-use systems (12%). Hydrogen and bioenergy together account for an additional 8% of emissions reductions.
- **Southeast Asia's** emissions decline 20% from 1,850MtCO2 to 1,478MtCO2 over 2024-2030. Emissions decline a further 64% over the next decade to 490MtCO2 in 2040 before reaching net zero by 2050 in our NZS. Clean power accounts for the largest share (35%) of abated emissions over 2024-2050, followed by electrification (19%), CCS (19%) and energy efficiency (14%). Hydrogen and bioenergy each account for 6% of additional emissions reductions during this time.
- **Japan and South Korea's** emissions decline 40% from 1,504MtCO2 in 2024 to 908MtCO2 in 2030. Between 2031 and 2040, emissions decline a further 75% to 206MtCO2 before reaching net zero by mid-century under the NZS. Both clean power and CCS each account for just under 30% of emissions abatement by 2050, followed by electrification (19%), and energy efficiency (12%). Hydrogen and bioenergy together account for another 11% of abatement during this period.

Figure 9: Carbon dioxide emissions reductions from fuel combustion in selected Asia Pacific markets, Net Zero Scenario versus 'no transition' scenario



Source: BloombergNEF. Note: GtCO2 is billion metric tons of carbon dioxide. ETS is the Economic Transition Scenario. NZS is the Net Zero Scenario. The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 for shipping). 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage (CCS), hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry. Includes 'Carbon removals' needed to offset incomplete capture from point-source carbon capture processes.

The net zero power system undergoes a radical transformation, built around renewables

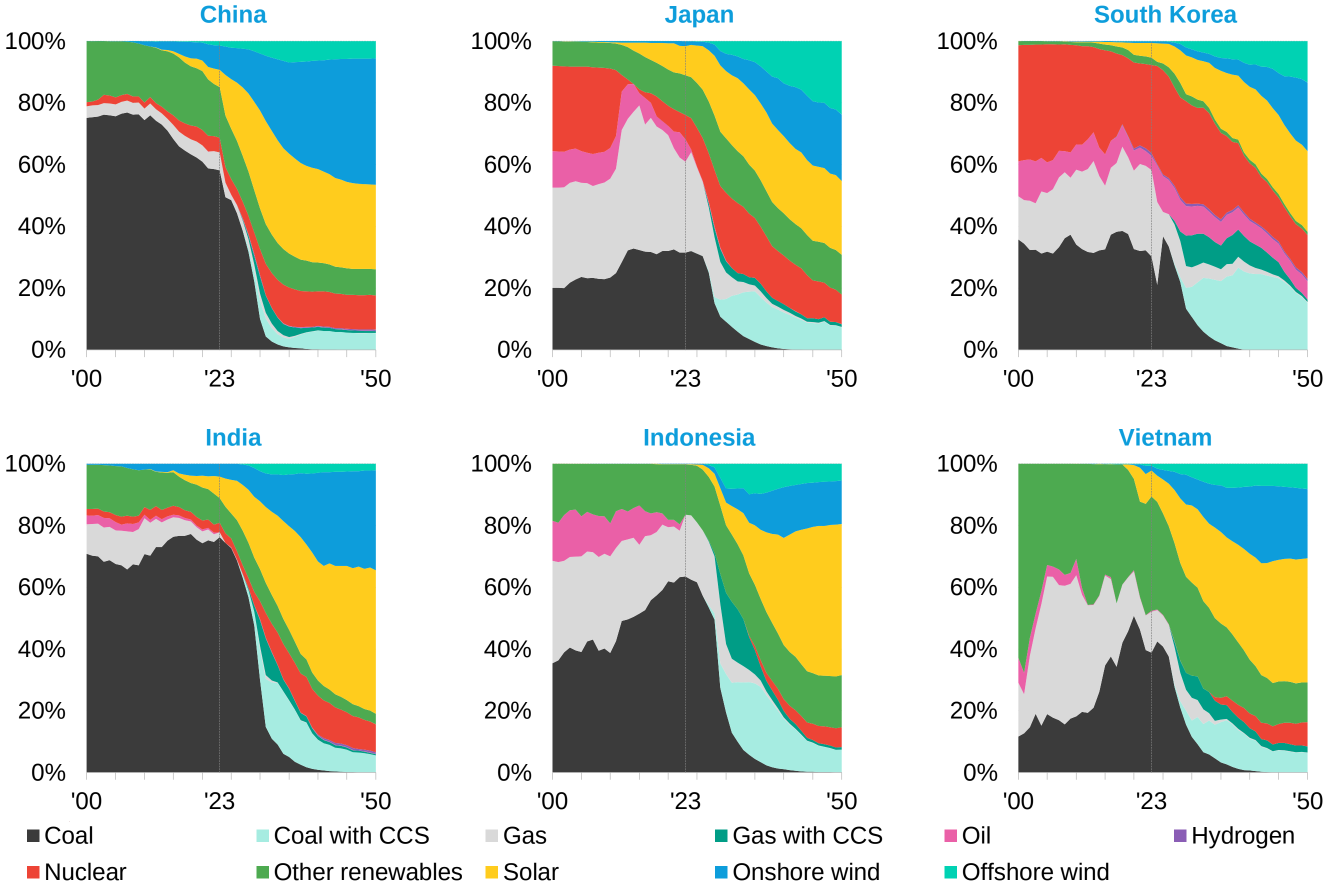
In the NZS, power systems across Asia Pacific markets shift from relying on unabated, baseload coal and gas power plants, to ones dominated by variable renewable energy. The shift to cleaner power happens much faster, at a bigger scale and more fundamentally than in the ETS. Low-carbon dispatchable alternatives, which can act as backup for renewables whenever they are unable to meet load, take the place of carbon-emitting power plants. In the NZS, the most cost-effective option that is available in the short term is CCS, outcompeting hydrogen and long duration storage in most economies. Nuclear also steps up to decarbonize the power sectors in Asia Pacific, especially in markets with existing nuclear capacity. However, we expect it to continue to need strategic government support, which limits its total deployment out to 2050.

Our net zero modeling assumes an immediate moratorium on new unabated coal build, including the near-term pipeline incorporated in our base-case. Under the NZS, polluting coal plants start to retire at a faster pace than under the ETS, before the end of their technical lives, to remain compliant with a carbon budget that achieves a 1.75C warming outcome by 2050 with no overshoot or net-negative emissions after 2050.

- In **China**, the share of generation accounted for by unabated fossil fuels falls from 54% to 12% during 2024-2030 and is almost completely phased out by 2038. Fossil fuel generation paired with CCS starts to scale during this decade, making up 11% of supply in China by 2030 before falling to 6% by 2050. Nuclear also plays a larger role in the NZS, supplying 11% of China's electricity by 2050, up from 5% today. These technologies are crucial to provide backup for solar and wind, which see their share of generation more than double from 24% today to 54% by the end of this decade, and further rising to 74% by 2050. Onshore wind emerges as the most important source of generation, making up 41% of China's power mix by mid-century compared to 27% from solar.

- In **Japan**, unabated fossil fuels see their share of supply decline from 65% today to 18% by 2030, before being largely phased out in the mid-2040s. CCS-paired coal and gas make up 11% of total supply by 2030 before falling to 8% by mid-century. Nuclear restarts play a more significant role under the NZS, increasing the share of nuclear power from 10% today to 22% in 2030, before declining to 10% by 2050 in favor of generation from cheaper, renewable alternatives. Nuclear and CCS-paired fossil fuels help firm up generation from solar and wind, which make up nearly 70% of supply by 2050, up from 12% today, and 31% in 2030. Overall, renewables make up 82% of generation by mid-century. Government policy (such as auctions) and land constraints see offshore wind emerge as Japan's largest source of electricity by 2050, accounting for a quarter of total supply, followed closely by onshore wind, which makes up just over one-fifth.
- In **South Korea**, generation from unabated fossil fuels falls from 48% to 17% over 2024-2030 before being phased out by 2050. CCS-paired fossil fuels supply 20% of the country's power by 2030 before falling to 16% by 2050. Nuclear plays a significant role in South Korea's generation mix but its share of the total halves from 32% in 2024 to 16% by 2050. Solar and wind, meanwhile, see their share of output rise from 7% today to 18% by 2030, before rising further to 62% by 2050. Solar emerges as the largest source of generation by 2050 under the NZS, responsible for 26% of supply.
- **Indonesia's** share of generation from unabated fossil fuels sees a steep decline from 83% today to 29% by 2030, before being phased out in the mid-2040s. CCS in power generation begins to scale this decade to account for nearly 30% of supply by 2030 in the NZS before falling to 8% by mid-century. Nuclear, which does not feature in Indonesia under the ETS, accounts for 6% of the country's power supply by 2050 in the NZS. Wind and solar, meanwhile, see their share of Indonesia's output rise from a negligible level in 2024 to 20% in 2030, rising to nearly 70% by 2050. Solar emerges as the most important source of generation by mid-century in the NZS, accounting for 49% of all output.
- **Vietnam's** share of generation from unabated fossil fuels, much from its relatively young coal fleet, declines quickly from 53% to 19% during 2024-2030 before being phased out by the mid-2040s. CCS-paired fossil fuel generation increases in importance simultaneously – making up 12% of generation by the end of this decade before seeing its share fall to 8% by mid-century. Vietnam also produces electricity via nuclear in the NZS, starting in the mid-2030s. The technology makes up 8% of Vietnam's supply by 2050. Much of the country's renewables growth comes from wind and solar – their share of generation grows from 12% in 2024 to 38% by 2030 and 71% by 2050. Hydro plays a similar role in Vietnam in the NZS as it does in the ETS – its share of output gradually declines from around 34% in 2024 to 11% in 2050. Solar is the most significant source of generation in Vietnam by 2050 under the NZS, accounting for 40% of total output.

Figure 10: Share of electricity generation by technology in selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF. Note: Includes electricity generation for hydrogen production under the Net Zero Scenario. 'Other renewables' comprise all other non-combustible renewable energy, including hydro, bioenergy, geothermal and solar thermal. CCS is carbon capture and storage.

2.4. Investment

Decarbonizing Asia Pacific's energy systems will require a substantial scale-up of capital directed toward low-carbon assets and infrastructure. Under both the ETS and NZS, the energy investment opportunity between 2024 and 2050 totals $74 trillion and $89 trillion respectively. The falling costs of some low-carbon solutions, such as electric vehicles and clean power, and new policy commitments are closing the spending gap between the two scenarios. However, vastly different investment choices need to be made if net zero by mid-century is to be achieved.

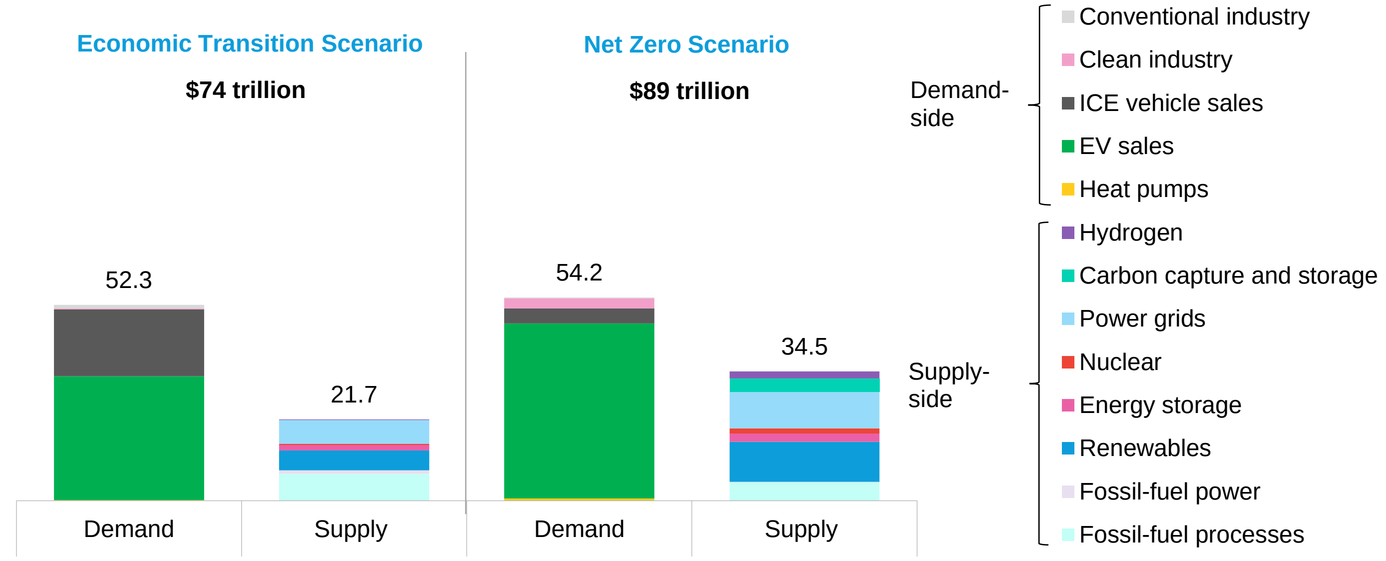
Investment and spending are only 20% higher in the Net Zero Scenario

In the ETS, companies, financial institutions, governments, and consumers invest a total of $74 trillion on energy-related infrastructure, technology, and products (Figure 11) in Asia Pacific by 2050, representing more than 40% of the total global spend. This is split across $22 trillion for energy supply (both fossil fuels and low-carbon) and $52 trillion for demand-side products (almost entirely for vehicles, both electric and internal combustion engine-based).

Total investment across Asia Pacific in the Net Zero Scenario is only 20% higher, at $89 trillion – also around 40% of the global figure. This comparatively small difference between the scenarios is because EVs are expected to reach cost-competitiveness with ICE vehicles in the coming years, meaning demand-side spending is only slightly higher than in the ETS at $54 trillion.

But supply-side investment is 57% larger in the NZS than in the ETS at $35 trillion. This is because clean energy technologies are more capital expenditure intensive than traditional energy sources. That said, operating expenditure is excluded from this analysis and would likely be higher for fossil-fuel technologies.

Figure 11: Asia Pacific energy investment and spending across 2024-2050, Economic Transition Scenario and Net Zero Scenario

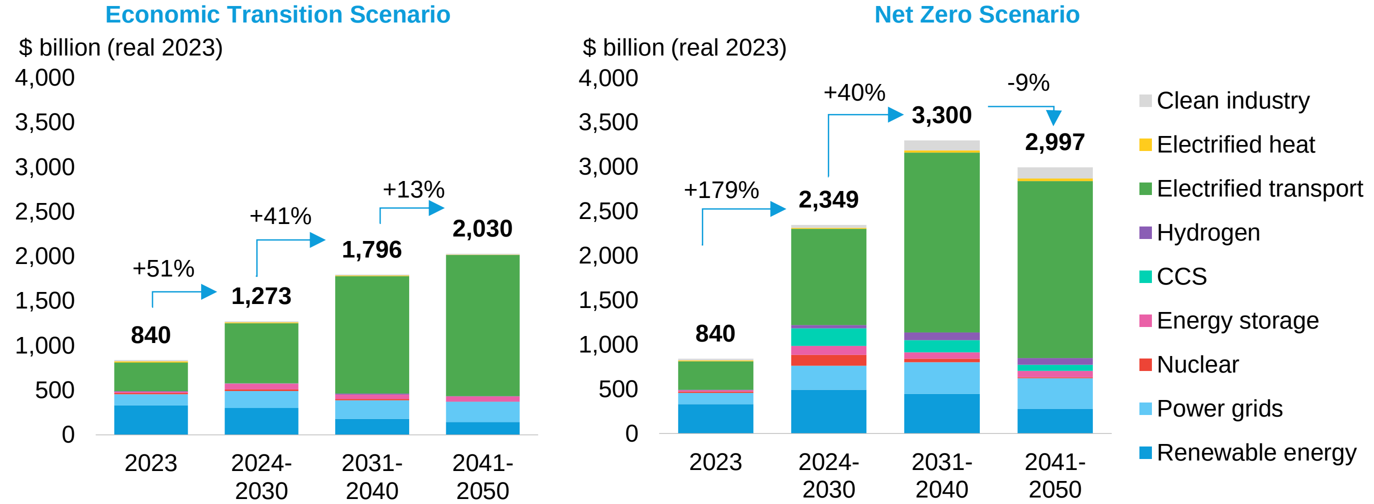


Source: BloombergNEF. Note: ICE is internal combustion engine. EV is electric vehicle. The numbers above the bars indicate cumulative investment and spending figures from 2024 to 2050. Investment in bioenergy is included under renewables.

Investment in low-carbon technologies accelerates under the Net Zero Scenario

BNEF's annual *Energy Transition Investment Trends* report is the definitive review of investment and spending on net-zero aligned technology and infrastructure. The report estimated that around $840 billion was invested in low-carbon technologies across Asia Pacific in 2023. Using the same scope, the ETS requires this figure to rise to an average of $1.2 trillion per year from 2024 to 2030 – 51% greater than the current pace of investment (Figure 12). The scale-up in the NZS is breathtaking, requiring annualized investment to triple to $2.3 trillion over 2024-2030. This figure rises a further 40% over the next decade.

Figure 12: Energy transition investment in Asia Pacific – 2023 estimate versus required annualized levels across 2024-2050, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: Value for 2023 is an estimate. Excludes investment in fossil-fuel processes and power and conventional energy, and spending on internal combustion engine vehicles, which are not captured in 2023 investment figures reported in BNEF’s Energy Transition Investment Trends report (web | terminal). CCS is carbon capture and storage.

The two scenarios’ totals are in the same ballpark, but represent fundamentally different choices

The 20% difference in the investment totals across Asia Pacific in the NZS and ETS is in the same ballpark by 2050, and lower operating costs for clean energy could narrow the gap further. But the difference masks large changes in investment choices, with the NZS representing a huge leap in the speed of clean technology deployments (Figure 12). This underscores the need for stable, long-term policy signals – empowered by strong political will – to divert investment away from fossil-fuel based pathways and toward low-carbon solutions at the scale and speed required by the NZS. Investment levels can also differ between markets within Asia Pacific based on the current state of their respective energy transitions (Figure 13).

- **China** pulls in $40.7 trillion of investment over 2024-2050, or 55% of the Asia Pacific total, into its energy system under the base-case ETS, underscoring its outsized role in the region’s energy transition. In the NZS, total investments into China are only 14% higher at $46.3 trillion, or 52% of the region-wide total. The increase is primarily driven by supply-side investments – which are 35% higher in the NZS. By 2050, investments in renewables and energy storage total $5.2 trillion to get to net zero in China – 45% higher than in the base case. Investment in the power grid is also up 39% to $4.7 trillion in the NZS, to accommodate greater levels of renewable penetration and higher rates of electrification. The NZS also sees more than a tripling of investment in nuclear compared to the ETS – up to $0.7 trillion by 2050. CCS and hydrogen, which do not feature in the ETS, require $1.1 trillion and $0.9 trillion in investment, respectively. On the demand side, spending on EVs totals $27.2 trillion in the NZS over 2024-2050, up 21% compared with the ETS. Spending on heat pumps is around $0.5 trillion, around five times higher than in the base-case.
- **India** represents a $12.4 trillion investment opportunity in the NZS – 34% more than in the ETS. The increase is again driven primarily by supply-side investments, which more than double under the NZS to $6.8 trillion. Investment in renewables and energy storage increases

137% to $2.2 trillion over 2024-2050 to get to net zero. The NZS sees a quintupling in investment on nuclear, totaling $0.3 trillion during this period. Power grid investment is up to $1.8 trillion – an 88% increase over the base-case ETS to get to net zero by mid-century. On the flip side, investments across the fossil-fuel value chains declines 46% in the NZS to around $0.94 trillion compared to the ETS. Demand-side spending declines around 8% in the NZS relative to the base case to $5.6 trillion, driven by lower spending on vehicles as EVs become cheaper. Spending on EVs nearly doubles to $4.4 trillion in the NZS compared to the ETS, equivalent to 36% of the scenario's overall capital expenditure. Overall spending on vehicles, including ICEs, declines nearly 16% in the NZS compared to the ETS.

Figure 13: Cumulative energy investment and spending across 2024-2050 in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario

Source: BloombergNEF. Note: ICE is internal combustion engine. The numbers above the bars indicate cumulative investment and spending figures from 2024 to 2050.

- **Japan's** energy system requires $7.7 trillion in investment over 2024-2050 to get to net zero – a 38% premium over the ETS. Supply-side investment doubles to $2.0 trillion in the NZS, while demand side investment increases 21% compared to the ETS. Investment in renewables and energy storage in the NZS is nearly $1.0 trillion, a 151% premium over the base-case. Power grids require 67% more investment than in the ETS to get to net zero, totaling $0.7 trillion over 2024-2050. Spending on CCS and hydrogen, which play a prominent role in getting to net zero, is $0.2 trillion and $0.1 trillion, respectively. Investments across the fossil-fuel value chain totals just $0.009 trillion during this period in the NZS, 75% lower than in the ETS. On the demand side, spending on heat pumps totals $0.1 trillion in Japan under the NZS, up nearly 80% compared to the ETS. EV sales are almost twice the amount in the ETS to get to net zero, equaling $4.8 trillion.

- **Indonesia** requires $3.8 trillion in investment to get to net zero by 2050, just 15% more than in the ETS. Supply-side investment over 2024-2050 hits $2.1 trillion, 32% more than in the ETS. Investment on renewables and energy storage reaches $0.9 trillion, a 138% premium over the ETS. Investment in power grids also increases 66% over the ETS, totaling $0.5 trillion. Investment in CCS and hydrogen in Indonesia during this period totals $0.2 trillion and $0.05 trillion, respectively, in the NZS. Investment across the fossil-fuel value chain totals $0.5 trillion, 48% less than in the ETS. Demand-side investment is the same across both scenarios at $1.7 trillion, but the makeup of the investment changes significantly between them. In the NZS, spending on EVs during 2024-2050 in Indonesia is $1.5 trillion – 88% more than in the ETS, while spending on ICE vehicles is 90% lower at $0.1 trillion.
- In the NZS, **South Korea's** energy system represents $2.7 trillion of investment and spending over 2024-2050, 37% higher than in the ETS. Supply side investment almost triples in the NZS compared to the base case, reaching $1.1 trillion by 2050. Investment in renewables and energy storage almost quadruples over the ETS to $0.4 trillion to reach net zero by mid-century. Spending on nuclear also increases 23% to $0.04 trillion to get to net zero by 2050. Around $0.3 trillion is invested in power grids over 2024-2050 in South Korea under the NZS, a 73% premium over the ETS. Investment across the fossil-fuel value chain totals just $0.01 trillion in the NZS, 68% lower than in the ETS. Demand-side investment rises just 3% in the NZS compared to the ETS, but the makeup of the spending varies drastically between the two scenarios. Spending on EVs, for instance, reaches $1.3 trillion between 2024 and 2050 to reach net zero, a 46% increase over the ETS. At the same time, spending on ICE vehicles declines 73% to $0.2 trillion in the NZS.
- In the NZS, **Vietnam** requires $2.4 trillion in investment, 54% more than in the ETS. Supply side investment doubles to $1.4 trillion under the NZS during this period. Investment in renewables and energy storage jumps 127% compared to the base-case to reach net zero, requiring $0.6 trillion over 2024-2050. Around $0.05 trillion is also invested in nuclear during this period in the NZS. Power grid investment jumps 81% over the ETS to $0.3 trillion in the NZS. Simultaneously, investment across the fossil-fuel value chain declines 49% in the NZS relative to the ETS, totaling $0.1 trillion. Nearly $0.3 trillion is also spent across CCS and hydrogen to help scale up these emerging technologies in the NZS. Total demand side spending in the NZS is around 14% higher in Vietnam compared to the ETS. EV sales jump 92% between 2024 and 2050 in the NZS relative to the ETS to equal $0.8 trillion, while spending on ICE vehicles declines 87% relative to the ETS to $0.05 trillion over the same period.

2.5. Assessing the ambition of Nationally Determined Contributions against NEO scenarios

This section assesses the ambition levels of six Asia Pacific markets' 'Nationally Determined Contributions' (NDCs) – their climate plans to help meet the goals of the Paris Agreement – against the two scenarios developed in the *New Energy Outlook* 2024.

Under the 2015 Paris Agreement, countries committed to collectively limit the increase in the global average temperature above pre-industrial levels to "well below 2C", and to "pursue efforts" to limit warming to 1.5C. The latest UN assessment of NDCs concluded that signatories of the treaty need to ratchet up their emissions pledges to meet either of these pathways,[2] and BNEF analysis shows that all six of the markets outlined in Table 4 have scope to examine potential opportunities to increase the ambition of their NDCs. Parties to the deals are due to submit their next set of NDCs over the next year.

A step change in ambition is needed

Many parties need to ratchet up the ambition of their NDC targets to get on track to reach net-zero emissions by 2050. Crucially, policymakers will also need to implement sufficient support to achieve these ambitions. The six markets covered in this analysis were responsible for an estimated 47% of global energy sector emissions in 2023. Based on their NDCs as of April 2024, we find:

- **Japan and South Korea**, which were responsible for 5% of global energy sector emissions in 2023, have NDCs that are **more ambitious than BNEF's Economic Transition Scenario, but not enough to be aligned with the Net Zero Scenario**. This suggests that achieving their NDC targets would deliver more emissions abatement than our economics-driven base case. However, they would need to ratchet up their 2030 goals to be consistent with global net zero by mid-century.
- **India**, representing 8% of global energy sector emissions in 2023, has an NDC **in line with the ETS**, meaning it is aligned with a pathway that optimizes the use of economically competitive technologies. As a developing economy, India's trajectory is, at least apparently, cost-efficient. But given that the ETS is consistent with a 2.6C warming outcome, India's NDC target falls significantly short of the Paris-aligned goal of limiting the global temperature increase to well below 2C.
- **China**, **Indonesia** and **Vietnam** accounted for an aggregate 35% of global energy sector emissions in 2023 and each have an NDC that is **less ambitious than the** ETS (Table 4). This implies that if these markets realize their NDCs, a substantial share of global energy emissions would be above – and in the case of China, well above – even the pathway that optimizes the use of current technologies. They would therefore need to significantly ratchet up their NDC targets to get on track for a net-zero trajectory. What is more, these NDCs even fall short of an economically efficient energy transition pathway. Raising their ambition could thus reduce energy system costs compared with their current plans.

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[2] The UN's 'synthesis report' published in November 2023 found that if parties deliver on their 2030 targets, global emissions would decrease by 5.3% over 2019-2030. This is far short of the 25% reduction needed to limit global warming to 2C and the 43% cut required for a 1.5C pathway. For more, see *UN Climate Talks: Was the 28th Time the Charm? Not So Much* (web | terminal).

More transparency on commitments

Performing an accurate like-for-like comparison of parties' goals is challenging, mainly due to the diverse types of emissions targets, sectors and greenhouse gas coverage, base years, unique national circumstances, and equity- and development-related considerations. But transparency of NDCs and emissions reporting is important, as it builds trust among parties and credibility for the annual COP climate meetings and outcomes. This year will see governments issue their first biennial reports based on the new rules to improve consistency and transparency, though some variability will remain as developing economies were granted flexibility provisions.

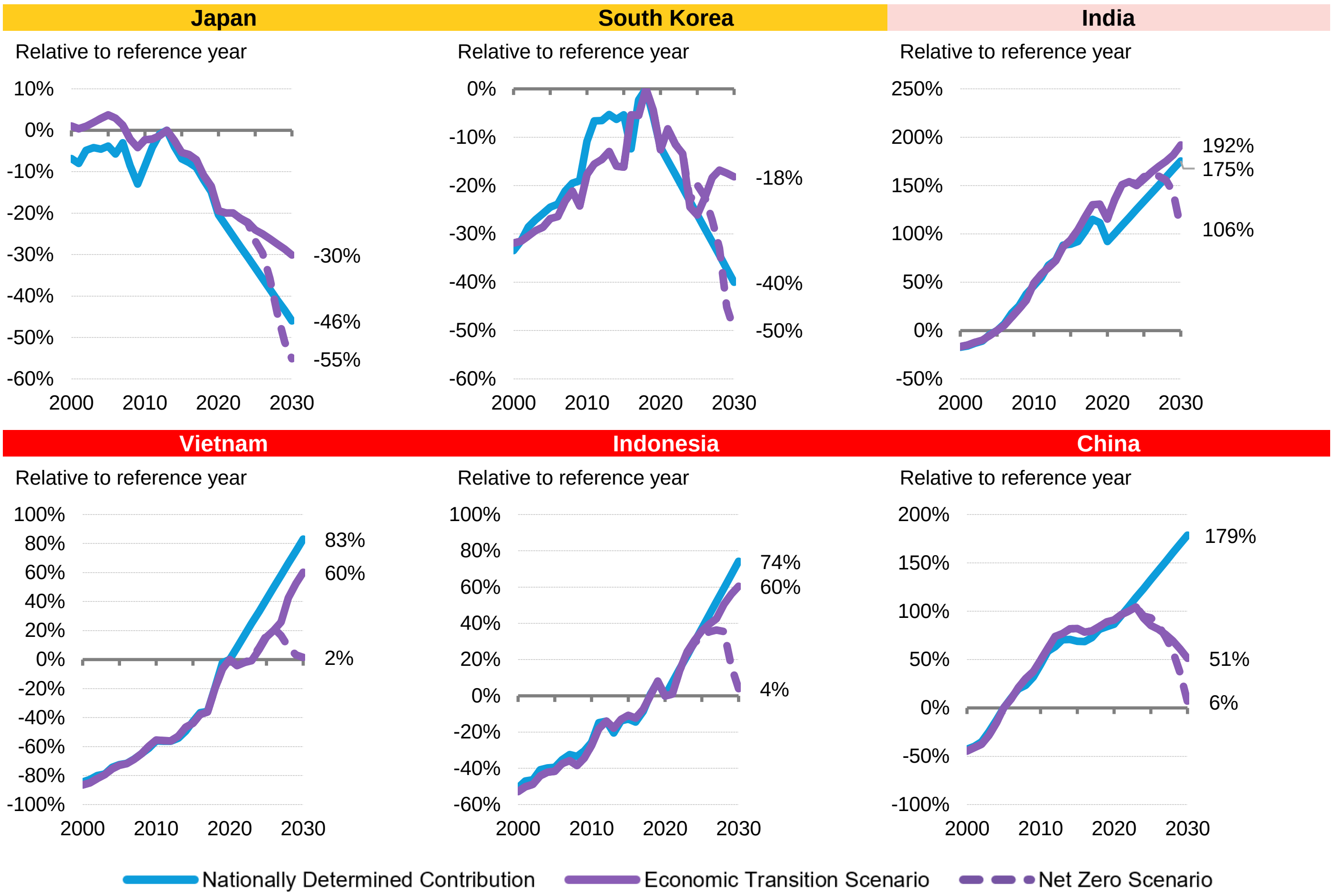
Table 4: Change in selected Asia Pacific markets' energy-sector emissions under their Nationally Determined Contributions and BNEF's Economic Transition Scenario and Net Zero Scenario – 2030 versus base year

				Energy-sector emissions change, 2030 versus base year			
Market	**Target**	**Description**	**Base year**	**NDC**	**ETS**	**NZS**	**NDC ambition**
Japan	Absolute emissions reduction	Reduce greenhouse gas emissions by 46% in fiscal year 2030 from fiscal year 2013 levels	2013	-46%	-30%	-55%	More ambitious than ETS
South Korea	Absolute emissions reduction	Reduce greenhouse gas emissions by 40% by 2030 from 2018 levels (727.6 million metric tons of CO2 equivalent) by 2030	2018	-40%	-18%	-50%	More ambitious than ETS
India	Emissions intensity	Reduce emissions intensity of its GDP by 45% by 2030 from 2005 levels	2005	175%	192%	106%	In line with ETS
Vietnam	Baseline scenario	Unconditional target of 15.8% emission reduction relative to business-as-usual (BAU) scenario; conditional target of 43.5% relative to BAU	2020*	83%	60%	2%	Less ambitious than ETS
Indonesia	Baseline scenario	Unconditional target of 31.89% emission reduction relative to BAU, conditional target of 43.2% emission reduction relative to BAU	2020*	74%	60%	4%	Less ambitious than ETS
China	Emissions intensity	Lower its carbon intensity by over 65% in 2030 from 2005 levels	2005	179%	51%	6%	Less ambitious than ETS

*Source: BloombergNEF, Fourth Biennial Update Report of the Republic of Korea, greenhouse gas data from World Resources Institute CAIT, Nationally Determined Contributions (NDCs) from United Nations Framework Convention on Climate Change, GDP data from International Monetary Fund. Note: ETS is Economic Transition Scenario; NZS is Net Zero Scenario. Applies parties' economy-wide, unconditional, greenhouse gas targets for 2030, apart from China, which only has a CO2-related target. Where target is a range or is for a reduction of "at least x%", the least ambitious figure is used. France and Germany use the EU-level target of "at least 55%", as the bloc submits one climate plan. NDC ambition assessments take into account the absolute difference in emissions, crossover points and overall trajectory. Does not distinguish between Annex I and non-Annex I countries, as defined by the UN. *For Indonesia and Vietnam, this NDC value is based on the governments' estimated baseline scenario for 2030 emissions. We then calculated the implied change in emissions between 2020 (the latest year for which we have data) and 2030.*

A key next step would be for parties to use a consistent structure for their emissions targets. In that respect, an absolute, economy-wide greenhouse gas target delivers the most certainty in terms of projected outcome. This may be a tough ask. Rapidly growing developing economies such as India and Indonesia show little sign of moving away from intensity-based targets that allow them to grow their economies but meet their climate goals. There are early indications that China may shift away from an intensity-based target for its 2035 NDC. As the charts in Figure 14 illustrate, this suggests that even if such markets deliver on their 2030 targets, they could increase emissions beyond an economics-driven pathway – and far beyond a trajectory consistent with the Paris Agreement.

Figure 14: Selected Asia Pacific markets’ energy sector emissions targets in Nationally Determined Contributions compared to Economic Transition Scenario and Net Zero Scenario, 2000-2030

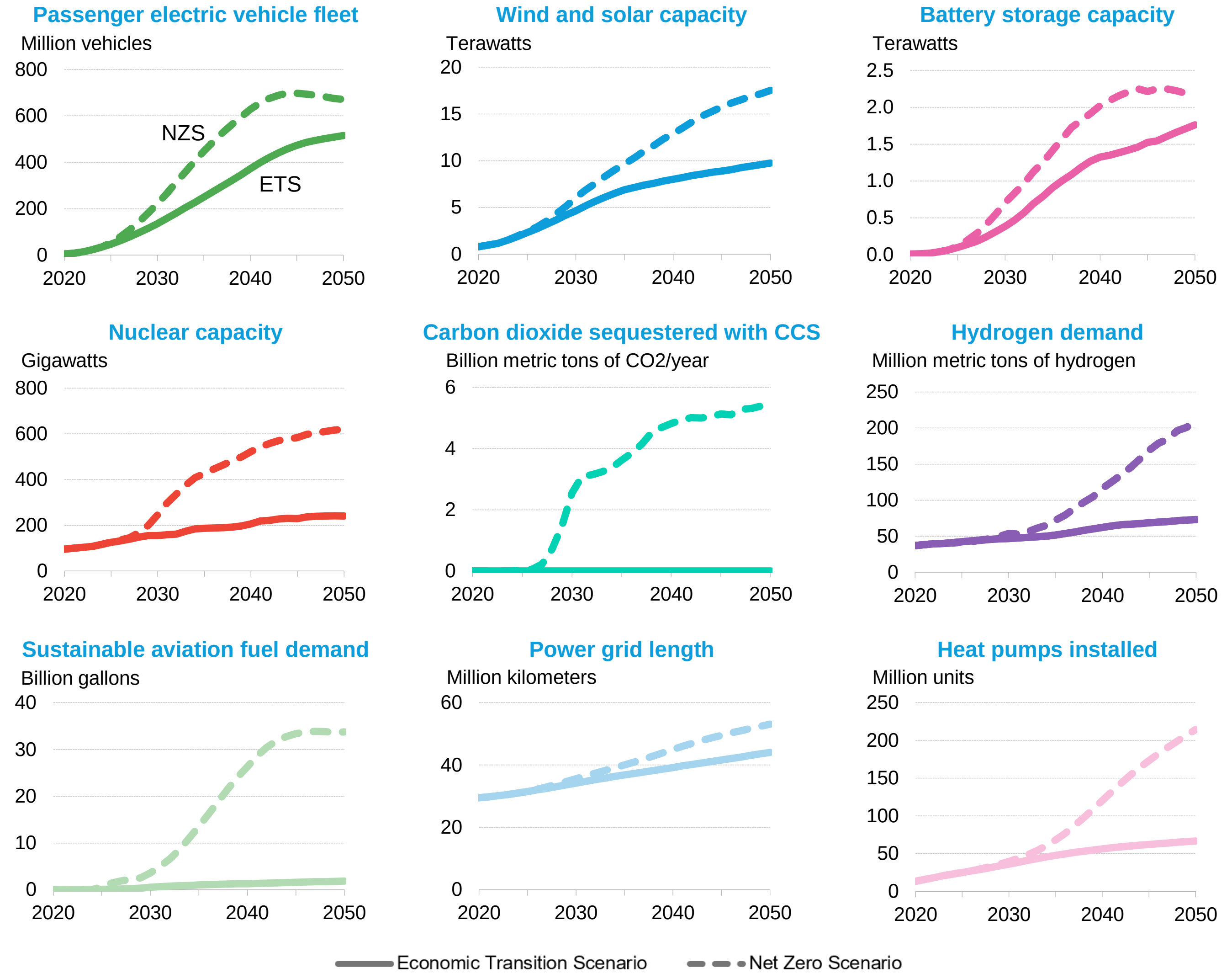


Source: BloombergNEF, greenhouse gas data from World Resources Institute CAIT, Nationally Determined Contributions from United Nations Framework Convention on Climate Change, GDP data from International Monetary Fund, Korea emissions data from Fourth Biennial Update Report of the Republic of Korea. Note: ETS is Economic Transition Scenario; NZS is Net Zero Scenario. Applies parties’ economy-wide, unconditional, greenhouse gas targets for 2030, apart from China, which only has a CO2-related target. Where a target is a range, the least ambitious figure is used. France and Germany use the EU-level target; both markets have an NDC of “at least 55%”. Does not distinguish between Annex 1 and non-Annex 1 countries, as defined by the UN. Legend: More ambitious than ETS; in line with ETS; less ambitious than ETS.

Section 3. Technology drivers

Achieving net zero in Asia Pacific's energy systems will require a portfolio of technologies of varying maturity that jointly deliver the deep decarbonization required. BNEF's modeling identified nine technology pillars that will make or break the region's transition from a high- to low-carbon energy system.

Figure 15: Selected technology drivers in BNEF's Asia Pacific scenario modeling



Source: BloombergNEF. Note: ETS is Economic Transition Scenario. NZS is Net Zero Scenario. Wind includes offshore and onshore. Solar includes small-scale and utility-scale solar photovoltaic. Battery storage includes stationary storage. CCS is carbon capture and storage and the Economic Transition Scenario shows the current project pipeline.

By 2050, in the NZS for Asia Pacific:

1. The EV fleet grows to 671 million vehicles and while the region does not see a complete phase-out of internal combustion engine (ICE) vehicles before 2050, new ICE vehicle sales fall 97% by 2040 against 2023. Between 2041 and 2050, new ICE vehicles sales stagnate at an average of 2.3 million vehicles per year.
2. Total wind and solar capacity reaches 17.5 terawatts (TW) – this represents 57% of global capacity in 2050. Total renewable energy capacity almost quadruples from today by 2030, and then triples again from 2030 to 2050.
3. Installed battery storage capacity hits 2.2TW by 2050 – more than 60 times of 2023 levels, representing 56% of global capacity.
4. Nuclear power capacity grows almost sixfold to 620 gigawatts (GW).
5. Carbon capture capacity grows to 5.4 billion metric tons of carbon dioxide (GtCO2) sequestered per year from nearly zero today.
6. Clean hydrogen use reaches 211 million tons per year by 2050 – five times today's fossil-fuel-based hydrogen demand and 54% of global demand in that year.
7. Sustainable aviation fuel consumption hits 34 billion gallons per year – up from minimal levels today. By 2050, Asia Pacific represents 38% of global SAF demand.
8. Asia Pacific's power grid grows to 53 million kilometers in length – almost double from today to account for nearly half of the world's power grid in length.
9. Heat pumps reach over 200 million installed units cumulatively – a near 10-fold increase from today.

Among the nine pillars, only four are mature, commercially scalable technologies with proven business models: electric vehicles, renewable power, energy storage, and power grids. These still require a significant acceleration to get on track for net zero, but there is little to no technology risk and economic premiums are generally small or non-existent. However, these technologies may still face different levels of regulatory risks in each market. As seen in Figure 15, each of these technologies sees strong growth in the ETS, demonstrating their maturity and economic competitiveness.

By contrast, nuclear, carbon capture and storage (CCS), hydrogen, SAFs, and heat pumps are not currently cost-competitive or face challenges scaling up commercially. As a result, their deployment stagnates under the ETS. But each of these technologies must scale rapidly to achieve the trajectories laid out in the NZS, and each plays a different role in the transition. Achieving commercialization of these technologies within the next decade will be imperative. The following sections explore the trajectory of each technology in greater depth.

