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The global climate risks of Asia's expansive carbon capture and storage plans

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About Climate Analytics

Climate Analytics is a global climate science and policy institute. Our mission is to deliver cutting-edge science, analysis and support to accelerate climate action and keep warming below 1.5°C.

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Executive summary

Asia, whose economies generate more than half the world's fossil fuel and greenhouse gas emissions, has a defining role in global climate action under the Paris Agreement. How fast the region's economies cut emissions – and reduce them to zero – will have a huge impact on whether peak global warming can be limited to 1.5°C or close to it, with a limited period of overshoot, before returning below 1.5°C before the end of the century.

This report considers the climate and economic implications of Asia's promotion of carbon capture and storage (CCS) to reduce fossil fuel emissions.

We assess current and prospective future CCS deployment in Asia, looking at some of its largest and/or most influential economies, energy users, and emitters: China, India, Japan, South Korea, Indonesia, Thailand, Malaysia, and Singapore, as well as Australia (which has strong integration with Asian fossil fuel trade and CCS plans).

We find that if Asian countries were to follow a high-CCS pathway, it could lead to additional cumulative GHG emissions of almost 25 billion tonnes of CO_2-equivalent by 2050. About 22 Gt of the total would be CO_2, and the remainder would be methane.

This is more than the cumulative fossil fuel CO_2 emissions individually generated by all but three Asian countries (China, India, and Japan) over all time. These additional emissions would fatally undermine Asia's alignment with the Paris Agreement.

The additional emissions would result from CCS not capturing close to all emissions when applied to fossil fuels, as is required under 1.5˚C aligned 'high-CCS' scenarios. We instead consider that CCS will continue to operate in line with observations to date, which would likely fail to meet Asian performance expectations by a wide margin.

CCS has had a poor track record so far: it has failed to achieve anywhere near industry claims, often capturing 50% of emissions at best, or considerably less. A large proportion of captured emissions are used to extract more fossil fuels. Contrary to many proposed Asian uses, CCS also carries higher costs than alternative zero emission solutions, led by renewables, storage, and electrification.

But CCS being deployed and failing to adequately capture CO_2 is not the only climate risk Asia faces. Cost and technical challenges have meant past promises of expansive CCS deployment have not been realised. If this continues to be the case in Asia, it would come at the cost of diverting capital, time, and other resources from zero emission solutions. It would keep unabated fossil fuels in energy mixes far longer than needed.

Deployed CCS capacity in Asia is, indeed, very likely to remain low for the remainder of this decade. But regional governments and industry, led by the countries we focus on are increasingly presenting CCS as a frontline mitigation strategy across numerous sectors. Projects and plans more often seek to continue and even expand fossil fuel use, than to meet the Paris goals. Governments continue to subsidise and support fossil fuel companies pursuing CCS, despite its consistent historic failure to deliver results.

No 1.5˚C-aligned high-CCS scenario sees fossil fuel use remain at current or expanded levels. But Asian countries are setting targets and supporting projects that promote deployment at rates, and in use cases, that go beyond the least risk CCS role, as a last resort mitigation solution, where all other options have been exhausted. Project plans will either directly facilitate fossil fuel expansion or come at the expense of viable options to cost-effectively eliminate CO_2 emissions at-source.

CCS also creates huge economic risks

Asian countries promote CCS for largely economic reasons. Japan and South provide considerable support to CCS at home and abroad and seek to lead related technology markets. They continue to build up fossil fuel infrastructure, particularly for gas and LNG, in parallel. Australia and Southeast Asian countries are promoting themselves as CO_2 storage and transit hubs, likely extending the life of fossil fuel production (while potentially failing to ensure safe long-term storage). Leading regional emitters China and India have less clear CCS plans. China already has a strong CCS presence, but it is also the most advanced country in deploying zero emissions technologies. If China or India turn more decisively to future CCS dependence, it could have disastrous climate results.

However, high-CCS plans pose economic risks in addition to climate risks. CCS in the power sector is estimated capable of doubling the cost of power relative to renewables backed by storage. Non-CCS climate solutions are also increasingly available in so-called ‘hard-to-abate’ sectors. Plans for fossil energy and industrial installations with CCS – and even unabated fossil installations – are increasingly uncompetitive with viable options for eliminating emissions at-source, led by renewables and electrification.

Many Asian countries are moving towards some combination of an ‘underperforming high-CCS’ and ‘unachieved high-CCS’ pathway. Paris-aligned climate action dictates that they should avoid CCS as anything but a last resort abatement technology. This means avoiding proposed use in sectors, such as power and transportation, which already have low-cost, near-term emissions abatement options. Equally, there are increasing solutions for hard-to-abate sectors that do not require CCS.

Despite what governments and fossil fuel interests claim, pursuit of a ‘deliberate low-CCS’ pathway – which would logically promote deployment of low cost and zero emissions renewables and electrification technologies – represents Asia’s most effective and economically competitive option for aligning with the Paris Agreement.

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Introduction

Carbon capture and storage (CCS) is at the heart of Asia's[1] current climate plans. Regional governments and industry members are promoting the ability of CCS to manage purported Asia-specific decarbonisation challenges and emissions from so-called 'hard-to-abate' sectors. **However, many, if not most, proposed Asian CCS use cases serve to sustain or expand either fossil fuel production or consumption.**

Asian countries supporting CCS as anything other than a last resort mitigation option is likely to result in considerable residual carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions. This would be inconsistent with achieving the early peak and rapid decline in global emissions specified in Article 4.1 of the Paris Agreement [2] It would increase the already considerable pressure to scale up carbon dioxide removal (CDR) to compensate and achieve global net zero GHG emissions, as Article 4.1 also specifies.

Current and future CDR deployment at-scale is already needed to compensate for emissions reductions achieved too slowly in Asia and across the world. Asia's CCS drive could in turn threaten global ability to keep peak global warming to the 1.5°C limit established in Paris Agreement Article 2.1, or close to that level, with a limited period of overshoot, before returning below 1.5°C before the end of the century.[3]

Every global region and sector must limit CCS dependence. But there is most at stake in Asia, which is at the heart of the necessary transition from fossil to clean energy. Asian economies typically also balance climate action with significant development challenges. A false step towards CCS could be hugely damaging for the global climate and the region's economic competitiveness alike.

In all 1.5°C-aligned scenarios examined in the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report (AR6), and those subsequently developed, fossil fuel use peaks immediately and declines rapidly from today's levels.[4] However, some CCS proponents believe this technology can slow the pace of fossil fuel decline, sustaining higher long-term use.

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[1] In this report, we use differing definitions of Asia based on how the region is covered by relevant international institutions and processes. Descriptions of the reference regions incorporating Asia in the IPCC AR6 database are provided in the Appendix. When assessing Asia's presence in the IEA's CCUS database, we include all countries with entries from mainland and maritime Asia, excluding Russia and the Middle East, as well as a handful of Pacific countries: Australia, China, Japan, Malaysia, Timor-Leste, Indonesia, Singapore, South Korea, India, New Zealand, Papua New Guinea, Taiwan, and Thailand. We also identify where we are focused only on our nine case study countries.
[2] UNFCCC, "PA2015."
[3] UNFCCC, "PA2015."
[4] SEI et al., *Production Gap Report 2023*.

High-CCS scenarios, which retain a sizeable role for fossil fuels 'abated' with CCS, carry hidden risk. A robust definition of abated fossil fuels would include >95% CO_2 capture rates, and fugitive upstream methane emissions reduced below 0.5%[5]. But this is far from reality in current projects, where capture rates are closer to 50% or lower.[6]

In this report, we assess the current pipeline and prospective future of CCS in Asia as a whole, and in some of its largest and most influential economies, energy users, and GHG emitters: China, India, Japan, South Korea, Indonesia, Thailand, Malaysia, and Singapore, as well as Australia, which is a key fossil fuel exporter and prospective CCS partner to Asia. We find that Asian strategies for future CCS deployment are misaligned with achievement of the Paris Agreement.

Regional countries are setting targets, pursuing policies, and supporting projects that seek to deploy CCS at rates, and in use cases, that go beyond last resort mitigation.

Despite rising support, it is highly likely that most proposed Asian CCS projects will fail to materialise in the short-term. Anticipated regional deployment by 2030 will remain well off the pace necessary to align with a high-CCS by 2050 scenario. But regional deployment might rapidly accelerate after 2030. The possibility of Asia's CCS deployment aligning with a high-CCS scenario by 2050 needs to be taken seriously and its implications properly assessed, as we do in this report.

We find that Asia's CCS strategies create two key climate, and related economic, risks. The first is that Asian countries and the collective region will pursue and achieve high-CCS deployment, but with capture rates performing more in line with current observation than a robust, 1.5°C-aligned definition of emissions abatement. We call this an 'underperforming high-CCS' pathway.

The second major risk of current Asian CCS strategies is that regional countries will continue to support but not achieve high-CCS deployment, even after 2030. We call this an 'unachieved high-CCS pathway'. Any CCS capacity deployed under this second scenario could also underperform. But its more major risk would be locking in unabated fossil fuel use. This would result from countries still seeking to scale up CCS, beyond the point at which it has proven wholly ineffective. This would come at the opportunity cost of allocating capital, time, and other resources towards scaling up alternative zero emissions technologies in place of unabated fossil fuel capacity.

We directly assess the emissions risk from an underperforming high-CCS pathway. We note how an unrealised high-CCS pathway could create comparable or even greater emissions, as well as stranded fossil fuel assets.

We close by noting how Asia has alternative potential for a 'deliberate low-CCS pathway'. This would prioritise a phaseout of fossil fuels and deployment of renewables,

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[5] Bataille et al., "Defining 'Abated' Fossil Fuel and Industrial Process Emissions."
[6] Stockman et al., *Funding Failure: Carbon Capture and Fossil Hydrogen Subsidies Revealed*; Robertson and Mousavian, *The Carbon Capture Crux*.

electrification, and other options for eliminating emissions at-source, while purposefully limiting CCS deployment. A deliberate low-CCS pathway would better align with the Paris Agreement and also be more economically appealing for Asian countries.

Section one of the report considers Asia's importance to global climate action.

Section two considers the relationship of CCS to climate action.

Section three considers Asia's current and emerging CCS landscape.

Section four assesses additional emissions risks of a high-CCS Asian trajectory.

Section five considers Asia's potential to pursue an alternative, low-CCS pathway.

Asia’s importance to global climate action

Asia is critical to realising the Paris Agreement climate goals. The wealthiest and most mature economies have greatest capacity to rapidly decarbonise and keep the 1.5°C warming limit and mid-century net zero emissions goals of the Paris Agreement in sight.[7] But countries with pressing developmental challenges, of which Asia has many, must also decouple economic and social goals from fossil fuel use.

Asian countries generate more than half the world’s CO_2 and GHG emissions (see Figure 1).[8] Emissions in the major advanced regional economies of Japan and South Korea appear to have peaked in the past decade, and China may have now joined them.[9] But peaking is not enough – achieving rapid and deep reductions post-peaking matters most. The rate at which future emissions decline will hugely impact the level at which the global climate stabilises. Emissions from many Asian economies, led by India and other developing countries in South and Southeast Asia, also show no imminent sign of peaking and rapidly declining, but must quickly reach this tipping point.

Fossil fuels continue to dominate Asian energy mixes. Coal alone provides 49% of total energy supply.[10] Many Asian economies also heavily depend on fossil fuels and related goods and services for economic and employment opportunities. Indonesia is the world’s largest coal exporter, followed by Australia, which is also a top three liquefied natural gas exporter and has high per capita emissions.[11] China, India, South Korea, and Japan are in the top six oil refining countries.[12] Singapore is also a global hub for processing, transiting, and trading fossil fuels, Japan plays a dominant role in global gas, LNG, and related technology markets, and South Korea leads on LNG shipbuilding.[13] In addition, emissions-intensive production and consumption of steel, cement, fertilisers, and other materials have been historically inseparable from Asian development.

7 UNFCCC, “PA2015.”
8 Jones et al., “National Contributions to Climate Change Due to Historical Emissions of Carbon Dioxide, Methane, and Nitrous Oxide since 1850.”
9 Friedlingstein et al., “Global Carbon Budget 2024”; Myllyvirta, “Analysis,” May 14, 2025.
10 IEA, “World Energy Balances 2025.”
11 Energy Institute, “Statistical Review of World Energy.”
12 Energy Institute, “Statistical Review of World Energy.”
13 Stapczynski et al., “How Japan Ignored Climate Critics and Built a Global Natural Gas Empire”; Climate Analytics, “LNG Shipbuilding Industry Heading to Huge Oversupply.”

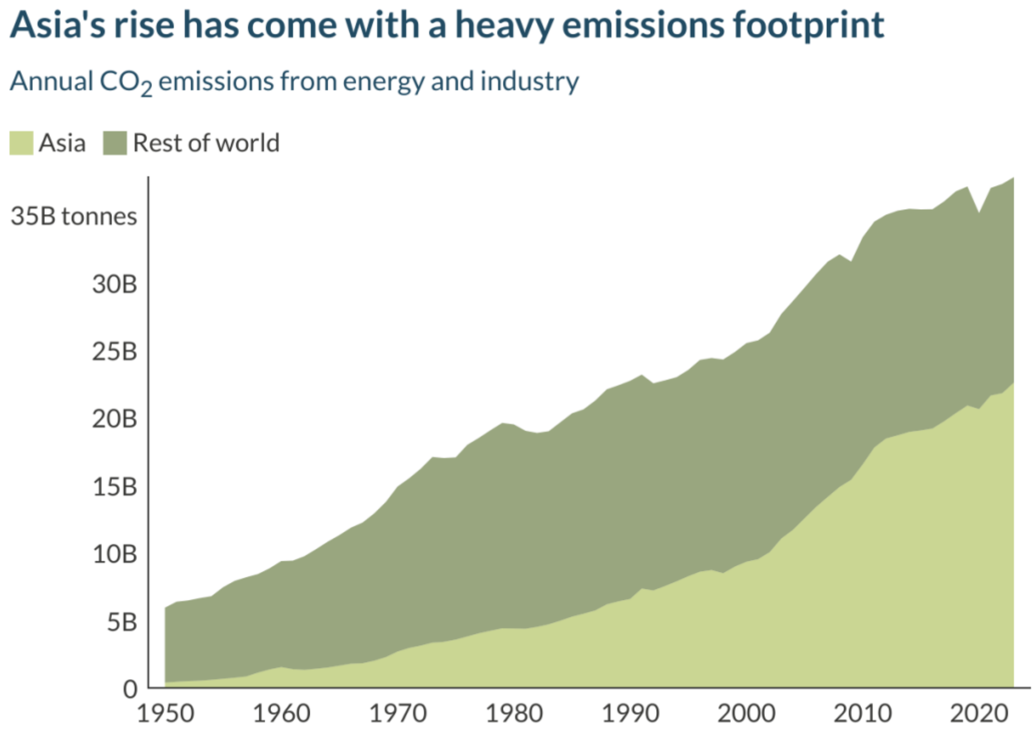

Figure 1. Annual CO_2 emissions from energy and industry, global 1950-2023. Source: Friedlingstein (2024).[14]

Climate Action Tracker rates the climate targets and policy frameworks of countries assessed in this report – China, India, Japan, South Korea, Indonesia, Thailand, Malaysia, Singapore, and Australia – as either insufficient (which would be consistent with 2-3˚C of warming if all the world's countries adopted the same level of ambition), highly insufficient (3-4˚C of warming), or critically insufficient (more than 4˚C of warming).[15]

Asian governments need to continue to lift their climate ambition. For reasons outlined in subsequent sections, they need to avoid dependence on CCS while doing so.