Table 5: Technology scale-up required under Economic Transition Scenario and Net Zero Scenario in Asia Pacific

Technology (units)		Economic Transition Scenario		Net Zero Scenario		Key challenge to keeping on track for net zero
	2023	2050	Multiplier versus 2023	2050	Multiplier versus 2023	
Solar (gigawatts)	987	6,781	x6.9	11,676	x11.8	Rapid scaling
Wind (GW)	536	2,970	x5.5	5,847	x10.9	Rapid scaling
Battery storage capacity (GW)	36	1,761	x48.5	2,227	x61.3	Rapid scaling
Passenger electric vehicle fleet (million vehicles)	23	515	x22.2	671	x28.9	Rapid scaling
Power grid (thousand kilometers)	30,509	44,036	x1.4	53,101	x1.7	Socio-political acceptance
Nuclear capacity (GW)	107	240	x2.2	620	x5.8	Socio-political acceptance and technology commercialization
Carbon dioxide emissions captured by carbon capture and storage (million metric tons of CO2 per year)	-	-		5,367		Technology commercialization
Hydrogen demand (million tons of hydrogen (140 megajoules per kilogram))	40	73	x1.8	211	x5.3	Technology commercialization
Sustainable aviation fuels demand (million gallons)	28	1,844	x66.7	33,775	x1,221.9	Technology commercialization
Heat pumps (million units)	21	67	x3.2	214.32	x10.3	Rapid scaling

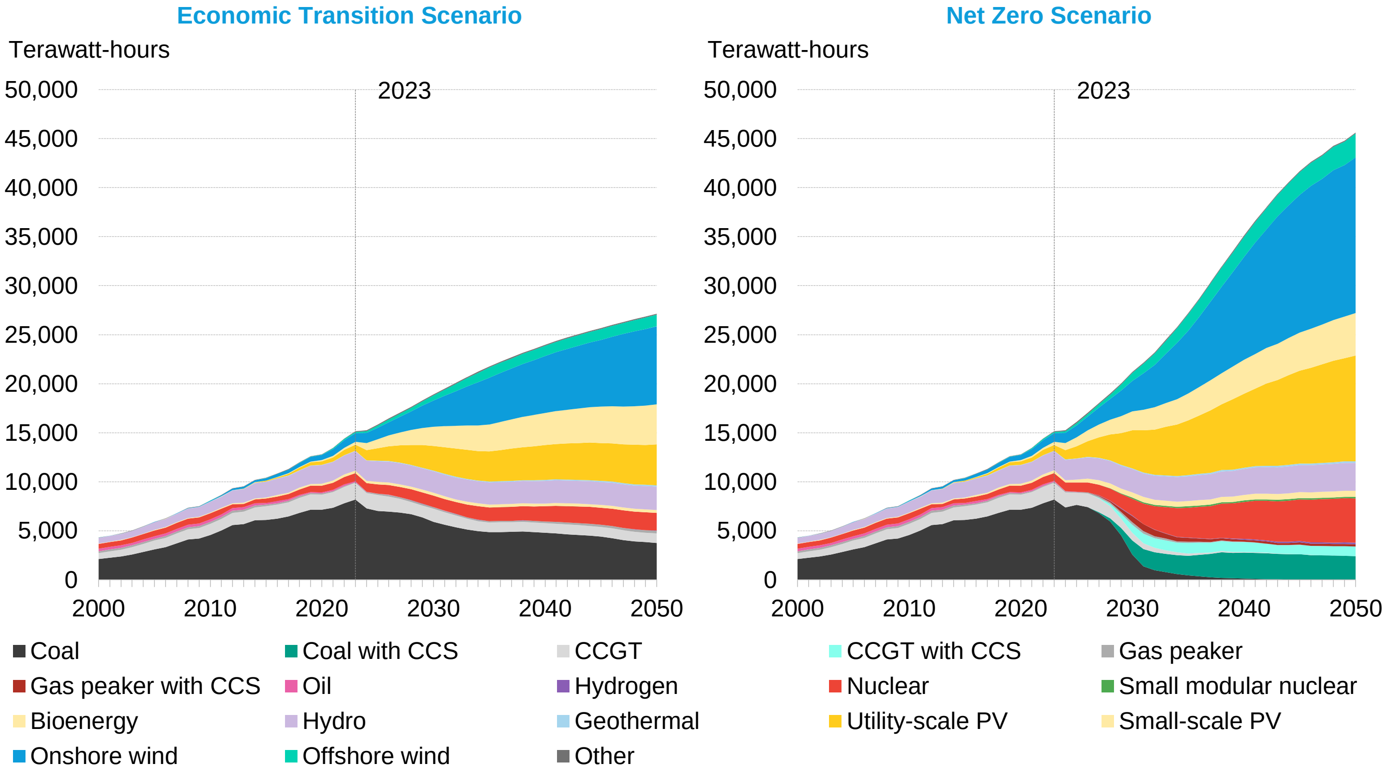
Source: BloombergNEF. Note: Hydrogen demand today is largely served by fossil fuel-derived hydrogen, so the multiplier for low-carbon hydrogen is many orders of magnitude larger.

3.1. Fossil fuel-based power generation

Rapidly growing economies and industrial activities in many of the Asia Pacific markets drives significant growth in electricity demand under both the ETS and NZS. Total generation in the region increases 31% from 15,152 terawatt-hours (TWh) in 2023 to 27,135TWh by 2050 under the ETS. By comparison, total generation increases by 86% to 45,619TWh by 2050 under the NZS.

Achieving net zero by 2050 means the NZS is not merely an evolution of the ETS – it will have to function and operate as a completely different power system, as shown by Figure 16. The increasing cost-competitiveness of clean power, and the ever-rising decarbonization ambitions of nations, are fundamentally changing how power systems are developing, transforming them from being fossil fuel-centric to dominated by renewables. In particular, solar and wind supply the bulk of electricity across the Asia Pacific. For a net zero-aligned pathway, Asia Pacific must also see the phase-out of unabated fossil fuel use. This is a significant challenge given the dominance of coal and gas in the power sector today.

Figure 16: Electricity generation by technology/fuel in Asia Pacific, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: Refer to Appendix A for the full list of geographies included in the chart. CCS is carbon capture and storage. CCGT is combined-cycle gas turbine. PV is solar photovoltaic.

Today, fossil fuels collectively supply two-thirds of the region's power demand, of which unabated coal dominates with 54% of total generation. By 2050, under the ETS, coal's share of the region's generation mix falls to 14%. However, in some markets with relatively young coal fleets, such as Indonesia, its share remains as high as 32% by mid-century. Under the NZS, unabated coal's share of generation in the region falls precipitously to 12% by 2030 before being largely phased out by 2040 in all Asia Pacific markets. In both scenarios, the region's unabated coal fleet will struggle to compete economically against new solar and wind generators but needs to see a faster phase-out in the NZS than in the ETS to stay on track for net zero.

Gas will progressively play a larger role, supplying high value, low volume electricity to the region's power systems in times of need. By 2050, unabated gas accounts for just 5% of generation in Asia Pacific under the ETS, and is completely phased out under the NZS, from 12% in 2023.

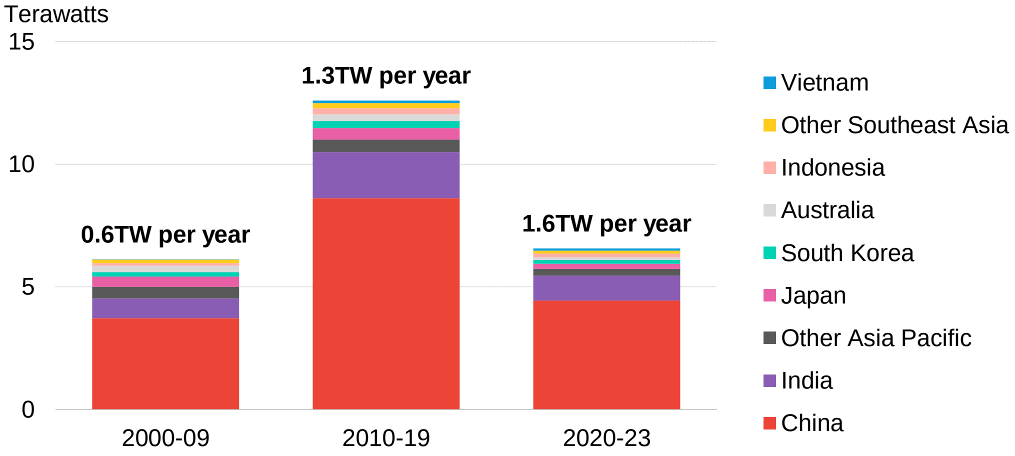
CCS allows coal and gas to retain a role, albeit a small one, in the region's power system. Under the NZS, coal and gas paired with CCS account for 5% and 3% of the region's generation in 2050, respectively.

Unabated coal phase-out can be costly for many Asia Pacific markets

Phasing down and eliminating the use of coal can be a financially costly and politically sensitive task for many of the Asia Pacific countries with deeply entrenched coal industries beyond the power sector. Many countries in the region have acknowledged the need to and expressed their commitment to transition away from unbated coal. Bringing these plans into action and accelerating the momentum to be in line with a net-zero pathway will require increased government will and potentially international financial support.

Many Asia Pacific markets such as India and Vietnam face the uphill task of ensuring a secure, affordable, and stable power supply to drive economic growth and industrialization while balancing long-term climate targets. Historically, coal has been the technology of choice for expanding power market across the region thanks to the abundance of coal resources in China, India, Indonesia, and Australia. In response, power grids were built around large, centralized generators. A power grid dominated by decentralized intermittent generators, such as solar and wind, needs to be operated very differently, prompting hesitancy and reliability concerns from power system operators and regulators who are less experienced with it.

Figure 17: Coal generation capacity addition in Asia Pacific by market and time period



Source: BloombergNEF. Note: Time period lengths differ. Refer to Appendix A for the full list of geographies included in the chart. Figures above bars are annual average coal-fired capacity additions.

The region is also host to a relatively young coal fleet, which will be costly to retire early. Rapid economic growth over the last two decades drove a significant increase in Asia Pacific's coal capacity. Half of the region's coal generation assets that were added from 2000 to 2023 occurred in the 2010s alone. Between 2020 and 2023, the region added an average of 1.6TW of coal generation capacity per year, compared to the average of 0.6TW per year in the 2000s and 1.3TW per year in the 2010s (Figure 17).

Countries have taken steps toward phasing out coal, but progress is slow

Governments and coal asset owners in a few Asia Pacific markets – Indonesia, Vietnam and the Philippines – have initiated discussions with both private financial institutions and multilaterals like the Asian Development Bank, and initiatives such as the Just Energy Transition Partnership (JETP) to potentially accelerate the phase-out of coal power plants. However, apart from a successful case by ACEN in the Philippines, little progress has been made. Governments have run up against the harsh realities of JETP negotiations and challenges in reaching agreement on terms that all parties would find palatable No funding has been released so far under the JETP deals secured in 2022 by both Indonesia and Vietnam.

What about ammonia co-firing in coal plants or blending of hydrogen with natural gas?

Many Asian markets are eyeing ammonia co-firing and blending of green hydrogen with natural gas to abate coal- and gas-fired power plant emissions, respectively. Fuels like hydrogen and ammonia do not release carbon dioxide during combustion given the absence of carbon in their molecular chemistry. These markets also hope to prevent existing assets from becoming stranded. Governments in Japan and South Korea, along with companies in each country, are rushing to scale the technology on a commercial basis across the region, leading to a frenzy of announcements and activity around these fuels.

BloombergNEF analysis finds that coal ammonia co-firing and blending of green hydrogen with natural gas are not cost-effective emission reduction approaches as they entail higher safety and financial risks. Co-firing of ammonia and blending of green hydrogen with natural gas have limited emissions reduction benefits at low ratios.

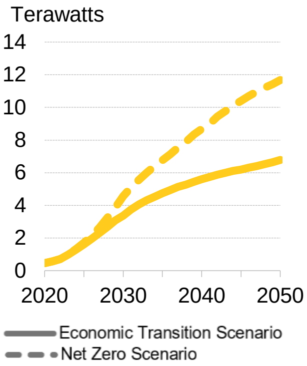
To achieve tangible emission reduction, an existing coal power plant would have to be retrofitted to be capable of co-firing ammonia with coal at energy ratios above 50%. Currently, only co-firing 20% ammonia with coal (on an energy content basis) has been tested in pilot projects. Higher co-firing ratios require significantly more investment in retrofitting the thermal power plant. They also raise fuel procurement costs for countries dependent on hydrogen and ammonia imports and may jeopardize a country's energy security.

Seaborne transportation and onsite storage of ammonia is also more costly and entail higher safety risks than coal and LNG. Combustion of ammonia creates nitrogen oxides (NOx) – a major pollutant – as well as nitrous oxide (N_2O) emissions – a greenhouse gas more powerful than CO_2.

BNEF's Net Zero Scenario sees a role for 100% ammonia or hydrogen compatible peaker gas turbines as critical back-up in fully decarbonized power systems. However, the annual utilization rate of such peaker plants is still relatively low in this scenario due to their higher fuel costs.

3.2. Variable renewables

Figure 18: Asia Pacific installed solar capacity in BNEF's scenario modeling



Source: BloombergNEF. Note: Includes small- and utility-scale solar photovoltaic.

Solar and wind are the main drivers of decarbonization in Asia Pacific and are set for a massive scale-up across the region under both the ETS and NZS, driven by declining costs, generous incentive schemes, and improving routes-to-markets for projects (through programs like auctions).

Together, wind and solar accounted for 75% of Asia Pacific's generation capacity additions in 2023. However, the level of development varies significantly across the region. China is a global leader in solar and wind deployment driven by government ambition, incentive support, and economies of scale from its the large domestic clean energy manufacturing sector. Today, China accounts for 69% of installed solar capacity and 85% of installed wind capacity in Asia Pacific. Some 87% of solar and wind capacity additions in 2023 took place in China. On the other end of the scale, Indonesia only has 0.7GW of combined solar and wind capacity, which represents a mere 0.05% of the country's coal-dominated power system as of 2023.

Regardless of each country's starting point, solar and wind installations see a large jump under both of BNEF's modeled scenarios. In the ETS, wind and solar combined make up 41% of power generation in the region by 2030 and 64% by 2050. Under the NZS, the two renewable energy sources collectively contribute 46% of the power mix by 2030 and 73% by 2050. The NZS sees accelerated deployment of solar and wind compared to the ETS to lower power sector emissions for a much larger electricity system in line with the carbon budget compliant with the goals of the Paris Agreement.

Table 6: Installed solar and wind capacity in Asia Pacific by market and scenario – 2023 versus 2050

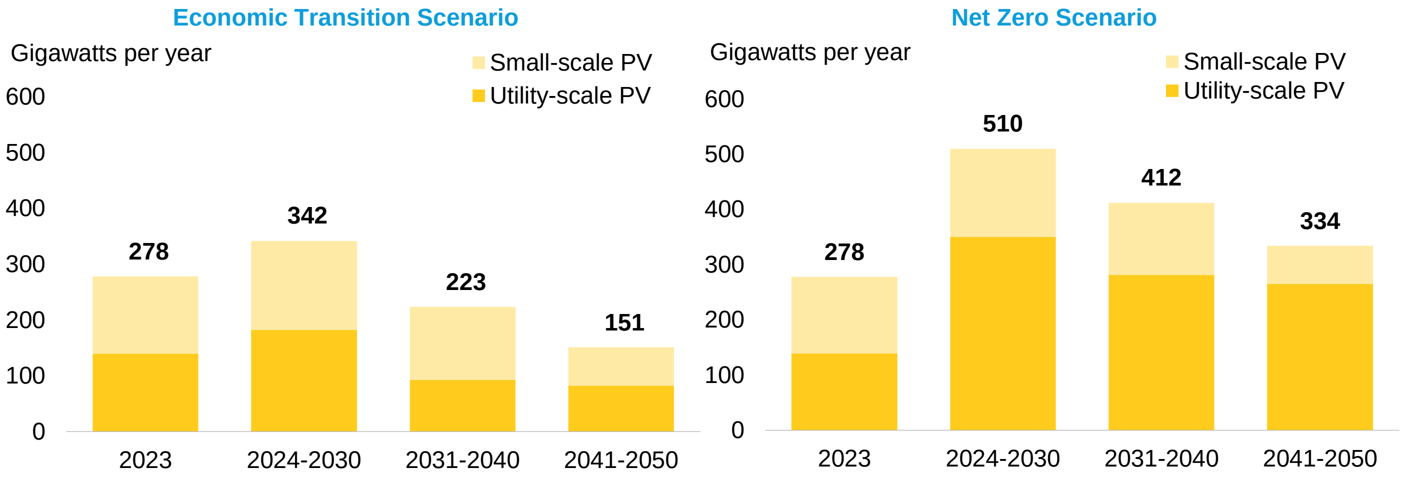
		Economic Transition Scenario		Net Zero Scenario	
Gigawatts	**2023**	**2050**	**Multiplier versus 2023**	**2050**	**Multiplier versus 2023**
Australia	45	166	x3.7	290	x6.5
China	1,137	5,925	x5.2	8,408	x7.4
India	139	1,616	x11.6	4,328	x31.1
Indonesia	1	346	x495.5	891	x1,275.1
Japan	96	275	x2.9	580	x6
South Korea	29	94	x3.2	304	x10.4
Vietnam	26	331	x12.8	682	x26.4
Other Asia Pacific	39	612	x15.9	1,146	x29.7
Other Southeast Asia	12	385	x32.8	895	x76.3
Asia Pacific	**1,523**	**9,751**	**x6.4**	**17,523**	**x11.5**

Source: BloombergNEF. Note: 'Other Southeast Asia' includes Malaysia, Thailand and the Philippines. Refer to Appendix A for the full list of geographies included under 'Other Asia Pacific'.

Solar

Solar, utility- and small-scale collectively, sees massive expansion in Asia Pacific under both the ETS and NZS to become the second-largest source of power supply by mid-century. Increasing to 31% and 33% of generation, respectively, up from a mere 6% in 2023. Solar already leads installations in Asia Pacific, accounting for 60% of capacity additions in 2023.

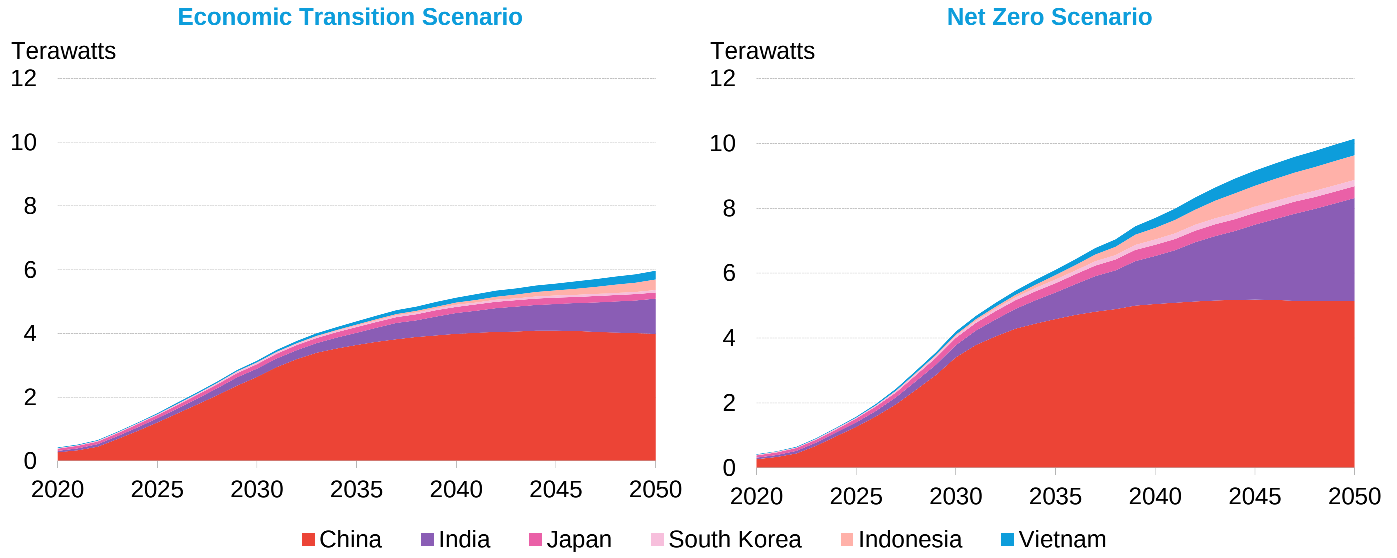
Figure 19: Annual average solar capacity addition in Asia Pacific by time period, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: PV is solar photovoltaic.

Solar technology and supply chains are mature and well established, allowing for the rapid scaling up. To stay on track for net zero, the region needs to ramp up deployment immediately, with efforts concentrated in this decade. Between 2024 and 2030, Asia Pacific needs to add an annual average of 342GW of solar capacity under the ETS and 510GW per year under the NZS. This translates to a 23% increase under the ETS and 84% jump under the NZS against actual solar capacity installed in 2023.

Figure 20: Installed solar capacity in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

- **China's** uptake of solar grows rapidly until the mid-2030s in both scenarios, before tailing off. Installed capacity increases from 680GW in 2023 to just under 4TW by 2050 in our base-case ETS. To reach net zero, China's uptake of solar grows a further 29% over the ETS by 2050 to an astonishing 5.1TW. Small-scale solar systems make up 60% of the solar capacity installed in the ETS. In the NZS, utility-scale projects make up the majority, with just over half of the total installed capacity by 2050. Solar constitutes around 30% of China's generation in both the ETS and NZS, up from less than 6% in 2023.

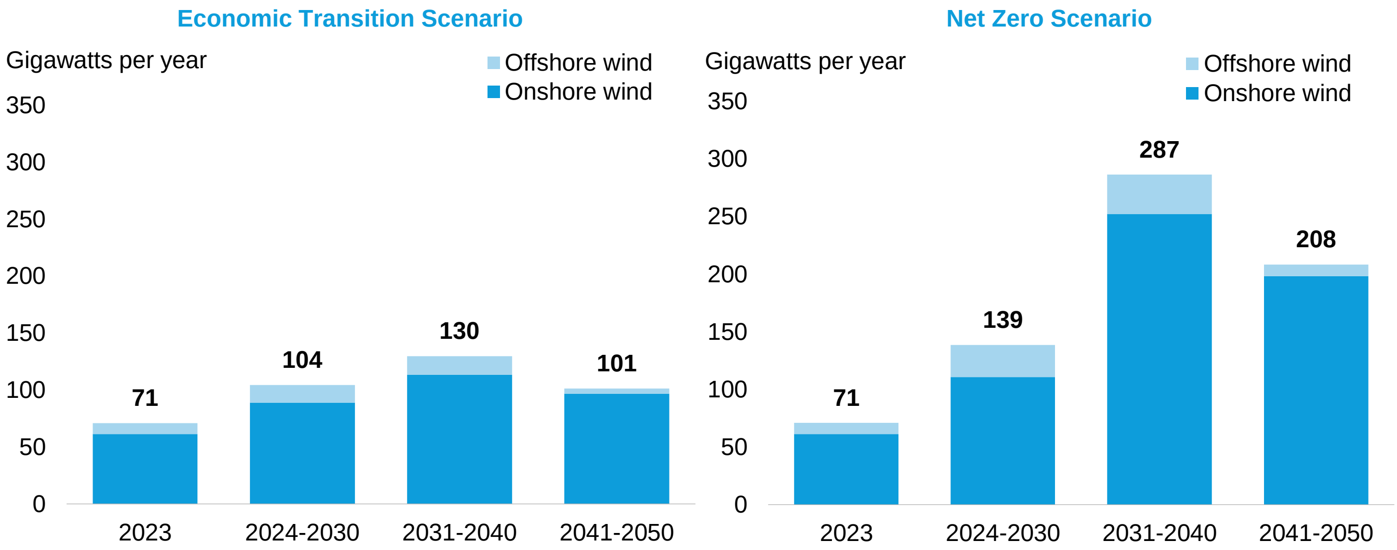
- **India's** uptake of solar accelerates over every decade in both scenarios, increasing from a base of 94GW in 2023 to 1.1TW in 2050 under the ETS. The NZS sees a near-tripling of the installed capacity under the ETS, rising to nearly 3.2TW by mid-century. Utility-scale installations dominate solar build in both scenarios by 2050, making up 66% of capacity in the ETS and 88% in the NZS. Solar accounts for 33% of supply in the ETS and 46% in the NZS by 2050, up from 8% in 2023.
- **Indonesia's** installed solar capacity grows from a low base of just 0.5GW in 2023 to 333GW by 2050 in the ETS. To reach net zero, uptake must more than double the level in our base case to 758GW by 2050. Like India, the rate of uptake accelerates every decade and utility-scale installations make up most of the capacity in both scenarios, with 78% in the ETS and 91% in the NZS by 2050. Solar is responsible for 38% of Indonesia's supply in the ETS mid-century. In the NZS, it accounts for nearly half of the country's generation.
- Solar capacity in **Vietnam** accelerates during the 2030s and 2040s, growing from 21GW in 2023 to 274GW by 2050 in the ETS, and 512GW in the NZS. The country already has a larger base of solar capacity than many of its peers in Southeast Asia due to a generous feed-in tariff program it ran a few years ago to encourage uptake. Utility-scale projects make up 66% of installed solar capacity in the ETS and 82% in the NZS, by 2050. Solar accounts for around 40% of Vietnam's total output by 2050 in both scenarios, up from 8% in 2023.
- **Japan's** installed solar capacity growth accelerates during the 2030s but slows down significantly after 2040. Uptake rises from 90GW in 2023 to 194GW by 2050 in the ETS and 366GW in the NZS. In the ETS, small-scale systems account for 60% of the buildout, as land constraints and technology costs hinder the implementation of utility-scale solar photovoltaic (PV). In the NZS, these large-scale projects make up 68% of total solar capacity by 2050. Solar is responsible for 21% of Japan's electricity generation by 2050 in the ETS and 24% in the NZS, up from 9% in 2023.
- **South Korea** sees its installed solar capacity grow from 27GW in 2023 to 77GW by mid-century in the base case. Uptake in the NZS more than doubles that in the ETS to 194GW by 2050. Utility-scale solar projects make up most of the capacity in both scenarios to 2050 – 59% in the ETS and 84% in the NZS. Overall, solar accounts for 15% of South Korea's generation in the ETS by 2050. This rises to 26% under the NZS – up from 5% in 2023.

Wind

Wind development in most Asia Pacific markets, except for China and India, pales in comparison to solar due to relatively poorer wind resources, especially for onshore projects. Developing a wind project is also more complex than solar and requires a longer development time frame, and therefore needs more time to build up domestic capabilities.

However, wind generation is helped by the technology's higher capacity factors and more stable generation profile compared to solar. Although solar capacity additions between 2024 and 2050 outstrip wind, the latter grows to become Asia Pacific's single-largest source of power. By 2050, wind supplies 34% (9,126TWh) of the region's electricity demand under the ETS and 40% (18,329TWh) under the NZS, from 7% (1,018TWh) in 2023.

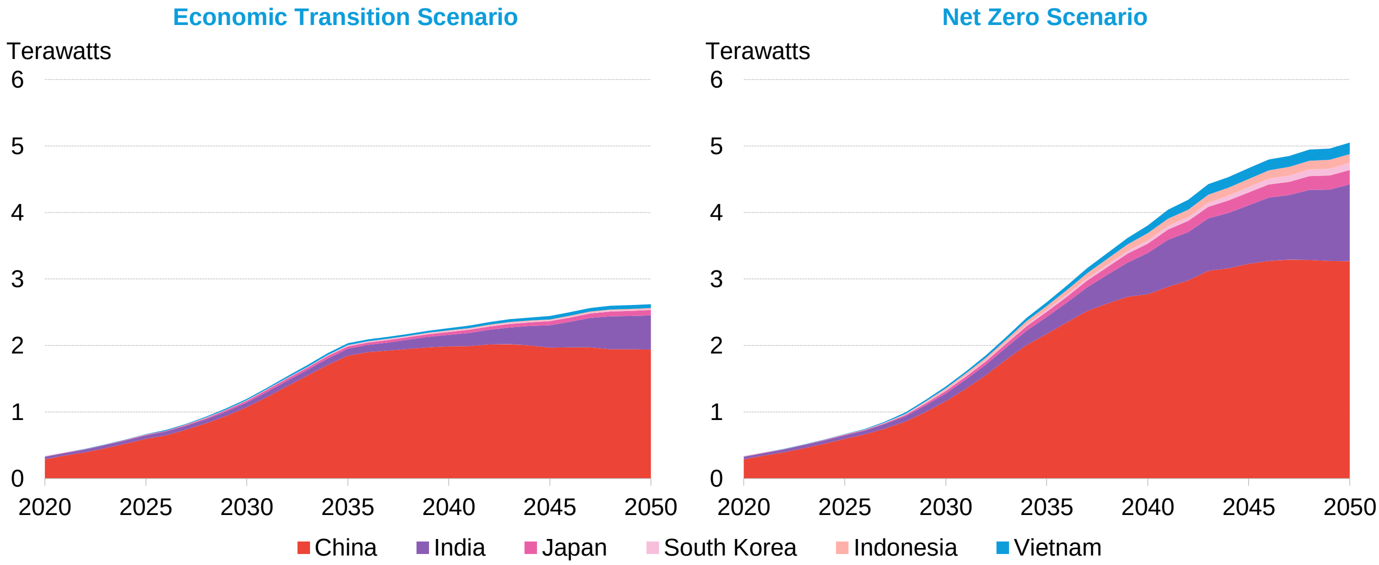
Figure 21: Annual average wind capacity addition in Asia Pacific by time period, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

While solar additions take center stage between 2024 and 2030, the momentum for wind development in Asia Pacific also needs to pick up over the remainder of this decade and peak in the 2030s. Under the ETS, the region sees an average of 104GW of wind capacity added each year to the end of the decade, an almost 50% increase against the 71GW installed in 2023. Under the NZS, almost twice as much wind capacity needs to be added every year over 2024 to 2030 compared to 2023 levels, and annual new build doubles again in the 2030s to 139GW.

Figure 22: Wind capacity installed in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

- **China's** installed wind capacity increases from 457GW in 2023 to 1.9TW by 2050 in our ETS and 3.3TW in the NZS. In both scenarios, build accelerates in the 2030s, but slows down in the 2040s, particularly in the ETS. Onshore wind accounts for around 89% of installed capacity by 2050 in both scenarios, with offshore wind accounting for the rest. Wind makes up 40% and 47% of China's generation in the ETS and NZS by 2050, respectively, up from 9% in 2023.
- **India's** cumulative wind capacity grows 45GW in 2023 to 515GW by 2050 in the ETS, and double that in the NZS with nearly 1.2TW. Offshore wind only begins to be built in 2030 in both scenarios and it is a small fraction of additions. By 2050, onshore wind represents 97% of total installed capacity in the ETS and 96% in the NZS. Wind makes up over 30% of India's generation in both scenarios by 2050, up from 4% in 2023.
- **Japan's** installed wind capacity grows from a relatively small base of 6GW in 2023 to 81GW in the ETS by 2050. NZS uptake is almost triple that in the ETS, with 215GW by 2050. Japan sees a much more even split between onshore and offshore wind capacity than other markets in both scenarios. Land constraints, existing policies, and relative costs give offshore wind the edge in the ETS as it accounts for 54% of wind build by 2050. In the NZS, onshore wind accounts for 54% of total wind capacity deployed by mid-century. Wind makes up 29% of Japan's generation in the ETS, rising to almost half in the NZS by 2050 – up from less than 2% in 2023.
- **Vietnam's** uptake of wind jumps from 5GW in 2023 to 56GW by 2050 in the base case by 2050. In the NZS, uptake is triple that in the ETS, reaching 171GW by mid-century. Onshore wind makes up 79% of wind installations in Vietnam by 2050 in both scenarios. Wind accounts for 19% of Vietnam's generation in the ETS by 2050 and 30% in the NZS, up from just 2% in 2023.
- **Indonesia's** wind power capacity grows from a low base of less than 0.2GW in 2023 to 13GW by 2050 in the ETS. Uptake is limited by challenging economics and low wind speeds. However, the NZS calls for a 10-fold increase over the ETS, reaching 133GW by mid-century. Onshore wind makes up about 80% of wind installations in both scenarios. Wind constitutes just 4% of Indonesia's generation in the ETS by 2050. In the NZS, it makes up a larger share of the power mix with 14%.
- Like Indonesia, Vietnam, and Japan, **South Korea** also experiences a significant divergence in installed wind capacity between the two scenarios. Cumulative build increases from 2.1GW in 2023 to 110GW in the NZS – more than six times the 17GW in the ETS. Like Japan, a combination of relatively lower costs, government policy and land constraints drive offshore build to make up the majority of wind installations by 2050 in South Korea with 65%. In the NZS, onshore wind deployment accelerates to comply with the carbon budget, accounting for 67% of wind capacity by 2050. Wind is responsible for just 8% of total output in South Korea under the ETS by 2050. In the NZS, its share of supply rises to 35% by mid-century.

Technology improvements and cost declines drive the economic transition

Technological improvements, economies of scale in manufacturing capacity, and increased financing and development capabilities have substantially lowered solar and wind costs over the last two decades.

Solar is the poster child for the power of the experience curve in energy: the price of modules has fallen from $30 per watt in 1976 – which, adjusted for inflation, is $129 in today's money – to $0.125 at the end of 2023 and $0.113 per watt as of April 2024 (Figure 23). Wind turbine price developments have been less dramatic, but per-megawatt prices for turbines in 2023 were typically half those in 2014.

Figure 23: Price of solar modules and cumulative deployment, 1976-2023

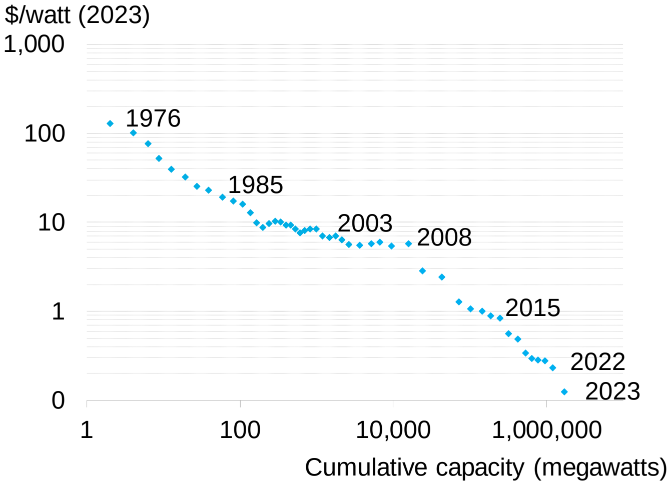
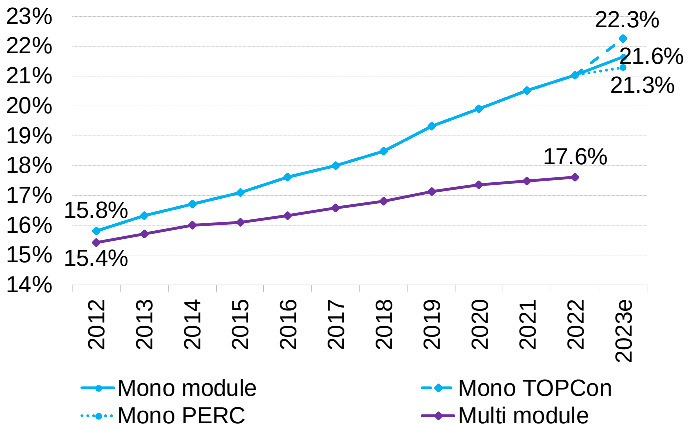
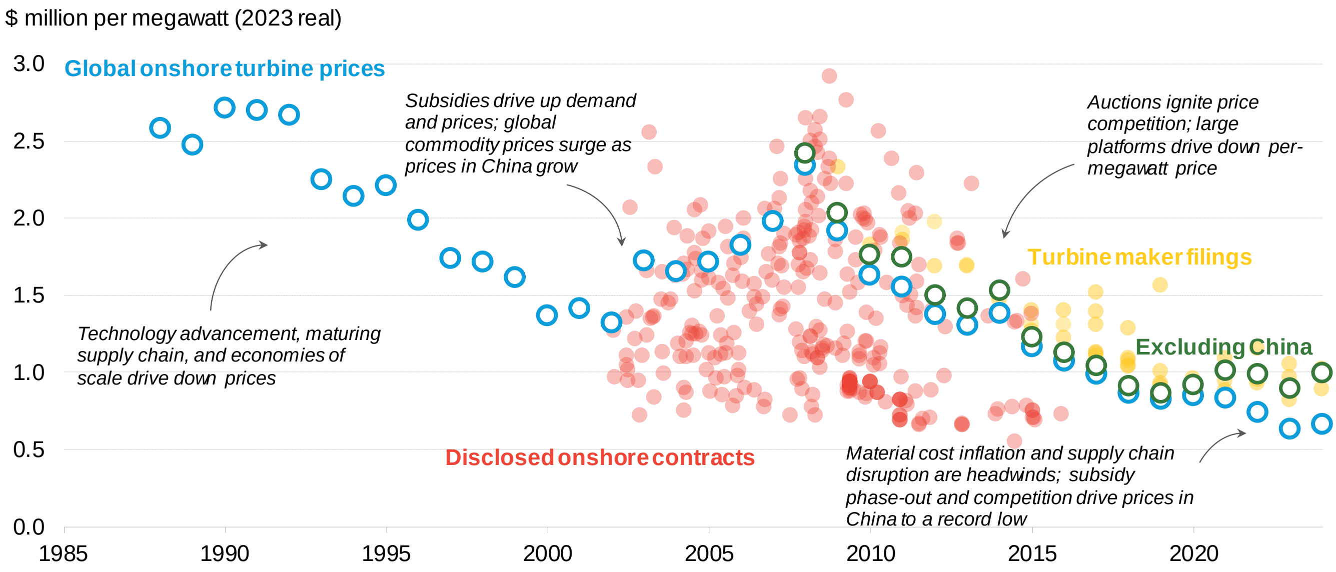


Figure 24: Average efficiency of commercial solar modules



Source: BloombergNEF Note: TOPCon is tunnel oxide passivated contact. PERC is passive emitter rear contact.

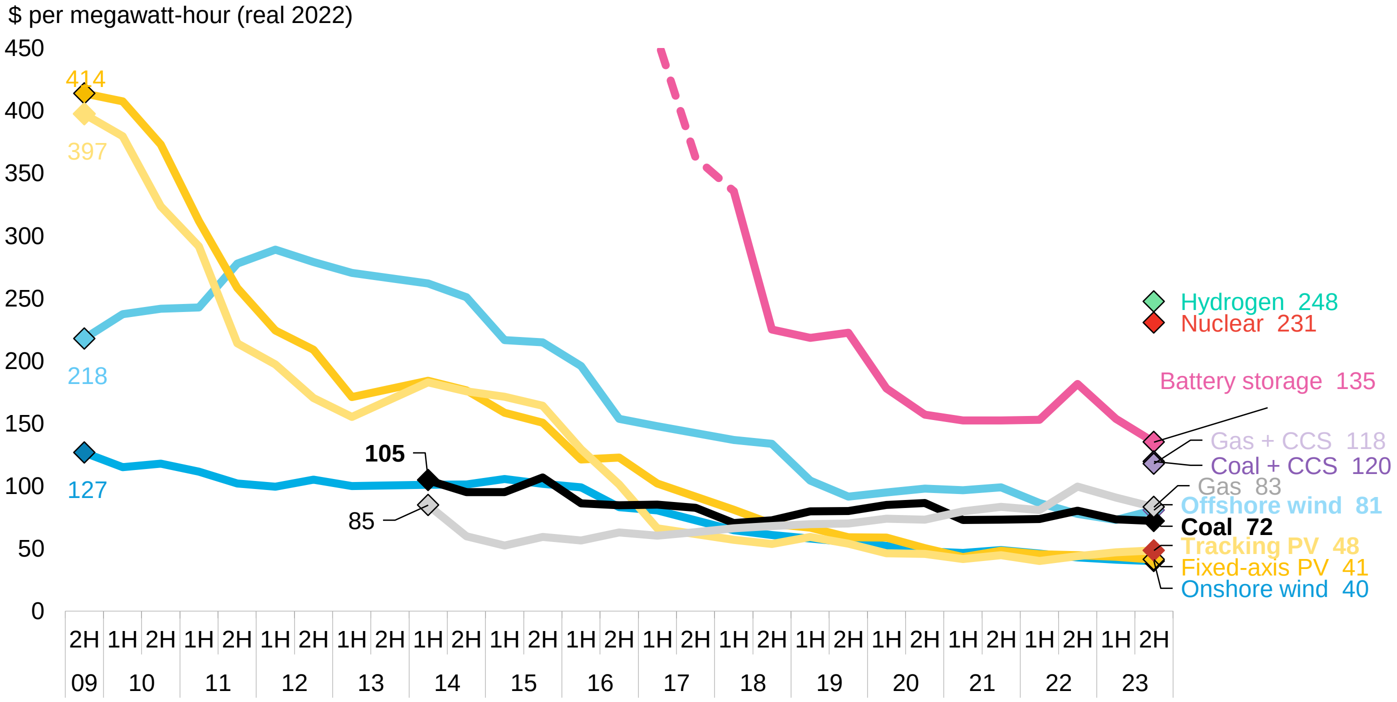
Figure 25: Price of wind turbines worldwide, and key drivers



Source: BloombergNEF, Lawrence Berkeley Laboratory (LBL), ExTool (Germany and Denmark), turbine maker company filings. Note: Pre-2008 global onshore wind prices are based on data from ExTool, LBL and contracts compiled by BNEF. Turbine manufacturer data points calculated from company filings, typically 'order intake value per order intake megawatt'. Prices converted to US dollars using exchange rate on day, or year, of order, then values were converted to real 2023 dollar terms. Prices grouped by contract signing date and company filings' publication date.

Today, a new wind or solar plant is the cheapest source of bulk power generation in markets, accounting for 59% of global electricity generation. New wind and solar projects are also outcompeting existing fossil fuel power plants in markets that account for more than half of total electricity generation and global GDP.

Figure 26: Global levelized cost of electricity benchmarks

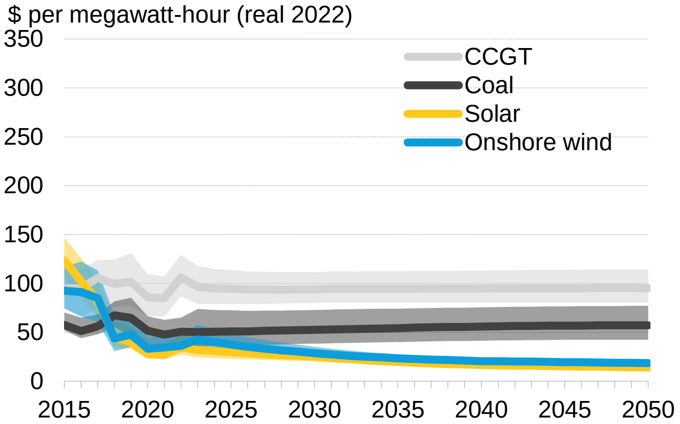


Source: BloombergNEF. Note: Levelized cost of electricity figures are as of 2H 2023. The global benchmarks are capacity-weighted averages using the latest country estimates – apart from nuclear, hydrogen and carbon capture and storage (CCS), which are simple averages. Offshore wind includes offshore transmission costs. Coal- and gas-fired power include carbon pricing where policies are already active. PV is solar photovoltaic. Dotted line for battery storage reflects LCOE values implied by historical battery pack prices and solid line reflects values from project data.

The total levelized cost of electricity has risen over the last three years due to upticks in commodity prices stemming from inflation, supply chain disruptions, and interest rate increases. However, generally clean technologies are still far cheaper than they were a decade ago, and costs are once again falling (Figure 26).

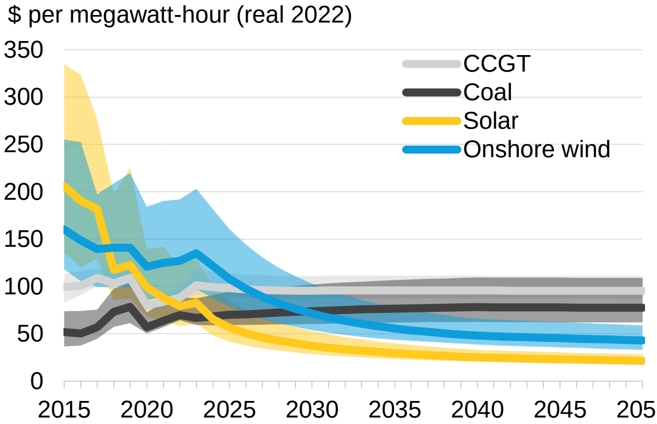
The cost-competitiveness of renewables against fossil fuel generators varies around Asia Pacific. Mainland China and India deliver renewables at some of the lowest costs worldwide. China is home to the cheapest onshore wind ($33 per megawatt-hour) and offshore wind ($63/MWh), due to its manufacturing capabilities. The $39/MWh cost of fixed-axis PV in China is only second to those in India, at $34/MWh. In contrast, a new coal plant is still the most cost-competitive in some markets such as Indonesia and Japan, but variable renewables are on track to becoming the cheapest source of bulk electricity generation.

Figure 27: Levelized cost of electricity for new-build power plants in India



Source: BloombergNEF. Note: CCGT is combined-cycle gas turbine.

Figure 28: Levelized cost of electricity for new-build power plants in Indonesia



Source: BloombergNEF. Note: CCGT is combined-cycle gas turbine.

This transforms the optimal least-cost portfolio of generation technologies for many Asia Pacific markets, from one where fossil-fuel based plants provide the majority of baseload requirement to one where renewables dominate. The greater proportion of variable renewables in the dispatch mix will require power systems to operate very differently.

Figure 29: Indonesia’s hourly generation in a week in July 2024, Economic Transition Scenario

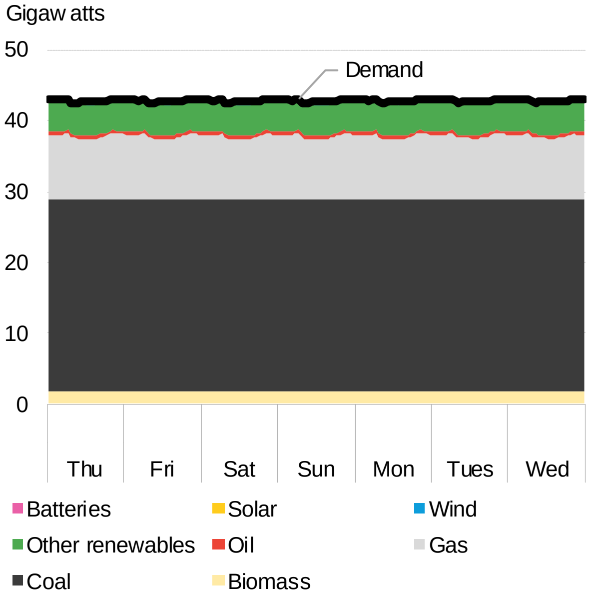
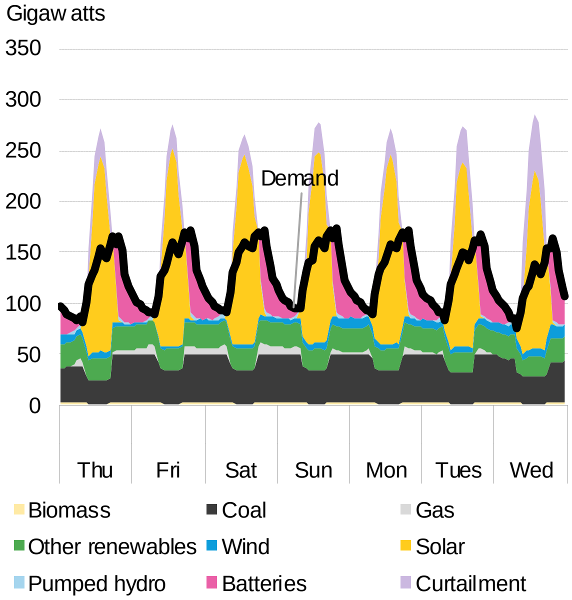


Figure 30: Indonesia’s hourly generation in a week in July 2050, Economic Transition Scenario



Source: BloombergNEF. Note: ‘Other renewables’ include hydro and geothermal.

The economic limits of additional renewables deployment

In both the ETS and NZS, renewable energy penetration tends to grow more slowly or level off after a certain point. While solar and wind are edging out other generation technologies on a cost basis, further build of these technologies is constrained by their basic properties and the limited flexibility of the power system.

New wind and solar plants generate energy at the same time of day as existing plants, often exceeding power demand even with many loads shifted to provide system flexibility. This means that new renewable energy plants have high curtailment and therefore low useful capacity factors, pushing up their per-megawatt-hour cost until they are no longer worth building.

Markets reach a saturation point when adding more variable renewables does not lower overall system cost further, though this point is dynamic and these markets will build more renewables again when overall power demand increases, flexibility rises, or existing power plants decommission.

Figure 31: Solar electricity penetration, selected Asia Pacific markets

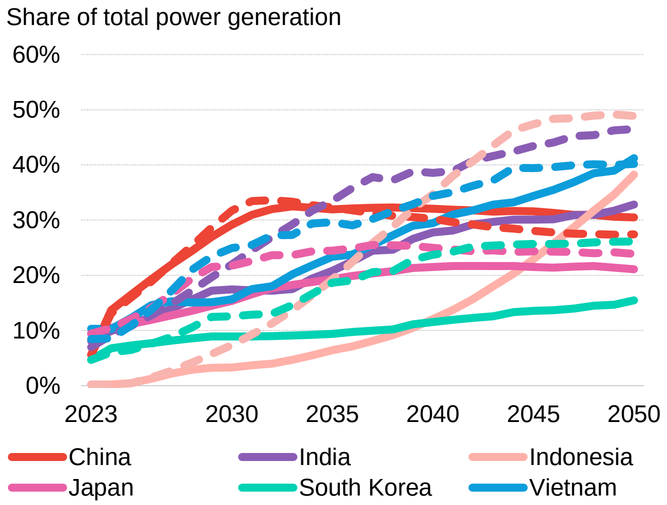
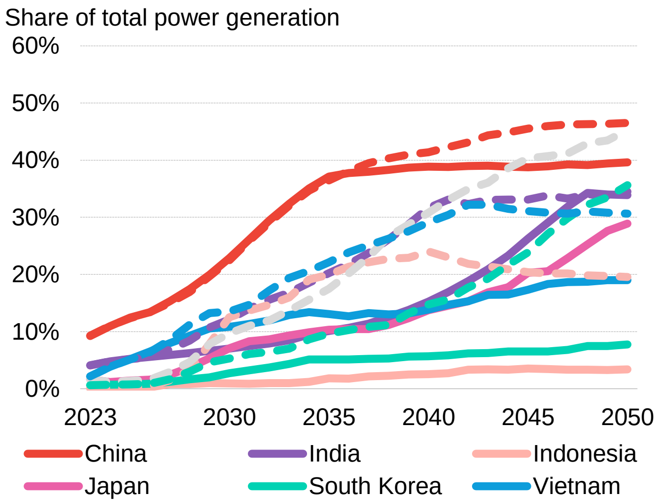


Figure 32: Wind electricity penetration, selected Asia Pacific markets



Source: BloombergNEF. Note: Dashed lines indicate Net Zero Scenario, solid lines indicate Economic Transition Scenario. Generation figures are modeled results.

3.3. Dispatchable renewables

To achieve net zero, countries need to leverage all available low-carbon energy resources. While solar and wind dominate renewable capacity expansion in the region, hydro, geothermal, and nuclear also play crucial roles in markets where they are available. All three technologies can help boost clean power penetration that is required under the various net-zero pathways.

However, the technologies are also complex and expensive to develop with costs varying widely between sites. Nuclear often also faces safety concerns from local communities. Projects often experience delays due to developmental challenges such as land acquisition and permitting issues. This underscores the importance of policy support from the government for the success of these technologies.

Hydro

Hydro already plays a prominent role in the power systems across Asia Pacific with total installed hydro capacity in the region reaching 554GW in 2023. The region's hydro capacity is highly concentrated in just a few markets. China leads with a wide margin at 377GW of hydro capacity as of 2023, or 68% of the region's capacity, followed by India (47GW) and Vietnam (23GW). However, hydro generation globally is facing growing volatility due to extreme weather events that frequently coincides with the summer months and higher power demand.

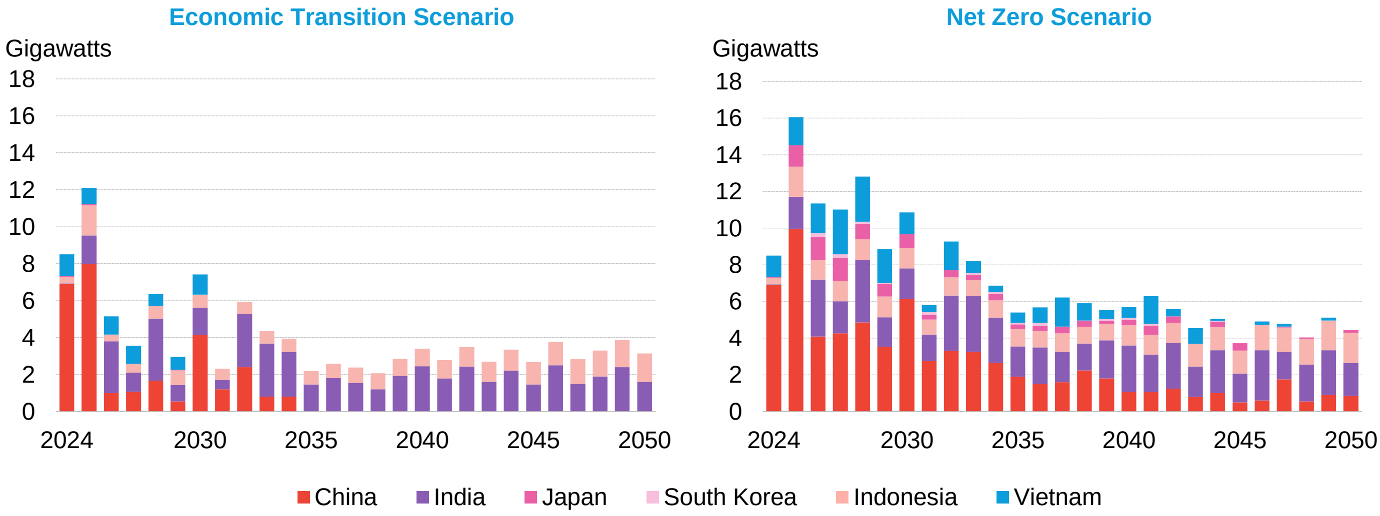
Hydro power costs are highly site specific and are often not cost competitive against solar and wind. Under the ETS, hydro capacity in the region grows just 20% from 2023 levels to reach 666GW in 2050, mostly driven by existing pipeline projects in each respective countries and government ambitions. Three countries – China, India and Indonesia – account for 92% of all new hydro capacity addition between now and 2050 under the economic-led pathways.

In **China**, hydro capacity grows 8% from 2023 levels to 405GW in 2050, driven by the country's current pipeline of under-construction projects. Over the next three decades, **India**'s hydro capacity more than doubles from 47GW in 2023 to 96GW in 2050, the largest hydro capacity addition in gigawatt terms among all Asia Pacific countries.

In **Indonesia**, hydro capacity grows more than 4.5 times from 2023 levels to 32GW in 2050 under the ETS, driven by the state-owned utility's ambition for the technology under the country's electricity supply plan (or locally known as the Rencana Usaha Penyediaan Tenaga Listrik or RUPTL), which strongly governs the technology choice for power sector development in the country. Indonesia has turned its attention to hydro to support growing industrial demand in the country.

Hydro has been central to **Vietnam's** power system, accounting for 27% of installed capacity and 36% of electricity generation in 2023. Under the ETS, the country adds just 6.5GW of additional hydro capacity between now and 2050 as growing demand is met through lower-cost solar and wind generation.

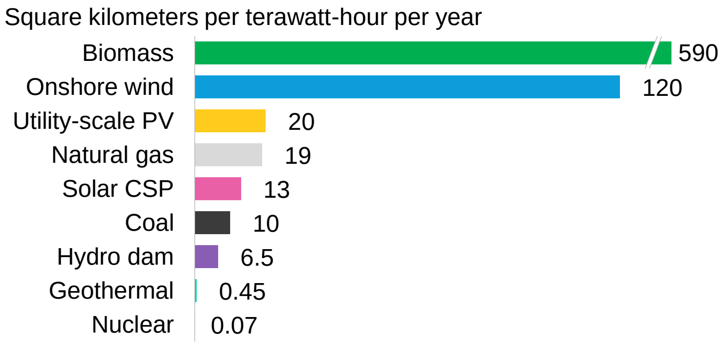
Figure 33: Annual hydro capacity addition in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

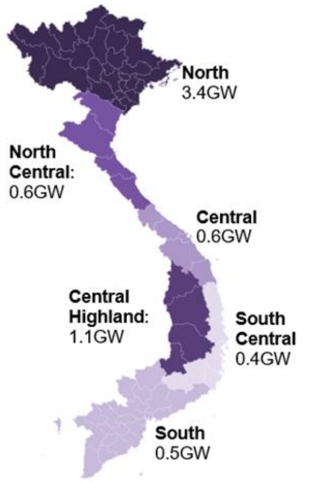
Greater electrification under the NZS sees power demand in Asia Pacific reach 45,619TWh in 2050, a tripling from 2023 levels, and 1.6 times higher than under the ETS. This increases the challenge of reducing power sector emissions in the region and requires countries to tap on more available hydro resources than under the ETS. The lower land-use intensity for hydro power generation can also help countries such as South Korea, Japan, and Indonesia circumvent land constraint challenges associated with solar and wind projects and increase their share of renewable energy in their respective power mix.

Figure 34: Land-use intensity of electricity production



Source: Lovering J et al (2022), BloombergNEF. Note: Includes total of generation and extraction site areas. PV is solar photovoltaic. CSP refers to concentrated solar power.

Figure 35: Vietnam's planned hydro capacity addition between 2023 and 2030 by region



Source: Implementation Plan for Power Development Plan VIII, Power Development Plan VIII, BloombergNEF.

Under the NZS, Asia Pacific sees 249GW of additional hydro capacity from 2024 to 2050, more than double the new build under the ETS. Under the net-zero pathway, **China** sees its hydro capacity growing 19% (71GW) to reach 448GW in 2050 with new capacity added annually. This contrasts with the economics-led pathway where no new hydro capacity is expected post-2034 as the technology is edged out by more cost-competitive renewables. **India** sees 55GW of hydro capacity addition over the next three decades under the NTS, just 11% (or 5.6GW) higher than under the base case.

Indonesia adds 30GW of hydro capacity between 2024 and 2050 under the NZS, 20% more than the 25GW in the ETS. Under the NZS, **Vietnam** adds 24GW of hydro capacity between 2024 and 2050, more than 3.5 times the 6.5GW in the ETS. Hydro plays an important role in balancing regional power supply and demand in Vietnam's northern region, which has abundant hydro resources and is where power demand growth is expected to be the strongest. The north has also relatively weaker solar and wind resources compared to other regions, affecting the cost-competitiveness of projects there.

Under the NZS, hydro plays a much larger role even in countries that see little to no hydro additions under the ETS. Notably, **Japan** adds 11GW of hydro capacity over 2024 and 2050 under the net zero pathway compared to just 0.1GW under the ETS. Similarly, **Malaysia, Thailand, and the Philippines** (grouped under 'Other Southeast Asia' in this report) adds 21.4GW of hydro capacity under the NZS compared to just 1.9GW under the economics-led pathways. However, **South Korea** bucks the trend and sees hydro playing a negligible role under both scenarios. Under the NZS, only just 1.5GW of hydro capacity is added in South Korea between 2024 and 2050.

Geothermal

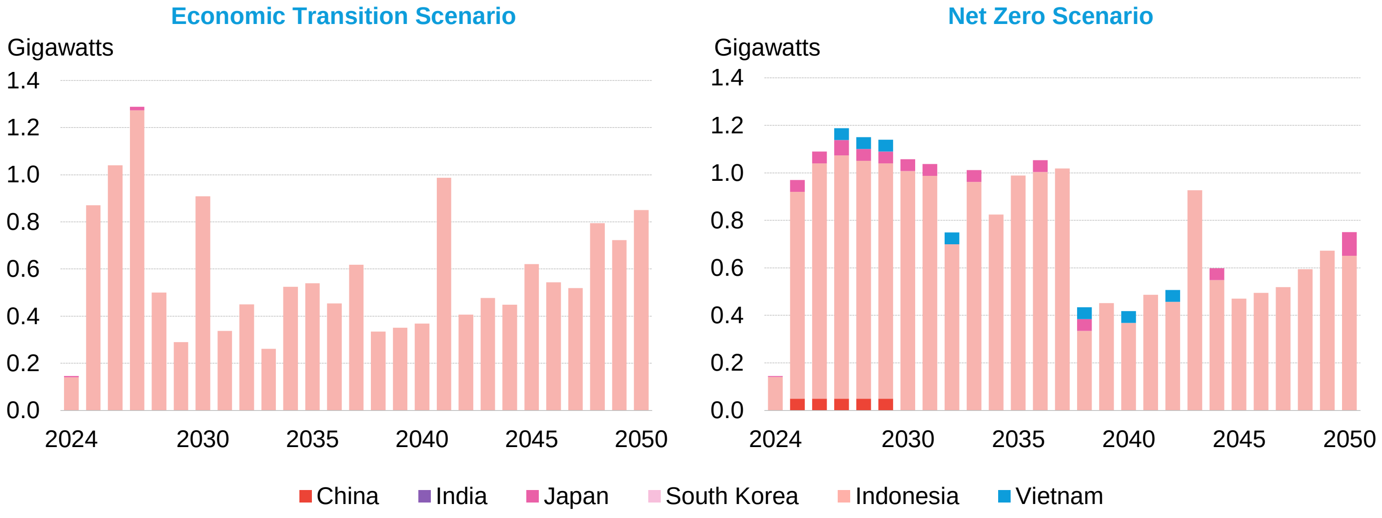
Geothermal is a highly country-specific solution, limited by geological characteristics. In Asia Pacific, most of the geothermal potential and hence capacity addition under both the ETS and NZS is limited to Indonesia. Like hydro, geothermal development requires both ambition and support from the government.

Geothermal has been a focus of the Indonesian government as a non-intermittent generation source that holds the potential to green the country's power system without too much disruption to grid operations. The country currently has 2.6GW of operational geothermal capacity as of 2023, the second-largest in the world after the US at 4GW. Under the ETS, 15.6GW of geothermal capacity is added in Indonesia between 2024 and 2050, rising to 19.5GW under the NZS.

Despite the country's experience in the technology and the involvement of state-owned enterprises in project development, geothermal projects in Indonesia often experience delays and fall behind the government's target. Geothermal projects bear high early-stage development and exploration risks. which can deter private investors.

Indonesia also regulates the power purchase agreement tariffs that project developers could potentially negotiate. Frequent changes to this regulation in the past damped investor confidence for these long-term projects. The tariff levels have also been deemed too low for projects to be economically feasible. Risk-sharing facilities such as that being explored by the Philippines with the Asian Development Bank could help to de-risk resource exploration and encourage investments in the sector.

Figure 36: Annual geothermal capacity addition in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

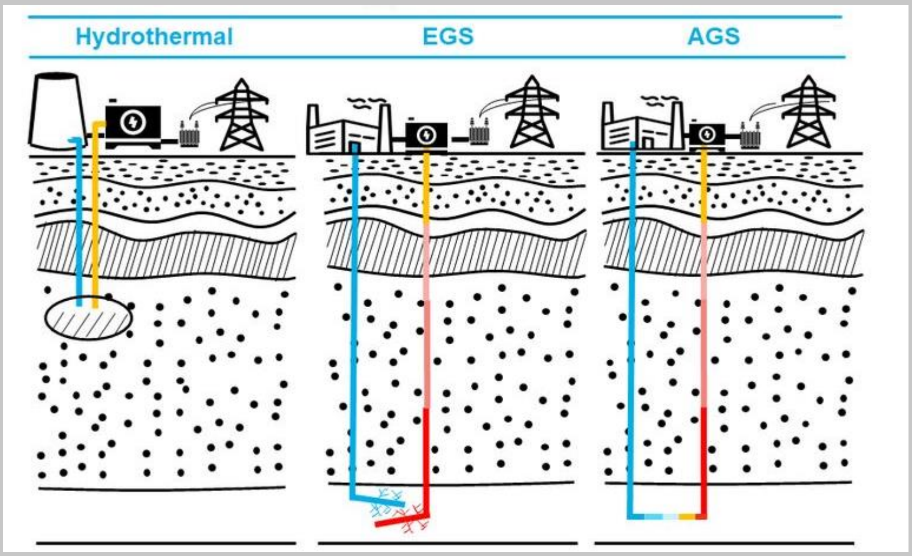
Next-generation geothermal technologies

Geothermal power is a firm, clean energy source that has played a marginal role in global power systems to date. Traditionally, geothermal developments are largely confined to hydrothermal sites – shallower resources with high temperatures, naturally occurring water, and sufficient rock permeability. In these systems, a fluid absorbs energy as it flows through hot rocks. However, these easily accessible resources are highly constrained, with most located near volcanoes.

Next-generation geothermal technologies such as enhanced geothermal systems (EGS) and advanced geothermal systems (AGS) are gaining traction, led by developments in the US. These technologies aim to unlock sites where there is a lack of water and permeability for nature exploitation.

- EGS relies on artificial permeability by fracturing rocks to create a man-made reservoir. This unlocks sites with hot rocks but lack natural permeability.
- In AGS, a closed-loop system consisting of long section of sealed pipes is drilled into the rock, through which a fluid circulates and is heated.

Geothermal technology illustration



Source: BloombergNEF, ClearPath. Note: EGS is enhanced geothermal system. AGS is advanced geothermal system.

While interest in geothermal is seeing a resurgence globally, the new-generation technologies are still in early-stage development and face affordability, financing, and technical scalability challenges. The potential role of these emerging geothermal technologies in Asia Pacific is dependent on global technological advancements.

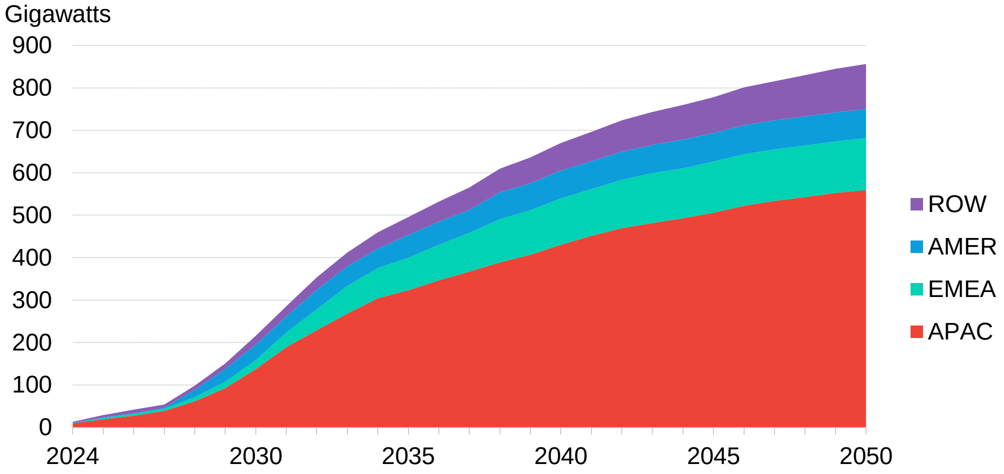
Nuclear

As net-zero ambitions increase, the idea that nuclear energy can contribute to decarbonization is becoming more widely accepted. Some 25 nations pledged to triple nuclear capacity by 2050 at the COP28 summit in Dubai last year. Indeed, expansion is the trend: several countries are either building reactors for the first time or are planning to do so.

Nuclear power capacity expansion is concentrated in Asia Pacific

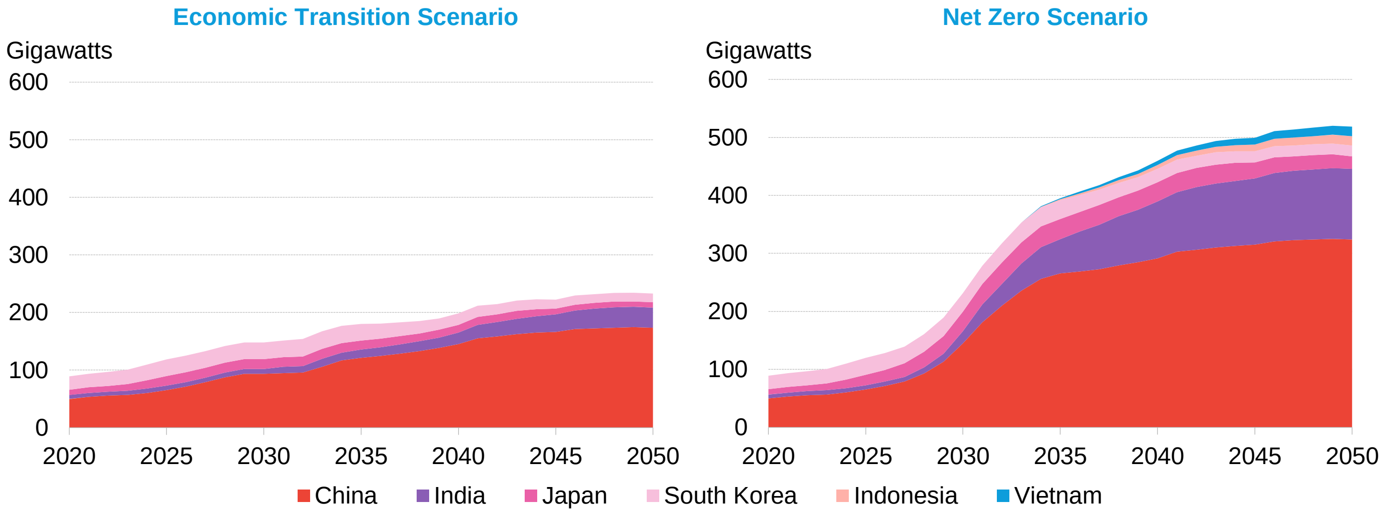
Today, the nuclear fleet is more or less evenly distributed across Asia Pacific; the Americas; and Europe, the Middle East and North Africa. Each of the three regions is home to 107-116GW of capacity in 2023, with another 45GW in the rest of the world. However, electricity demand growth and full-power sector decarbonization means that nuclear capacity expands most in the region in the NZS. Some 559GW, or 65%, of the 856GW nuclear capacity added between 2024 and 2050 are concentrated in Asia Pacific.

Figure 37: Cumulative nuclear power capacity additions by region, Net Zero Scenario



Source: BloombergNEF. Note: ROW is rest of the world. AMER is the Americas. EMEA is Europe, the Middle East and Africa. APAC is Asia Pacific. Includes conventional nuclear and small modular reactor capacity.

Figure 38: Installed nuclear capacity in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

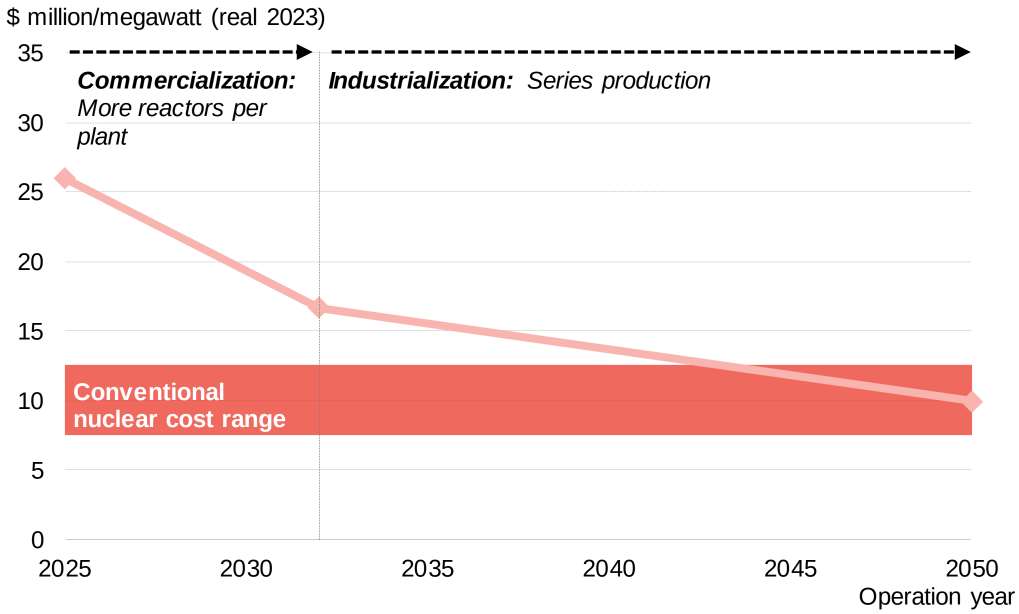
- The momentum behind **China's** current nuclear capacity expansion continues in both scenarios. China overtakes the US as the largest market for nuclear, with the size of the fleet growing from 57GW in 2023 to 173GW in the ETS and 324GW in the NZS by 2050. Only 5% of the installed nuclear capacity in China by mid-century is made up by small modular reactors (SMRs), due primarily to higher costs. Nuclear makes up 9% of China's generation in the ETS and 11% in the NZS in 2050, up from 5% in 2023.
- **India's** more than fivefold increase in electricity demand under a net-zero pathway would require 122GW of nuclear capacity by 2050 compared with the 7GW fleet operating today, or 35GW in the ETS. Only 2% of the fleet is made up of SMRs in 2050 in the NZS. The technology's share of India's generation mix increases from 5% in the ETS to 9% in the NZS by 2050, compared to just 3% in 2023.
- **Japan's** installed nuclear capacity falls from 12GW in 2023 to 9GW in the ETS as nuclear transitions to assume more of a backup role for cheaper renewables. In the NZS, nuclear capacity increases to 22GW by mid-century. SMRs only provide 0.6GW of the 22GW of nuclear capacity in the NZS by 2050. Nuclear makes up around 7% and 9% of Japan's generation mix in the ETS and NZS by 2050, respectively, compared to 8% in 2023.
- Like in Japan, **South Korea's** nuclear fleet declines from 25GW in 2023 to 15GW in the ETS and 18GW in the NZS in favor of cheaper renewables. SMRs make up just 0.8GW of total capacity by mid-century in the NZS. Nuclear makes up around 15% of South Korea's generation in both scenarios by 2050, down from 29% in 2023.
- Southeast Asian countries (Indonesia, Malaysia, Thailand, and Vietnam), emerge as new entrants in nuclear in the NZS, thanks to rapid growth in electricity demand. Collectively, these countries install 87GW by 2050, from having none today.
- In the NZS, nuclear first enters the power system in **Indonesia** and **Vietnam** in 2034. Installed capacity of nuclear in the NZS growth to 16GW and 17GW by 2050 in Indonesia and Vietnam, respectively. In Indonesia, only 0.2GW of the total nuclear installed capacity by mid-century is SMR technology. In Vietnam, all the nuclear build is made up of conventional nuclear technology. Nuclear makes up around 7% of the generation mix in both Indonesia and Vietnam by 2050 in the NZS.

Small modular reactors play a marginal role due to high costs

Small modular nuclear reactors, or SMRs, power plants made up of several sub-300MW reactor units, are a promising technology due to their modularity and anticipated quicker construction time relative to conventional nuclear plants. However, first-of-kind projects have struggled in North America, and it is unclear whether these new reactor projects will experience delays and cost overruns typical of conventional nuclear plant construction in Europe and the US.

For first-of-a-kind projects, capital expenditure on a per-MW basis can be a factor of 2 to 3.5 times that of large-scale conventional nuclear plants (Figure 39). Future costs for SMR power plants are therefore dependent on the ability to mass-produce small-reactor units in factories. Mass production will require a large market to absorb these units. Given the high first-of-a-kind costs, subsidy support is vital to kick-start the industry this decade and to deploy the tens of gigawatts in the subsequent years, providing scale to the manufacturing base.

Figure 39: Capital expenditure trajectory for small modular reactors



Source: BloombergNEF. Note: Early capex estimates are based on company estimates for current first-of-a-kind demonstration projects. Estimates for nth-of-a-kind reactors are based on company statements, plus BNEF's interpretation of contingencies. In the absence of any completed projects, all estimates are based on company targets and subject to uncertainty.

Nuclear fusion offers the potential of 24/7 clean electricity without radioactive waste

While fission – the process current nuclear power plants rely on – involves splitting atoms of heavy elements to produce energy, fusion involves bringing together lighter elements such as two different isotopes of hydrogen, typically deuterium and tritium to release energy in the same manner as the sun. Deuterium is common and can be extracted from seawater. Tritium is rare but can be created in fusion reactors. Fusing these together creates helium and in the process releases a huge amount of energy.

The advantage of fusion over fission is the potential to generate significantly higher volumes of clean energy without the challenges of radioactive waste. A fusion reactor would also need very limited amount of deuterium and tritium.

However, fusion is incredibly difficult because the particles do not naturally want to fuse together and capturing the energy is challenging because the energy, though vast, fades almost instantly. Until recently, nuclear fusion research and development had been mainly the domain of national labs, with the largest effort to-date being the International Thermonuclear Experimental Reactor (ITER) in Southern France supported by 35 nations.

Over the last decade, private sector efforts in support of fusion have increased significantly. BNEF tracks more than 45 private sector companies presently pursuing fusion. Private sector investment in fusion jumped to more than $2.5 billion in 2021 up from approximately $300 million in both 2019 and 2020. Some fusion startups have also signed power purchase agreements with potential customers: in 2023, Helion signed an agreement with Microsoft for a 50MW fusion power plant set to start generating electricity by 2028. General Fusion has an even more ambitious timeline, aiming for “scientific breakeven” by 2026. While other startups such as Helical Fusion aims for “steady-state fusion reactor up and generating electricity within the next 10 years.” Fusion experiments thus far have succeeded in generating net positive energy for relatively short bursts of time. If by the mid-2030s, current efforts succeed in developing a reactor design capable of providing continuous net positive energy generation, then it is possible for fusion technology to have an impact on emission reductions required by mid-century.

As fusion technology remains unproven, BNEF’s New Energy Outlook modeling does not consider its utilization.

3.4. Energy storage

Power system flexibility rises in importance as renewable penetration grows. Short-term duration energy storage such as batteries provide crucial supply-side flexibility that supports wind and solar as the main drivers of power sector decarbonization in the ETS and NZS. Longer-duration storage technologies, like pumped hydro, also play a crucial balancing role in some markets, but are often more expensive to build and can be subject to significant cost overruns and delays. Today, pumped hydro projects are driven largely by government ambitions and plans, such as in South Korea, China, and Vietnam.

Batteries

Advances in battery technology and economies of scale from the rise in EV adoption is driving down lithium-ion battery costs, making it increasingly economic to install for power applications. Asia Pacific’s battery storage assets are concentrated in China, which accounts for 75% of the region’s installed battery storage capacity. A growing number of provincial governments in China are mandating the co-location of energy storage assets with renewable energy plants in response to the central government’s 2025 installed battery storage capacity target of 40GW. Australia (2.2GW), Japan (3.5GW), and South Korea (3.1GW) collectively account for 24% of the region’s battery storage assets as of 2023.

In contrast, in several highly regulated power markets, such as in Indonesia and Vietnam, the lack of a regulatory framework to allow for the participation of battery storage assets in the power market has held back installations. As of 2023, both markets have a negligible amount of battery storage capacity.

Table 7: Installed battery storage capacity in selected Asia Pacific markets by scenario – 2023 versus 2050

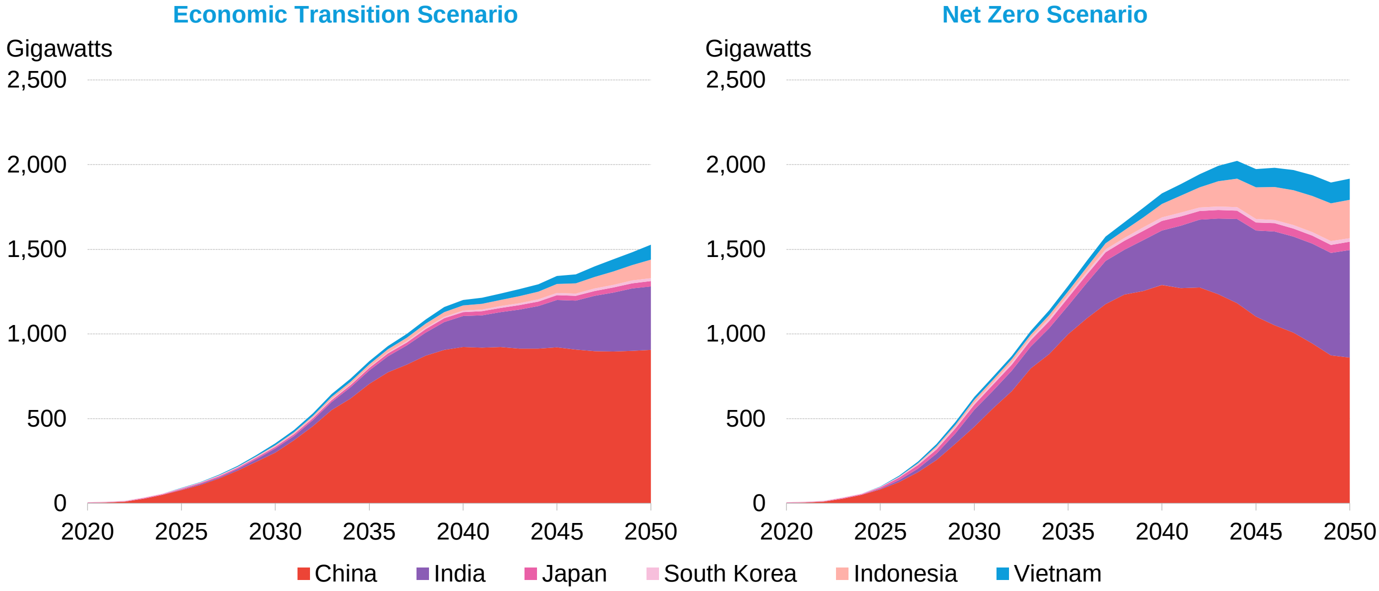
		Economic Transition Scenario		Net Zero Scenario	
Gigawatts	**2023**	**2050**	**Multiplier versus 2023**	**2050**	**Multiplier versus 2023**
China	27.1	905.2	x33.4	860.1	x31.8
India	0.2	375.5	x2,465.1	636.0	x4,175.5
Indonesia	0.0	109.9	x10,175.5	226.1	x20,932.2
Japan	3.5	31.6	x9	48.1	x13.7
South Korea	3.1	16.6	x5.4	21.7	x7.1
Vietnam	0.0	88.1	x5,762.6	124.4	x8,134.4
Asia Pacific	**36.3**	**1,760.8**	**x48.5**	**2,226.8**	**x61.3**

Source: BloombergNEF. Note: 'Other Southeast Asia' includes Malaysia, Thailand and the Philippines. Refer to Appendix A for the full list of geographies included under 'Other Asia Pacific.' Utility-scale batteries are assumed to be four-hours in duration. Small-scale batteries are assumed to be approximately 2.5 hours in duration.

Under both the ETS and NZS, all Asia Pacific markets see a large scale-up of battery storage assets to provide the required power system flexibility as renewable penetration increases. In countries with a wholesale power market such as Australia, growing price volatility stemming from the higher volume of solar generation in the day is increasing arbitrage opportunities for battery assets, improving their economics.

- **China** sees a dramatic increase in deployed battery storage capacity out to 2040 in both scenarios. Between 2024 and 2040, installed capacity increases 34-fold under the ETS and 48-fold under the NZS to hit 923GW and 1,289GW, respectively. After 2040, China's battery capacity hovers between 900GW and 920GW under the ETS. In the NZS, installed battery capacity declines slightly as renewables begin to get saturated and demand becomes more flexible to land at 860GW in 2050. Under both scenarios, utility-scale batteries account for about 82-83% of total battery capacity.
- **India** sees momentum for battery storage deployment pick up significantly in the 2030s to reach 183GW in the ETS and 322GW in the NZS by 2040. By 2050, battery build grows to 375GW in the ETS and 636GW in the NZS. Utility-scale batteries make up 80% of the total capacity by 2050 in the ETS and 88% in the NZS. Unlike China, India does not see installed battery capacity peak before 2050.
- **Indonesia** sees a much slower uptake of battery storage compared to its peers in the region. Installed battery capacity grows from a negligible level to 29GW by 2040 and 110GW by 2050 under the ETS. Under the NZS, buildout accelerates to provide backup support for renewables, reaching 78GW by 2040, before almost tripling again to 226GW by mid-century. Utility-scale systems dominate battery deployments in Indonesia under both scenarios, making up 85% of total capacity by 2050 in the ETS and 93% in the NZS.

Figure 40: Battery storage installed in key Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: Utility-scale batteries are assumed to be four-hours in duration. Small-scale batteries are assumed to be approximately 2.5 hours in duration.