[14] Friedlingstein et al., "Global Carbon Budget 2024."
[15] Climate Action Tracker, "Climate Action Tracker."

CCS's relationship to climate action

CCS has a contested climate role in Asia and globally. Some scenarios that limit warming to 1.5°C can include a significant emissions mitigation contribution from CCS. However, the IPCC has demonstrated CCS has among the highest costs and lowest potential of all possible emissions abatement levers.[16] This reflects major economic, technical, environmental, and social barriers that prevent rapidly scaling up this technology and ensuring acceptable performance levels.

Even if continued cost and reliability breakthroughs prove possible, dependence on CCS as anything other than a last resort emissions reduction tool – after exhaustion of all other technically feasible solutions – still threatens achievement of the Paris Agreement. If deployed, or even promoted but not necessarily deployed, in place of options for eliminating emissions at-source, CCS would necessarily prolong the use of fossil fuels and exacerbate risks of residual emissions.

What are CCS and CCU? And how do they differ from CDR?

Carbon capture and storage (CCS) refers to processes that separate CO_2 generated by energy or industrial applications, then compress, transport – via pipeline, ship, or other mode – and inject it into depleted oil reservoirs, aquifers, or other geological structures, targeting long-term storage.

Carbon capture and utilisation (CCU) avoids the storage component and uses captured CO_2 as an input or feedstock to the production of industrial and consumer goods. Utilised CO_2 is generally released back into the atmosphere more quickly than stored CO_2, leading to greater residual emissions risk. In use cases such as fertiliser production, it is essentially released instantaneously.

CCS and CCU are often grouped together as CCUS, though CCUS can also refer to processes that combine utilisation and storage elements. One example is enhanced oil recovery (EOR), which is tied to most CCS facilities currently in operation. EOR injects CO_2 into oil reservoirs to increase extraction rates. Some CO_2 remains in the oil reservoir, but some returns to the surface. Combustion of extracted oil creates far larger CO_2 emissions than CO_2 sequestered.[17]

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[16] IPCC, *Synthesis Report of the IPCC Sixth Assessment Report (AR6).*
[17] "Carbon Capture and Storage (CCS)."

In this report, we use CCS as shorthand for either, or a combination of both, storage and utilisation processes, but CCU where it is specifically relevant.

Carbon dioxide removal (CDR) refers to activities that remove atmospheric CO_2 and durably store it in geological, terrestrial, or ocean reservoirs, or in goods. CDR includes technological processes – such as bioenergy with CCS (BECCS) and direct air carbon capture and storage (DACCS) – and biological processes such as afforestation, reforestation, and enhanced rock weathering.

CCS can only reduce atmospheric CO_2 levels relative to allowing unabated fossil fuel use. It creates additional CO_2 emissions if helping to maintain or expand fossil fuel use. CDR, by contrast, can achieve net negative emissions.

Likely CCS deployment remains low in the near future

The IEA's 1.5°C-aligned NZE scenario sees CCS capture about one gigatonne of CO_2 by 2030 and several gigatonnes by 2050.[18] But total operating CCS capacity at present is just 50 million tonnes of CO_2 per year (assuming all projects operate at stated capture rates, which is highly unlikely).[19] This is approximately 0.1 per cent of annual global CO_2 emissions.[20] The latest Production Gap report – measuring the discrepancy between the Paris goals and fossil fuel expansion – found that if all CCS facilities planned or in development as of 2023 became operational, they would still only capture 0.25 $GtCO_2$/yr by 2030.[21]

Estimates of potential CCS contributions to 1.5°C-aligned climate action have also been downgraded in recent years, on the back of unmet expectations and comparative improvements in genuine zero emissions technologies. The 2023 update of the IEA NZE, for example, reduces the CO_2 volume captured by 2030 by 39%, and the volume captured by 2050 by 22%, compared with the first NZE from 2021.[22]

All 1.5°C-aligned scenarios examined in the IPCC's Sixth Assessment Report (AR6), and those subsequently developed, lead to fossil fuel demand peaking and declining.[23] This includes even 1.5°C-aligned 'high-CCS' scenarios. This, then, challenges any claims that CCS explicitly tied to production or distribution of fossil fuels can be Paris-aligned. It

[18] IEA, "Net Zero Roadmap."
[19] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.
[20] Friedlingstein et al., "Global Carbon Budget 2024."
[21] SEI et al., *Production Gap Report 2023*.
[22] IEA, "Net Zero Roadmap."
[23] Lebling et al., *7 Things to Know About Carbon Capture, Utilization and Sequestration*.

also challenges the dominant use case for currently captured CO_2; about 80% of current temporary CCS storage capacity use CO_2 for enhanced oil recovery (EOR).[24]

CCS does not eliminate emissions and remains expensive

Numerous other factors challenge the climate value of CCS. No installation ever operates at 100% capture rates. This means CCS at best creates low-carbon, but not zero-carbon, energy or industrial goods. It thus produces net emissions growth if ensuring fossil fuel installations continue to operate.

CCS typically also operates well below industry-claimed capture rates of 90-95%, depending on application and technology.[25] Assessment and verification of the potential of geological sites to durably store CO_2 have also been slow, and have generally failed to remove doubts about the safety of more widespread future utilisation.[26]

Applying CCS adds inevitable expense compared with operating unabated capacity. In some sectors, CCS is already economically uncompetitive with options for eliminating emissions at-source, through zero emissions technologies and processes. Applying CCS in the power sector is, for example, estimated at a global level to produce a levelised cost of electricity (LCOE) at least 1.5-2 times that of renewables firmed with storage.[27]

CCS costs could fall, and more carbon capture and utilisation (CCU) use cases could help offset expenses. But CCS installations have high technical complexity and are usually individually tailored to applications.[28] Cost-effective and timely CCS operation also runs into challenges arising from its own energy- and, when powered by fossil fuels, emissions-intensive nature, and the technical and regulatory complexity involved with treating, transporting, and durably storing CO_2.

These factors mean **CCS is unlikely to experience the same learning rates and cost reductions of smaller-scale, more modular zero emissions technologies.**[29] Solar, wind, and battery storage cost reductions in the past decade have made renewable energy installations competitive with even unabated coal and gas plants in almost every global market.[30] A 2021 study found advances in low-cost renewables could erode the value of CCS in mitigation scenarios 15%–96%, through competition with abated fossil power and concurrent electrification of end-use sectors.[31]

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[24] IEA, "Operating and Planned CO2 Storage Facilities by Storage Type as of 2023."
[25] Australian Government, *Independent Review of ACCUs Final Report*; SEI et al., *Production Gap Report 2023*.
[26] Japan Organization for Metals and Energy Security, "Advanced Efforts for Commercialization of CCS- JOGMEC Selects Nine Projects as Japanese Advanced CCS Projects."
[27] Salt and Ng, *CCS For Power Yet to Stack Up Against Alternatives*.
[28] Malhotra and Schmidt, "Accelerating Low-Carbon Innovation."
[29] Wilson et al., "Granular Technologies to Accelerate Decarbonization."
[30] BloombergNEF, *Global Cost of Renewables to Continue Falling in 2025 as China Extends Manufacturing Lead*.
[31] Grant et al., "Cost Reductions in Renewables Can Substantially Erode the Value of Carbon Capture and Storage in Mitigation Pathways."