- Like Indonesia, **Vietnam's** installed battery capacity today is negligible. However, deployment occurs at a faster pace compared to Indonesia. By 2030, battery capacity hits 12GW in the ETS and 17GW in the NZS. By 2040, installed capacity grows by more than 3.5-fold to 64GW in the NZS – double the total in the ETS as supply-side flexibility requirement scales in line with increasing renewable penetration. Between 2041 and 2050, installed battery capacity again nearly doubles under the NZS to land at 124GW in 2050.
- Under the ETS, **Japan's** deployment of batteries triples to 10GW by 2030 and 32GW by 2050 from its current installed base of 3.5GW. Under the NZS, battery deployment over the next seven years increases ninefold to hit 31GW by 2030 – the total size of Japan's 2050 battery storage portfolio under the ETS. Like China, Japan's battery storage capacity peaks in 2040 at 57GW under the NZS before declining 15% to 48GW by 2050 driven by the retirements of assets. Small-scale batteries dominate deployments across both scenarios in Japan, making up 79% of the total capacity installed in the ETS by 2050 and 52% in the NZS, due to the relatively higher penetration of small-scale PV in both scenarios compared to other Asia Pacific markets due to land constraints.
- Battery uptake in **South Korea** under the ETS is slow before 2030, increasing by just 1GW out to 2030 from the current base of 3GW in 2023. Post-2036, deployment accelerates to reach 17GW by mid-century. The uptake trajectory is vastly different under the NZS. Between now and 2030, the country's battery storage capacity grows 3.5-fold to 10GW by 2030, then more than doubles by 2050 to hit 22GW. Existing dispatchable capacity in the form of nuclear, for example, reduces the need for batteries to support renewables growth in South Korea under both scenarios, thus limiting uptake. The main driver of battery deployment differs between the scenarios. In the ETS, small-scale batteries account for 58% of South Korea's battery build by 2050. In the NZS, utility-scale energy storage systems form a larger share, making up 56% of total battery buildout by mid-century.

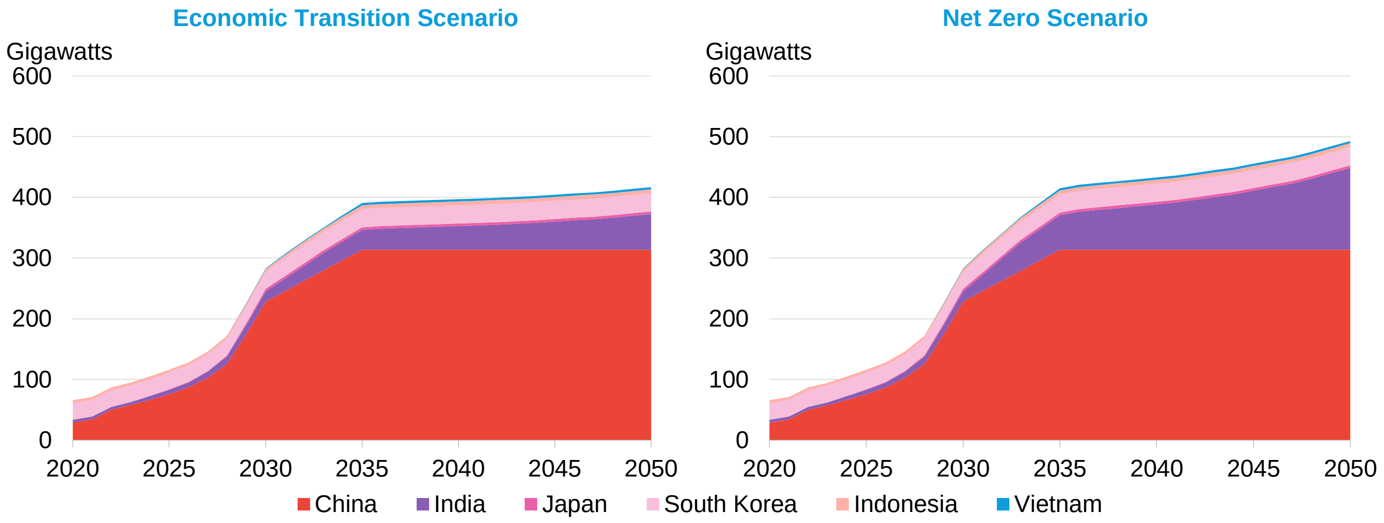
Pumped hydro

Pumped hydro storage provides flexibility on longer timeframes than batteries, making them a key enabler to net zero, but their deployment is limited compared to battery storage. This is because of the technology's high capital costs and long construction lead times, with projects often suffering from cost blowouts and development delays. For example, in Australia, the federal government's flagship Snowy 2.0 pumped hydro project was initially mooted to cost A$2 billion ($1.33 billion) and come online in 2024. It is now estimated to cost in the region of A$12 billion and expected to be commissioned in 2029. The suitability of pumped hydro can also vary greatly based on location – limiting uptake to specific geographies in our modeling.

Total installed pumped hydro capacity is fairly consistent across both scenarios in Asia Pacific, driven largely by each country's current project pipelines and government targets. While some countries have the resources to expand beyond the current pipelines, further expansion is often constrained by economic competitiveness and ecological concerns.

- **China's** pumped hydro capacity is identical in both scenarios, driven by the current project pipeline established by the government. Capacity increases from 58GW in 2023 to 314GW by 2035 and then stabilizes at that level.
- In **India**, clean power project developers like Greenko and Adani have made big bets on pumped hydro storage[3] and the federal government has also identified storage potential of 176GW across the country. In the ETS, capacity increases to 59GW by 2040 from 5GW today. It rises nearly 30-fold in the NZS, with over 135GW installed.
- In **Indonesia**, **Vietnam**, **Japan**, and **South Korea**, uptake of pumped hydro is relatively limited and identical across both scenarios. In Indonesia and Vietnam, pumped hydro first enters the power system in 2025 and 2029, respectively. By 2050, Indonesia installs 4.2GW of pumped hydro, and Vietnam installs 3.6GW. In Japan, pumped hydro capacity increases just 9% to 30GW over 2023-2050. Uptake is fairly limited in South Korea, increasing from 4.7GW in 2023 to 6.5GW by 2050.

Figure 41: Pumped hydro installed in key Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: Pumped hydro assets are assumed to be six-hours in duration.

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[3] For more, see *Big Bets on Pumped Hydro Storage for India Decarbonization* (web | terminal).

Most long-duration energy storage technologies are still nascent and too costly

The need for long-duration energy storage, or LDES, is rising as renewable energy generation grows to address intermittency over longer periods. BNEF defines LDES as technologies that target durations of at least six hours.

BNEF’s inaugural LDES cost survey, published in May 2024, covers a wide variety of storage technologies – electrochemical, thermal, and mechanical. Compared to lithium-ion batteries, most are still nascent and expensive. Duration, project size, and location all affect costs. Gravity energy storage has the highest average capital cost at $643 per kilowatt-hour, whereas thermal energy storage and compressed air storage are the least expensive technologies, at $232/kWh and $293/kWh, respectively.

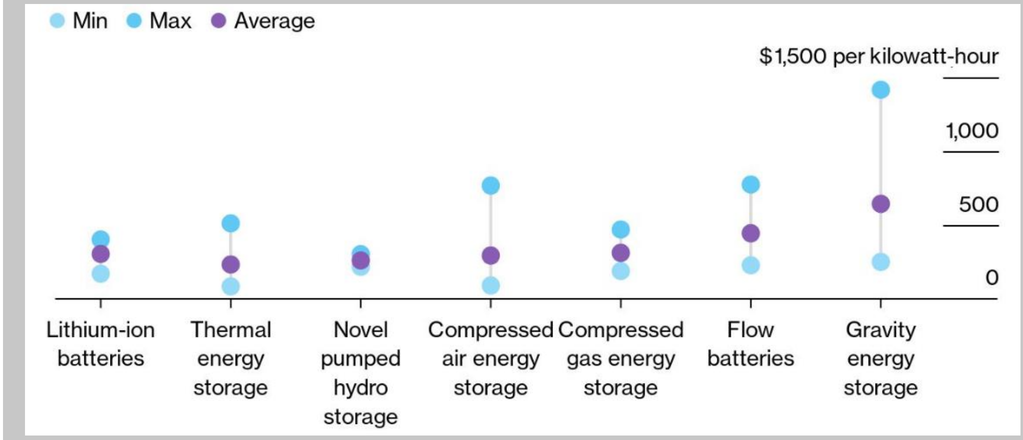
A key feature of a good LDES technology is that energy-related and power-related costs are substantially decoupled, so the energy storage duration can be scaled up cheaply. Compressed air energy storage and thermal energy storage have the lowest energy-related costs, making them better positioned for long-duration applications. Flow batteries, especially those based on vanadium, may only be able to aim for mid-duration (for example, up to 12 hours) storage applications due to their high energy-related costs.

Beyond capital expenditure, LDES technologies differ significantly in performance characteristics that impact lifetime costs and suitability for applications. They typically feature a long cycling life and low degradation compared to lithium-ion batteries, though many companies do not have years of operational data. Drawbacks include low roundtrip efficiency and low energy density, which makes their siting less flexible.

Ongoing advances in technology and deployment experience will improve the feasibility and performance of these storage options for long-duration applications. Favorable policies may be essential to drive early adoption and accelerate their commercialization.

Generally, BNEF does not expect LDES technologies to attain the same rate of cost reduction as lithium-ion batteries. They are unlikely to replicate the economies of scale seen for lithium-ion batteries, which have been aided by massive EV demand.

Fully installed energy storage system capital costs by technology



Source: BloombergNEF. Note: Values shown in real 2023 dollar terms. Costs for projects delivered between 2018 and 2024 and durations between one and 20 hours. For novel pumped hydro, storage costs for projects delivered between 2018 and 2030. Lithium-ion battery costs for a four-hour duration system in 2023.

3.5. Power grids

Net-zero power grid investment happens in two waves

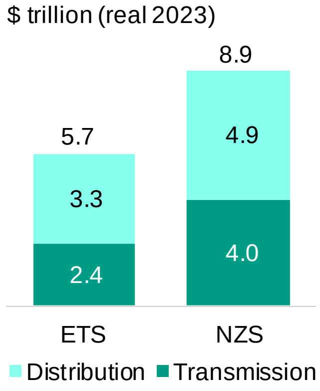
The shift to renewable energy and the electrification of road transport, buildings and industry necessitates a concurrent overhaul of the power grid. Global annual power grid investment in both the base-case ETS and the NZS rises, reaching two to three times historical annual investment, which has hovered around $300 billion between 2020 and 2023.

Across Asia Pacific, grid investment in the NZS accelerates through this decade, with annual spending growing 2.3 times to about $370 billion by 2030. This represents a compound annual growth rate of 15% in investment needed to stay on track for net zero between 2024 and 2030 (Figure 43). From 2030, the growth rate slows, peaking at $380 billion in 2041.

The spending profile to 2050 is characterized by two discrete cycles of investment. The **first wave** of investment, between 2024 to 2035, is driven by a rapid buildout of renewables. Solar and wind assets are often sited based on land and resource availability, but these sites frequently lack grid access or are far from densely populated centers, necessitating investment for grid buildout. A **second wave** of investment from 2035 to 2050 is driven by economic growth and new demand sources – such as EVs and hydrogen electrolyzers – rather than power generation.

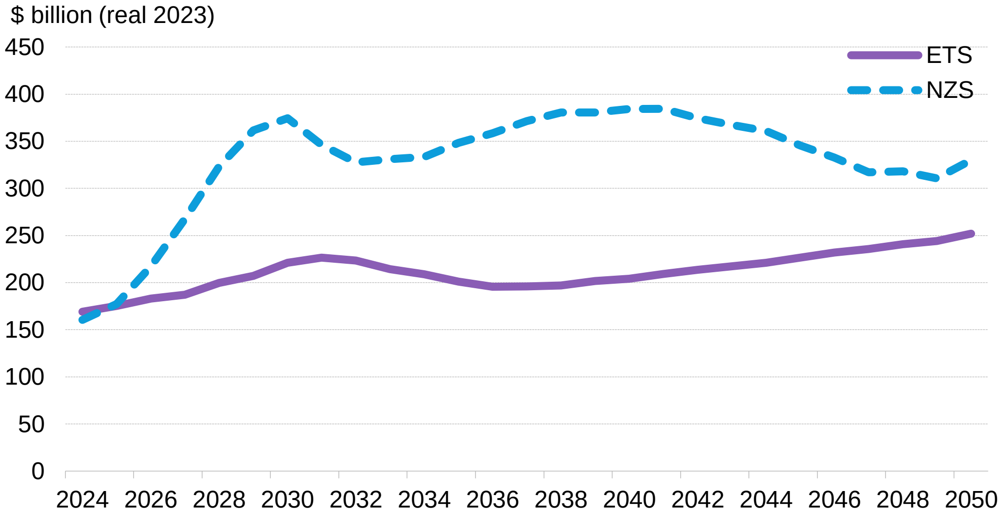
Cumulative capital expenditure on grids in Asia Pacific by 2050 is $8.9 trillion in the NZS – 1.6 times as much as the 5.7 trillion invested in the ETS (Figure 42). The ETS shows a more modest rise in grid investment this decade, reaching only $221 billion per year by 2030 or a 5% compound annual growth rate. Investment in the ETS continues to rise through to 2050, eventually reaching $252 billion per year.

Figure 42: Cumulative grid investment in Asia Pacific 2024-2050, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NZS is Net Zero Scenario.

Figure 43: Asia Pacific's annual power grid investment outlook, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: ETS stands for Economic Transition Scenario, NZS is Net Zero Scenario.

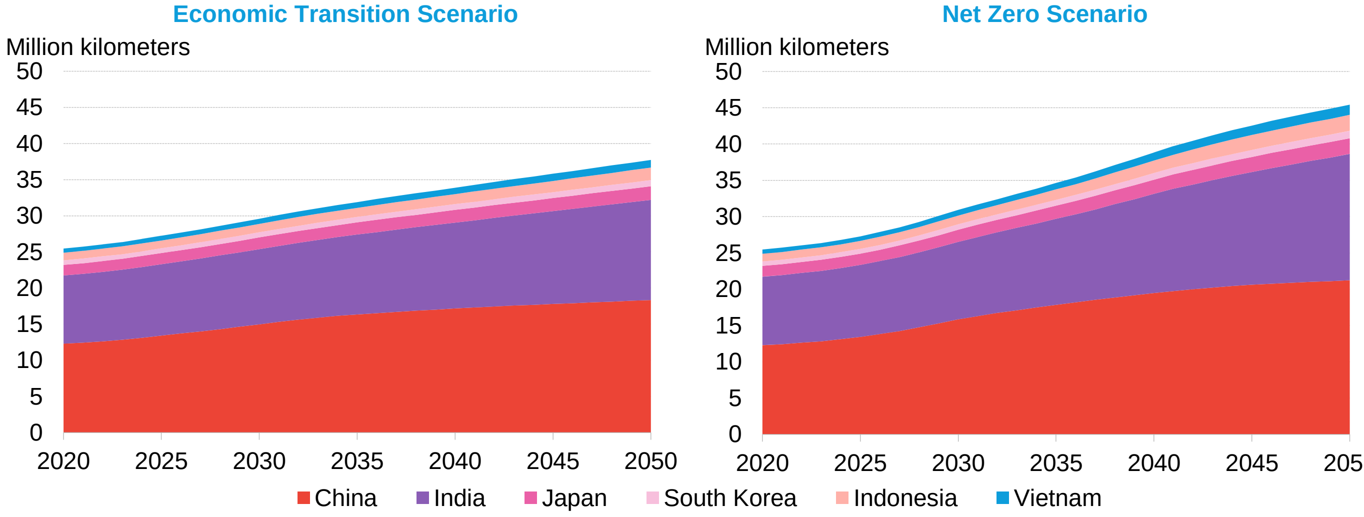
A larger power grid is required to support the energy transition

The length of **China's** grid reaches 18.3 million kilometers by 2050 in the ETS, up 40% from 13.1 million kilometers in 2024, after a cumulative investment of around $3.0 trillion. In the NZS, China's grid length reaches 21.2 million kilometers by mid-century, or about 16% more than in the ETS. This comes at a cumulative cost of $4.3 trillion, around 42% higher than in the ETS. Annual grid investment averages at $160 billion in the NZS, peaking in 2030 at $244 billion – more than double the investment in 2024.

India's grid expands from around 9.8 million kilometers today to 13.9 million kilometers by 2050 in the ETS – a 42% increase – at a cost of around $870 billion. To reach net zero by 2050, India's grid length reaches 17.4 million kilometers, around 26% more than in the ETS. Total grid investment in the NZS is $1.6 trillion over 2024-2050 – an 84% premium over the ETS driven by almost a tripling in spending on new connections and a doubling in grid reinforcements to accommodate the acceleration in renewable energy uptake and demand growth. India's annual grid investment in the NZS peaks in 2050 at $93 billion. Unlike most other markets, India's grid investment is not split into two discrete waves. The twin transitions of renewable energy integration and electrification of demand play out more coincidentally in India, resulting in a single larger and more prolonged cycle of grid investment.

In our base case, **Japan** sees its grid expand 24% from under 1.5 million kilometers in 2024 to 1.9 million kilometers by 2050 at a cost of around $370 billion. This increases 62% to $600 billion in the NZS as the length of the grid increases to almost 2.2 million kilometers by mid-century – 14% longer than in the ETS. Japan experiences two discrete waves of grid investment, in line with the global trend. In the first wave, annual investment peaks in 2027 at around $26.6 billion. The second wave of grid investment between 2035 and 2050 hits a record high of $27.2 billion in 2037.

Figure 44: Length of power grid in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

South Korea's grid length increases 31% from 649,770 kilometers in 2024 to 852,510 kilometers in 2050 under the ETS at a cost of around $160 billion. Grid investment over 2024-2050 rises 81% under the NZS to around $290 billion as the grid expands to cover over 1 million kilometers by mid-century – around 19% longer than in the ETS. In the first wave, investment peaks in 2028 at $15 billion, over 2.6 times greater than investment in 2024. In the second wave, investment hits the highest point in 2041 at around $13 billion.

In the ETS, **Indonesia’s** grid increases 58% from 1.09 million kilometers to 1.73 million kilometers over 2024-2050 at a cost of $250 billion. In the NZS, the grid stands at more than 2.2 million kilometers by mid-century – 28% longer than in the ETS. Cumulative grid investment increases to $408 billion in the NZS, which is 62% more than in the base case. Indonesia’s grid investment profile in the NZS resembles that of India; rather than two distinct waves, the country undergoes a single, prolonged grid investment cycle that peaks in 2043 at around $240 billion – nearly seven times more than in 2024.

In the base case, the length of **Vietnam’s** grid expands 74% from 610,711 kilometers to more than 1 million kilometers over 2024-2050 at a cost of nearly $170 billion. In the climate scenario, the grid expands by a further 31% to nearly 1.4 million kilometers by mid-century, more than double its length in 2024, at a cost of $300 billion. Annual grid investment in Vietnam peaks in 2040 at $207 billion under the NZS, almost six times more than investment in 2024.

Interest in inter-regional electricity links, particularly in Southeast Asia, is rising but challenges remain

BNEF’s modeling does not consider new interconnection between countries aside from those already constructed. Building interconnections across regions like Southeast Asia could enable markets with more limited local renewable resource potential, for example Malaysia and Singapore, to access areas with higher renewable resource potential, such as Laos and Vietnam. While an Association of Southeast Asian Nations (ASEAN) integrated power grid has been considered for decades, limited progress has been made until very recently.

Inter-regional interconnection to connect populous island nations to clean energy capacity sited in larger landmasses is an alternative decarbonization pathway, not modeled in our New Energy Outlook, that would encourage the more efficient use of land for renewable development. This is pertinent for markets in Asia Pacific and interest is growing in Southeast Asia (Figure 45).

Figure 45: Proposed number of grid interconnections across Southeast Asia as of 2023

Source: BloombergNEF. Note: Only new announcements and projects with development progress in 2023 are included. The numbers denote the different transmission projects announced and starting construction in the region. Vietnam-Laos transmission line started construction in 2023. Lines that are not numbered are from project number 1.

Notable recent announcements include the Brunei Darussalam-Indonesia-Malaysia-Philippines Power Integration Project (BIMP-PIP) inaugurated during Indonesia's 2023 ASEAN chairmanship to develop regional electricity trading among the countries involved. Singapore's Energy Market Authority has also granted conditional approvals for 4.2GW of clean electricity imports – 1.2GW from Vietnam, 2GW from Indonesia and 1GW from Cambodia – to meet its goal of importing up to 6GW of clean electricity by 2035.

In September 2024, Singapore and Indonesia announced an additional 1.4GW of clean electricity export projects from Indonesia to Singapore. Malaysia is also exploring the possibility of exporting 1GW of clean power to Singapore through an undersea cable by 2032. Vietnam has started construction of a 500-kilovolt transmission line to connect to a 600MW wind power project in Laos, with an expected commissioning in October 2024.

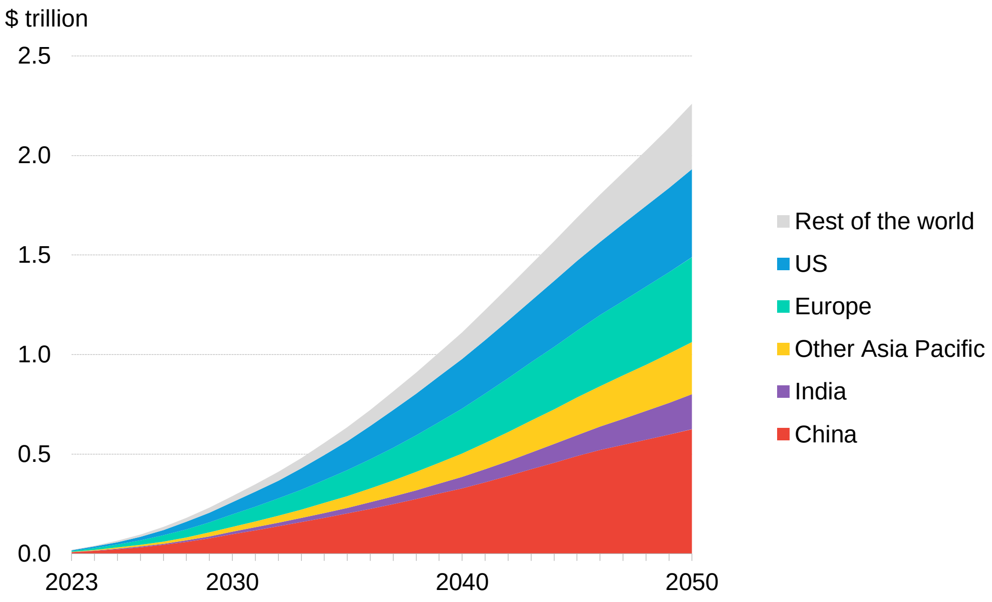
While these projects are promising, much still needs to be done to set up both the regulatory framework and the physical infrastructure required for an integrated ASEAN power grid.

Grid digitalization could enable more clean power on existing infrastructure

Utilities today are predominantly digitalizing grids to move more clean power on existing lines, ensure that power flows reliably, and integrate distributed energy resources (DERs). In Europe, digitalization is primarily an enabler of a flexible grid that can help balance supply and demand, supporting faster decarbonization. Utilities are deploying DER management systems (Derms) and demand response (DR) to monitor and optimize the use of DERs and provide flexibility services.

In the US, digitalization primarily targets resiliency, to ensure outages can be prevented, detected and restored in a timelier manner. Utilities are also using new technologies to avoid outages due to climate risks, such as wildfires and floods. For example, Iberdrola and Woza Labs partnered to develop digital solutions, such as satellite image analytics, to predict climate risks and potential grid damage.

Figure 46: Global cumulative capital expenditure on power grid digitalization by region over 2023-2050, Net Zero Scenario



Source: BloombergNEF. Note: Excludes smart meters.

Asia Pacific spends the most on grid digitalization by 2050

China accounts for the largest share of total digitalization capex between 2023 and 2050, at 28% or $625 billion. It has the largest national capacity of solar, wind and battery storage in 2050 in BNEF's NZS, and significant grid investment is needed to support this.

China has already shown substantial effort in grid digitalization. State Grid Corp. of China, one of the country's two major utilities, makes most of the software in-house. For example, the utility in January 2023 developed a digital three-dimensional model of its grid in Jiangsu province, using satellite imagery and artificial intelligence (AI). This includes 100,000 kilometers of overhead transmission lines and 280,000 towers.

Globally, most large utilities are adopting predictive maintenance, automating grid operations, and using drones for grid inspections. Europe is more active in digitalization than most Asia Pacific and US peers, which are piloting projects or inactive in some areas. However, we expect that Asia Pacific and the US will catch up as utilities grow in-house digital staff and co-develop technologies. For example, US-based utility Duke Energy and industrial player Honeywell International began jointly deploying DERs and virtual power plants (VPPs) to boost resilience against extreme weather among low- and middle-income homes in 2022. The US accounts for 21% of global digital spending over 2023-2030 in the NZS, versus Europe's 22% (Figure 46).

Sensors and software help maximize grid use

The real-time conditions of power equipment in the field are a blind spot for many utilities, particularly on the quickly growing distribution grid. Implementing software-based grid solutions, such as smart sensors and dynamic line ratings (DLRs), can increase visibility and offer new opportunities.

The main purpose of a DLR is to calculate the real-time rating of a power system element (such as a transmission line or transformer) using site specific conditions (for example, equipment temperature, air temperature and wind speed). These systems can provide an increase in equipment capacity if the real-time conditions are less severe than the conservative conditions assumed when calculating a static equipment rating. Utilities can then safely increase power line capacity to connect more renewables, more efficiently balance supply and demand to reduce congestion and improve resiliency by reducing outage response time.

Utilities across the world are increasingly turning to this solution. The Italian transmission operator, Terna, began implementing DLRs in 2013 as a stopgap measure for network upgrades. Uruguay's utility, Nacional de Usinas y Trasmisiones Eléctricas (UTE), reduced renewable curtailment with DLRs by increasing power flow during periods of high demand. South Korea's utility Korea Electric Power Corp. (Kepco) deployed DLRs on susceptible power lines that were causing outages.

Policymakers have been quick to recognize the benefits of smart grid sensors, which have led to regulation in several countries. The US Federal Energy Regulatory Commission (FERC) released a notice in February 2022 to identify ways to support DLR implementation – over 15 US utilities already use DLRs including Duke Energy, Xcel Energy and Arizona Public Service. In Vietnam, the World Bank partnered with the National Power Transmission Coordinator (NPT) in 2016 to identify regulatory parameters for deploying a dynamic rating initiative.

3.6. Hydrogen

Hydrogen, both direct and indirect consumption, becomes an important decarbonization vector in hard-to-abate sectors, such as shipping, steel, and aviation. However, hydrogen is not a silver bullet and is less competitive where low-carbon alternatives already exist or are emerging, due to its high costs. This includes the power sector, buildings, and the road transport sector. Electrification remains the most affordable decarbonization option where possible.

The buildout of the region's hydrogen production infrastructure in Asia Pacific needs to focus on electrolysis. Today, almost all ammonia and hydrogen produced is fossil-fuel based (typically referred to as gray hydrogen[4]) which offers no emissions reduction benefits. This necessitates the scale-up of renewable energy alongside hydrogen production to ensure sufficient affordable and clean power.

Hydrogen demand

Today, 59% of Asia Pacific's hydrogen is consumed as a feedstock for ammonia and methanol production, followed by 37% used by oil refiners for hydrotreating and hydrocracking crude oil. About 5% of the region's demand is used in iron oxide reduction.

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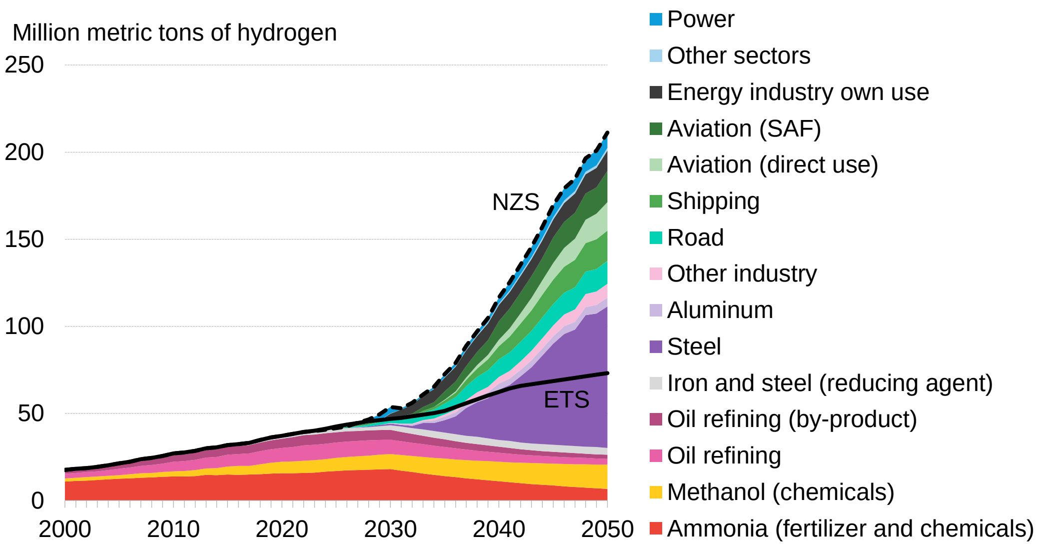
[4] Gray hydrogen is produced via steam reforming of methane or gasification of coal without CCS – the most common method today that releases large volumes of carbon emissions.

Hydrogen demand quintuples to 2050 under the NZS, growing from about 41 million metric tons (Mt) in 2024 to 211Mt by mid-century. Most hydrogen demand growth happens after 2030 due to the expected timing of cost reductions and the period needed to commercialize technologies like hydrogen-compatible gas turbines, boilers, and direct reduction furnaces.

The largest source of hydrogen demand in Asia Pacific is China, which accounts for over 40% of the region's consumption by 2050 in the NZS. China also benefits from having the lowest levelized cost of producing green hydrogen in the region by 2030 (Figure 47), in part due to lower costs of Chinese alkaline electrolyzers compared to other varieties.

Figure 47: Asia Pacific hydrogen demand by sector and application, Net Zero Scenario



Source: BloombergNEF. Note: Energy industry own use includes energy consumed to produce final energy carriers from primary energy carriers and energy industry own use. SAF is sustainable aviation fuel. Assumes gravimetric energy density of 140 megajoules per kilogram for hydrogen.

The sectors that rely most on hydrogen in 2050 under the NZS are those that are hardest to electrify, either because of the lack of commercially available electric processes, for example, in primary steel production, or because of the low gravimetric energy density of batteries, which limits their use in EVs over long distances in aviation, shipping and trucking (Figure 48). Wherever electrification is possible, it will be easier and cheaper. We therefore expect little or no demand from heating for commercial and residential buildings, rail transport, passenger road transport, petrochemicals, and cement production. Hydrogen plays a limited role in heavy road transport but has effectively been eliminated from our passenger vehicle outlook.

In shipping, hydrogen's high gravimetric energy density compared to batteries and ability to be produced at scale make it a key solution to decarbonize maritime trade. It fulfills 74% of the sector's energy demand in 2050.

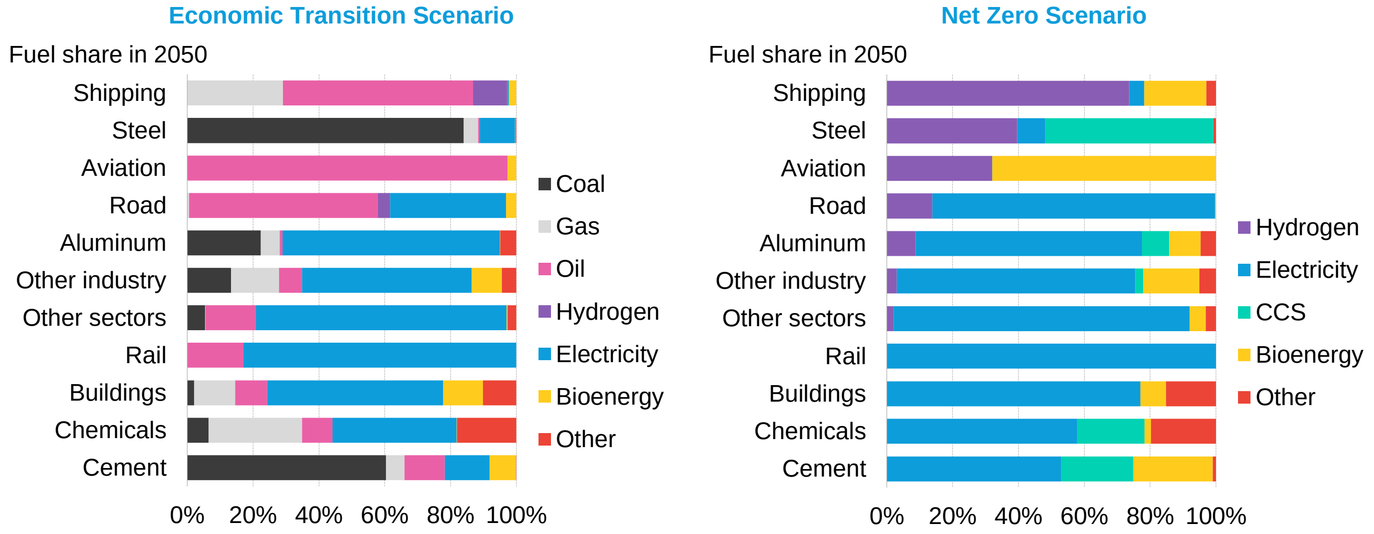
Similarly, in aviation, the fuel's high volumetric energy density makes aircraft fueled by pure hydrogen a suitable alternative for short- and medium-distance travel. However, its volumetric energy density is lower than kerosene, suggesting that aircraft may need to reduce cabin space or redesign to install hydrogen tanks to fly the same distance as a fossil fuel counterpart.

Liquid hydrogen is likely to be the only option for large passenger planes, such as regional turboprops and narrowbody aircraft. This poses various technical challenges around storage tanks, thermal management, and the fuel supply system, as hydrogen must be in a cryogenic state to be liquid. Hydrogen supply chains, including liquefaction, transportation and refueling, are required at or near many airports, as well.

On the other hand, aircraft fueled by sustainable aviation fuel (SAF) made with clean hydrogen can be used for longer distances. Electric airplanes, which can help decarbonize commuter routes, face challenges due to battery size and weight. In SAF, hydrogen is either used for cracking biogenic kerosene or as a feedstock for synthetic fuels.

Using hydrogen as a process fuel in iron oxide reduction can be an economic alternative to blast furnaces with carbon capture and storage (CCS) in economies where fossil fuels are relatively expensive, such as in China. In Asia Pacific, the share of hydrogen reaches 40% in steel making in 2050. That compares with 8% electricity use, which is mostly used in secondary production and in arc furnaces.

Figure 48: Final energy consumption in Asia Pacific by fuel, Economic Transition Scenario and Net Zero Scenario, 2050



Source: BloombergNEF. Note: Refers to direct uses of hydrogen only. Bioenergy refers to solid, liquid and gaseous fuels. Does not include use of hydrogen in sustainable aviation fuels (captured under ‘bioenergy’), for example as input in e-fuels or for fuel processing. CCS is carbon capture and storage.

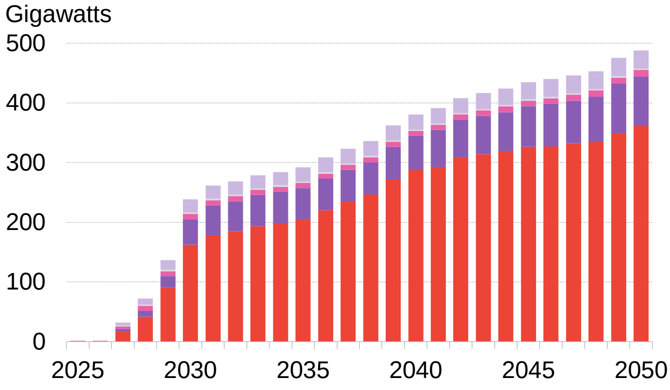
The role of hydrogen in its traditional end-uses declines in the Net Zero Scenario

We continue to expect hydrogen to play a limited role as a fuel for road vehicles due to the greater cost-competitiveness of battery EVs both in the passenger and most of the trucking segment. In 2050, hydrogen meets just 14% of final energy use in the sector.

Following further evidence from real-world trials, we no longer consider hydrogen an economic option for decarbonizing rail transport or as a substitute for natural gas in heating buildings.

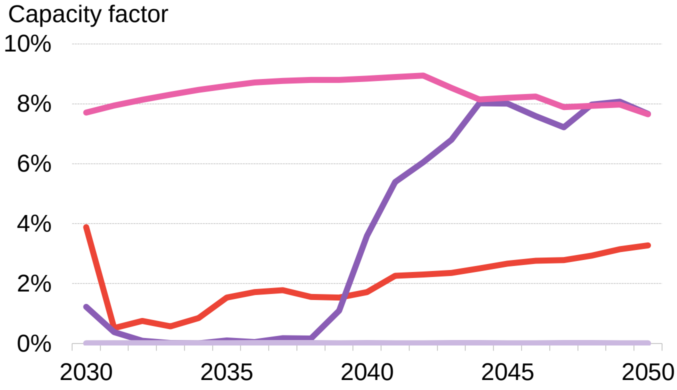
Based on our modeling, hydrogen plays a minor role as a fuel in a decarbonized power sector. While it is a viable backup technology and can bridge longer gaps in intermittent renewable energy generation that batteries may struggle to fill, our high-resolution hourly power sector modeling shows fossil fuel plants with CCS and other low-carbon technology are cheaper to operate in most cases. Across Asia Pacific, hydrogen demand in the power sector grows to 9Mt in 2050, or 4% of total demand in that year under the NZS.

Figure 49: Hydrogen power generation capacity of selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF

Figure 50: Hydrogen power capacity factors of selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF

Demand for hydrogen increases across Asia Pacific

Hydrogen demand in **China** increases 45% from 25Mt in 2024 to 36Mt by 2050 in the ETS, but almost quadruples to 88Mt under the NZS over the same period. Iron and steel production is the single largest user of hydrogen by 2050 in China under the NZS, accounting for 29% of total demand. Aviation uses 14Mt of hydrogen in China by mid-century, representing 15% of the NZS total. Total hydrogen demand in shipping reaches 7Mt in China under the NZS, making up 8% of the fuel's NZS demand by mid-century.

The use of hydrogen in incumbent sources of demand declines as use of nitrogen fertilizers and refined oil products falls. Demand for hydrogen in nitrogen fertilizer in China peaks at 13Mt in 2030 before falling to 5Mt by 2050. Ammonia-based fertilizers emit nitrous oxide (N_2O) after application, a gas with a global warming potential 273 times that of CO_2. Demand for hydrogen in oil refining peaks at 8Mt in 2024, falling to 3Mt in 2050 under the NZS. However, increased demand for chemicals and plastics drives up hydrogen demand in the methanol sector to 10Mt by 2050, up from 5Mt in 2024.

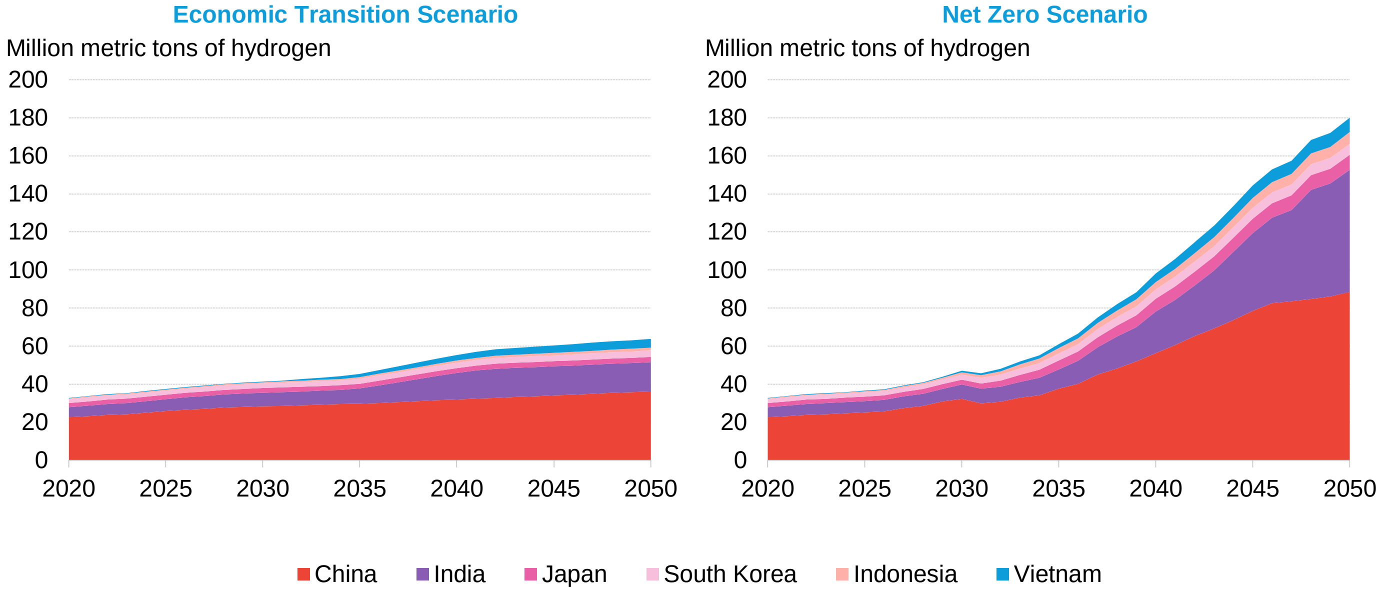
In **India**, demand for hydrogen more than doubles under the ETS from 6Mt in 2024 to 15Mt by 2050. Under the NZS, demand increases nearly 11 times to 64Mt by mid-century. Iron and steel production makes up over 80% of demand under the NZS in India, rising to 48Mt by 2050 in the NZS. Hydrogen for aviation makes up 8% of demand and 5% is accounted for by the power sector. Incumbent sources of hydrogen demand, such as for ammonia-based fertilizers and oil refining, see their share of the fuel's demand decline from 18% and 45% in 2024 to just 2% and 1% by 2050, respectively.

China and India account for the largest share of hydrogen demand in the NZS, with 23% and 16% of the global total respectively. China and India are regions with strong industrial demand, particularly from steel.

In **Japan**, hydrogen demand grows from 2Mt today to 3Mt by 2050 in the ETS but more than triples to 8Mt by mid-century in the NZS. Iron and steel production makes up 2Mt, or 31% of hydrogen demand, in the NZS by 2050. In the transportation sectors, aviation accounts for 16% of demand while road and shipping each carve out 13% of hydrogen consumption in the NZS by

2050. The share of demand from ammonia-based fertilizers falls from 26% to 3% over 2024 to 2050, while hydrogen for oil refining also falls from 53% to 3% over the same period.

Figure 51: Hydrogen demand in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

Hydrogen demand in **Vietnam** grows from low levels today to reach 5Mt by 2050 in the ETS and 8Mt in the NZS. Iron and steel production makes up nearly three-quarters of hydrogen demand in the NZS by mid-century. Aviation accounts for another 11%, while road transport makes up 8% of demand by 2050.

Indonesia's demand for hydrogen also grows from low levels in 2024 to reach 1Mt by 2050 in the ETS and 6Mt in the NZS. Unlike other peers in Asia Pacific, the single largest source for hydrogen demand in Indonesia under the NZS is the aviation sector, which accounts for 33% of demand by mid-century. Road transport and steel production make up 18% and 16% of hydrogen demand in the NZS by 2050, respectively. Energy industry own use, which is energy consumed to produce final energy carriers from primary energy carriers, accounts for 12% of demand by 2050.

Demand for hydrogen in **South Korea** rises from 2Mt in 2024 to 3Mt in 2050 in the ETS and 6Mt in the NZS. Methanol for chemicals accounts for the largest share hydrogen demand in the NZS by 2050 with 24%, followed by 17% used by shipping. Aviation constitutes 14% and road transport 7% of hydrogen demand. Energy industry own use makes up 15% of South Korea's hydrogen use by 2050 in the NZS.

Hydrogen production

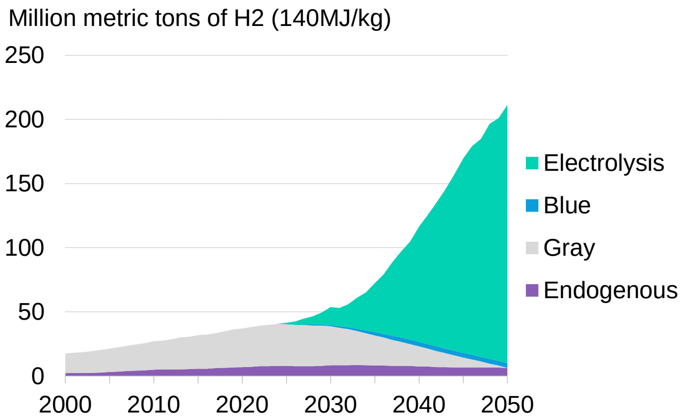
Today, about 81% of hydrogen production in Asia Pacific is 'gray' hydrogen produced from unabated fossil fuels. By 2050, thanks to the falling costs of renewables and electrolyzers, low-carbon hydrogen produced via electrolysis becomes the dominant pathway in the NZS, meeting 95% of demand in Asia Pacific, or 201Mt. New electrolyzers drive significant increases in power demand, with resulting capacity build. All hydrogen in our modeling is assumed to be produced and consumed domestically.

Table 8: Hydrogen classification by production process

Hydrogen type	Description
Gray hydrogen	Produced from unabated fossil fuels. Natural gas is usually converted to hydrogen using steam methane reforming, while coal and oil involve gasification.
Blue hydrogen	Produced from fossil fuels paired with carbon capture and storage. We assume the CCS sequesters up to 90% of emissions.
Green hydrogen	Electrolysis of water (H_2O) produces hydrogen (H_2) and oxygen (O_2) with the injection of a direct electric current into an electrolyzer. Considered 'green' or carbon-neutral when using low-carbon sources of electricity, such as renewables. Accounting methodologies for electricity use vary by country.
Endogenous hydrogen	Also referred to as by-product hydrogen, this is endogenously produced as by-product in some chemical processes.

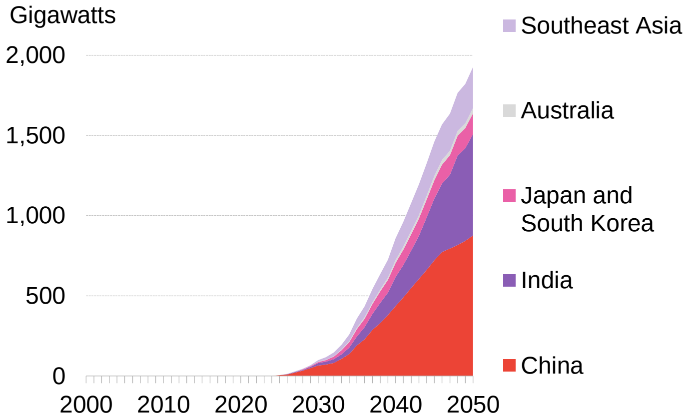
Source: BloombergNEF

Figure 52: Hydrogen consumption by type of production, Net Zero Scenario



Source: BloombergNEF. Note: Assumes gravimetric energy density of 140 megajoules per kilogram for hydrogen.

Figure 53: Cumulative electrolyzer capacity by region, Net Zero Scenario



Source: BloombergNEF

Gray hydrogen is phased out by 2050 in the NZS. Fossil fuel-based hydrogen production with CCS, also referred to as blue hydrogen, plays a small role as our country-by-country modeling suggests green hydrogen is cheaper than blue in most places most of the time. Blue hydrogen production occurs mostly in markets with domestic fossil-fuel resources and strong CCS policies. In 2050, blue hydrogen accounts for 2% of supply from Asia Pacific.

Seasonality and implications for storage

Unlike natural gas storage, the need for which is mainly driven by demand fluctuations, demand for hydrogen storage is driven by variations in supply. This is because hydrogen production can be highly seasonal by 2050 as most is made by electrolysis using intermittent renewable energy. On the other hand, hydrogen demand remains largely flat throughout the year as the sectors that use it most – steel, ammonia, oil refining and transport – require a steady input of hydrogen.

Storage is thus needed to ensure security of supply at any hour of the year, regardless of how much is being produced and when. Hydrogen storage needs therefore depend on the source of power generation for electrolyzers and the type of demand, which both vary by market.

Our demand modeling suggests most markets require a minimum storage capacity of 7-22% of their annual hydrogen demand, depending on production patterns. To add redundancy and ensure security of supply, we assume a safety factor of two, meaning storage capacity needs to be twice the required minimum. This results in a storage capacity range of 14-45% of annual demand. The global median is 25%, the equivalent of 94 days of global storage.

For this report, we assume that hydrogen storage uses either salt or rock caverns with monthly cycling capabilities, depending on the respective market.

Economics of hydrogen delivery

Green hydrogen costs fall significantly in the NZS, making hydrogen competitive against other low-carbon options in the sectors mentioned earlier. BNEF's *2023 Hydrogen Levelized Cost Update* (web | terminal) projects the levelized cost of hydrogen produced from dedicated onshore wind or solar (off-grid solution) to fall by an average of 85% globally by 2050. In the ETS, we assume a slower rate of cost decline after 2030, with electrolysis capex staying flat but renewable energy generation costs continuing to fall.

The cost decline in 'green' hydrogen is driven by cost reductions for electrolyzers and the renewable electricity used to power them. In 2050, BNEF projects the average cost of production to be around $1.06 per kilogram, varying based on the type of electrolyzer used and source of renewable electricity.

What about rising electrolyzer cost?

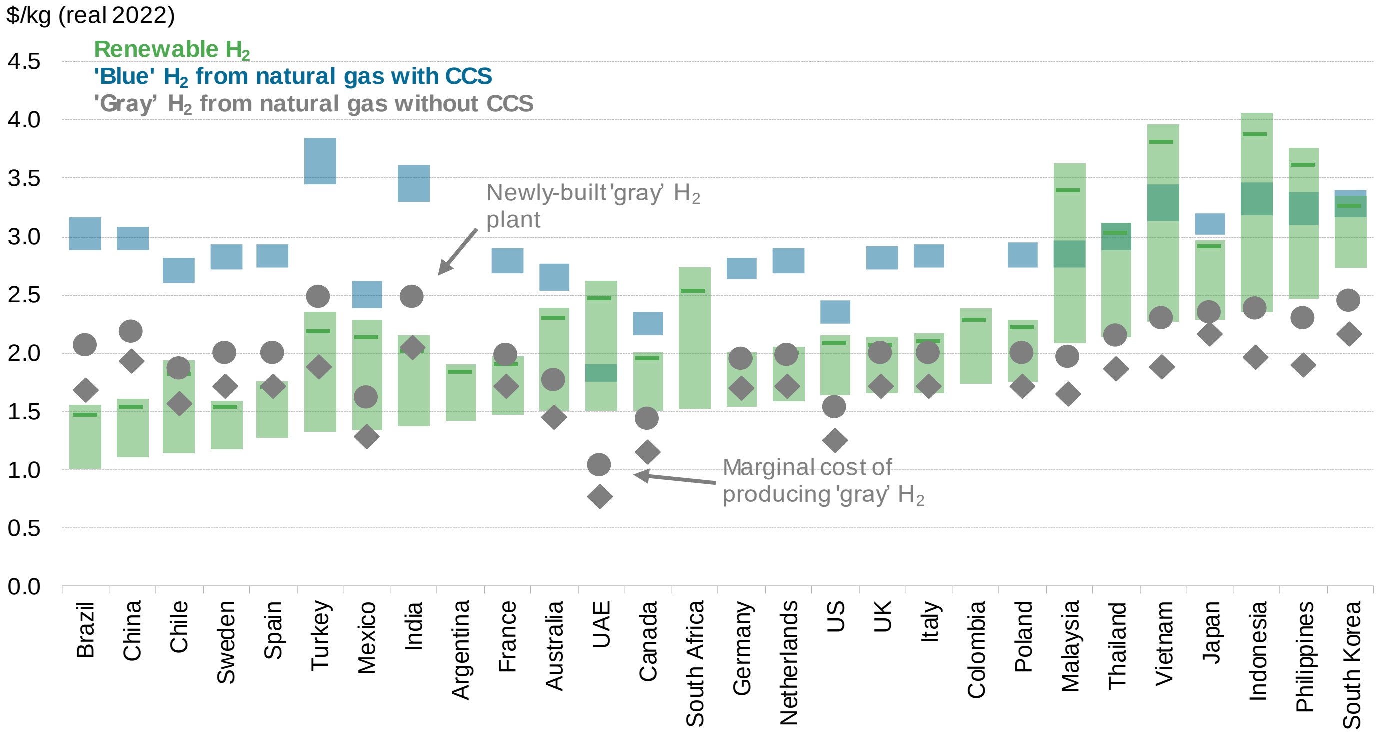
Inputs for the New Energy Outlook 2024 are based on BNEF's *2023 Hydrogen Levelized Cost Update* (web | terminal). Since then, BNEF has published an updated electrolyzer capex survey in early 2024 that suggests capex may in fact be higher than previously estimated. See *Electrolyzer Price Survey 2024: Rising Costs, Glitchy Tech* (web | terminal) for details. BNEF will produce a new capex forecast reflecting this update.

Based on our 2023 cost estimates, the levelized cost of hydrogen from a new green facility by 2030 is cheaper than a new blue hydrogen facility using natural gas in most countries, assuming alkaline electrolyzers are used (Figure 54). Following a least-cost approach, most hydrogen production is based on electrolysis.

However, the need for transmission grid buildout due to electrification, local renewables resource constraints, and the need to site hydrogen production close to the point of use (for example, as feedstock in industrial processes) means that 100% electrolysis-based production may not be practical.

Instead, we expect that some countries meet as much as 8% of their total hydrogen needs over 2025-2050 via blue hydrogen from natural gas with CCS. The global average share for 'blue' hydrogen production over 2025-2050 is 3%, while 69% is produced from electrolysis (green hydrogen) and 20% is gray hydrogen, produced from unabated natural gas. The volume of blue hydrogen deployed depends on natural gas prices and the cost and availability of suitable CCS infrastructure. The lower the gas price, the larger the share of blue hydrogen could be, and vice versa.

Figure 54: Range of levelized hydrogen costs for selected markets by production method, 2030



Source: BloombergNEF. Note: For more details, see 2023 Hydrogen Levelized Cost Update (web | terminal). Renewable H_2 shows hydrogen produced with wind and solar electricity via proton exchange membrane (PEM) electrolyzers (top of range) and alkaline electrolyzers (bottom of range). Blue H_2 is produced using steam methane reforming of natural gas (top of range) and autothermal reforming of natural gas (bottom of range), both with 95% CO_2 capture rate. Hydrogen costs consider domestic production and excludes subsidies. CCS is carbon capture and storage.

3.7. Carbon capture and storage

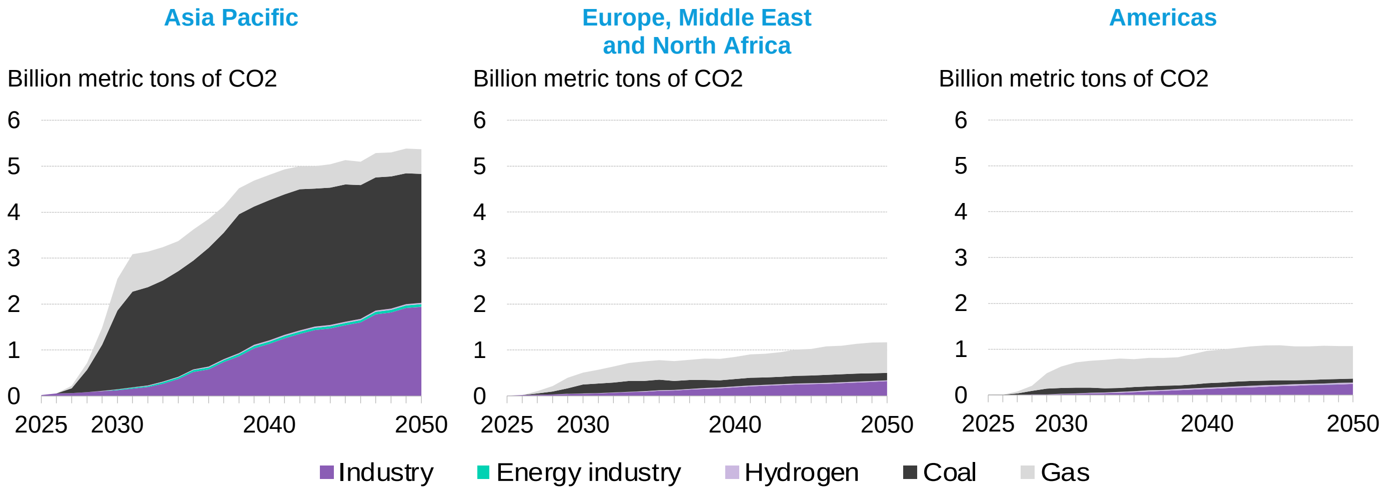
For Asia Pacific’s fossil-fuel dominated energy mix, acceleration of CCS technology maturation and deployment over the next decade is critical. While high costs limit the technology to a nearly negligible role under the ETS, CCS deployment needs to scale under the NZS to enable the steep emissions reduction the region needs to see starting immediately, especially for the power sector.

Asia Pacific dominates CCS deployment in the NZS

Two-thirds of emissions captured by CCS in our NZS originate in the Asia Pacific region (APAC), predominantly in China and India. Roughly 22.4 billion metric tons of carbon dioxide (GtCO2) is being captured from industrial processes in APAC. Given the prevalence of industry in the region, this figure is greater than the respective 19.1GtCO2 and 20.1GtCO2 of all emissions captured in Europe, Middle East, Africa (EMEA) and the Americas (AMER).

Emissions captured from industrial processes are significant, but CCS abatement in the power sector is three times larger. The expansive coal fleet fitted with CCS in APAC, particularly in India and China, means that this is the largest point source of emissions across the region, totaling 58.2GtCO2 captured. In comparison to APAC, natural gas is the dominant fuel used for power generation with CCS in EMEA and AMER, and makes up the largest point source in these regions.

Figure 55: Annual carbon dioxide emissions sequestered by carbon capture and storage, by application and region, Net Zero Scenario



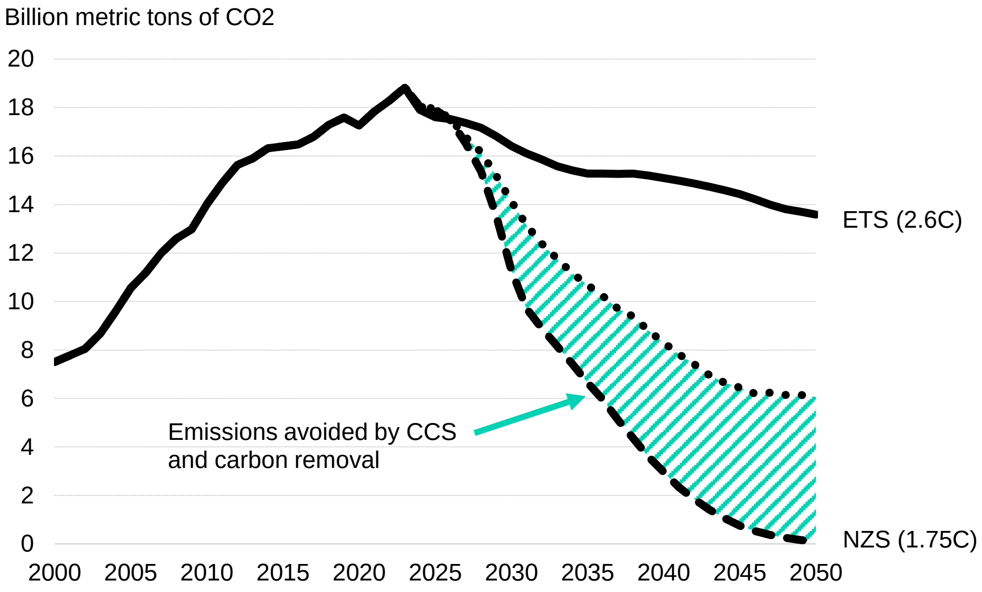
Source: BloombergNEF. Note: Includes applications in industry, power and hydrogen production. Gas and coal use in power sector.

Failing to scale CCS will derail a Paris Agreement-aligned energy transition

In our NZS, CCS has a much larger role – but this will only materialize if the industry can step up and deliver the cost reductions expected. The NZS sees CCS playing a high-value low-volume role as clean backup power capacity for extended periods of low renewable energy generation output. The provision of firm backup allows renewables to scale to the full potential and deliver urgently needed carbon reductions in the next 10 years – the period in which rapid cost cuts count the most. While this is a significant challenge for a solution that is still in early ramp-up stages, CCS is still relatively more mature than alternative sources of dispatchable clean capacity such as hydrogen or bioenergy.

In the NZS, CCS and carbon removals[5] are responsible for 45% (106GtCO2) of incremental emissions abated in Asia Pacific between 2024 and 2050, compared with the base case. This makes it one of the key technologies needed to reach net zero.

Figure 56: Asia Pacific's emissions trajectory and impact of captured emissions



Source: BloombergNEF. Note: ETS is Economic Transition Scenario. NZS is Net Zero Scenario. Shaded area includes emissions captured from point sources and stored, as well as carbon removals needed to offset incomplete capture processes, assumed to be only 90% complete. No other carbon removals included.

- **China**'s CCS deployment scales up toward the end of this decade to reach 1,452 million tons of CO2 (MtCO2) from none today, driven by the need to decarbonize its fossil-fuel dominated power system and limited alternative low-carbon solution. The volume of captured carbon declines slightly between 2031 and 2034 as unabated fossil fuel generation falls. CCS plays a large emissions abatement role in hard-to-abate sectors such as steel and aluminum in the 2030s. By 2050, CCS abates 2,387MtCO2 per year in China.
- **India** sees CCS deployment scale from 2027 to reach 388MtCO2 by 2030, driven by power sector emissions reduction needs. From 2035, CCS plays a larger role in the steel industry. By 2050, total carbon emissions abated by CCS totals 1,376MtCO2, almost half of which comes from the steel sector and 43% from the power sector.
- Unlike China and India, **Japan**'s steel sector kickstarts CCS deployment in the country from 2025. CCS use in the power sector scales rapidly from 2027. Annual carbon emissions

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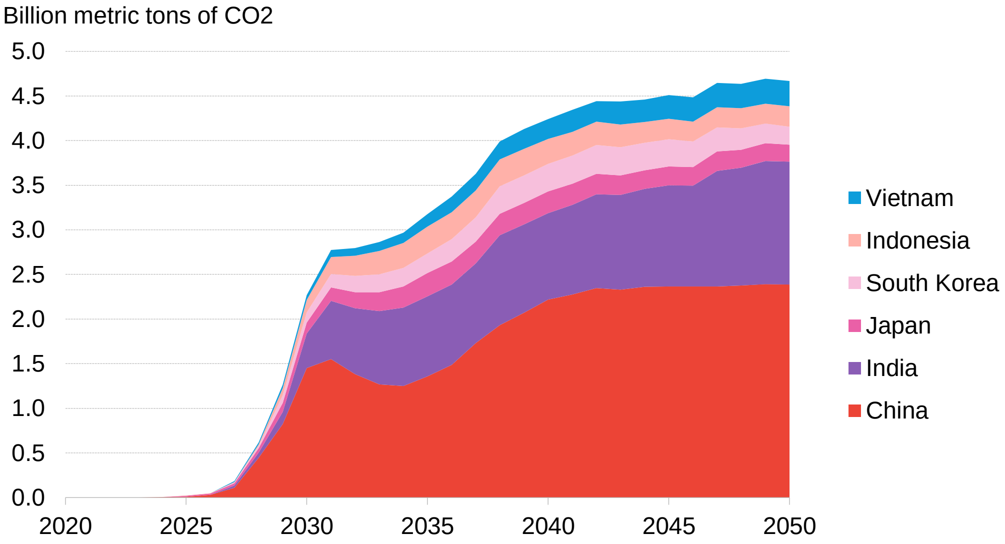
[5] Includes the carbon removals needed to offset incomplete capture from point-source carbon capture processes, which are up to 90% complete. CCS is responsible for 14% of cumulative emissions abatement between 2024 and 2050, against a 'no transition' scenario in which there are no further efforts to decarbonize.

captured by CCS totals 120MtCO2 in 2030 and peaks in 2035 at 262MtCO2, before declining slightly to 191MtCO2 in 2050 as fossil fuel use in the power sector falls.

- Similar to Japan, **South Korea's** first CCS deployment happens in the steel sector but the power sector quickly becomes the largest source of emissions captured by CCS. By 2030, CCS captures 115MtCO2 per year, 95% of which is from the power sector. Captured emissions peaks at 320MtCO2 in early 2040s before falling to nearly 40% to 200MtCO2 by 2050 in line with increasing renewable penetration in the country's power system.
- CCS plays an important role in abating emissions from **Indonesia**'s coal-dominated power system. By 2030, CCS abates 142MtCO2 of emissions, 96% of which comes from the power sector. The volume of carbon emissions captured by CCS peaks in 2038 at 304MtCO2 before declining to 230MtCO2 in 2050 as the use of fossil-fuels, in particular coal, in the power sector falls.
- **Vietnam's** CCS capacity starts to scale from late 2020s to reach 52MtCO2 sequestered per year, 86% from the power sector and 12% from the steel sector. From mid 2030s, the country sees CCS deployment in the cement sector as an emissions abatement solution. CCS capacity grows steadily out to 2050 even as power sector emissions fall, driven by growing emissions from industries.

Figure 57: Carbon dioxide sequestered by carbon capture and storage in selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF

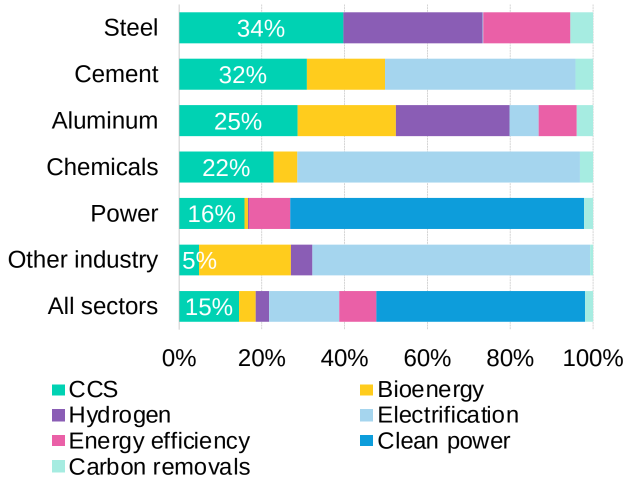
Applications in power and industry

CCS has broad applications in industry, hydrogen production and the power sector.

Across Asia Pacific, CCS is responsible for 34% of energy emissions abated in steel production, 32% in the cement sector, 25% in aluminum production and 22% in chemicals processing between 2024 and 2050, against a 'no transition' scenario in which there are no further efforts to decarbonize. For 'blue' hydrogen production, CCS is fitted to steam methane reformers and auto-thermal reformers, which account for 2% of total hydrogen production in 2050.

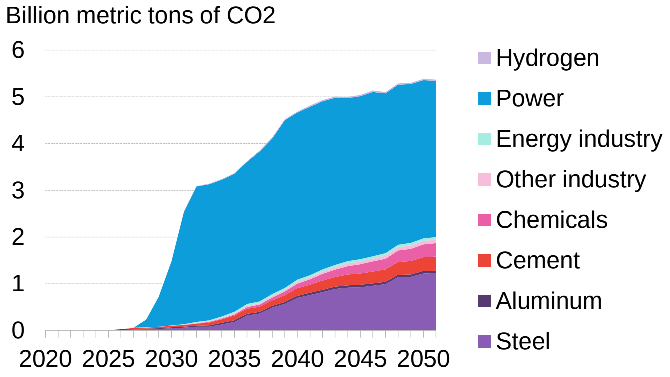
The annual rate of emissions captured in the NZS grows from very low levels today to 2.5GtCO2 in 2030, 4.8GtCO2 in 2040 and 5.4GtCO2 by 2050 (Figure 59). Cumulatively, a total volume of around 95GtCO2 is captured in 2024-2050 – 10 times larger than direct power sector emissions from Asia Pacific in 2023. While CCS is an important abatement technology in hard-to-abate sectors, most emissions in absolute terms (75%) are captured in the power sector. This is followed by 15% of emissions originating from steel manufacturing, 4% from cement production, and the rest in other industrial sectors and hydrogen production.

Figure 58: Share of carbon capture and storage in total emissions abatement in Asia Pacific, 2024-2050, Net Zero Scenario



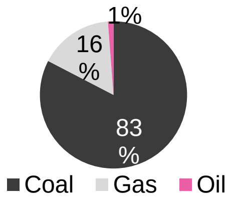
Source: BloombergNEF. Note: Shows cumulative emissions abatement compared with a ‘no transition’ scenario for energy emissions only; process emissions are not included. Aluminum is primarily recycling and alumina. CCS is carbon capture and storage.

Figure 59: Annual carbon dioxide emissions sequestered by carbon capture and storage in Asia Pacific, by sector, Net Zero Scenario



Source: BloombergNEF

Figure 60: Carbon capture and storage by fuel, 2024-2050, Net Zero Scenario



Source: BloombergNEF. Note: Includes applications in industry, power, and hydrogen production.

Across Asia Pacific, CCS yields the greatest emissions reductions when it captures CO2 from coal-based processes, such as in coal-fired power plants or industrial furnaces (Figure 60). This is because coal has the highest emissions intensity of fossil fuels, releasing around 69% more CO2 per unit of energy than natural gas. In the NZS, more than 80% of Asia Pacific’s total cumulative emissions are captured in processes combusting coal, 16% from gas and just 1% in oil.

3.8. Electric vehicles

Direct electrification via batteries is the most efficient, cost-effective, and commercially viable route to fully decarbonizing road transport. Fuel-cell vehicles play a role in some hard-to-electrify long-haul trucking applications, but are not prominent in the larger passenger vehicle market. Biofuels play a limited role in road transport, due to often offering a less economic option for decarbonization than electrification along with need to prioritize limited feedstocks for other transport sectors, such as aviation. Synthetic fuels do not arrive at scale in time or at a price point needed to have a material impact on road transport.

BNEF's Electric Vehicle Outlook

Road transport modeling in the *New Energy Outlook 2024* incorporates and builds on country and sector results from the *Electric Vehicle Outlook 2023* (web | terminal). The report is BNEF's annual publication looking at how electrification, shared mobility, demographic shifts autonomous driving and other factors will impact road transport in the coming decades.

BNEF published a 2024 update for the *Electric Vehicle Outlook* in June 2024 (web | terminal).

Batteries and EVs have taken center stage in new discussions on industrial policy, with countries competing to attract investments and build new clusters of high-value manufacturing. Meanwhile, regulators and grid operators are looking at ways to ensure EVs benefit the power system.

Electrification is not the only vector of change. Shared mobility, vehicle connectivity and, eventually, autonomous vehicles are set to reshape automotive and freight markets around the world. Urbanization also continues its steady march, leading to increased concerns around vehicle congestion and urban air quality.

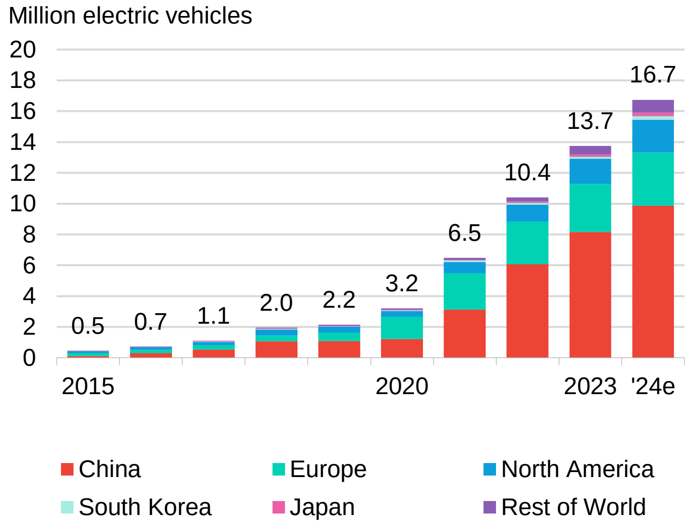
Battery-electric vehicles dominate passenger and commercial road transport

Despite a relative slowdown in EV sales growth against some forecasts over the last six months, there is still strong momentum behind battery cars. With 4.4 million units sold globally in the fourth quarter, and 13.7 million in 2023, EVs made up 18% of total passenger vehicle sales in the world last year.

EVs account for 44% of global passenger vehicle sales by 2030 and 75% by 2040 in our ETS. After increasing rapidly from 2022 to 2035, EV sales growth slows slightly in the late 2030s in the main markets like Europe, China, and the US as they begin to saturate. Although public charging infrastructure is growing at pace globally, it still presents a potential barrier to electrifying the last 10-20% of the market in many countries.

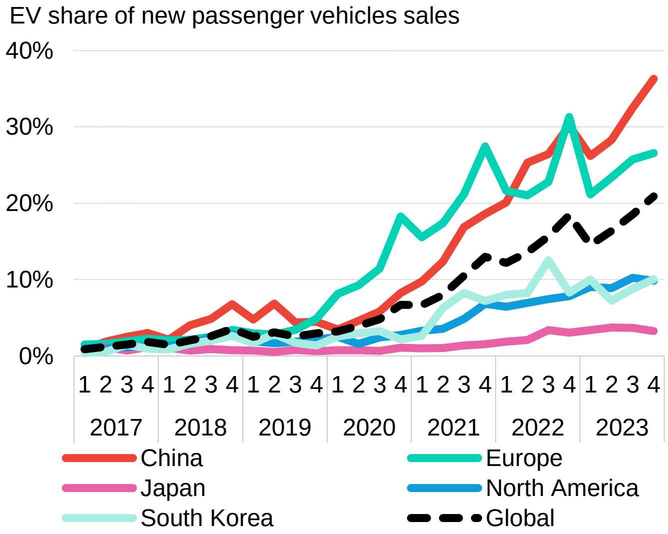
While EV sales exhibit a traditional 'S-curve' for adoption, each country and region start on this trajectory at different times due to variations in household income and other factors. The varied start time and slowdown points between countries mean that the global average appears more linear than any individual country. Despite rapid EV adoption, less than 50% of the global passenger vehicle fleet is electric by 2040 in our base case.

Figure 61: Historical and forecast electric vehicle sales



Source: BloombergNEF, MarkLines, vehicle registration agencies, JATO Dynamics. Note: Electric vehicle sales include battery-electric vehicle and plug-in hybrid vehicle sales. Europe data includes EU27 countries plus Norway, Switzerland, Iceland and the UK. China data excludes low-speed EV sales and commercial vehicles. Data as of March 2024.

Figure 62: Electric vehicle share of new passenger vehicle sales

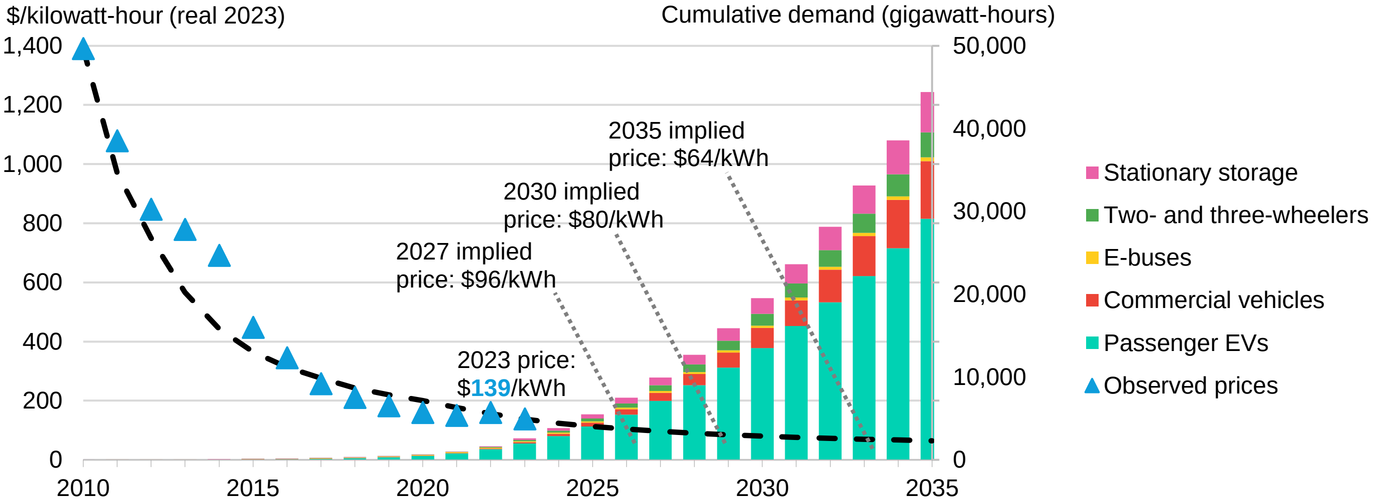


Source: BloombergNEF, MarkLines, vehicle registration agencies, JATO Dynamics. Note: Electric vehicle sales include battery-electric vehicle and plug-in hybrid vehicle sales. Europe data includes EU27 countries plus Norway, Switzerland, Iceland and the UK. China data excludes low-speed EV sales and commercial vehicles. Data as of March 2024.

A major driver for the spread of EVs are advances in battery technology. BNEF research shows battery pack prices have come down from a temporary increase in 2022 and are again back in line with the implied long-term experience curve. We now expect average pack prices to fall below $100/kWh by 2027. The $100/kWh threshold is often referenced as the point where EVs reach price parity with internal combustion engine (ICE) vehicles, though price parity varies significantly by vehicle segment and region.

At the time of writing, there are discussions of very low battery prices coming out of China, with Chinese battery manufacturer CATL announcing that it expects to be able to sell battery cells under $60/kWh this year. BNEF investigates how sustainable these prices are and how that affects the future trajectory in the *2024 Electric Vehicle Outlook*.

Figure 63: Lithium-ion battery pack price, learning curve and demand outlook

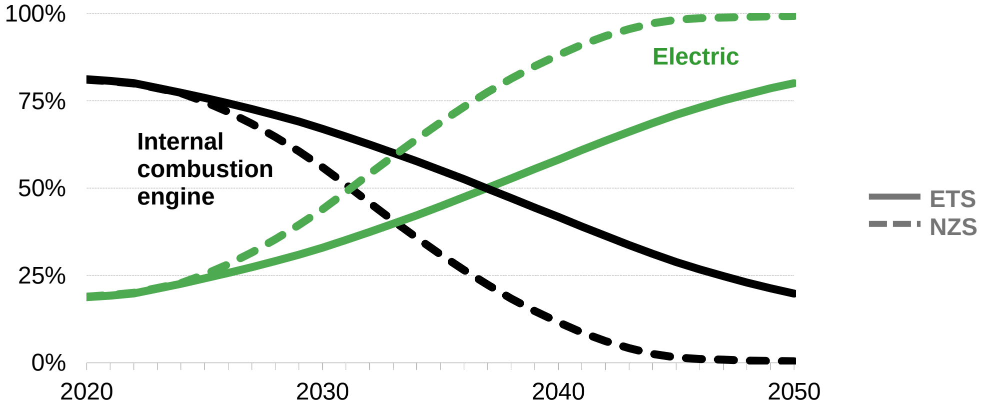


Source: BloombergNEF

Scenarios in the New Energy Outlook for Asia Pacific

Despite significant advances in electrification, vehicle fleets (including passenger and commercial vehicles, buses, and two- and three-wheelers) in Asia Pacific do not reach net zero by 2050 in our base case. The zero-emission vehicle (ZEV) share of the fleet in Asia Pacific reaches 80% in our ETS by 2050, up from 19% in 2020. Fuel-cell vehicles do not play any meaningful role in the passenger vehicle market in either scenario.

Figure 64: Asia Pacific vehicle fleet split by drivetrain, Economic Transition Scenario and Net Zero Scenario

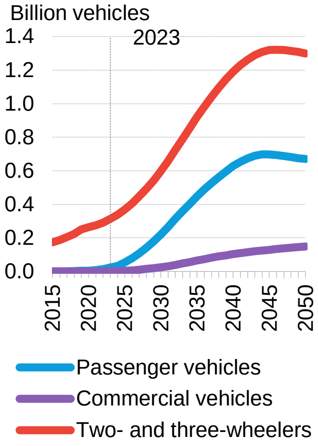


Source: BloombergNEF. Note: NZS is Net Zero Scenario, ETS is Economic Transition Scenario. Electric vehicles include battery-electric vehicles and a small number of plug-in hybrid vehicles. Internal combustion engine vehicles include traditional hybrids. Net Zero Scenario based on New Energy Outlook 2024, which shows a 1.75C-equivalent pathway as opposed to 2.0C-equivalent pathway in Electric Vehicle Outlook 2023.

In the NZS, the ZEV share of Asia Pacific's vehicle fleet reaches 99% by 2050. ICE vehicle sales fall almost 70% over 2024-2030. By 2030, EVs make up 44% of the fleet, up from about 23% in 2024. To stay on track for net zero, EVs need to reach 99% of new vehicle sales by 2040.

The two- and three-wheeler segments dominate uptake of EVs across Asia Pacific in both our scenarios. In the Net Zero Scenario, uptake of two- and three-wheeler EVs increases from a relatively established base of 338 million vehicles in 2024 to 1,300 million by 2050 across Asia Pacific (Figure 65). By comparison, uptake across all other segments rises from 36 million to 823 million over the same period. Two- and three-wheelers make up 61% of the region's total EV fleet by 2050 in our NZS, compared to 22% in Europe, the Middle East and North Africa, and 19% in the Americas.

Figure 65: Electric vehicle fleet by segment in Asia Pacific, Net Zero Scenario



Source: BloombergNEF

What about hydrogen fuel-cell vehicles?

We have removed fuel-cell vehicles (FCVs) from our passenger vehicle outlook due to very low volumes of sales, little consumer interest, high geographic concentration, limited model availability and a lack of commitment to high-volume manufacturing from automakers.

Passenger FCVs continue to face three major challenges: First, there are currently no other mass-market applications for fuel-cell systems that could support scale for cost reductions. Second, there is limited existing hydrogen refueling infrastructure, and the price of hydrogen at the pump remains significantly more expensive than other fuels. Third, the value proposition of FCVs for consumers is getting weaker, as battery EV technology continues to improve and scale.

Demand for hydrogen at the pump depends on the uptake of **heavy-duty fuel cell trucks** and, to a lesser degree, **buses**. Hydrogen trucks are just under 4.5% of the global fleet by 2050 and they are almost exclusively medium- and heavy-duty vehicles, rather than lighter vans. Even within these segments, adoption varies depending on use case and consists of vehicles used in regional and long-haul duty cycles.

The main reason for the limited adoption of hydrogen trucks in other applications is the existence of suitable and economically viable battery trucks. About half of the total truck fleet is used in urban duty cycles. Deployment of electric trucks has already started in these use cases, while companies work out the challenges related to charging infrastructure. Such early adoption tends to limit the long-term addressable market for hydrogen vehicles.

Even though battery trucks and their corresponding charging infrastructure for long-haul duty cycles start to emerge, these vehicles have yet to be used in any appreciable volume. We believe that hydrogen trucks can capture market share in these applications. However, the outlook is more uncertain than for battery trucks, with high-volume series production across the industry still years away and challenges in expanding the suitable refueling network.

China's early progress toward greater EV adoption makes it an outlier compared to its peers in Asia Pacific. In the base case, China's total EV fleet increases from a relatively established base of 357 million vehicles to 845 million over 2024-2050. During this period, the fleet of ICE vehicles falls sharply from 467 million to 43 million. In the NZS, the EV fleet is only 5% larger at 887 million vehicles by 2050, but ICE vehicles are completely phased out.

In **India**, the size of the EV fleet increases from 8 million vehicles to 461 million vehicles over 2024-2050, making up 78% of the country's fleet by mid-century. The share of ICE vehicles drops from 98% in 2024 to 78%, or 133 million vehicles, by 2050. In the NZS, the size of the EV fleet is 27% larger at 587 million vehicles by 2050, making up 99% of the entire fleet.