Broader sustainability challenges could also hamper CCS progress. CCS risks pollution of marine and terrestrial ecosystems and communities adjacent to installations. It also has considerable water consumption needs.[32]

Available alternatives should be prioritised in all sectors

There is a lingering perception CCS might still be important to decarbonise 'hard-to-abate' sectors, in line with the Paris goals.[33] This term is often loosely applied but mostly refers to applications where electrification and deployment of renewables is hardest, due to current reliance on energy-dense fuels, and generation of 'process' emissions from chemically transforming raw materials.

But applying CCS is often more expensive and difficult in hard-to-abate sectors, due to factors such as low CO_2 concentrations in waste gases. In the US context, for example, capturing CO_2 from a cement plant costs up to USD205/tCO_2, compared with up to USD132/tCO_2 for coal-fired power (these figures do not incorporate capturing CO_2 generated by CCS itself).[34] Accelerated deployment of existing decarbonisation levers, further technology breakthroughs, and demand reduction — supported by stronger policy and regulatory commitments — often delivers more cost-effective mitigation.

CDR cannot be relied on for emissions compensation

CCS dependence must be minimised in all sectors to keep the Paris Agreement goals in sight. Reaching global net zero CO_2 emissions around mid-century, and net zero GHGs emissions soon after, is critical to keeping the 1.5°C warming limit in sight. This will require negative emissions from CDR to compensate for residual anthropogenic emissions. But CDR faces similar challenges to CCS in cost-effectively scaling, while simultaneously avoiding other negative sustainability outcomes.[35]

There is potential for CCS and CDR to compete for access to finite CO_2 storage. Available resources are theoretically sufficient to accommodate 1.5°C-aligned high-CCS pathways. However, the share of resources that is 'bankable' (of a known size and suitable porosity for exploitation) remains unclear.[36]

Achieving the Paris goals depends on minimising the already considerable pressure on CDR, by reducing the potential of CCS to generate residual emissions. Finite CO_2 storage must also be allocated to the most valuable applications. Decarbonising fossil fuel production and consumption would be near the bottom of this list, below CDR, and eliminating process-related emissions, such as those from cement.[37]

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[32] Rosa et al., "The Water Footprint of Carbon Capture and Storage Technologies."
[33] Paltsev et al., "Hard-to-Abate Sectors: The Role of Industrial Carbon Capture and Storage (CCS) in Emission Mitigation."
[34] Moch et al., *Carbon Capture, Utilization, and Storage*.
[35] "Barriers to Negative-Emissions Technologies."
[36] Martin-Roberts et al., "Carbon Capture and Storage at the End of a Lost Decade."
[37] E3G, "Carbon Capture and Storage ladder" (2023): https://www.e3g.org/publications/carbon-capture-and-storage-ladder/

Asia's CCS landscape

Despite Asia's dominance of global energy, economic, and emissions activity, the region has so far had a small level of CCS deployment or even project proposals relative to other regions. However, Asia-wide interest and support for CCS has begun to spike in recent years, as more countries have set net zero goals, emissions reductions targets, and long-term strategies in line with their nationally determined contributions (climate targets) to the UN Framework Convention on Climate Change.

The regional CCS pipeline favours continued fossil fuel use

The IEA records a pipeline of 156 CCS projects in Asia (here including Australia and Pacific nations, but excluding Russia and the Middle East), with a further four previously cancelled. However, just 18 are currently operational, and only a further 10 are under construction. The remaining 128 (82% of the total) are in the planning stage.[38] Based on past example, there is a strong chance many proposals will not become operational.

Operational Asian CCS projects have a maximum capacity of 7.54 MtCO_2/yr and all but three are in China (with one in Japan and two in Australia).[39] If all proposed Asian CCS projects became operational, their maximum capacity would be 171 MtCO/yr (though not all projects have indicated capacity, and there is some double counting across the supply chain). There are 959 CCS projects either operational, planned or under construction at a global level. This global total has a much more significant transport only contribution, without which capacity would be close to 1.5 Gt. North America and Europe together account for the vast majority of projects (758) and potential capacity (1.2 GtCO_2/yr without transport).[40]

Asia's CCS pipeline includes 52 'full chain' projects spanning capture, transport, and storage; 96 projects with one or two of these elements; and eight CCU projects. Figure 2 shows the breakdown of projects by location, status, type, and CO_2 destination. China, Australia, and Japan have the most significant presence for capacity and individual project numbers. Japan and Australia also collaborate on five projects and are each engaged with other partners on the remaining nine shared projects

The project pipeline can in turn be divided into 99 projects directly associated with a sector/facility and 57 only identified as transport and/or storage projects. Despite being significantly fewer in number, non-sector-specific transport and storage projects account for 110 MtCO_2/yr capacity – almost two-thirds of the total.[41]

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[38] IEA, "CCUS Projects Database."
[39] IEA, "CCUS Projects Database."
[40] IEA, "CCUS Projects Database."
[41] IEA, "CCUS Projects Database."