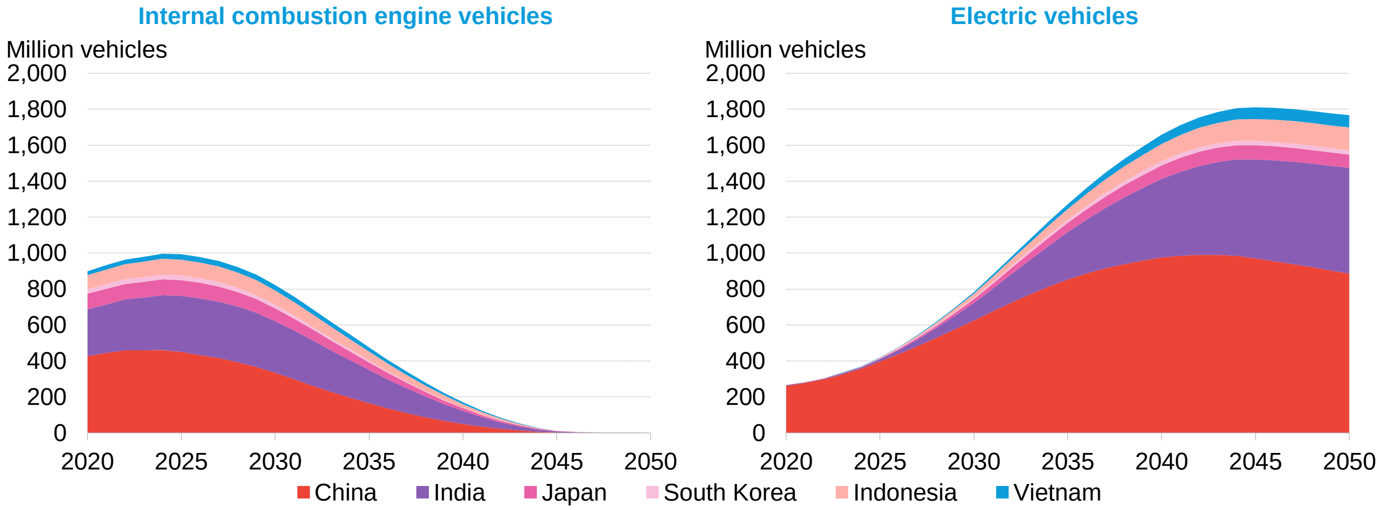
EV uptake in **Japan** increases from around 930,000 vehicles to 49 million vehicles over 2024-2050, or 66% of the total fleet. ICE vehicles make up the remaining 34%, or 25 million vehicles, by mid-century, falling from 89 million in 2024. In the NZS, the size of the EV fleet is around 50% larger at 74 million vehicles, making up 99% of the fleet as early as 2048. The remaining 1% is largely made up of heavy-duty fuel-cell trucks and buses.

South Korea's uptake of EVs increases from just under 1.1 million vehicles to 20 million during 2024-2050 in the base case, already making up 83% of the fleet. ICE vehicles' share of the country's fleet slips from 96% to just 16%, or 4 million vehicles, over the same period. In the NZS, the size of the EV fleet increases 19% to 23 million by mid-century, achieving a 99% share by 2046. Like Japan, around 1% is accounted for by hydrogen fuel-cell trucks and buses.

Indonesia's EV uptake grows from just over 2 million in 2024 to 81 million by 2050 in our ETS, making up 62% of the country's fleet. Fossil fuels make up the remaining 38%, but the size of the fleet declines from 91 million to 49 million over the same period. The size of the EV by mid-century in the NZS grows to 128 million – 59% larger than in the ETS. Just over 1% of the total fleet by 2050 is made up of vehicles powered by bioenergy, with the rest accounted for by EVs.

In **Vietnam**, EV uptake increases from around 620,000 vehicles to 42 million by 2050, which equates to around 62% of the total fleet. The ICE vehicle fleet falls from 28 million to 26 million over the same period, but this represents a decline from 99% of the total fleet to 38%. In the NZS, the EV fleet grows to 67 million vehicles by 2050 – 61% larger than in the ETS and equal to 100% of the entire vehicle fleet as all other types are phased out.

Figure 66: Size of vehicle fleet in selected Asia Pacific markets by drivetrain, Net Zero Scenario



Source: BloombergNEF

3.9. Sustainable aviation fuels and clean aviation

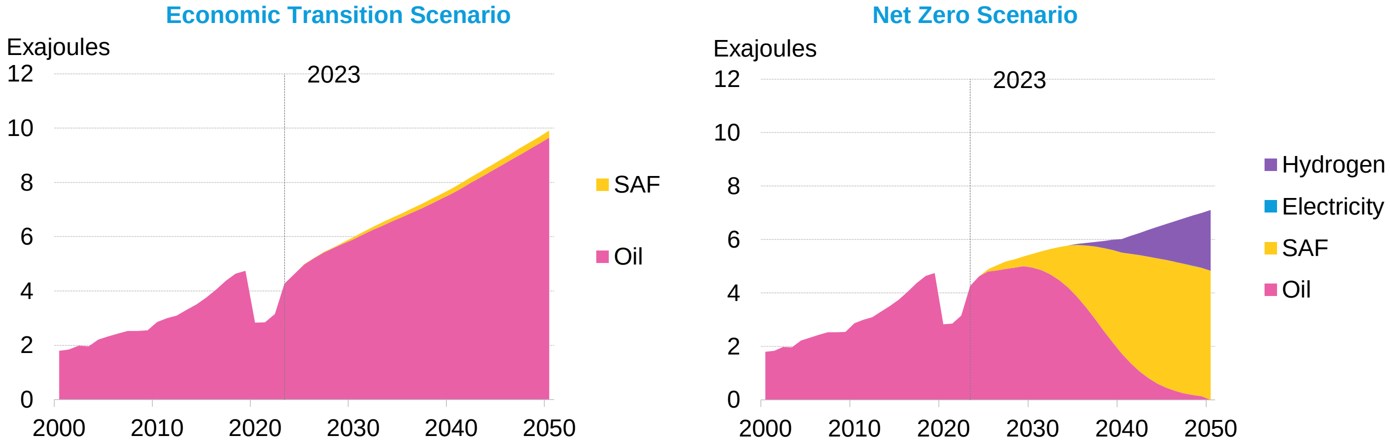
Aviation is a hard-to-abate sector and must use all possible technology options to achieve net-zero by 2050, as no single pathway can decarbonize the sector on its own.

Sustainable aviation fuel (SAF) – an umbrella term for drop-in jet fuels made from non-petroleum feedstocks – is one of the few technologies with the potential to help decarbonize aviation, and the only feasible option in the near term. While demand for passenger and freight aviation is rising, the uptake of SAF is hampered by high costs, limited feedstock availability and insufficient policy incentives. Our base-case scenario sees a SAF share of only 3% of 9.9 exajoules (EJ) of final energy use in 2050 across Asia Pacific, with the remaining 97% fossil jet fuel.

In the NZS, the mass deployment of next-generation engines and novel airframes leads to an overall lower final energy demand of 7.1EJ in 2050 in Asia Pacific, 28% lower than in the ETS. Hydrogen-fueled aircraft contribute 32% of final energy use. In our global modeling, we assume turboprops or smaller aircraft powered by battery-electric or fuel cells are able to enter the market in 2030. The use of electricity in final energy demand is negligible though, as this pathway only decarbonizes small planes flying routes of a few hundred kilometers. Hydrogen-fueled narrowbodies enter the market in about 2035 and could fly up to 4,000 kilometers.

Despite these innovations, some 68% of the final energy demand in 2050 across Asia Pacific in our climate scenario is met by SAF. It remains the sole option to decarbonize flights of widebody aircraft and other aircraft that cannot use electric or hydrogen propulsion.

Figure 67: Final energy use for aviation by source in Asia Pacific, Economic Transition Scenario and Net Zero Scenario

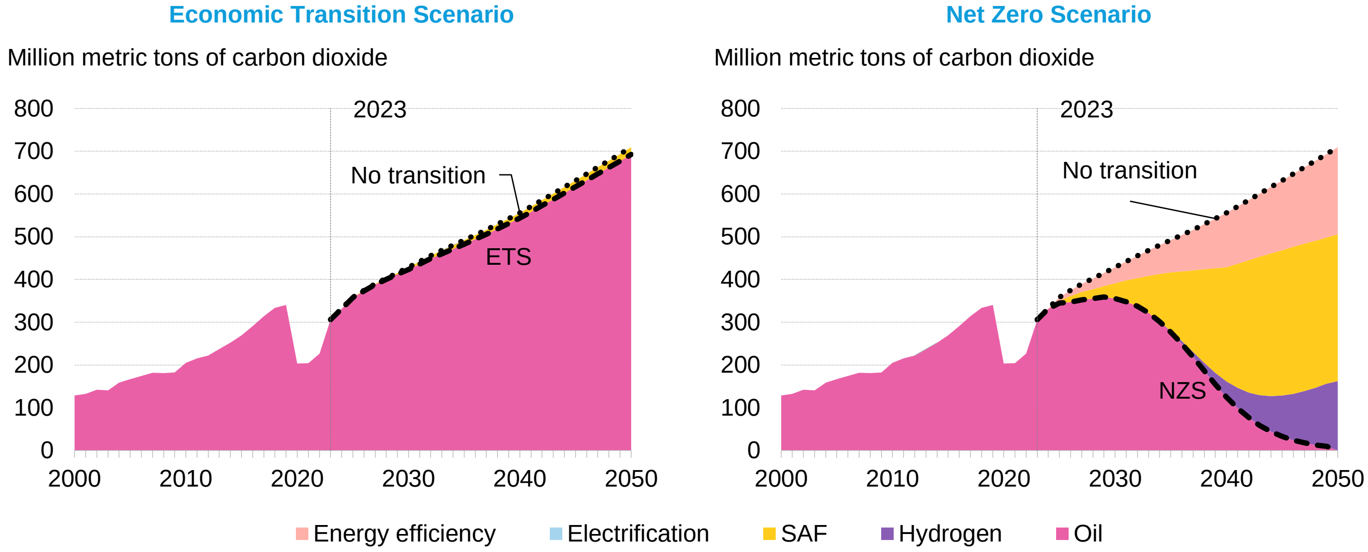


Source: BloombergNEF. Note: SAF refers to sustainable aviation fuels, including hydroprocessed esters and fatty acids (HEFA), alcohol-to-jet, and e-fuels. Hydrogen refers to direct use.

Under the ETS, some 17MtCO2 per year of carbon emissions are abated in 2050, equivalent to 2% less emissions over 2024-2050 than in a 'no transition' scenario in which there are no further climate actions.

In the NZS, aviation meets its sectoral carbon budget through a combination of aircraft fleet renewals using more fuel-efficient engines and novel airframes ('energy efficiency' in Figure 68), hydrogen-fueled aircraft ('hydrogen'), and SAF. Compared to a 'no transition' scenario, SAFs contribute 57% to abatement, followed by energy efficiency measures (30%) and hydrogen (13%).

Figure 68: Carbon dioxide emissions abatement in aviation in Asia Pacific by type/technology, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF. Note: The 'no transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes that the future fuel mix does not evolve from 2023. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry. SAF is sustainable aviation fuel.

Sustainable aviation fuel

SAF is produced mostly from renewable biomass and waste resources today, and has a lower carbon footprint compared with conventional jet fuel. SAF supply is currently extremely limited, with just a handful of producers globally, but the industry continues to show promise.

The number of offtake agreements between airlines and producers developing facilities has surged since 2021 as airlines demonstrate their commitment to the fuel, with over 100 agreements at different stages of commitment as of March 2024. BNEF has also tracked a flurry of new projects announced to boost production capacity. But significant hurdles remain, including high costs and competition for resources with renewable diesel, a road transport biofuel.

Apart from cost, the most pressing issue for producing SAF at the scale required is the lack of diversification in production pathways, which limits the potential pool of feedstocks. If unaddressed, this could lead to substantial bottlenecks and cause the aviation industry to fall short of its ambitious goals.

SAF can be produced from a variety of feedstocks, via several technology pathways. In our long-term scenarios we consider the three main technologies that have reached, or are closest to, commercialization.

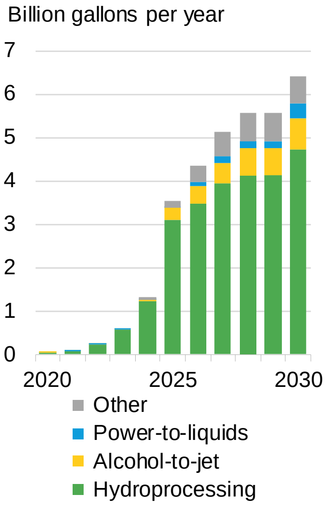
- **Hydroprocessed esters and fatty acids (HEFA)** is the dominant technology – practically all SAF produced today is via the HEFA pathway. In the process, lipid feedstocks, such as vegetable oils or used cooking oils, are deoxygenated and hydroprocessed to produce hydrocarbon molecules. These molecules then go through a refining process to separate them into different products like diesel and jet fuel. HEFA is by far the most commercialized pathway, largely due to the fact that the process closely mirrors oil refining, so the technology and infrastructure is already established at scale. Oil refiners consequently dominate the space. They own over 90% of current production capacity, mostly in the form of oil refineries.

that have been converted to produce biofuels instead of refining crude oil. Much like in traditional oil refining, product yields can be flexed to a degree, in accordance with the producers' preference and commercial considerations. Currently, most capacity is focused on producing renewable diesel for road transport due to historically healthier margins and stronger policy support. However, as demand and policy support for SAF increase, so too are anticipated yields at planned projects over the next five years.

- **Alcohol-to-jet (ATJ)** converts alcohols like ethanol or iso-butanol to a mix of hydrocarbons. Ethanol or iso-butanol is typically produced via fermentation of sugar and starch crops such as sugarcane and corn, and increasingly other biomass feedstock types such as waste biomass like corn stover, bagasse, and sorghum. The alcohol then goes through dehydration, oligomerization and hydroprocessing to produce hydrocarbons, including diesel and jet fuel. Only one commercial-scale ATJ facility is currently operational, LanzaJet's Freedom Pines plant in Georgia, US, but several more are under development.
- **E-fuel**, also known as power-to-liquid fuel, is a synthetic fuel made from captured carbon dioxide and hydrogen using renewable electricity. These fuels are considered to have high potential as an alternative aviation fuel, as they do not rely on biogenic feedstocks and can have extremely low or even neutral lifecycle carbon emissions. However, these are still at an early stage of development, and proof of their commercial effectiveness has yet to be seen at scale. Costs are extremely high – BNEF estimates e-kerosene to cost five to nine times more than fossil jet fuel today, and it is likely to remain relatively expensive compared to other SAF pathways.

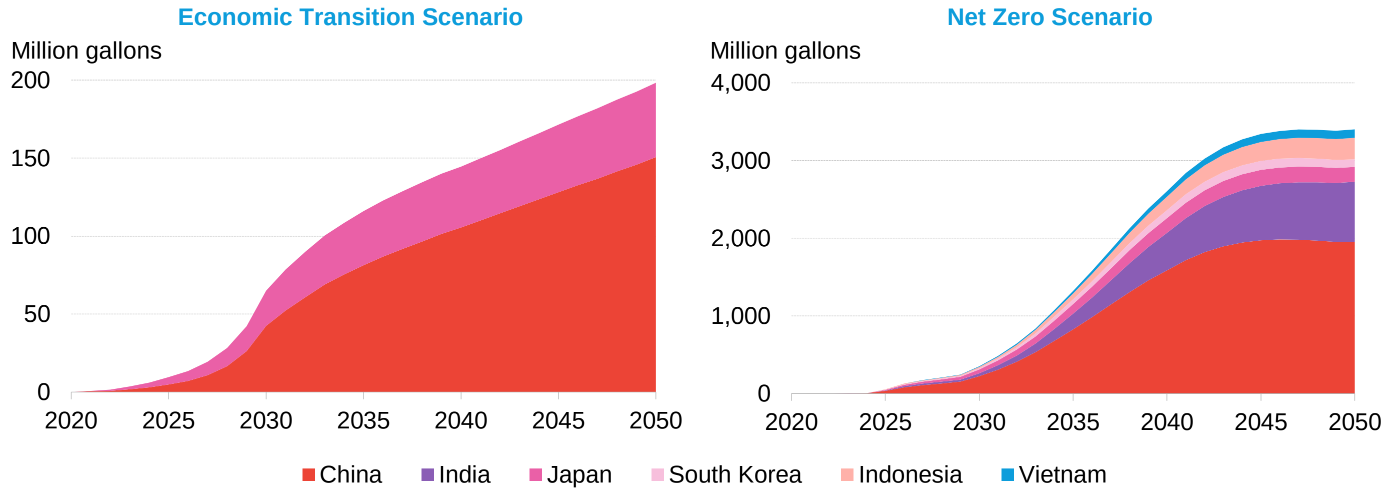
The role of SAF in Asia Pacific's aviation (included under 'bioenergy' in our energy balances) varies substantially across our two scenarios. In the ETS, it makes up just 3% of total energy demand from aviation by 2050 – up from less than 1% in 2024. Our NZS, on the other hand, sees SAF rising to 68% of the sector's energy demand by 2050. In energy terms, this equates to an 18-fold increase in SAF requirements across Asia Pacific in the NZS compared to the ETS.

Figure 69: Planned sustainable aviation fuels capacity by pathway



Source: BloombergNEF. Note: For more, see Global Renewable Fuel Projects Tracker (web | terminal). Data as of February 2024.

Figure 70: Demand for sustainable aviation fuels in selected Asia Pacific markets, Economic Transition Scenario and Net Zero Scenario



Source: BloombergNEF

Section 4. Barriers, opportunities, and the way forward

Asia Pacific markets are marching forward on the energy transition, but progress varies across the markets. The window for achieving net zero by 2050 is rapidly closing. Governments need to back their climate commitments with actionable policies, and accelerate decarbonization efforts in the next decade, starting immediately, or risk missing climate goals.

4.1. Accelerating deployment of mature climate solutions

Achieving net zero by 2050 is reliant on emerging technologies, but the urgency of global decarbonization now means governments and corporates will need to act by leveraging on commercially available, low-carbon technologies as much as possible. These mature technologies are already scaling today, and without any new policy implementations will continue to see economic-driven deployment out to 2050 – but not at the pace required to reach net zero (Table 9). To stay on a Paris-aligned trajectory, more will be needed from government, regulators, investors, corporates, and technology providers to bridge the gap.

BNEF's NetZero Pathfinders

BNEF's **Delivering Net Zero: A Framework for Policymakers** is a handbook for governments to design and implement decarbonization strategies. It aims to serve as a fundamental resource for key stakeholders by outlining the policy actions needed to reach net zero. The public NetZero Pathfinders web platform displays a library of the most effective policies to date. These policies, known as best practices, can be replicated in other markets to accelerate progress to net zero.

To help governments navigate potential policy paths to net zero, the Pathfinders actions are split into four pillars:

1. Accelerate deployment of mature climate solutions
2. Support development of new climate solutions
3. Phase out carbon-intensive activities
4. Create appropriate climate transition governance structures

See https://www.netzeropathfinders.com for more.

Table 9: Opportunities to accelerate deployment of mature climate solutions

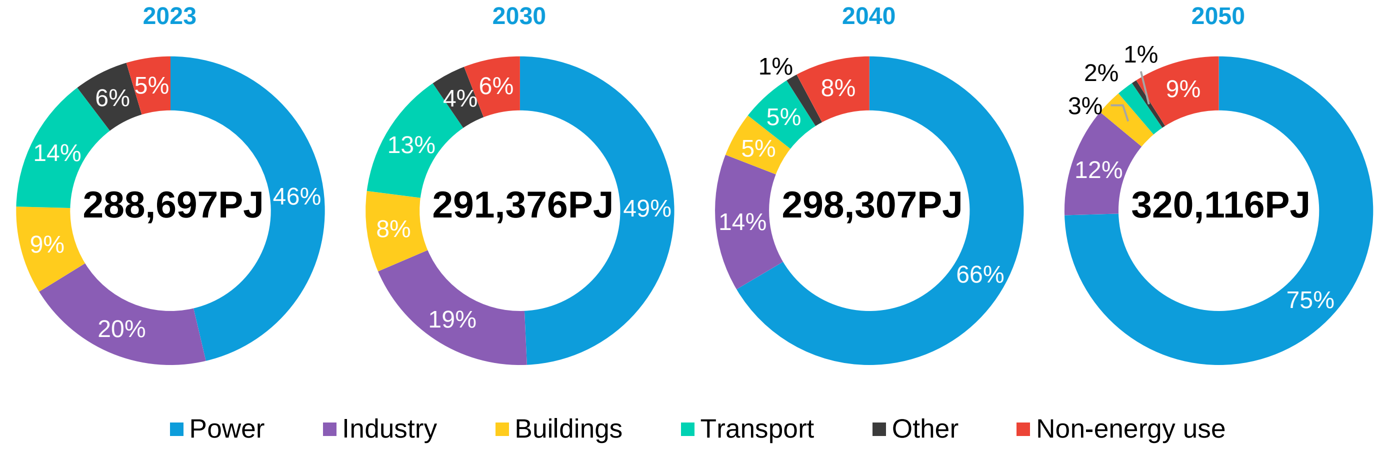
Technology (units)	Economic Transition Scenario, 2050 *(Multiplier versus 2023)*	Net Zero Scenario, 2050 *(Multiplier versus 2023)*	Key challenge to keep on track for net zero	Possible solutions
Solar (gigawatts)	6,781 *(x6.9)*	11,676 *(x11.8)*	Rapid scaling	• Binding phase-out targets for unabated fossil fuel power plants • Regulatory and market reforms to unlock renewable opportunities • Easing potential grid bottlenecks • Minimizing site acquisition hurdles through land allocation for renewable project development • Clear, long-term procurement programs
Wind (GW)	2,970 *(x5.5)*	5,847 *(x10.9)*	Rapid scaling	
Battery storage capacity (GW)	1,761 *(x48.5)*	2,227 *(x61.3)*	Rapid scaling	• Standalone or hybrid auctions • Power market reforms to allow for participation of batteries in ancillary service, energy, and capacity markets
Passenger electric vehicle fleet (million vehicles)	515 *(x22.2)*	671 *(x28.9)*	Rapid scaling	• Stringent fuel-economy or tailpipe emissions standards • Mandate electrification of business fleets • Subsidies and/or tax incentives to ease purchase barriers • Developing sufficient charging infrastructure • Introduce and legislate a complete phase-out date for sales of new internal combustion engines
Power grid (thousand kilometers)	44,036 *(x1.4)*	53,101 *(x1.7)*	Socio-political acceptance	• Minimizing site acquisition hurdles by facilitating easement rights • Regulatory reforms to spur greater private investments and open access to larger pool of capital

Source: BloombergNEF

4.1.1. Phase out unabated thermal power generation, especially coal

A low-carbon power system will be the foundation of a net-zero energy sector, comprising 75% of the region's energy consumption by 2050 (Figure 71). Clean power alone could abate 50% of Asia Pacific's cumulative emissions between 2024 and 2050. Reducing emissions from the region's power sectors needs to be of utmost priority. It is also one that can be actioned immediately with a fast scaling of low-carbon technologies and swift end to financing of new unabated fossil fuel plants. In the NZS, the share of generation from solar and wind increases from 19% to 73% over 2024-2050 in the NZS. The relative economic competitiveness of these technologies translates into a significant scale up under the ETS too, reaching 64% of the region’s output by mid-century (Section 3.2).

Figure 71: Asia Pacific energy consumption by macro sector, Net Zero Scenario

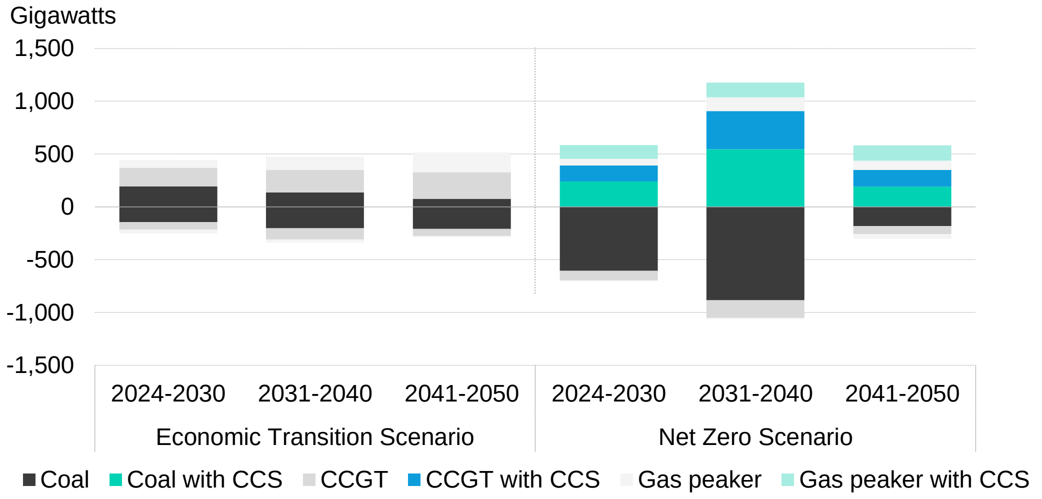


Source: BloombergNEF. Note: PJ is petajoules. ‘Non-energy use’ is non-combusted fuel consumption; consumed mostly in industry (chemicals).

Further addition of unabated fossil fuel generation capacity, in particular coal, is incompatible with a net zero by 2050 goal, according to the NZS (Figure 72). Limiting thermal power capacity expansion, and the introduction of carbon capture technology for new and existing plants, will be critical in all Asia Pacific markets, to set the region on track for net zero.

China is the world’s largest investor in the energy transition, however its growing coal power plant fleet is one of the major impediments to the world getting on track for meeting the Paris Agreement goal. While China has already taken positive steps to reduce emissions from coal power plants by phasing out older, higher-emitting plants as well as requiring more flexibility from newer plants to be able to run at lower load factors, it will need stronger measures to achieve the retirement of over 330GW of existing coal power plants required by the Net Zero Scenario. India, Japan, South Korea, and Southeast Asia also face a similar need to accelerate the closure of coal assets. Nearly 1.7TW of coal capacity is retired across Asia Pacific over 2024-2050 in the NZS – more than three times as much as in the ETS (Section 3.1).

Figure 72: Asia Pacific gross cumulative fossil-fuel generation capacity addition and retirement by time period



Source: BloombergNEF. Note: Negative values represent capacity retirements. CCS is carbon capture and storage. CCGT is combined-cycle gas turbine.

While Japanese and Korean utilities are considering reducing emissions from existing coal power plants by co-firing coal with cleaner fuels such as ammonia or biomass, their current strategies are not set to deliver the scale of emission reduction required. Countries in the region need to set binding targets for phase-out of unabated coal power plants. To alleviate the burden on existing power plant owners, in the short term, these markets can consider introducing incentives for "brown to green" transition of existing coal assets via reverse auctions partially backed by state funding. Japan's sovereign-backed green transition bonds, along with its low-carbon power capacity auction, are good examples of such approaches although the current lax design of these programs is not sufficient to deliver the emission reductions required. As discussed later, voluntary carbon offsets can also provide an additional revenue source for early retirement of existing coal power plants.

Power market reforms to allow for appropriate market price signals to guide investments

The lack of a competitive wholesale power market in several key Asia Pacific markets, such as in Indonesia and Vietnam, means there is a lack of appropriate pricing signals to incentivize closure of uneconomic coal generators. Terminating a planned power project in Indonesia and Vietnam operating on a single buyer model, whereby one entity, typically the state-owned utility, procures all electricity supply, is also legally and financially challenging. This is reflected in the results of our ETS: by 2050, unabated coal still accounts for 33% of Indonesia's generation, compared with 22% in India, 22% in Japan and South Korea, and 9% in China.

It is imperative that power purchase agreements signed today do not cause a long-term lock-in of less economic and carbon-intensive technologies. Historically, to attract the required financing and investments for power projects, many coal generators were offered decades-long contracts often accompanied by revenue protecting clauses such as a take-or-pay clause. Many of the agreements have little agility built in for early termination without financial penalties, effectively binding the offtakers to the contracts, which schemes such as the JETP and Asian Development Bank's Energy Transition Mechanism are trying to address. This contrasts with power markets such as Australia's, where coal and gas generators are exposed to daily market price signals and are already experiencing a squeeze on their dispatch hours, edged out by cheaper renewable assets.

Timely evaluation of planned thermal plants in national power plans

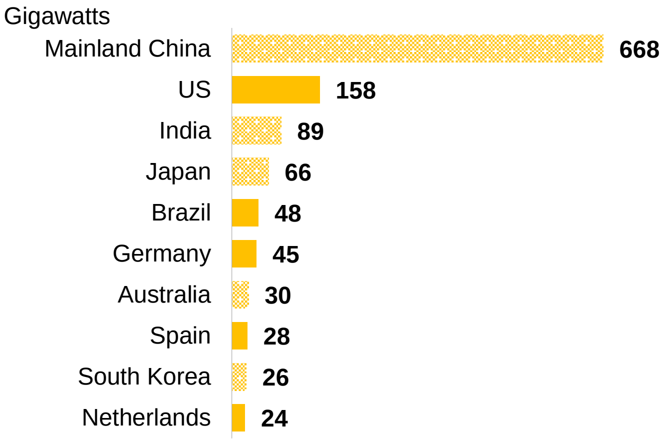
It is critical to perform timely reviews on the feasibility of pipeline fossil-fuel generation projects. Prompt cancellation of projects that are no longer economically viable or compliant with the country's climate targets will help to reduce the magnitude of the energy transition challenges.

As international financing turns away from carbon-intensive projects, pipeline thermal power projects yet to secure financing will find it increasingly challenging to do so. Delays in planned coal and gas power plants due to financing challenges in Vietnam have led to power supply shortages. This prompted the country to shift its focus toward solar and wind projects, and to implement a review process and a deadline to achieve financial closure for pipeline coal projects. Projects that fail to secure financing by the designated deadline will also be canceled. Introducing such designated deadline for projects could be a consideration for Indonesia. This enhances energy security and allows the country to choose the most economical options to meet growing power demand.

4.1.2. Accelerate the buildout of renewable power

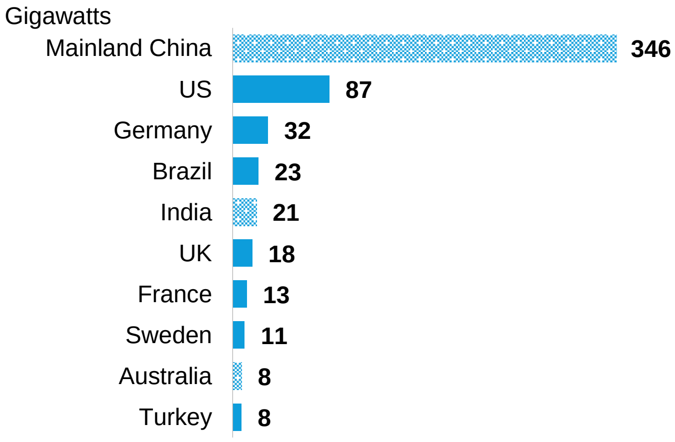
Progress on clean power deployment varies significantly across the region. Several Asia Pacific markets including China and India have been global leaders in the deployment of solar and wind capacity in the last 10 years, driven by ambitious national renewable targets backed by concrete actions and enabling development frameworks to see it through.

Figure 73: Top 10 global solar cumulative installed capacity additions by market, 2014-2023



Source: BloombergNEF. Note: Dotted-filled bars indicate Asia Pacific markets.

Figure 74: Top 10 global wind cumulative installed capacity additions by market, 2014-2023



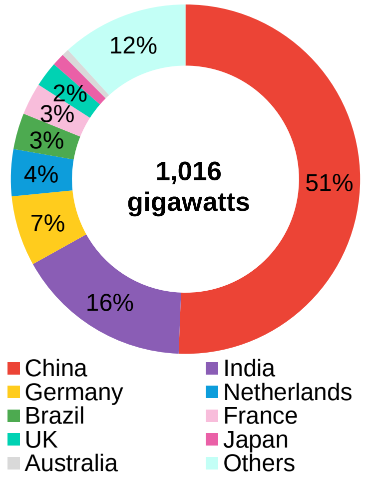
Source: BloombergNEF. Note: Dotted-filled bars indicate Asia Pacific markets.

Indonesia would benefit from regulatory and market reforms to help unlock renewable project opportunities

In contrast to leading markets like China and India, Indonesia added less than a gigawatt of solar (including both utility-scale and small-scale systems) from 2014 to 2023, hindered by an overcapacity of coal plants in the country's main grid systems that leave little space for additional generation capacity. Frequent changes to regulations on renewable development and tariffs, and the lack of transparency in the market add to the challenges. A small renewable power procurement appetite from the state-utility, Perusahaan Listrik Negara (PLN), coupled with a lack of alternative routes to market for renewable projects, limits project opportunities. To overcome obstacles impeding clean power deployment, Indonesia should consider:

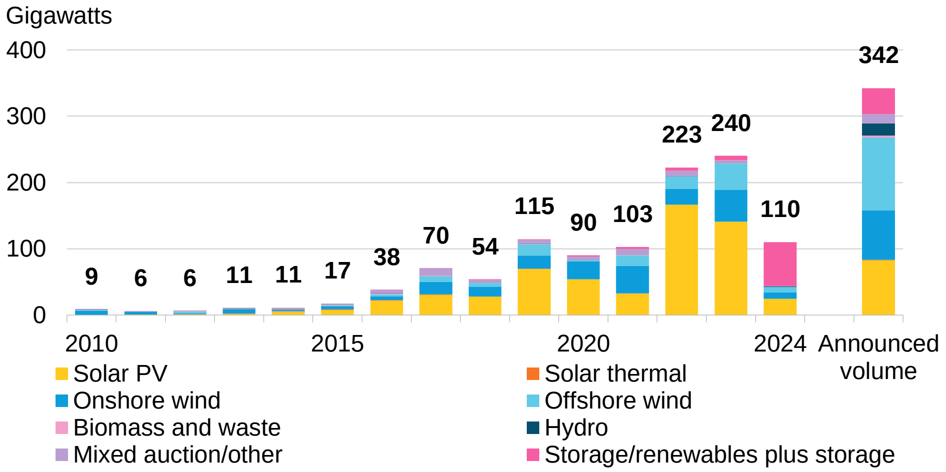
- **Leveling the playing field for renewable power:** Existing regulations hinder uptake of renewable energy generation technologies. Current power purchase tariff regulations force clean energy to compete with subsidized coal power. To unlock more renewable opportunities, it is imperative to re-evaluate both direct and indirect subsidies for fossil fuel plants. This allows different generation technologies to compete on an economic basis which can help to reduce overall supply cost over time. Moreover, opening access to PLN's networks for power wheeling could potentially boost corporate clean power procurement and remove the financial burden of supporting new clean power projects from the government and PLN.
- **Enhancing transparency through clear renewables procurement programs:** Auctions have been effective in driving renewable capacity addition globally. From 2004 and 2022, over 1 terawatt of renewable energy capacity has been awarded, with China accounting for more than half of total capacity (Figure 75). Indonesia currently carries out tenders to procure power capacity, primarily through state-owned utility Perusahaan Listrik Negara (PLN). The current power procurement process is opaque, limiting competition and price discovery. This increases costs to the public purse. Greater policy stability and transparency would help attract investment: for instance, a clearly defined long-term renewable procurement program could encourage growth of a local solar manufacturing and deployment value chain. Standardized power purchase contracts would also help.

Figure 75: Completed auction capacity by market



Source: BloombergNEF. Note: Figures are cumulative over 2004-2022. Uses plant-level data for auctions where support is awarded for generation. Numbers are rounded to the nearest whole value for addition purposes. Data as of 3Q 2024.

Figure 76: Annual auctioned and announced renewables capacity, by technology

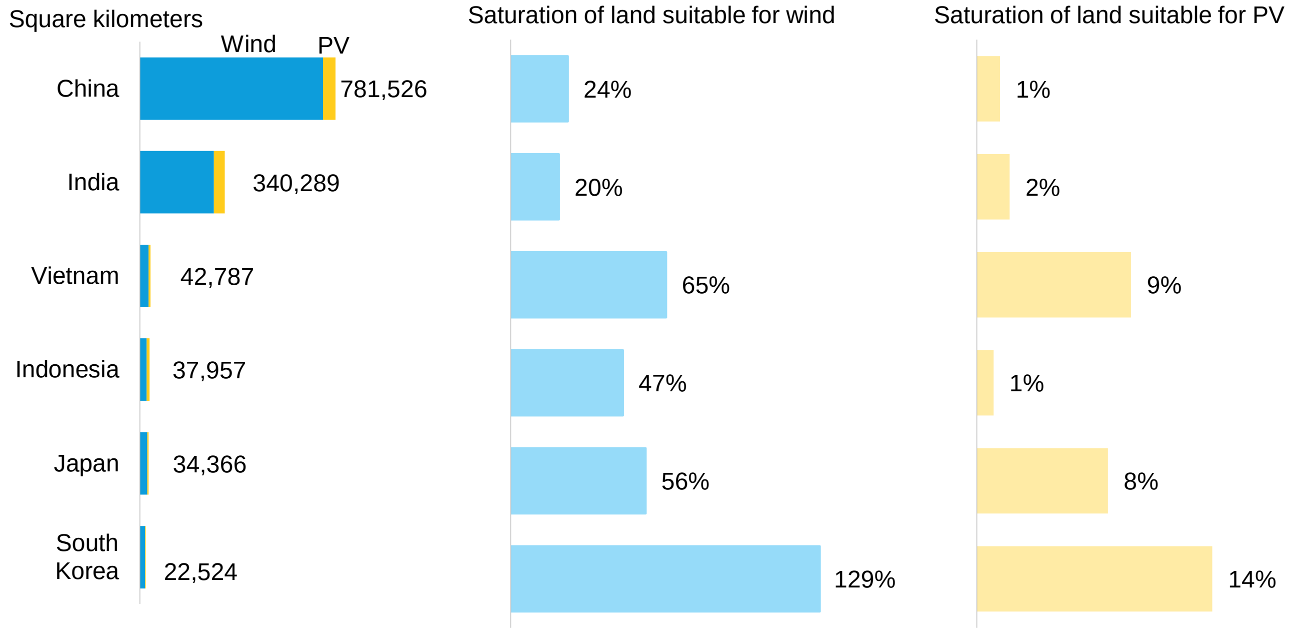


Source: BloombergNEF. Note: Uses plant-level data for auctions where support is awarded for generation. The growth in auctioned solar photovoltaic (PV) capacity in 2022 compared to previous years is partially due to improved data availability for Chinese auctions in 2022. Data as of 3Q 2024.

Assisting project developers to navigate site acquisition challenges

Difficulties in land acquisition can impede efforts to deploy more renewable energy projects across the Asia Pacific markets. Utility-scale renewable projects, in particular solar and wind, require large contiguous land areas. Aside from finding large parcels of land in areas with viable resources and access to grid interconnection, project developers may also have to compete with agriculture and industrial businesses. Increased renewable capacity deployment can also raise competition and in turn prices of suitable parcels of land.

Figure 77: Regional land demand of peak renewables and saturation levels in key Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF. Note: Wind is onshore wind. PV is solar photovoltaic. Saturation is the land required (demand) as a proportion of the land that has been identified as suitable (supply), for the respective technology. Suitable land constraints account for land characteristics and resource availability, but not for proximity to existing grids, infrastructure, or local labor availabilsity. See full methodology in Appendix E.

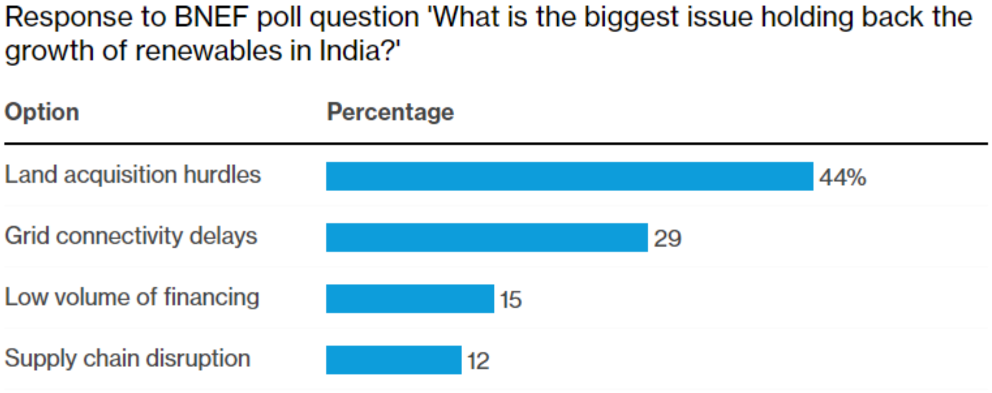
BNEF’s modeling of land use suggests that, theoretically, apart from availability of suitable land for wind capacity deployment in South Korea, all other key Asia Pacific markets have enough suitable land for renewables deployment required under the NZS. But there could be pinch points. Our geospatial analysis shows that land supply is tightest in South Korea under the NZS, where wind installations could require 29% more land than is deemed suitable. South Korea, Vietnam and Japan are also the most land-constrained countries for solar deployment out of the six key Asia Pacific markets discussed. The available land in these regions is constrained due to large areas of protected land, as well as challenging terrain.

Where the suitable land for deployment is exhausted, these countries may need to find ways to increase energy yields per hectare through technological innovation, or strategically invest in alternative technologies that are more expensive today but less land-intensive in the future, such as offshore wind, geothermal or nuclear.

Where land is available, project developers could also face acquisition barriers that governments could assist in easing.

- **India**'s industry players polled by BNEF scored land acquisition as the biggest hurdle to accelerating India's clean power transition. Land ownership in India is fragmented and land titles can be unclear. Project developers also face differing land acquisition rules and procedures by state. Digitizing land records, promoting uniformity in acquisition rules and aggregation of land by state agencies would help de-risk and accelerate project development.

Figure 78: Barriers to accelerating India's clean power transition



Source: BloombergNEF. Note: Shows results of poll conducted at the BNEF Summit New Delhi on September 5, 2024 with 78 responses.

- Similarly, **Japan** has a lot of land with unknown ownership. The area of such land (based on the registry) accounts for 20% of the land sample, according to a survey conducted by the Ministry of Land, Infrastructure, Transport, and Tourism in 2016. With Japan's economy and demographic shift, this amount could keep rising in the future. Effective management of such land by Japan's government could increase access to land for renewable energy deployment. In 2022, Japan revamped its land policy, extending the use of land with unknown ownership to 20 years from 10 years for public purposes.
- In **South Korea,** many municipal governments have their own geographic restrictions on solar project development (e.g. distance from public roads, residential area, etc.). Standardizing such regulations and providing clear guidelines by which legal claims can be made will reduce conflicts with local communities.
- Offshore wind projects in **Vietnam** face a lack of regulations around sea use permit and seabed leasing regulations and process, and the construction and operation of submarine cables. The country is currently developing a national marine spatial plan which could offer developers clarity around the rights to seabed. Clear seabed allocation for offshore wind development would also lower uncertainty around site selection for developers.

Governments can help to address site acquisition hurdles

Land or site, and grid access are two of the largest development risks for renewable project investors. Some markets, such as India and Australia, have turned to solar parks or renewable energy zones, providing land, grid connection and basic infrastructure (roads and water supply). This helps to de-risk projects for independent power producers and can spur renewable energy deployment.

As the best sites with the highest-quality renewable energy resources and nearby grid access are utilized, the challenge of finding suitable sites for new renewable energy projects increases and can hold back capacity deployment. Governments can help to mitigate this barrier through:

- Providing a national registry on suitable land and ownership
- Streamlining permit approval processes. This can be achieved through a government 'one-stop shop' for all permitting and connection applications
- As much as feasible, standardizing land-use regulations and guidelines on a national level
- Offering available and suitable government-owned land through reverse tenders.
- Coordinating and facilitating grid infrastructure development and basic civil works for suitable sites, including acquiring required necessary land rights

4.1.3. Expand and upgrade power grids and systems

As renewable penetration on a grid increases, markets are experiencing grid capacity constraints, grid connection permitting bottlenecks and high curtailment rates from a lack of adequate flexible capacity in the grid. Addressing these issues early on and as part of auction designs can prevent delays resulting from infrastructure bottlenecks. In the ETS, Asia Pacific markets commit around $5.7 trillion toward grid investment over 2024-2050. Greater renewable buildout in the NZS requires 56% more grid investment – or $8.9 trillion – over the same period (Section 3.5).

- **China** has been building transmission networks including high-voltage direct current (HVDC) lines at an unprecedented rate. However, the combination of technologies used and current power market regulations have limited renewables from increasing their utilization of such grid infrastructures. More work is needed to ensure China's national and local grids can boost – not hinder – renewable uptake.
- In **Japan and India**, demand centers can be quite far from regions with high renewable resources. Hence, ensuring sufficient transmission grid capacity, including inter-regional infrastructures, are key to enabling higher uptake of renewables. Improved transparency around grid connections processes, timelines, and costs would also enable the significant scale-up of renewable capacity required for the countries' net-zero goals.
- In **Indonesia** and **Vietnam,** where the state-owned utilities retain a monopoly in the transmission and distribution segments, reforms to enable private grid investments can increase access to the required capital and accelerate necessary grid infrastructure upgrades.

4.1.4. Augment power system flexibility

All regional governments, regulators, and power system operators need to prioritize flexibility – from both the supply and demand side – to enable higher renewable generation shares. Inadequate power system flexibility can result in high levels of renewable curtailment or sub-optimal dispatch of resources. Total energy storage capacity deployment (batteries and pumped hydro) in the NZS across Asia Pacific increases from 170GW in 2024 to 2.7TW by 2050, compared with 2.2TW in the ETS (Section 3.4).

Indonesia and Vietnam's power market regulations currently do not allow for the participation of storage assets. Both countries' power sector plans also favor pumped hydro developments and present limited opportunities for battery storage assets. Implementing frameworks for the participation of all types of flexible assets in Vietnam's and Indonesia's power systems could help these countries leverage economic dispatchable generation sources. This could also ease any curtailment challenges and enhance grid flexibility for the integration of variable renewable energy sources. This includes the use of controllable load assets such as virtual power plants, demand response and interruptible load schemes, which can increase the stability of the grid and better align both countries' demand profiles with the generation profiles of renewable energy plants.

To facilitate storage capacity deployment, some Asia Pacific markets have employed energy storage capacity auctions, regulations, or auction designs to shift the responsibility of firming variable renewable generation onto the power producers. Notably, India is pioneering a series of complex renewable energy auctions, where projects need to combine multiple technologies to reduce the intermittency of output, increase capacity factors and move closer to firm, dispatchable clean power. This model could be emulated by other countries in the region. As of March 2024, India has called for 31 complex auctions which can be broadly classified into four categories.

Table 10: India's renewable auction designs

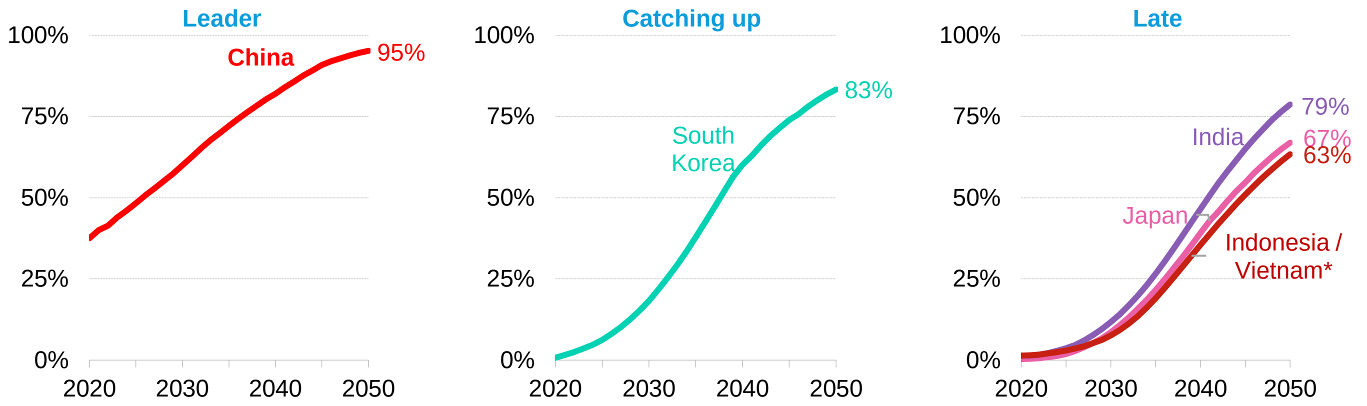
Parameter	Hybrid	Peak power	Round-the-clock	Load-matching
Technologies	Wind, solar	Wind, solar and energy storage. The latter is mandated in some projects and deployment will happen in almost all projects to meet supply conditions.		
Sizing	Minimum capacity of each source must be 33% of total capacity	No restrictions on sizing of wind and solar components. Some tenders mandate minimum size of storage required, and storage must be charged using renewable power.		
Key supply conditions	Annual capacity factor (CF) of 30%	Specify energy dispatch or availability for four to six peak hours daily	Specify minimum availability and capacity factor on annual or monthly basis	Projects may be called on to meet representative hourly demand profile for 25 years
Third-party power transactions	Not allowed or needed	Specify energy dispatch or availability for four to six peak hours daily		

Source: BloombergNEF, tender documents. Note: Table shows typical tender terms, each tender has small variations.

4.1.5. Rapidly electrify road transport

Rapid and complete electrification of road transport holds the key to fully eliminating emissions from the sector. Today, electrification of passenger vehicles is the most accessible option that governments already can tap into for immediate emissions reduction in the transport sector. Light electric vans and trucks are already being adopted in several countries but see a slower uptake compared to passenger vehicles.

Figure 79: Electric vehicle share of passenger vehicle fleet, Economic Transition Scenario



*Source: BloombergNEF. Note: *Trajectories for Indonesia and Vietnam overlap and are represented by the same line in the chart. Passenger vehicles include buses, cars, trucks, and two- and three-wheelers.*

EV uptake differs significantly across countries in the Asia Pacific region, both presently and in our forecasts. While China gets close to a full phase-out of internal combustion engines in its passenger vehicle fleet by 2050 under the Economic Transition Scenario, India, Japan, Indonesia and Vietnam fall short and are not on track to achieving net zero by 2050 unless urgent policy action is taken today.

To drive increased adoption of EVs across all segments, governments will need to step up and implement some or all of the measures below:

- Introduce or tighten fuel economy standards and/or tailpipe CO2 emissions standards, accompanied by effective penalties on failure to comply, to incentivize automakers to prioritize supply of electric vehicles for the market. The lack of affordable EV models can hold back uptake, especially in more price-sensitive markets such as India and Southeast Asia.
- Introduce mandates for electrification of business vehicle fleets, including those of governments and transport operators such as taxis and ride-hailing services. The higher annual vehicle mileage clocked by business fleets lowers the total cost of ownership and enhances the economics of EV adoption.
- In markets where the upfront cost disparity between an EV and ICE remains high, direct purchase subsidies and/or indirect cost subsidies through tax incentives can be considered. Where constraints around direct financial subsidies exist, governments can consider implementing a CO2 emissions-based tax on ICEs to improve the relative economics of EVs.
- As the cost of batteries and correspondingly EVs fall, the role of financial incentives in driving uptake declines. Instead, governments should also focus on the whole ecosystem, such as ensuring sufficient charging infrastructure to support a larger EV fleet. This is critical in densely populated markets with many without access to a private home charger. Policymakers can introduce a charging infrastructure target at a level sufficient to meet the country's charging demand and a uniform charging standard. To ensure timely deployment of chargers, authorities can organize tenders for the installation and operation of charging infrastructure. Governments can also leverage building codes and standards to mandate the installation of EV chargers in new buildings.
- Impose regulations around battery warranties and repairs to alleviate concerns around depreciation and maintenance costs for EV adopters.

- Many countries are moving to onshore battery supply chain and manufacturing jobs in the name of job creation and energy security. The use of punitive trade policies must be done and designed carefully to ensure its effectiveness in scaling up the domestic industry. Failure to do so could severely limit the supply of affordable EVs in a market and slow the energy transition in the sector.
- Introduce and legislate a complete phase-out date for sales of new internal combustion engines. This conveys a clear and firm national transport decarbonization plan to automakers active in the market and allows them the necessary runway to ramp up supply of low-carbon vehicles.

The decarbonization role of transportation modal shifts

As governments target higher EV adoption in their respective markets, a push to reduce overall demand for vehicle usage and ownership also aids in decarbonizing the sector through the lowering of total energy demand. Higher-density zoning in urban areas, active transport options such as cycling and walking and the necessary supporting infrastructure, and investment in mass public transit all have an important role to play.

4.2. Supporting the development of emerging climate solutions

Achieving net zero by 2050 relies on a few developing technologies for which associated infrastructure and global supply chains are yet to scale up significantly and cost curves are still emerging. The urgency of global decarbonization means governments and corporates need to intensify efforts to ready and commercialize these technologies for deployment at scale within the next 10 years. The gap between the deployment of emerging technologies under the ETS compared to the NZS is far greater than that of mature solutions. This means more effort and innovation will be required to develop and deploy these technologies to stay on a Paris-aligned pathway.

4.2.1. Fund pilot projects for clean dispatchable firm power capacity

While solar, wind, and batteries will form the bulk of power capacity under the Net Zero Scenario, a fully decarbonized power system will also need clean dispatchable firm power. Governments across the region should consider funding pilot projects during this decade specifically for new technologies such as CCS for thermal power plants, next generation geothermal and nuclear as well as LDES.

4.2.2. Introduce policy support for hydrogen across the value chain

Hydrogen is an important decarbonization vector for high-heat industrial sectors. Globally, 53 markets had a hydrogen strategy by March 15, 2024, and 30 were preparing one. This includes all six markets discussed in this report – China, India, Japan, South Korea, Indonesia and Vietnam. However, clean hydrogen today comes with a higher price compared to the coal and gas it aims to displace and would require some form of policy support and/or subsidies. The lack of any new policy incentives to support clean hydrogen production in the ETS sees gray hydrogen still make up over 70% of the fuel's consumption by 2050, with the rest coming in the form of endogenous hydrogen. By contrast, the application of a carbon constraint in our NZS sees 95% of hydrogen being produced via green electrolysis by 2050 (Section 3.6).

Table 11: BNEF’s policy signposts, progress by region

Policy signpost	Americas (AMER)	Asia Pacific (APAC)	Europe, Middle East and Africa (EMEA)
Hydrogen strategies and targets	Most major markets have a H_2 strategy; some have targets	Most major markets have a H_2 strategy; some have targets	Most major markets have a H_2 strategy and targets
Government funding	$188 billion in funding available, most for H_2 producers	$32.5 billion available, an order of magnitude below AMER, EMEA	More than $140 billion available, more for users than AMER
Enforceable demand quotas	No quotas for clean H_2 use in AMER	South Korea has quotas; not all are for clean H_2	EU has the strongest H_2 quotas; some may be hard to enforce
Carbon prices that bite	Missing or insufficient carbon prices in all AMER markets	Missing or insufficient carbon prices in all AMER markets	EU and UK have CO_2 prices and plan to limit exemptions
H_2 midstream development	US firms are building salt caverns, but with little policy support	Chinese firms are planning pipelines, but policy support is low	Pipeline policy is starting to emerge in the EU and UK

Source: BloombergNEF. Legend: On a good track, some progress, more effort needed.

Pushing incumbent uses to low-carbon hydrogen

Existing hydrogen uses can drive the initial offtake for low-carbon hydrogen and support the first wave of low-carbon supply projects. Before hydrogen demand in hard-to-abate sectors scales, incumbent hydrogen use in the production of ammonia for fertilizers and chemicals, methanol for plastics and chemicals, and oil refining represent an immediate opportunity.

Policymakers can consider the use of an enforceable clean hydrogen quota to increase hydrogen demand. Quotas can be designed to increase in line with expected availability of supply and cost-competitiveness of the molecule, but not too insignificant that it fails to drive up demand. Today, **South Korea** is one of two markets with the most certain clean hydrogen demand in the short term, supported by the country’s quotas for hydrogen use in the power sector. **India** is also mulling quotas for clean hydrogen use by existing gray hydrogen users.

Supporting the infrastructure development of cost-competitive low-carbon hydrogen

Tax incentives, subsidies and/or contract for differences (CfD) will play a crucial role in Asia Pacific in reaching its hydrogen potential. Generous tax credits, like those seen under the US Inflation Reduction Act (IRA), could significantly reduce the cost of hydrogen production, making it competitive with its fossil counterparts. The regional governments could look to the IRA and introduce both a production tax credit mechanism and an investment tax credit covering a share of the upfront cost for a new clean hydrogen facility.

Midstream infrastructure development is missing as a priority for most policymakers today. A steady build out of infrastructure is needed to support the region’s hydrogen industry. Infrastructure in the form of ports, pipelines and storage facilities for hydrogen would be imperative if key Asia Pacific markets are to scale up production. Building new pipelines to transport hydrogen will be capital intensive and repurposing existing pipelines might not be feasible due to the technical properties of the fuel.

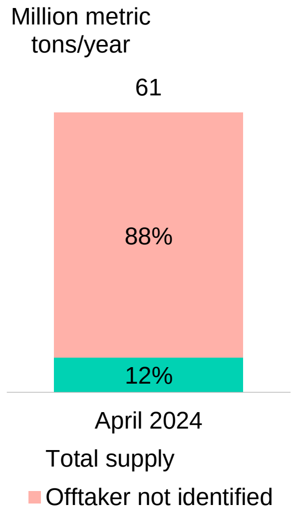
Cross-border hydrogen trade discussions among Asia Pacific markets are on the rise. However, infrastructure to support international hydrogen trade is largely lacking today. Whether a market is looking to export (such as Vietnam) or import (such as Japan and South Korea) hydrogen, policymakers need to ensure that they develop the required infrastructure to support their respective hydrogen ambitions. Industry will also have to build large-scale storage options for hydrogen for which governments can facilitate by conducting feasibility studies on. The establishment of hydrogen hubs can allow producers, users, and exporters to work together and achieve economies of scale from shared infrastructures and expertise.

It is imperative that the scale-up of hydrogen production is accompanied by a ramping up of a market's renewable power capacity and/or the CCS industry − although almost all hydrogen produced today is gray, which is not compatible with a net-zero transition. It is necessary to ensure a holistic ecosystem development to enable low-carbon hydrogen production for tangible emissions reduction benefits.

Supporting the scale-up of new sources of demand for low-carbon hydrogen

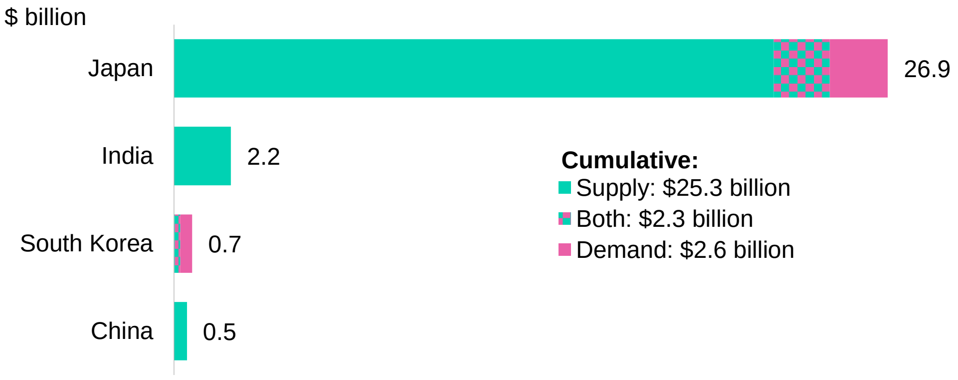
Clean hydrogen demand remains low compared to announced supply. By April 1, 2024, only 12% of production capacity planned to come online by 2030 has identified an offtaker (Figure 80). The low offtake rate is holding back supply projects from securing financial closure. Financial support for hydrogen today has been focused on production projects. Governments in China, India, Japan, and South Korea had collectively earmarked more than $30 billion for clean hydrogen by April 30, 2024 (Figure 81). Just 9% ($2.6 billion) is targeted at demand and comes exclusively from Japan and South Korea.

Figure 80: Clean hydrogen offtake by 2030



Source: BloombergNEF

Figure 81: Government support for hydrogen by market and target area



Source: BloombergNEF. Note: 'Both' includes supply, demand and support for hydrogen midstream (storage and transport). Data as of April 2024.

Focusing on demand-side incentives will be critical for the progression of hydrogen production facilities. Governments can consider:

- Tax incentives, subsidies and/or contract for differences (CfD) to spur clean hydrogen offtake. It is imperative to channel financial assistance into sectors where clean hydrogen will be the most effective decarbonization pathway. Japan's past hydrogen policies provided generous subsidies for applications such as fuel cell passenger vehicles, as well as residential fuel cell co-generation systems. However, there are cheaper and more effective ways to decarbonize the transport and buildings sectors.
- Introduce clean hydrogen quotas and/or effective carbon prices. Governments could also provide offtakes to hydrogen producers through state-owned entities.

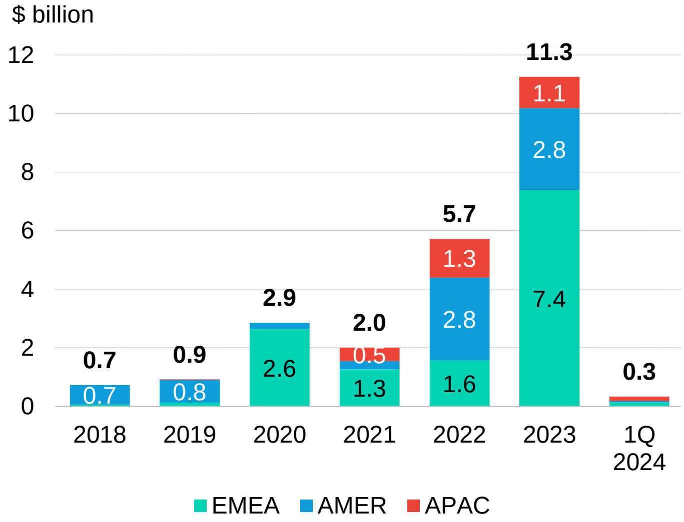
- Governments in the region could also look to cross-border collaboration on hydrogen supply and demand incentives targeting industries with the highest potential for clean hydrogen offtake. This includes sectors facing pressure from stakeholders to decarbonize such as steelmakers and automakers.

4.2.3. Catalyze carbon capture and storage adoption through incentives and regulations

Global CCUS capacity has grown at a 7% compound annual growth rate (CAGR) since 2010. Growth was initially incentivized by enhanced oil recovery (EOR), particularly in the US, but now net-zero goals and the subsequent demand for green products are the market's new driving force.

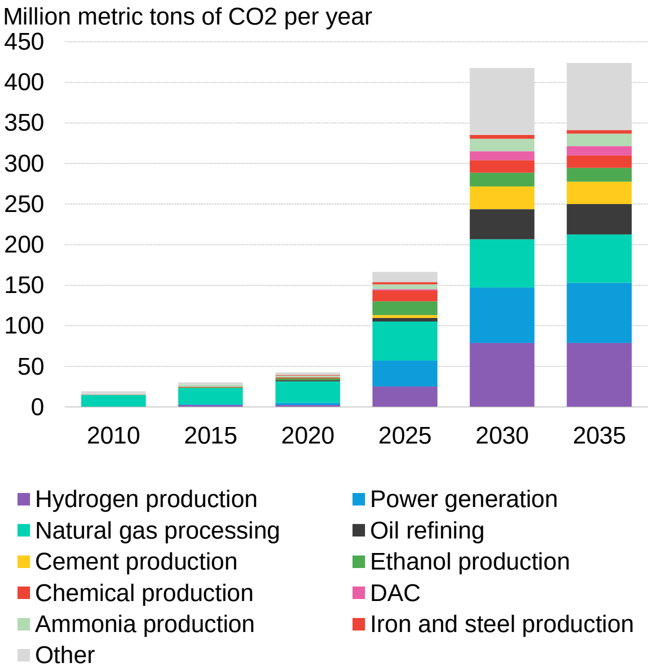
Investment in the technology is scaling both globally and in Asia Pacific. In 2023, global investment in carbon capture, transport and storage nearly doubled for the second year in a row, reaching a record $11.3 billion (Figure 82). However, rapid scale-up of the technology is still limited by costs, technological, and infrastructure constraints.

Figure 82: Global investment in carbon capture, utilization, transport and storage by region



Source: BloombergNEF. Note: APAC is Asia Pacific; EMEA is Europe, the Middle East and Africa; AMER is Americas. Includes asset finance, corporate research and development to develop first phases of specific projects, and government research and development for direct air capture plants and point source technologies.

Figure 83: Global carbon capture capacity by point source, historical and announced (cumulative)



Source: BloombergNEF. Note: DAC is direct air capture.

Globally, new project announcements have slowed, as investors continue to wait for more clarity from governments on incentives and regulations in the major markets such as the US, the UK, and Canada. The CCUS market today is dominated by natural gas processing, using the CO2 for

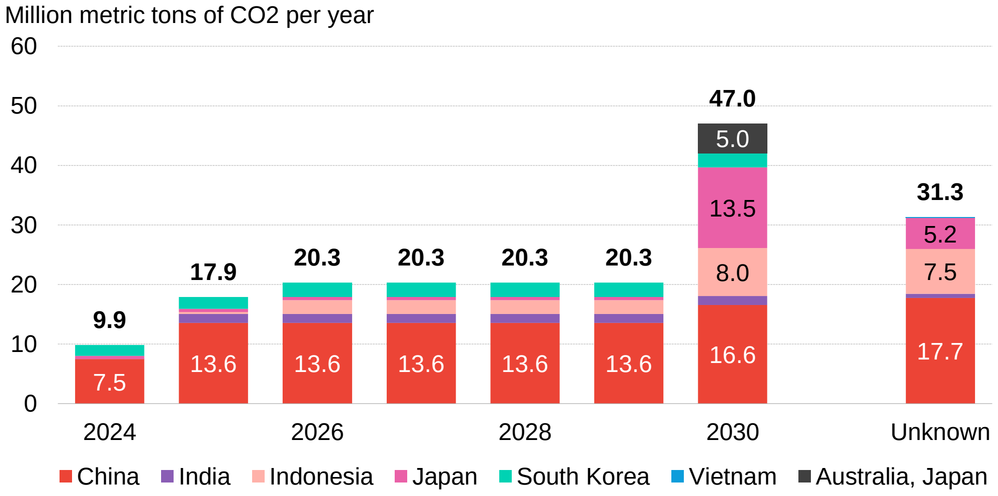
EOR (Figure 83). These are the cheapest applications for CO2 capture. However, under the NZS power generation and hydrogen production will gain significant market share from 2027.

Hydrogen continues its victory lap as the sector to beat in terms of new project announcements, despite a global slow down. While much of the market has remained quiet, locations with enforceable quotas to increase low-carbon hydrogen demand, like South Korea and the EU, have seen some activity[6]. These quotas could inadvertently increase blue hydrogen capacity in the US as developers target these markets for offtake. In January of this year, Posco and Adnoc announced plans to produce blue hydrogen at the Gwangyang terminal in South Korea. The companies have plans to start supplying clean hydrogen in 2029 to proximal iron and steel facilities and to other local industrial parks.

Transport and storage bottlenecks plague the industry

CCS holds immense emissions abatement potential in the fossil-fuel dominated energy systems around Asia Pacific. By 2030, operational and proposed pipeline projects total 47MtCO2 per year in the six key Asia Pacific markets, with China, Japan and Indonesia leading the pipeline in the NZS. Uncertainty surrounding policy, financing and transport and storage permitting woes could however hinder the materialization of these projects.

Figure 84: Cumulative carbon capture, utilization, transport, and storage capacity proposed by commissioning year and market



Source: BloombergNEF. Note: 'Unknown' refers to projects without an announced commissioning year. 'Australia, Japan' reflects a bilateral project. Excludes projects that are canceled or put on hold.

For CCUS to succeed as a decarbonization solution, transport and storage capacity should ideally exceed the proposed capture capacity. About 6Mt of combined transport and storage capacity is proposed to come online by 2030 in the six key Asia Pacific markets, far lower than the 41Mt of capture capacity proposed to come online by then (Figure 85).

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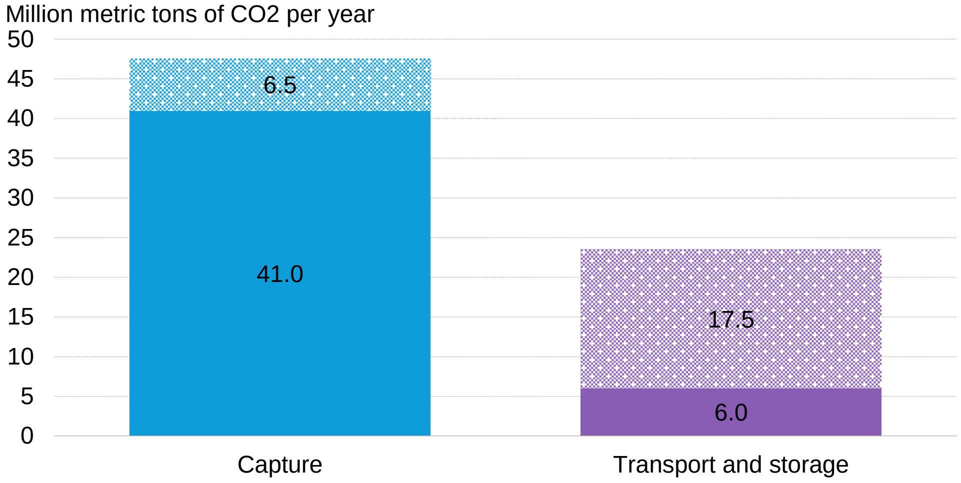
[6] The EU quota is for *green hydrogen,* but US blue hydrogen projects can qualify.

Figure 85: Proposed carbon capture, transport and storage capacity by segment in key Asia Pacific markets



Source: BloombergNEF. Note: Solid bars show cumulative capacity by 2030 and dotted-filled bars represent capacity with no announced commissioning year. Chart shows proposed capacities in China, India, Japan (including bilateral project with Australia), South Korea, Indonesia and Vietnam.

The region needs more clarity on regulations around CCS activities

Today, Asia Pacific largely lacks CCS-specific regulations governing domestic and cross-border capture, transport and storage permitting and activities which could slow project developments. While policy activities in most markets are currently subdued, some markets are showing some encouraging development such as Japan and Indonesia.

Table 12: Summary of major carbon capture, utilization and storage policy announcements in selected Asia Pacific markets, December 2023-May 2024

Policy	Market	Description	BNEF take
Carbon market update to include carbon offsets	Japan	Change in Japan’s carbon market rules to include offsets from CO2 removal projects including direct air capture and bioenergy with carbon capture	This could drive companies to seek out international carbon removal offsets, especially from markets that are signatories to the Joint Crediting Mechanism, as Japan transitions its carbon markets to a compliance market in 2026.
CCS Business Act	Japan	The act defines the rights for storage and drilling, monitoring responsibility and the regulations for pipeline transportation of CO2	The Act does not currently define any incentives that would be made available to projects. However, the legislation gives more long-term clarity to investors about Japan’s ambitions and sets the rules in place as the market scales up efforts to deploy the CCUS projects it has identified across seven different sites.
Indonesia limits CO2 imports	Indonesia	Limit international CO2 storage to 30% and prioritize domestic emissions	Indonesia is keen to develop storage infrastructure that it aims to monetize by parking emissions from regions such as Japan, Korea and Singapore. These regulations allow companies such as Pertamina and Exxon to start developing projects that can be marketed to emitters in other Asian markets.

Source: BloombergNEF

To accelerate CCS developments and ready it for deployment at scale as soon as possible, policymakers can consider:

- Finalizing the regulations and standards to enable the transport and storage of CO2 domestically or across international borders (such as the London Protocol). Enforce guidelines to reduce the permitting timelines for these projects.
- Providing funding into research and development and pilot projects in critical sectors dependent on CCS for emissions abatement.
- Introducing support, through tax incentives and/or CfDs, for CCS projects and infrastructure to lower upfront development costs. Similar to hydrogen hubs, governments could target industrial hubs for shared CCS facilities and infrastructure.
- Taking a lead on the exploration of potential onsite and offsite CO2 storage sites in their respective markets and coordinate investments into the development of feasible sites.

4.2.4. Scale up SAF and clean marine fuel production and usage through incentives and mandates

As discussed earlier, SAF and clean marine fuels will be critical for the decarbonization of aviation and shipping. To support the production and usage of SAF and clean marine fuels, governments will need to consider the following three measures:

- Phase out usage of feedstocks needed for SAF from low-value applications such as biofuels for passenger vehicles: governments will need to ensure the limited volume of available feedstocks needed for production of SAF and clean marine fuels are not used by applications that have alternative cheaper decarbonization options.
- Provide incentives for production and usage of SAF and clean marine fuel: in the short term, governments will need to provide subsidies to support scaling up of production of SAF and clean marine fuels and their usage. Governments need to collaborate to support efficient scaling up of the relevant infrastructure. For example, governments across the APAC region can designate specific flight routes and shipping lanes to benefit from targeted incentives.
- The governments across the region will need to set long-term targets for phase out of fossil fuels in favor of SAF and clean marine fuels. APAC regulators can learn from the EU's approach.

4.3. Scaling up finance for the energy transition

Reshaping and decarbonizing Asia Pacific's energy systems will require a substantial scale-up of capital directed toward low-carbon assets and infrastructure.

4.3.1. Enable access to affordable financing and debt

It is critical to accelerate access to low-cost finance for mature low-carbon technologies, as these tend to be associated with high capital expenditure. As low-carbon projects have increasingly come to resemble traditional infrastructure investments rather than risky alternatives, a larger pool of investment capital has emerged. However, project developers and commercial banks are still responsible for most clean energy project financing, and the cost to access this capital remains a limiting factor especially in the current high interest rate environment.

The higher the perceived risks of a project, the greater the unwillingness to finance or more unfavorable the terms will be. Key concerns for investors include:

- **Mitigating regulatory risks:** A lack of continuity in policy support can severely undermine a project’s economics and investors‘ confidence. Regulatory risks are difficult, if not impossible, to mitigate. While local partnerships can help to manage challenges such as information asymmetry, it is ultimately governments that are responsible for developing stable regulatory frameworks that minimize uncertainties.
- **Managing offtaker and curtailment risks:** The quality of the offtaker and the extent of curtailment can directly affect project revenues. For single-buyer electricity retail markets such as Indonesia and Vietnam, the credit profile of the state utility matters. In India, a history of delayed or missed payments by state-owned utilities (known as “discoms”) led to a halt in lending to new projects contracted with them by international banks. For renewable projects, the extent to which they are insulated from curtailment also matters. Terms viewed favorably include additional payment security mechanisms, compensation to IPP for grid unavailability, and financial protection in case of offtaker default and can hence improve the perceived “bankability” of the projects.
- **Strengthening market price signals for decarbonization:** This can be achieved through power market reforms, higher and more stringent carbon pricing mechanisms and/or a long-term roadmap for the roll-out of carbon tax adjustments.

4.3.2. Leverage development institutions to catalyze private investments

Emerging technologies may see higher barriers to financing due to the uncertainties around technology performance, supply chains and profitability, and may require greater support from governments and multilateral institutions at the start.

- **Establish priority sectors for lending:** Commercial banks may be guided to invest into certain sectors by each local markets’ central banks. To help banks manage some of the risks, government or development finance institutions can consider spearheading a risk-sharing facility or providing some form of guarantee for the loans.
- **Development finance can catalyze greater private investments**: Development institutions can help overcome higher financing costs for emerging technologies with concessional finance instruments – including loans, grants, and guarantees offered below market rate – to both decrease the cost of capital and improve access with longer repayment times and lower interest rates for renewables projects. When blended with commercial loans, emerging technology projects could find it easier to obtain financing deals with more palatable and financially viable costs.
- **Partnerships with foreign banks that are more experienced with the technologies:** Development of emerging technologies are more advanced in certain markets. For example, the much higher carbon price in Europe has generated many more hydrogen projects and more offtake there compared to Asia Pacific. Over time, European banks may be more comfortable with financing such deals compared to their peers in the Asia Pacific region. Partnerships between domestic and foreign banks for credit lines or syndicated loans can ease access to capital.

4.3.3. Recalibrate fossil fuel subsidies and carbon pricing policies

Subsidies need to be well-designed

Subsidies and tax incentives are common government interventions to support an emerging technology. While subsidies have a role in accelerating required decarbonization technologies, it is imperative to have a well-designed subsidy scheme. Schemes with unclear guidelines, eligibility criteria that are too onerous or ones that are set at insufficient levels can fail to achieve the intended outcomes. On the other hand, subsidy schemes that are too generous and lack a clear phase out timeline can cause inefficiencies in the sector and over-reliance on government support in the long run. Subsidies need to be targeted into sectors that need them in the short term, and should be phased out when financial support for the technology is no longer required.

To the extent possible, governments need to re-evaluate other direct and indirect subsidies that could distort the playing field for low-carbon technologies or skew market prices and investment signals. For example, fossil fuel subsidies (both direct and indirect) force low-carbon technologies to compete against an artificially low price.

Governments also need to recognize the potential of subsidies in limiting capital for low-carbon technologies. Subsidized or controlled retail power prices in markets such as Indonesia and Vietnam affect the financial positions of the state-owned utilities and limit their ability to fund the energy transition.

Higher and more stringent carbon prices required to support decarbonization

A robust carbon pricing instrument can be effective in driving decarbonization and provides a revenue source for funding the energy transition. This is especially important in hard-to-abate sectors as low-carbon solutions using hydrogen and CCS technologies won't be economically competitive against other alternatives without a high carbon price. Carbon pricing also works well in other sectors such as power and transport to support low-carbon solutions.

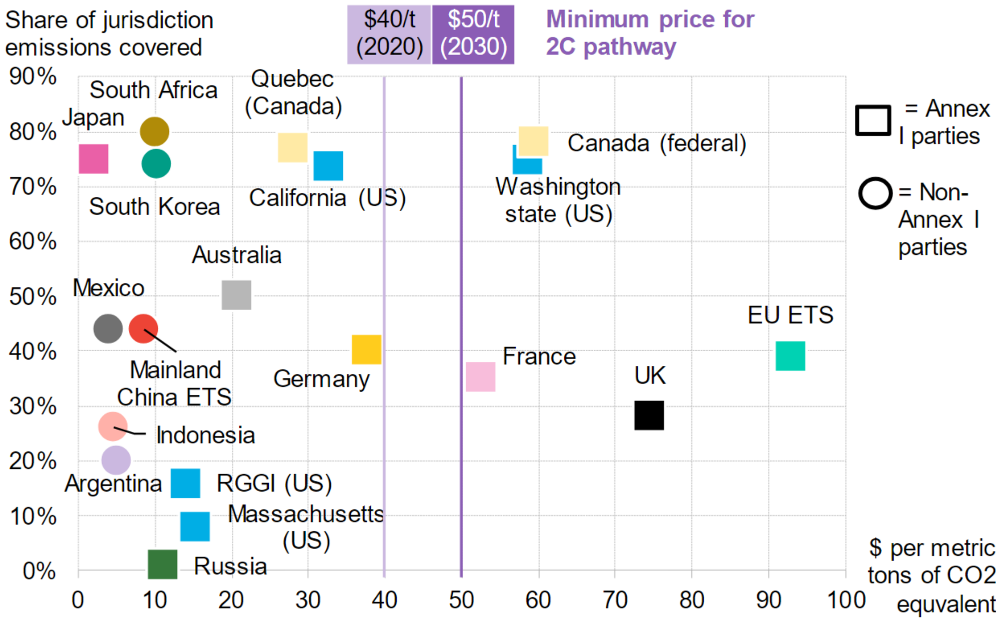
To be effective, a market's carbon pricing mechanism needs to be sufficiently high and should cover a significant share of emissions. Today, carbon prices in China, Japan, Indonesia, and South Korea are too low to drive material changes (Figure 86). In South Korea, an oversupply of permits and generous free allocation levels at 90% or more have kept carbon prices low.

The regional governments need to act decisively in implementing more stringent carbon pricing mechanisms to accelerate emerging technologies development and stay on track for net zero. Laying out the rollout timeline of a proposed carbon pricing mechanism or adjustments in advance provide a strong signal to businesses on the need for decarbonization. It also provides businesses with a pathway to make necessary plans.

There are concerns that a carbon price that is too high will diminish the competitiveness of domestic businesses against counterparts in countries with little to no carbon pricing. To address this, policymakers can leverage on transitory allowances for emissions-intensive trade-exposed companies to cover part of their emissions. Such allowances will need to be carefully designed as too generous a concession could make the carbon price ineffective and negate the incentive for abatement by companies.

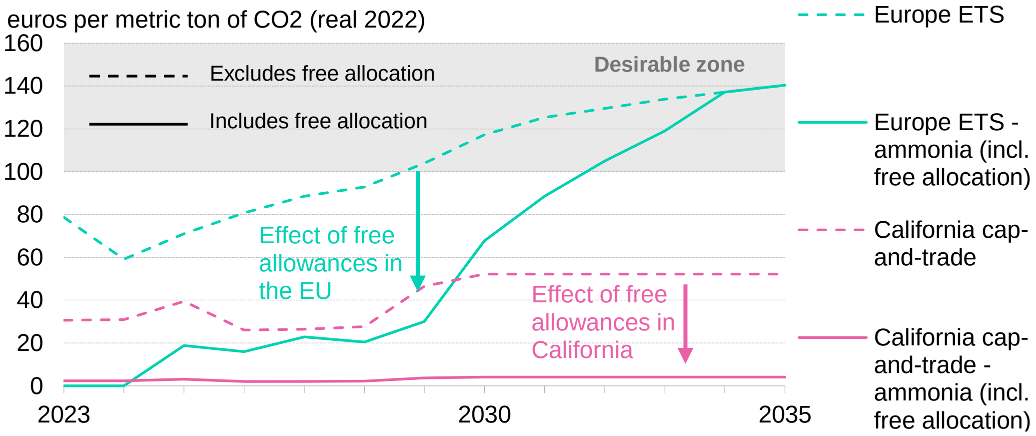
It is increasingly common for carbon pricing schemes to allow participants to use offsets for compliance. Introducing a cap on the level of emissions that can be offset through international carbon credits sends a strong signal to local entities that they must reduce emissions from their operations wherever possible. This avoids an over-reliance on offsets and helps to ensure a material reduction of domestic emissions.

Figure 86: Average carbon price and share of greenhouse gas emissions covered by carbon-pricing policies in G-20 members



Source: Governments, World Bank, BloombergNEF. Note: Only US subnational policies are included. Prices cover the three months to February 12, 2024. The Canada value shows the price as of April 1, 2024 (C$80 per metric ton) and Germany and South Africa the price as of January 1, 2024. The European Union Emissions Trading System (EU ETS) share includes ETS I only. RGGI is the Regional Greenhouse Gas Initiative. Annex I parties refer to the breakdown defined by the United Nations Framework Convention on Climate Change.

Figure 87: Carbon price projections by region



Source: BloombergNEF. Note: Europe ETS - ammonia values assume 2017-2021 average emissions from the ammonia sector and do not account for any activity level change. Benchmark values assumed to decline every five-year period by 3%. ETS in this chart refers to emissions trading system.

4.3.4. Leverage carbon finance through carbon markets

Voluntary carbon markets can help transfer financial resources from other markets into Asia Pacific countries and provide financial incentives for emissions reductions in multiple sectors.

The voluntary carbon offset market, where verified emission reduction credits are bought and sold for sustainability purposes, has increased significantly in interest and activity in the past seven years. Transaction volume in the offset market has been growing, with latest estimates putting the offset market's annual value at $1 billion to $2 billion. Total issuances of carbon supply offsets equaled around 1.1GtCO2 between 2015 and 2023. Energy generation, mostly from clean energy projects, made up 36% of this supply while energy demand, mostly from clean cookstoves, accounted for 6% of supply. Finally, emissions projects have constituted 12% of supply since 2015, mostly through industrial decarbonization and methane combustion projects.