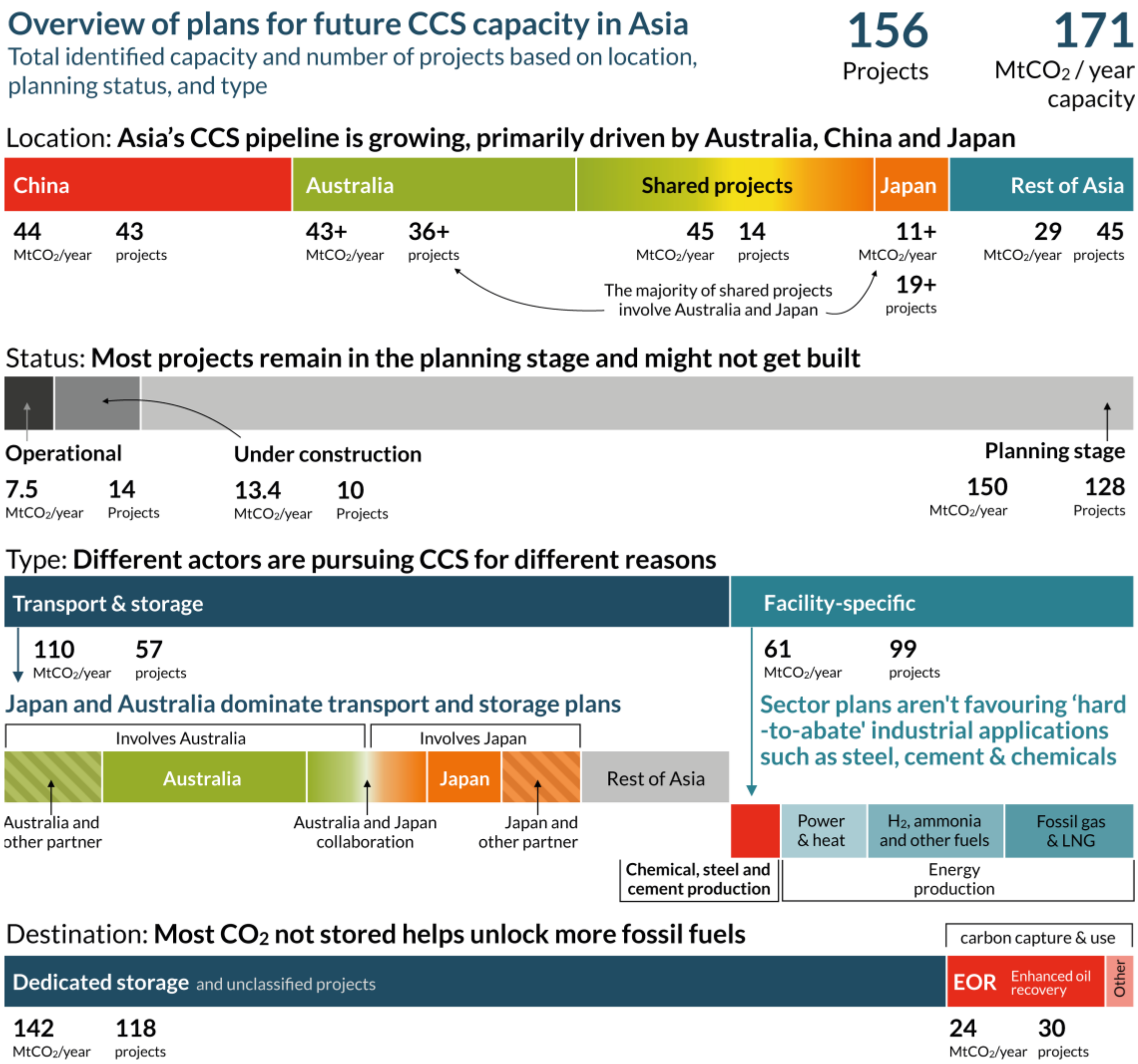

Figure 2. Representation of Asia (and Pacific) entries in the IEA CCUS database, by capacity and project number, allocated by country, status of project, sector, and fate of CO_2. Excludes cancelled projects but includes already operational plans. Includes transport only projects, which account for only four entries, with 2.5 Mt/yr capacity.

Australia, Japan, and Indonesia, are the biggest proponents of transport and storage plans not tied to a specific sector. These plans can, however, be easily attributed to fossil fuel interests (mostly production in Australia and Indonesia's case, and mostly consumption in Japan's case). All but six transport and storage projects have one or more oil and gas companies as a partner.[42] Meanwhile, the largest regional emitters have comparatively few transport and storage projects: China has five and India none.

The breakdown of sector-specific Asian CCS projects also provides clear insight into whether use cases might help sustain or expand fossil fuel use, and whether CCS is being used as a last resort mitigation solution. The most important findings are:

[42] IEA, "CCUS Projects Database."

- Natural gas and LNG processing, which clearly contribute to ongoing fossil fuel use, account for 16 projects, and 19.95 $MtCO_2$/yr capacity, or close to a third of the total of 61.2 $MtCO_2$/yr
- Power and heat account for the highest number of projects (21), and significant 13.04 $MtCO_2$/yr capacity, despite the competitiveness of alternative zero emission technologies in these sectors
- Just six projects, with a total 0.5 $MtCO_2$/yr capacity, target cement, which is among the sectors most frequently described as 'hard-to-abate'. A further six projects with a total of 2.1 $MtCO_2$/yr capacity support steel, and a further 14 projects with 4.41 $MtCO_2$/yr capacity target chemicals. Steel and chemicals are both often also put in the hard-to-abate category
- A large number of projects (35, with total capacity of 17.83 $MtCO_2$/yr) target hydrogen, ammonia, or 'other fuel transformations'. Some of these projects seek to substitute for the same fuels and feedstocks in existing use cases, but many seek to substitute for alternative materials, e.g. metallurgical coal in steelmaking. Many could crowd out alternative shifts that generate zero emissions at the point of use, including electrification of combustion, and use of the same fuels and feedstocks, e.g. hydrogen and ammonia, produced via renewable energy rather than fossil raw materials

The indicated fate of CO_2 potentially captured from Asia's CCS projects and proposals creates further climate concern. **Thirty projects with a combined 24.23 $MtCO_2$/yr capacity identify EOR, which will sustain fossil fuel use**. This compares with eight projects with 4.55 $MtCO_2$/yr capacity for other uses.

The vast majority of Asia's CCS projects – 30, with combined capacity of 124.73 $MtCO_2$/yr – target dedicated storage rather than use as the fate of CO_2. While this might appear advantageous in comparison with EOR or other temporary CO_2 uses, it will put pressure on geological storage and potentially compete with CDR.

On balance, **the Asian CCS project pipeline suggests regional countries are not supporting CCS as a last resort abatement solution, in sectors where no other options exist**. They seem to mostly favour projects likely to sustain or expand fossil fuel use.

Regional targets and policies support more expansive CCS use

National targets and policies which support development of current and future projects add to the climate challenge posed by Asia's CCS plans.

Our case study countries have all either set sizeable targets for future CO_2 capture and storage or been independently assessed as having high needs. As set out in Table 1, the upper end of the CCS capacity which some sources suggest China alone could require by 2030 is several times larger than total CCS plans in the current Asian pipeline. The aggregation of various official national targets across several different timeframes also creates a significantly larger total than this pipeline.

Asia's expansive CCS targets and assessments

Country	Target/assessment
Japan	Japan's Carbon Capture and Storage Long-Term Roadmap (2023) targets **6-12 $MtCO_2$/yr storage by 2030** and **120-240 $MtCO_2$/yr by 2050**
South Korea	South Korea's First National Carbon Neutral and Green Growth Basic Plan (2024) targets **4.8 $MtCO_2$/yr storage by 2030**
Thailand	Thailand's Long-Term Low Greenhouse Gas Emission Development Strategy targets **20 $MtCO_2$/yr by 2045** and **60 $MtCO_2$/yr by 2065**
Indonesia	Indonesia has no volumetric target but is seeking **15 operational projects by 2030**. The IEA estimates Indonesia will need to capture **over 6 MtCO2/yr by 2030** and **190 MtCO2/yr by 2060** to meet its net zero target
Malaysia	Malaysia's National Energy Transition Roadmap (NETR, 2023) targets **up to 15 $MtCO_2$/yr storage by 2030** and **40-80 $MtCO_2$/yr by 2050**. The NETR also targets **creation of three CCUS hubs by 2030 and three more by 2050**
Singapore	Singapore has no national-level target, but a plan for the country's Jurong Island (2021) targets: **2 $MtCO_2$yr by 2030** and **6 $MtCO_2$/yr by 2050**
Australia	Australia has no formal CCS targets. However, a 2023 report cited in official government documents suggests Australia would need **150 $MtCO_2$yr capacity by 2040**
China	China has no official CCS targets and estimates of its potential needs have huge variation. One study notes a range of estimates **from 20-408 $MtCO_2$ in 2030** and **600 $MtCO_2$-1.45 $GtCO_2$/yr in 2050**
India	India has no official CCS targets. One industry-derived roadmap suggests it could account for **15% of Asia-Pacific CCS capacity by 2050, capturing 123 $MtCO_2$/yr**

Table 1. Asian national CCS targets or estimates. Sources: METI, Government of the Republic of Korea, Government of Thailand, IEA, Government of Malaysia, Singapore Economic Development Board, Norton Rose Fulbright, Liu et al, Wood Mackenzie.[43]

Regional CCS policy support includes compliance and voluntary carbon markets that allow carbon price avoidance/credits via CO_2 capture; subsidising industry expenditure; legal and regulatory reform to allow CO_2 transportation and storage; enhanced research and development; provision of shared infrastructure; and forming cross-border partnerships.[44]

Many policies prominently refer to aiding emissions reductions in 'hard-to-abate' sectors. But supporting government and industry statements suggest **Asian CCS plans prioritise matters other than climate – most obviously, sustained fossil fuel production and revenues, and fossil fuel-informed strategic concerns, such as energy security**.