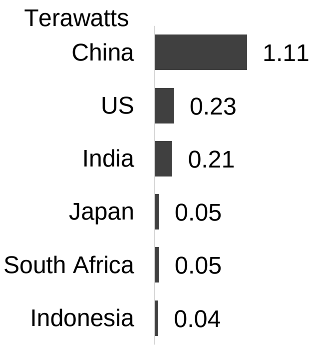
Less attention has been given to carbon markets' role as a source of capital for the energy transition in Asia Pacific. 40 million of the carbon offsets retired in 2022 were created in India (38 million) and Indonesia (2 million). In 2022, 21 million credits were retired from China. Purchase of credits has led to job creation, subsidization of low-carbon activities and co-benefits beyond decarbonization, such as biodiversity.

Since clean energy technologies such as wind and solar power are increasingly competitive without further financial support, there is an opportunity to redirect funding from the carbon markets to finance earlier-stage technologies that have a greater funding need.

Offsets in managed fossil fuel phase-out

In some of the largest coal-power producing countries in the world, including developing economies like China (1.11TW) and India (0.21TW), carbon offsets can be a valuable tool to make clean energy cost-competitive and support the phase-out of fossil fuels (Figure 88).

Figure 88: Top coal power producing countries, 2021



Source: BloombergNEF

Asset owners can be compensated with carbon credits in response to lowering emissions from fossil fuel projects gradually over time, with the offsets valued at revenue forfeited per ton of carbon emitted. This strategy could be important in coal-heavy emerging markets like India, where the economics for building solar and wind are at parity already, but coal plants are not being retired due to uncertainty in power demand and long-term power purchase agreements.

The Monetary Authority of Singapore (MAS) and McKinsey had explored the use of 'Transition Credits' specifically for the managed phase-out of coal plants.[7] MAS subsequently convened the transition credits coalition (TRACTION) to identify system-wide barriers and solutions for transition credits to be utilized as a credible financing instrument.

The Coal-to-Clean Credit Initiative (CCCI) is an initiative by the Rockefeller Foundation and GEAPP supported by RMI South Pole and CPI that aims to pilot transition credits to incentivize a just transition away from coal-fired power plants. To that end, CCCI is developing a carbon methodology under Verra and exploring partnerships with several emerging economies. Separately, Gold Standard has created a concept methodology for using avoidance offsets to phase out coal projects that have been operating for at least three years, and to replace them with clean energy.

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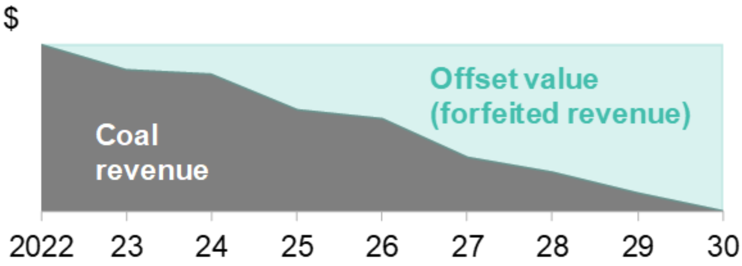
[7] 'MAS and McKinsey Explore the Use of High-integrity Carbon Credits to Accelerate and Scale the Early Retirement of Asia's Coal-fired Power Plants', Monetary Authority of Singapore (MAS), September 26, 2023.

Figure 89: Illustration of offsets in managed phase-out



Source: BloombergNEF

Integrity of carbon markets

While there is a clear business case to use carbon offsets for mechanisms like managed coal phase-out, several barriers exist to scaling beyond the economics mentioned above. In recent years, the voluntary carbon markets have come under sharp scrutiny around greenwashing, quality of supply, and lack of transparency. Improving the integrity of voluntary carbon offset markets will be critical to scale up their usage in applications such as accelerated coal power phase-out.

The other challenge revolves around the treatment of carbon abatement in country-level emissions accounting and National Determined Contributions (NDC). Article 6 of the Paris Agreement states that parties may collaborate in order to meet their NDCs.

Under Article 6.2, governments can collaborate by trading internationally transferred mitigation outcomes (ITMOs). ITMOs are carbon offsets with corresponding adjustments, a mechanism to prevent double-counting of the environmental benefit across different countries. Several governments such as Singapore, Switzerland, Ghana, Thailand and South Korea, have signed bilateral agreements to trade ITMOs that count toward their NDCs.

While Article 6.2 is in operation today, Article 6.4 has yet to be operationalized, following a failure to agree on its rules at COP28. Article 6.4 establishes a global crediting mechanism, which allows for the generation of carbon offsets that can be used as ITMOs or for other uses that do not require corresponding adjustments. The Supervisory Body, appointed by countries under the UNFCCC, is tasked with overseeing the operationalization of the mechanism. The most recent meeting of the Supervisory Body in October 2024 saw the standards on carbon removals and methodologies, and guidelines on sustainable development released.

Appendix A. Geographies

Table 13: Geographies

Markets	Details
China	Mainland China
India	
Japan	
South Korea	
Indonesia	
Vietnam	
Australia	
Other Southeast Asia	Malaysia, Philippines, Thailand
Other Asia Pacific	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Myanmar, Cambodia, Cook Islands, Fiji, French Polynesia, Guam, Hong Kong, Kazakhstan, Kiribati, North Korea, Kyrgyzstan, Laos, Macau, Maldives, Marshall Islands, Mongolia, Nauru, Nepal, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Pakistan, Palau, Papua New Guinea, Samoa, Singapore, Solomon Islands, Sri Lanka, Taiwan, Tajikistan, Timor-Leste, Tonga, Turkmenistan, Tuvalu, Uzbekistan, Vanuatu, Federated States of Micronesia

Source: BloombergNEF

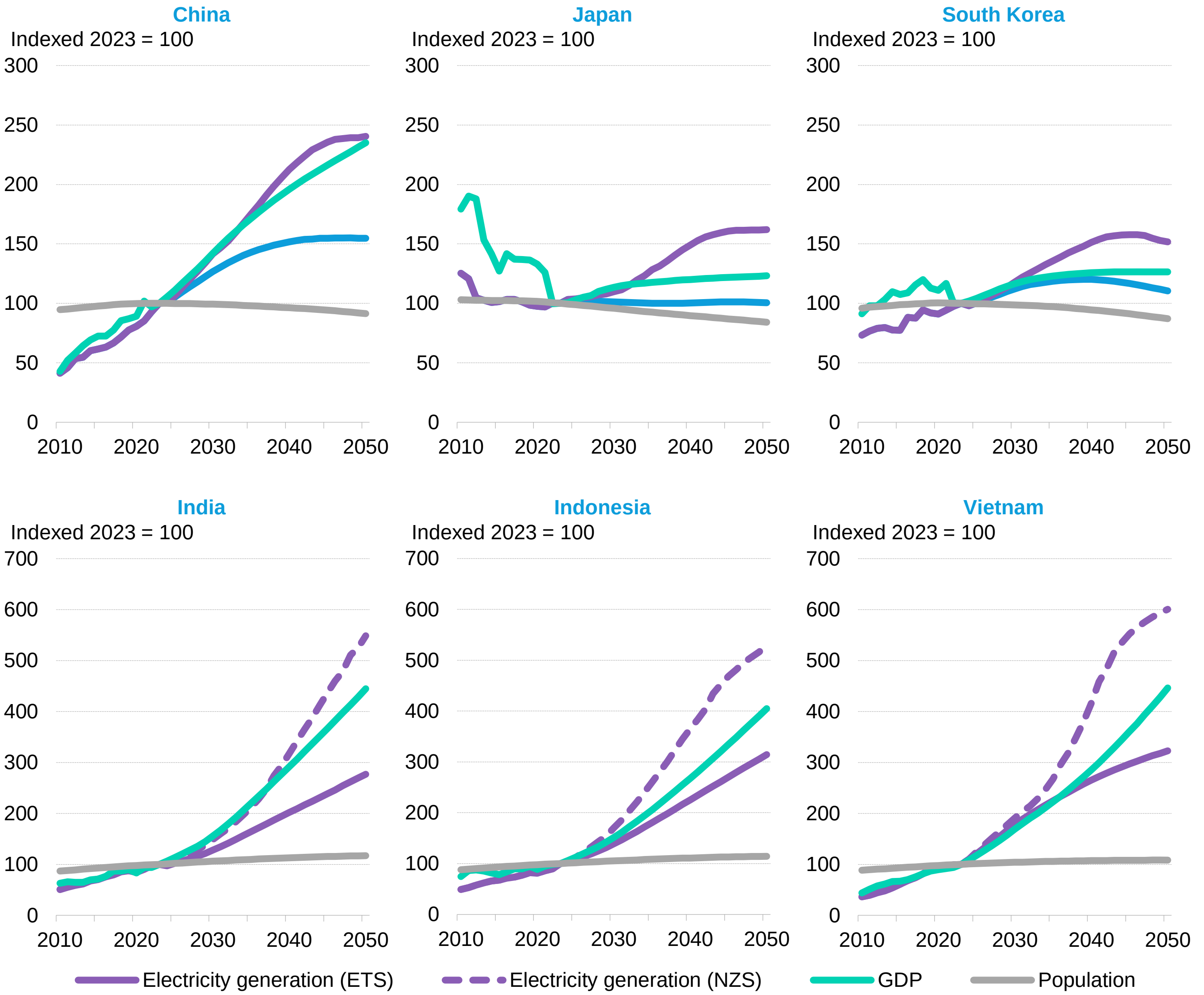
Appendix B. Emissions constraints in the New Energy Outlook

The Economic Transition Scenario does not have an emissions constraint. The Net Zero Scenario constrains global and sectoral emissions to achieve a Paris Agreement-aligned outcome, with temperature-change results based on Intergovernmental Panel on Climate Change carbon budget data. We do not use marginal abatement driven by an assumed global carbon price or run our own climate models.

- **A sector-led approach.** Carbon budgets are modeled at a sector level and account for historical emissions trends, projected emissions growth and available abatement options to ensure an ‘orderly transition’ that avoids step changes, wherever possible, and maintains economic and social security.
- **Skepticism toward unproven future technology solutions**. Our modeling relies on commercially available technologies today, and those that have shown technology readiness and a conceptual pathway to scale. We prefer technologies that could be globally available, have wide-ranging applications and pathways. We limit technologies that are unproven or in early development stages at the time of writing, such as direct air capture.
- **Country carbon budgets**. These are determined by the sectoral make-up of each country’s economy, the expected growth in those sectors, and their relative progress under the base-case ETS. In practice, this means that those countries with growing demand for power, say, end up with a higher power-sector budget than those with flat or falling demand. Neither historical ‘responsibility’ nor availability of finance are taken into consideration. Every sector and country must get to net zero by 2050. There are no exceptions.
- **No overshoot**. Our scenarios end in 2050 and do not rely on net-negative emissions post-2050. Over 99% of the emissions reductions are achieved by actual abatement, fuel switching or carbon capture and storage. Carbon-removal technologies, such as direct air capture technologies, are only used to address some residual emissions, such as those not captured by carbon capture and storage technologies.
- **No behavioral change**. BNEF modeling does not rely on behavioral change, assuming the same demand trends for useful energy services, such as mobility (air travel, demand for road transport services), materials (for example, steel and aluminum) and useful services from energy, in both scenarios.
- **Same effort assumption for non-energy emissions**. BNEF assumes emissions outside the energy sector will decline at the same rate as those covered in our analysis. This avoids making over-optimistic assumptions about hard-to-abate sectors outside the scope of our analysis, such as land-use and land-use change and forestry (LULUCF).

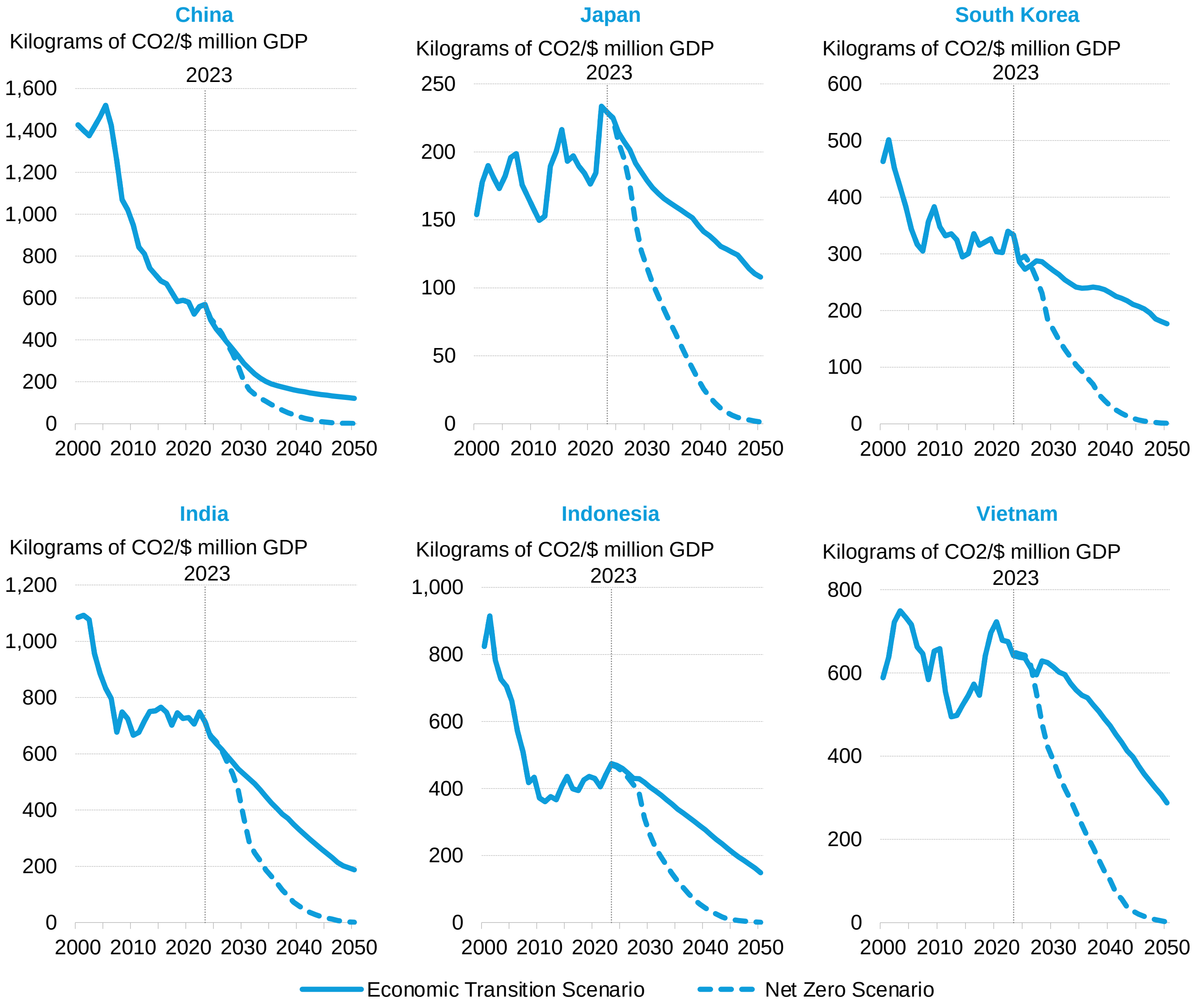
Appendix C. Macroeconomic indicators

Figure 90: Macroeconomic indicators of selected Asia Pacific markets



Source: BloombergNEF. Note: ETS is Economic Transition Scenario, NZS is Net Zero Scenario, GDP is gross domestic product.

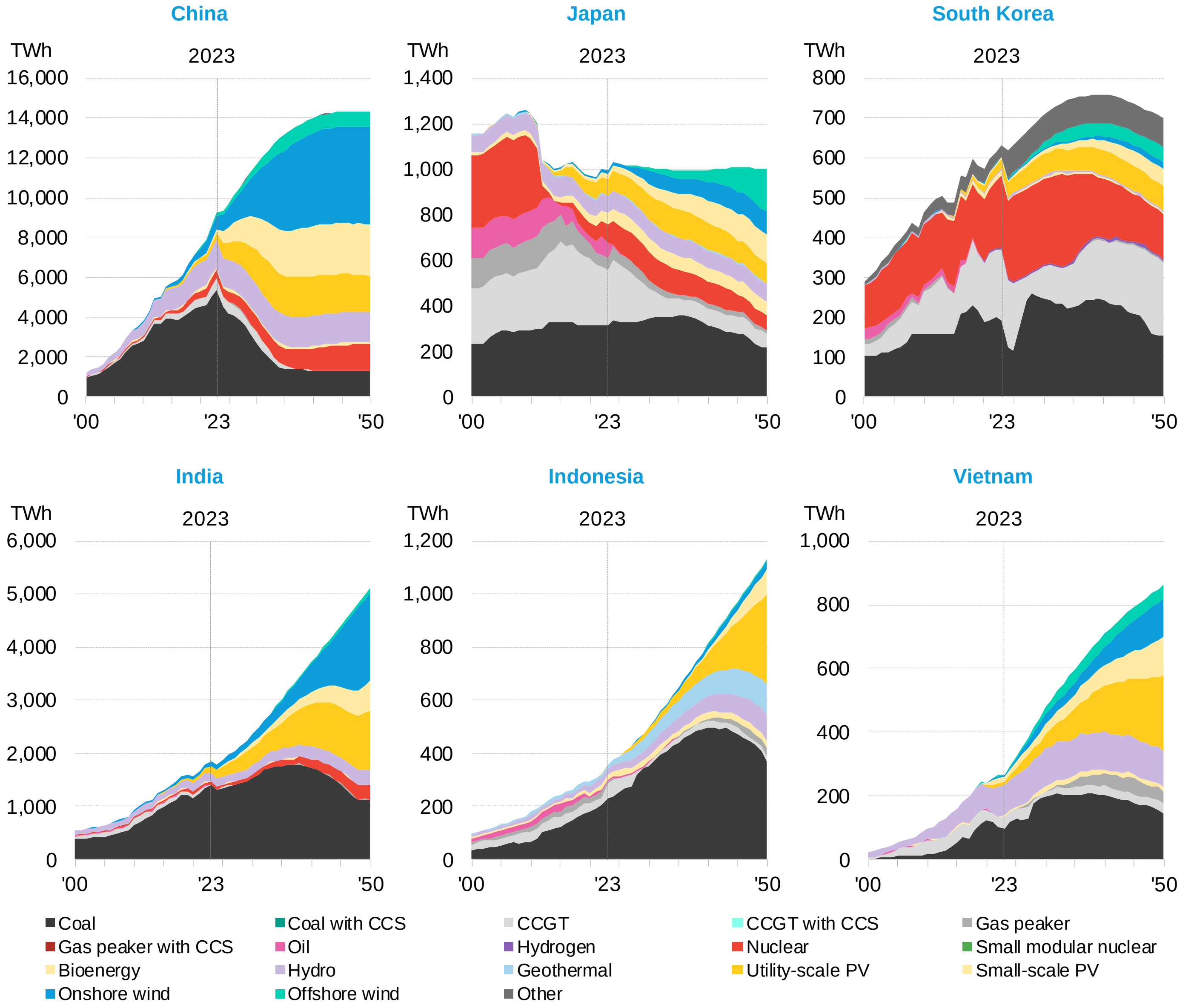
Figure 91: Carbon dioxide emissions intensity of gross domestic product, by market



Source: BloombergNEF. Note: Graphs shows CO2 emissions associated with fossil fuel combustion. ETS is Economic Transition Scenario, NZS is Net Zero Scenario, GDP is gross domestic product.

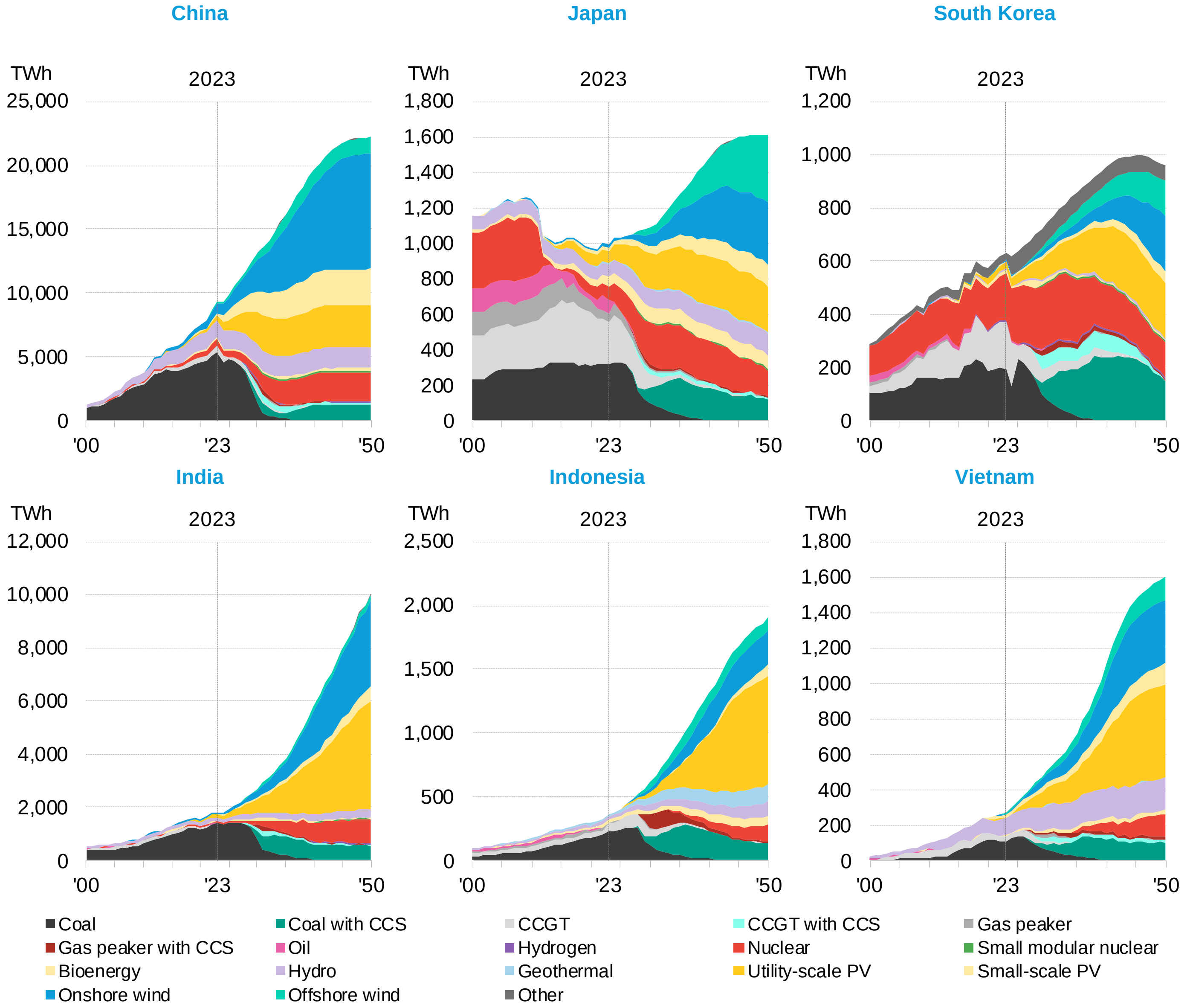
Appendix D. Electricity generation by technology in selected Asia Pacific markets

Figure 92: Electricity generation by technology in selected Asia Pacific markets, Economic Transition Scenario



Source: BloombergNEF. Note: TWh is terawatt-hours. 'Other renewables' comprise all other non-combustible renewable energy, including hydro, bioenergy, geothermal and solar thermal.

Figure 93: Electricity generation by technology in selected Asia Pacific markets, Net Zero Scenario



Source: BloombergNEF. Note: TWh is terawatt-hours. 'Other renewables' comprise all other non-combustible renewable energy, including hydro, bioenergy, geothermal and solar thermal.

Appendix E. Land use modeling methodology

BNEF’s analysis of land use compares supply and demand as a post-modeling analysis of our scenarios. We analyze demand from a select group of end-use sectors.

Table 14: End-use sectors covered in land use analysis

Sector	Description
Renewable energy	Utility-scale solar Onshore wind assets
Extractive	Mining sector demands on land
Food and feed	Crops and animal protein to feed a growing global population
Biomass for new materials	Crops to produce novel, sustainable materials
Biomass for energy	Feedstocks for biomass or biofuels for industry, buildings, power and transport
Carbon dioxide removals	Direct air capture

Source: BloombergNEF

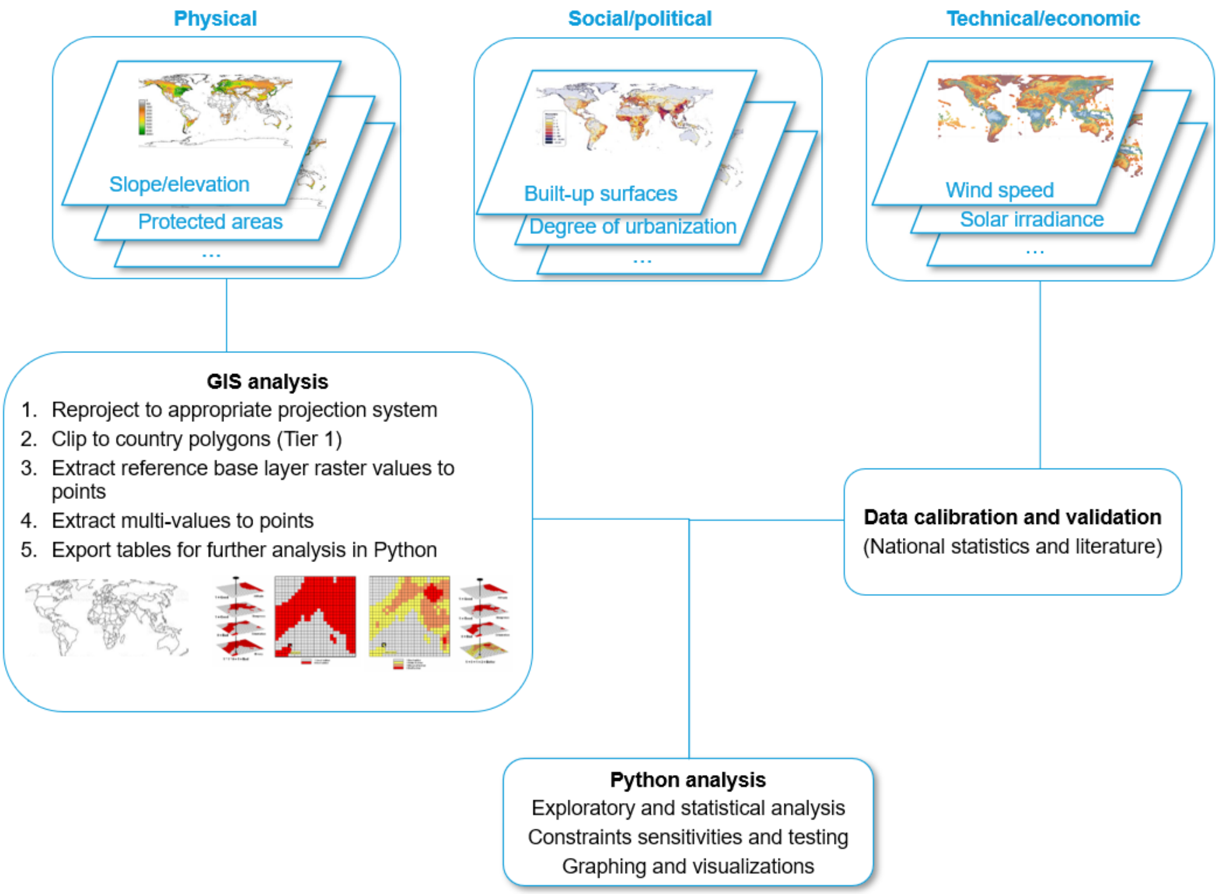
The demand for each of these sectors was converted to a land area using our own estimation of square kilometer per unit of demand, the definitions of which are detailed further below. This was then compared with the supply of land suitable to accommodate each sector in turn.

Determining land suitability

Overview

Geographic information system (GIS) software was used to determine the supply of land suitable for each of the given end-use sectors. The suitability criteria used to determine the areas are detailed in each of the sections below.

Figure 94: Overview of land use methodology



Source: BloombergNEF

Clean power

Spatial analysis was carried out using GIS software and Python to determine the amount of land suitable for the deployment of solar and onshore wind using publicly available data.

First, suitability criteria were used to provide an accurate picture of available land based on existing literature – the list of constraints is indicative but not exhaustive. Appropriate data files were sourced to allow the area of each country to be constrained by the defined criteria.

Table 15: Data sources for land supply analysis

Dataset	Type	Resolution	Data products	Source
Administrative boundaries level 0	Vector polygon	-	World country polygons	World Bank[8]
Global Human Settlement Layer (GHSL Data Package 2023)	Raster	1 square kilometer (km^2)	Built-up surfaces for residential and non-residential uses, Morphological Settlement Zones (MSZ), Degree of Urbanization, GHS-Land	European Commission's Joint Research Centre[9]
Global Agro-Ecological Zones v4 (GAEZ)	Raster	$1km^2$	Theme 1 - Land and Water Resources, Theme 3 - Agro-climatic Potential Yield, Theme 4 - Suitability and Attainable Yield, Theme 5 - Actual Yields and Production	UN Food and Agriculture Organization and International Institute for Applied Systems Analysis. Global Agro-Ecological Zones version 4 (GAEZ v4)
Global Wind Atlas 3.3	Raster	$1km^2$	Wind speed, power density at 50, 100, and 150 meters	Global Wind Atlas 3.3[10,11]
Global Solar Atlas 2.0	Raster	$1km^2$	Direct normal irradiation, global horizontal irradiation	Global Solar Atlas[12]

Source: BloombergNEF

Land demand for clean power installations and suitability constraints were modeled at a country level for Tier 1[13] countries, at a resolution of one square kilometer.

As a first step, Tier 1 country administrative boundary shapefiles were converted to vector files of 1 square-kilometer resolution, which represent the base layer of our analysis. Constraints were extracted and matched at the same resolution and sampled for all the unique points of each gridded polygon. We chose appropriate projection systems for each region and optimized raster files for further processing.

Once the data files were manipulated and converted, unique raster values were sampled for all points accounted in each region and raster calculations were performed to calculate the area of overlapping suitability among the imported layers. Counts of each raster value and other statistics were then extracted into CSV files for further manipulation and analysis in Python. Table 16 lists the criteria and assumptions considered for each technology.

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[8] The World Bank Data Catalog - Official Boundaries v2, 2023.

[9] European Commission, GHSL Data Package 2023, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/098587, JRC133256.

[10] Neil N. Davis, et al., The Global Wind Atlas: A high-resolution dataset of climatologies and associated web-based application; Bulletin of the American Meteorological Society, Volume 104: Issue 8, Pages E1507-E1525, August 2023, DOI: https://doi.org/10.1175/BAMS-D-21-0075.

[11] Wind speed and density data obtained from the Global Wind Atlas version 3.3, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas version 3.3 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information, see https://globalwindatlas.info.

[12] Solar irradiance obtained from the "Global Solar Atlas 2.0, a free, web-based application developed and operated by Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information, see https://globalsolaratlas.info.

[13] Tier 1 markets include China, Japan, South Korea, India, Indonesia, Vietnam, Australia, Germany, France, the UK, the US and Brazil.

Table 16: List of constraints applied to determine suitable land, by technology

Constraint		Excluded	Buffer zone (meters)
Social/political			
Human settlements			
	Urban/large settlements	✓	1,000
	Dense, semi-dense towns, suburban or peri-urban areas	✓	1,000
Infrastructure			
	Roadways	✓	500
	Airports	✓	5,000
	Railways	✓	1,000
	Industrial areas	✓	1,000
	Mining sites	✓	5,000
Physical			
Slope		≥17%	-
Elevation		≥4,000 meters	-
Water Bodies			
	Lakes	✓	200
	Rivers	✓	200
	Coasts	✓	200
	Wetlands	✓	200
Conservation			
Protected fauna flora habitat/biodiversity			
	Habitats	✓	1,000
	Birds areas	✓	1,000
	Biospheres	✓	1,000
	Wilderness	✓	1,000
Protected Areas			
	Landscapes	✓	1,000
	Reserves	✓	1,000
	Forests/parks	✓	1,000
	Monuments	✓	1,000
Technical/economic			
Resource			
	Wind speed	≤6 meter per second	-
	Solar irradiance	≤1,000 kilowatt-hour per square meter	-

Source: BloombergNEF. Note: ✓ *refers to both solar and wind, blue indicates wind only, yellow indicates solar only.*

Crops

The UN Food and Agriculture Organization provides detailed crop models through its Global Agro-Ecological Zones models (GAEZ v4), including Theme 3 (Agro-climatic Potential Yield) and Theme 4 (Suitability and Attainable Yield)

- The Theme 3, Agro-climatic Potential Yield[14], data product provides crop-specific information about potential biomass and yield, and related crop cycle attributes, calculated using an eco-physiological crop growth model and spatially detailed climate characteristics (radiation, temperature and precipitation) during different crop development stages. Growth cycle attributes include the day of crop emergence (in other words, the start of the crop cycle), the duration of the crop cycle from emergence to full maturity, crop-specific actual evapotranspiration, accumulated temperature sums and water deficits/net irrigation requirements during the crop growth cycle. The results of their comprehensive bottom-up analysis account for temperature limitations and moisture constraints that are affecting crop growth and development, and include yield-reducing effects due to potential pests, diseases and weeds, as well as climate related workability.
- Theme 4, Suitability and Attainable Yield[15], presents the results of the final step in the GAEZ crop suitability and productivity assessment, combining agro-climatic potential yields with the results of soil and terrain evaluations. The outcome of this is a gridded geospatial map where each grid cell of the resource inventory determines the respective make-up of land units in terms of soil types and slope classes, and applies yield reduction factors due to the constraints induced by soil limitations and prevailing terrain-slope conditions. Find more in the UN FAO's model documentation guide[16].

We analyzed the land suitability data for 20 major crops or crop groupings under rain-fed conditions and assumed high input/advance management for historical climatic conditions (1981-2010, CRUTS32). Where data is not available, we have assumed crop proxies with similar characteristics. Land suitability results for each crop are classified in six distinct classes; in our analysis, suitable land for crops includes 'very suitable' and 'suitable' land.

Table 17: Crops included in land use analysis and Global Agro-Ecological Zones proxies

Land cover	Global Agro-Ecological Zones crop proxy
Barley	Barley
Canola	Rapeseed
Cassava	Cassava
Cotton	Cotton
Horticulture	Rapeseed
Maize	Maize
Oil palm	Oil palm
Other cereals and grains	Wheat
Other fiber	Rubber

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[14] FAO and IIASA. Global Agro-Ecological Zones version 4 (GAEZ v4) – Theme 3.

[15] FAO and IIASA. Global Agro Ecological Zones version 4 (GAEZ v4) – Theme 4.

[16] Fischer, G.,et al., Global Agro-Ecological Zones v4 – Model documentation, 2021, Rome, FAO. https://doi.org/10.4060/cb4744en.

Land cover	Global Agro-Ecological Zones crop proxy
Other legume	Phaseolus beans
Other oil seeds and oil crops	Sunflower
Palm oil	Palm oil
Rice	Rice
Root vegetables	Cassava
Soybean	Soybean
Special use	Tea
Sugarcane	Sugarcane
Temperate tree crops	Citrus
Tropical tree crops	Coffee
Wheat	Wheat

Source: United Nations Food and Agriculture Organization's Global Agro-Ecological Zones model (GAEZ v4), BloombergNEF.

Table 18: Land suitability classes for crops

Land suitability class	Description/farm economics
Very suitable land (80-100% of maximum attainable yield)	Prime land offering the best conditions for economic crop production
Suitable land (60-80%)	Good land for economic crop production
Moderately suitable land (40-60%)	Moderate land with substantial climate and/or soil/terrain constraints, requiring high product prices for profitability
Marginally suitable land (20-40%)	Commercial production not viable; land could be used for subsistence production when no other land is available
Very marginally suitable (<20%)	Economic production not feasible
Not suitable	Production not possible

Source: United Nations Food and Agriculture Organization's Global Agro-Ecological Zones model (GAEZ v4), BloombergNEF. Note: BNEF considers the sum of 'very suitable' and 'suitable' for the purposes of our analysis.

Critical minerals

We identified current mining areas using data from Global-scale mining polygons (Version 2). The dataset contains 44,929 polygon features (vectorized data and shapefiles), covering 101,583 square kilometers of land (around the size of South Korea) used by the global mining industry, including large-scale and artisanal and small-scale mining. The data cover all ground features related to mining – in other words, open cuts, tailing dams, waste rock dumps, water ponds, processing infrastructure, and other land cover types related to the mining activities of coal and metal ore extraction.[17]

Mining spreads across all continents with hot-spot regions – for example, in northern Chile mainly due to copper extraction, northeastern Australia and East Kalimantan in Indonesia because of

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[17] Maus, Victor et al. "An update on global mining land use." *Scientific Data* vol. 9:1, 433. July 22, 2022, doi:10.1038/s41597-022-01547-4 (link).

coal mining (which is out of scope), and in the Amazon rainforest primarily due to small-scale gold mining.

A summary of the data aggregated by country shows that 52% of the mapped mining area is concentrated in only six countries: Russia, China, Australia, the US, Indonesia and Brazil. Another 21 countries account for 39%, and the remaining 118 countries add up to only 9% of the total mapped mining area. These results show that mining areas are highly concentrated in only a few countries.

On top of the mining geospatial locations, we overlayed exclusion areas derived from Theme 1 of the FAO's GAEZ v4 dataset. The dataset identifies land marked by a protection/exclusion status or with recognized biodiversity value compiled from three up-to-date and authoritative international datasets: the World Database of Protected Areas, the World Database of Key Biodiversity Areas and the Global Lakes and Wetlands Database.

As a first step, we identified mining locations that overlap with existing protected areas. This allowed us to reduce the amount of data under investigation as we assume this mining area to not be able to expand any further as some constraints have already been breached. Assuming a minimum 5-kilometer distance or buffer between any mining location and excluded area, we started constructing buffer rings around existing mining locations – in total five rings with an incremental 1-kilometer buffer between each one of them.

The process above allowed us to identify and quantify mining areas currently ‘at risk’ but also potential pressures on areas with high biodiversity values within the context of planning and reinforcing mine reclamation.

Determining technology footprint

Onshore wind

We used BNEF's onshore wind asset database of existing projects to extract turbine capacities and rotor diameters for each project. These figures were then used to calculate the per-gigawatt footprint of each project, which includes the physical footprint and land required for spacing. Both are a function of turbine size.

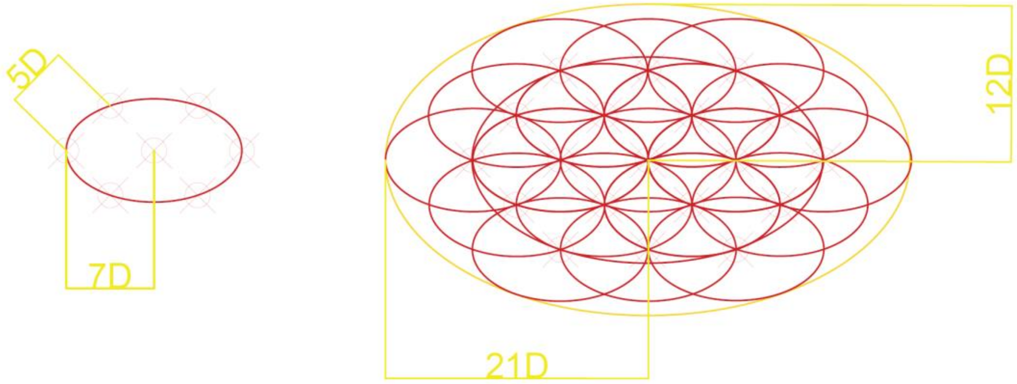
We assume turbine spacing follows a rule of 7 rotor diameters in the downwind direction, and 5 rotor diameters crosswind. Each turbine is allocated a 7D by 5D rectangle of space, where ‘D’ is the rotor diameter of a single wind turbine. As illustrated in Figure 92, as we add more and more 7D by 5D shapes, the outer area becomes a larger ellipse. For example, for a wind farm of 19 turbines, its footprint area (the shape of the ‘flower’) can be approximated using an ellipse with an area of:

$$21D * 12D * \pi$$

As turbine technology evolves and capacities increase, so does the rotor diameter. Each year we use a different average wind turbine capacity and hence a different rotor diameter – which is the main variable for the footprint calculation.

Average footprints of existing wind farms were derived from country-level historical projects commissioned back in 1980, to arrive at an average global footprint. Projections for future average rotor diameter and turbine capacity were then used to estimate future per-gigawatt footprints assuming Class II turbines (designed with mid-sized rotor diameter for average wind speeds of about 6-8 meters/second).

Figure 95: Illustrative onshore wind footprint calculation, physical footprint and distance



Source: BloombergNEF

Once the per-gigawatt footprint was derived for all countries and projected out to 2050, it was used to calculate the total projected land footprint for each country going forward. This was accomplished by multiplying the current estimated footprint for each country by that country's annual cumulative capacity, and then for every year following, multiplying that year's footprint projection by the gross capacity additions in that year and adding it to the previous year's footprint.

Capacity retirements are removed, assuming a 20-year operational lifetime, as land previously occupied by older wind farms that are decommissioned becomes available for new development. To calculate that area, we use historical turbine capacities (and rotor diameters) installed in the past (starting in 1981). Based on this assumption, an area that was occupied by wind farms in 2020 would only become available in 2040.

Utility-scale solar

For solar, a global average assumption was used for the per-gigawatt technology footprint. Historical and projected BNEF efficiency figures were used to extrapolate yearly increases to efficiency, which were then used to provide a projected per-gigawatt footprint for solar.

The per-gigawatt footprint estimate was then multiplied by the cumulative capacity projection for each country in the same year to arrive at a total area estimate for that year. For every subsequent year, the yearly footprint estimate was multiplied by the additional capacity added during that year, and the figure was added to the previous year's total footprint. Similarly, capacity retirements were subtracted using the same footprint.

Electrolyzers

Electrolyzer plants built today cover about 1,100 square meters per megawatt of capacity, which we assume shrinks to 500 square meters per megawatt by 2050 as the systems become more efficient, new technologies scale and sites are optimized. In our analysis, we assume this footprint includes the stacks, balance of plant, hydrogen purification unit, transformers, site offices, water supply, substations, oxygen capture unit, air compressors, and hydrogen storage vessels and racks.

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