Intimate regional connections between various national CCS perspectives adds to their potency; CCS is particularly important to the economic plans of a few high-capacity Asian governments, whose success depends on the acquiescence of regional partners.

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[43] Ministry of Economy, Trade and Industry, "Carbon Capture and Storage Long-Term Roadmap Japan"; Government of the Republic of Korea, "First National Carbon Neutral and Green Growth Basic Plan"; Government of Kingdom of Thailand, *Thailand's Long Term Low Greenhouse Gas Emissions Development Strategy*; IEA, *Carbon Capture, Utilisation and Storage in Indonesia*; Malaysia's Ministry of Economy, "National Energy Transition Roadmap"; Singapore Economic Development Board, *Sustainable Jurong Island*; Norton Rose Fulbright, "Understanding CCS in Australia"; Net Zero Australia, *How to Make Net Zero Happen: Mobilisation Report*; Mackenzie, "India Needs US$4.3 Billion Government Support to Enable CCUS Adoption"; Liu et al., "China's Pathways of CO2 Capture, Utilization and Storage under Carbon Neutrality Vision 2060."

[44] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.

Japan is a particularly influential Asian CCS proponent. It has provided significant financial and regulatory support to CCS at home and abroad. Japan is currently lending direct financial support to nine storage projects. Five of these are domestic and four are elsewhere in Asia – three in Malaysia and one only indicated as tied to "Oceania".[45]

Japan's CCS Business Act of 2024 refers to a need for CCS in hard-to-abate sectors, while including "power" and "mobility" within this definition.[46] This ignores the reality that renewables, batteries and electrification are superior alternatives for cost-effective emissions reduction in these sectors. Japan's 7th Strategic Energy Plan also notes "petroleum refining" and some transportation sectors – heavy duty trucks, aircraft, and shipping – as potential CCS targets.[47]

Japan's idiosyncratic climate plans – which are typically inseparable from national economic goals – inflate its CCS claims. These plans include phasing out only "inefficient coal-fired thermal power" from its power system, which reflects some ongoing scepticism of renewables and electrification as ill-suited to Japanese conditions. Perhaps more pertinently, embracing renewables and electrification would involve ceding energy market share to technologies whose production China already dominates.[48] **Distrust of renewables and electrification, and seeking to advance non-climate concerns, similarly animate South Korea's CCS support.**[49]

Japan and South Korea both promote CCS and related technology elsewhere in Asia. Japan has gone as far as to build regional institutions – including the Asia CCUS Network and Asia Zero Emissions Community – for this purpose, alongside gas and LNG promotion.[50] Japanese and South Korean CCS-linked financial and policy support to areas such as Southeast Asia and Australia ranges from targeting the relatively straightforward continuation of fossil fuel use cases, to encouraging fuel and feedstock shifts allowing integration of CCS-abated hydrogen and ammonia.[51]

Some Japanese and South Korean CCS pursuits mostly advance their own energy trading and technology companies. But there is often a sense of reciprocity for partnering countries' fossil fuel interests. Japan, South Korea, Australia, and various Southeast Asian countries have entered into numerous bilateral or broader partnerships

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[45] Japan Organization for Metals and Energy Security, "Advanced Efforts for Commercialization of CCS- JOGMEC Selects Nine Projects as Japanese Advanced CCS Projects."
[46] METI, "Cabinet Approvals on the 'Bill for the Act on Promotion of Supply and Utilization of Low-Carbon Hydrogen and Its Derivatives for Smooth Transition to a Decarbonized, Growth-Oriented Economic Structure' and the 'Bill for the Act on Carbon Dioxide Storage Businesses.'"
[47] Agency of Natural Resources and Energy, Ministry for Economy, Trade and Industry, Government of Japan, "7th Strategic Energy Plan."
[48] Bowen, *Toward Comprehensive Green Security for Asia and the Pacific*.
[49] "Civil Society Organizations at COP29 Call on Australia, Japan, and South Korea to Stop Their Fossil Fuel Cooperation."
[50] Ministry of Economy, Trade and Industry, Government of Japan, "Asia Zero Emission Community (AZEC) Ministerial Meeting and AZEC Public-Private Investment Forum Held."
[51] "Civil Society Organizations at COP29 Call on Australia, Japan, and South Korea to Stop Their Fossil Fuel Cooperation."

to advance transboundary CCS (the IEA captures 14 entries of this nature)[52]. Countries have also made necessary regulatory and legislative reforms, including Australia ratifying London Protocol amendments on offshore transboundary CO_2 storage.[53]

Australia has the largest number of CCS projects or plans among countries discussed in this report (when including shared projects). But many entered the pipeline under previous, more outwardly pro-CCS governments. Australia's current leadership has eschewed providing direct financial support to CCS. It has, however, still created a CCS-welcoming regulatory and legislative environment, including allowing linked credits under voluntary climate programmes and the mandatory Safeguard Mechanism.[54] Canberra now presents its CCS support as mostly about eliminating hard-to-abate emissions in sectors such as steelmaking.[55] However, Australian CCS policies and projects continue to heavily skew towards upstream fossil fuel expansion.[56]

Many Southeast Asian countries have similarly overhauled their policy regimes to facilitate CCS in recent years, including in response to other countries' proposals. Most regional efforts again appear overly geared towards sustaining fossil fuel use.

Indonesia has an investment attraction-centric CCS perspective. This is indicated in its project rather than volume-based CO_2 storage targets (see Table 1). Jakarta issued new CCS regulations in December 2024.[57] Fossil fuel interests celebrated the continued opportunities these regulations presented, in supposedly reducing industry carbon footprints and creating new storage revenues. Some of this praise again employed 'hard-to-abate'-like language. The Indonesian Petroleum Association, for example, welcomed the regulations as "enabling growth by providing solutions for industries that are difficult to decarbonise"[58]

Malaysia's National Energy Transition Roadmap supports CCS on the grounds that "**As an energy producing country, there is a pressing need for Malaysia to balance economic interests, energy security, and environmental sustainability."[59]** Industry analysts again celebrated the investment potential and retention of upstream fossil fuels. An industry-supportive report estimated Malaysia would attract more than USD10 billion in CCS-linked capital expenditure by 2030, and noted CCS was crucial for "ensuring the [oil and gas] sector's long-term sustainability and competitiveness".[60]

Thailand's CCS strategy is also squarely focused on fossil fuel-linked economic opportunity. Thailand is amending its petroleum legislation to facilitate CO_2 storage. The

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[52] IEA, "CCUS Projects Database."
[53] DCCEEW, "Offshore Carbon Capture and Sequestration."
[54] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.
[55] DCCEEW, "Carbon Management for Tough Emissions."
[56] See Seccombe, "Emails Reveal Labor Caved in to Santos."
[57] George, "Indonesia Unveils CCS Regulations To Spur Industry Growth."
[58] George, "Indonesia Unveils CCS Regulations To Spur Industry Growth."
[59] Malaysia's Ministry of Economy, "National Energy Transition Roadmap."
[60] Staff, "TA Securities Projects Carbon Capture Tech to Attract over $10B in Capital Expenditures into Malaysia by 2030."

government has identified sectors including natural gas processing and petrochemical manufacturing as eligible for "investment incentives" to develop storage proposals.[61] Reporting of Thai plans again celebrated opportunities such as job creation, economic growth, and energy security, more than climate outcomes.[62]

Singapore provides a good example of a regional government directly partnering with fossil fuel firms on CCS. The Singapore Economic Development Board is proposing a new regional CCS hub with ExxonMobil and Shell.[63] This project also shows how countries often use CCS to sustain their existing fossil fuel-linked development model; Singapore is currently a regional hub for oil and gas.

Asia's largest emitters, China and India, are largely disconnected from the Japan/South Korea-Southeast Asia-Australia CCS nexus. But their future pathways will ultimately most influence global climate action. China already has the second-largest CCS pipeline in Asia, after Australia. However, this is relatively small capacity compared with its vast energy and industrial use. India has little notable presence thus far.

Both China and India have more domestic fossil fuel resource abundance – particularly coal – than Japan and South Korea.[64] But both are also ushering in zero emissions technologies in sectors such as power and transportation, led by renewables and battery electric vehicles (EVs), and also green hydrogen in India's case.[65] Unlike Australia and Southeast Asia, China and India both also use domestic fossil fuels more for domestic needs than export revenue. They thus face less direct pressure to deploy CCS for market access reasons.

However, China and India's phase-ins of zero emissions technologies have not been accompanied by rapid fossil fuel phaseout. China is also the world's leading producer, and India a fast-rising rival, in industrial sectors such as cement and steel, in which CCS is a heavily favoured solution for hard-to-abate emissions.[66]

Both **China and India could increasingly turn to CCS in numerous sectors** in coming years. China's government has taken some steps in this direction. This includes supporting new projects under 2023's Plan for Green and Low-Carbon Technology Demonstration. China announced six successful CCS projects in August 2024, including those tied to a Huaneng coal-fired power plant, an Inner Mongolia steel plant, and several storage developments. [67] In July 2024, China also announced an action plan for considerably decarbonising its coal power plants by 2027, including via CCS. However,

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[61] Kiratisountorn et al., "Carbon Capture and Storage in Thailand."
[62] Nation Thailand, "Carbon Capture and Storage."
[63] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.
[64] See Energy Institute, "Statistical Review of World Energy."
[65] Yale E360, "How China Became the World's Leader on Renewable Energy"; Biswas et al., *A Green Hydrogen Economy for India*.
[66] See Global Cement and Concrete Association, "Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete"; Global Energy Monitor, "Global Steel Plant Tracker."
[67] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.

there are still only a handful of CCS references in Chinese policy documents and no cohesive strategy for facilitating pursuit via state finance or regulatory reform.[68] India is even less advanced than China on CCS policy support. But it is currently developing a national 'mission' aimed at scaling up deployment.[69]

[68] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.
[69] Global CCS Institute, *Global Status of CCS 2024: Collaborating for a Net-Zero Future*.

The global climate risks of Asia’s CCS plans

Asian countries have increasingly presented CCS as critical to meeting their own and others’ climate goals. However, growing regional dependence on this technology presents two key emissions risks. The first risk would involve the region achieving a high-CCS pathway but with deployed capacity that fails to achieve indicated CO_2 and upstream methane capture rates. This can be called a ‘underperforming high-CCS’ pathway. The second risk would be Asia pursuing but failing to achieve a high level of CCS deployment. This can be called an ‘unachieved high-CCS’ pathway. A combination of both risks is also possible, and perhaps more likely.

An underperforming high-CCS pathway could put Paris out of reach

The risk to global climate action of Asia achieving a high-CCS pathway, but with capacity failing to meet claimed performance thresholds, can be directly assessed. It can be deduced from studying Asian pathways under a high-CCS 1.5°C-aligned scenario and exploring the impact on emissions should CCS fail to deliver at industry-claimed levels (but more in line with current observations).

Our chosen high-CCS scenario from the AR6 database sees CCS applied to a 23% share of Asia’s primary energy from fossil fuels by 2030, and 68% of primary energy from fossil fuels by 2050. The scenario sees 5.8 $GtCO_2$/yr sequestration from fossil CCS by 2050 (see Appendix for more explanation of methodology and assumptions).

It is difficult to conclude that Asia as a whole or any of our case study countries are on such a high-CCS pathway in the short-term. There is high national and collective regional policy optimism for CCS deployment, but the near-term pipeline shows the hard reality that building CCS at-scale is expensive and technically difficult.

Even if all current projects are delivered at full capacity by 2030 (a highly unlikely prospect), the maximum regional capture *and* storage capacity possible from all projects whose capacity is assessed would be around 170 $MtCO_2$ by this time. While the number of operational regional CCS projects could grow in line with targets and policy priorities in coming years, it is highly unlikely that this would allow capacity expansion sufficient to put Asia on a high-CCS pathway by 2030.

To construct our high-CCS pathway, we therefore focus on a more plausible outcome. We assume that Asia will reach its current limited 2030 deployment targets and then accelerate post-2030, to reach 5.8 GtCO2/yr of deployment by 2050.[70]

[70] We assume a quadratic rate of growth where capacity additions of CCS grow linearly from 2030 to 2050

If Asia does achieve such a high-CCS trajectory, but performance remains closer to the level typical of current CCS projects – rather than ambitious assumptions that would be needed to truly constitute 'abated' fossil fuels[71] – **this would produce an additional cumulative total of 24.9 $GtCO_2$-e in GHG emissions by 2050.** The majority of this, 21.9 Gt, would be carbon dioxide, while 3 Gt would be methane.

This 24.9 $GtCO_2$-e figure is more than the cumulative historical CO_2 emissions from energy and industry individually generated by all but three Asian countries: China, India, and Japan. It is comparable to the cumulative individual emissions totals from South Korea (20.1 $GtCO_2$) and Australia (19.66 $GtCO_2$).[72] These additional emissions would fatally undermine Asia's alignment with the Paris Agreement.

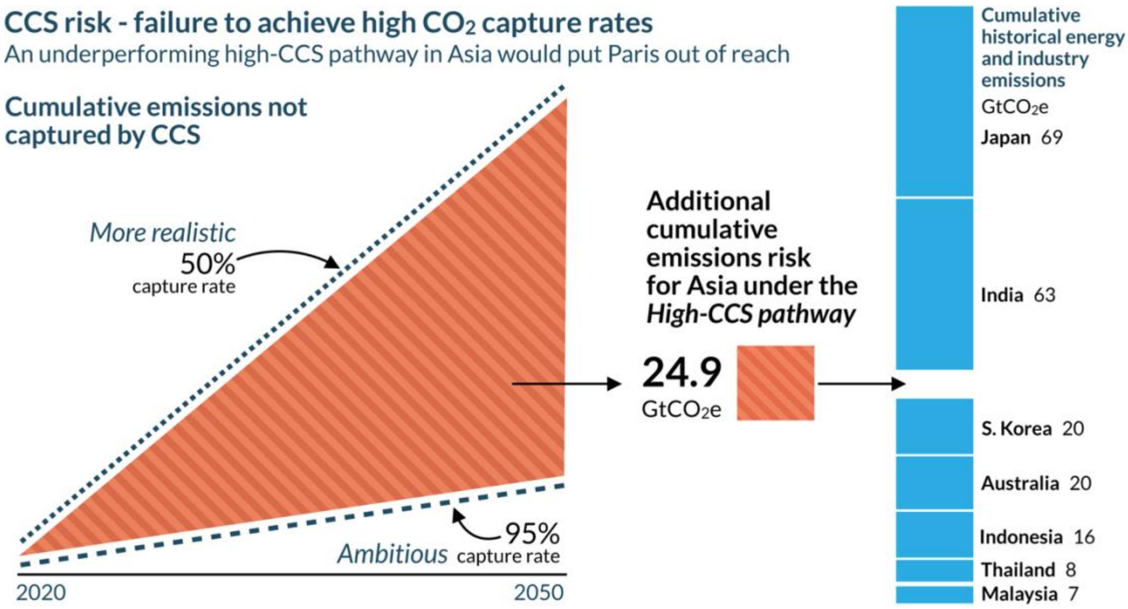

Figure 3. Additional emissions risk from Asia in high-CCS with under-performance scenario. See Appendix for methodology and regional definitions.

An unachieved high-CCS pathway could also be damaging

There is, on the other hand, a distinct possibility that Asia will struggle to achieve a high-CCS pathway, or something approaching it, even in the longer-term. CCS deployment has a history of disappointing against announced plans. There is a still sizeable climate risk attached to this trend continuing. Inasmuch as Asian governments and industry will still devote valuable time and resources to CCS promotion – as is currently occurring – it will create considerable opportunity costs for Asia's alternative pursuit of a low-CCS, 1.5°C-aligned future.

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[71] Rather than 95% capture rates for CCS and 80% fugitive upstream methane emissions capture, we assume a 50% CO_2 capture rate and 30% methane abatement rate to calculate the additional emissions risk.

[72] Friedlingstein et al., "Global Carbon Budget 2024.", with processing by Our World in Data.

There is evidence of how CCS can divert – wilfully or not – attention and resources from rapid, lowest cost emissions abatement. Australia, for example, saw generally disappointing results from the more than AUD1 billion it publicly invested in CCS in the first two decades of the 21st century.[73] While the current government has abandoned the public spending element of this strategy, Australia's attempts to achieve a low-CCS net zero pathway – in favour of renewables and electrification – have been hampered by past underinvestment in low cost abatement solutions and continued lobbying for CCS concessions from fossil fuel interests, including in Japan and South Korea.[74]

The conclusion that CCS delays fossil fuel phaseout is superficially logical. It is also empirically supported. Two 1.5°C-aligned low-CCS scenarios we also assess for this report (with zero shares of primary energy from fossil fuels with CCS applied in 2030 and 2050) respectively show 32% and 38% decreases in fossil fuel use in Asia between 2020-2030. This compares with just a 12% reduction in our high-CCS pathway. It in turn compares with a 30% median reduction in fossil fuel use across all 1.5˚C-aligned scenarios (with median 1% and 19% shares of CCS applied to primary energy from fossil fuels in 2030 and 2050, respectively) (see Appendix for more details of these scenarios).

However, the proper reference case for assessing the emissions risk posed by an unachieved high-CCS pathway is somewhere closer to the status quo, of largely unabated fossil fuel capacity. Asian countries might pivot from supporting a high-CCS pathway as the benefits of alternative zero emissions solutions become ever clearer. But diversion of resources and attention could still lock-in significant fossil fuel capacity and sustain major stranded asset risks in the intervening period.

The additional emissions risk from an unachieved high-CCS pathway is more difficult to directly measure. But it has potential to be as great or greater than that generated by an underperforming high-CCS pathway. This would have a commensurate impact, of putting 1.5°C even further out of reach.

Paris-aligned climate action depends on Asia minimising CCS and fossil fuel use

Based on current trends, Asia's potential climate future could be a mix of underperforming and underachieving high-CCS pathways. This requires urgent attention. As the world's largest GHG-emitting region now and likely well into the future, Asia will play the pivotal role in global pursuit of net zero emissions by mid-century. Residual emissions in all Asian countries and sectors must be minimised.

As Figure 5 shows, Asian countries continue to have excessive fossil fuels dependence. Extending support to high-CCS pathways – even those that might be ostensibly 1.5°C-aligned – will not eradicate this. As we have shown, there is a significant additional cumulative GHG emissions risk of almost 25 $GtCO_2$-e by 2050 in an underperforming

[73] Brown and Swann, *Money for Nothing*.
[74] Gergis, *Highway to Hell*.

high-CCS pathway, and potentially as much or more in an unachieved high-CCS pathway.

By contrast, the median of 1.5°C-aligned scenarios in the AR6 database shows a significantly lower 4.3 $GtCO_2$-e in cumulative additional GHG emissions risk from underperforming CCS deployed at the 1% and 19% levels noted for 2030 and 2050. Meanwhile, the cumulative additional emissions risk of suitably low-CCS scenarios can be essentially zero (as they avoid deploying fossil-CCS all together, relying instead on renewables, electrification and other zero-carbon technologies to displace fossil fuels).

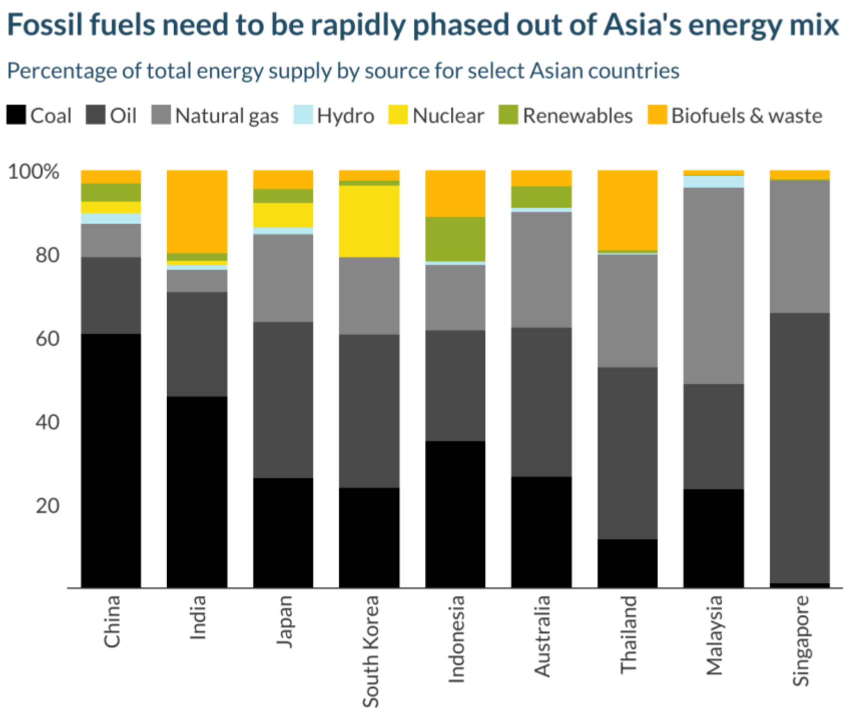

Figure 4. Percentage of energy mix by source for Asian case study countries in this report. Figure shows latest available value for 'total energy supply' in terajoules, divided into percentages of energy by source. Source: IEA World Energy Balances.[75]

To meet their own and global climate goals, Asian countries would be better placed avoiding dependence on CCS as anything but a last resort abatement technology, and prioritising rapid fossil fuel phaseout. This strategy also carries far less economic risk.

[75] International Energy Agency, "World Energy Statistics and Balances."

Asia’s alternative low-CCS climate future

Regional plans and policies reveal that economic considerations often motivate Asia’s expansive CCS plans. The economic case for CCS can, however, only be made in a narrow, fossil fuel-supporting sense, or assuming frustration of the Paris goals.

It is increasingly clear that, at an aggregate level, CCS dependence will be expensive and technically challenging. Globally, Bacilieri et al. (2023) find a high-CCS net zero pathway could cost at least USD30 trillion more than a low-CCS pathway by 2050. The authors conclude that countries which centralise CCS in net zero plans “risk losing competitiveness to countries that opt for a much cheaper, and almost certainly more deliverable strategy centred on renewable electricity, energy efficiency and electrification.”[76]

An underperforming high-CCS pathway would likely see Asia waste considerable investment on failing capacity, which could have been far better spent on zero emissions solutions that are more assured of putting the region on a Paris-aligned climate path. An underachieved high-CCS pathway would also delay investment in zero emissions solutions and likely bring exorbitant stranded asset costs.

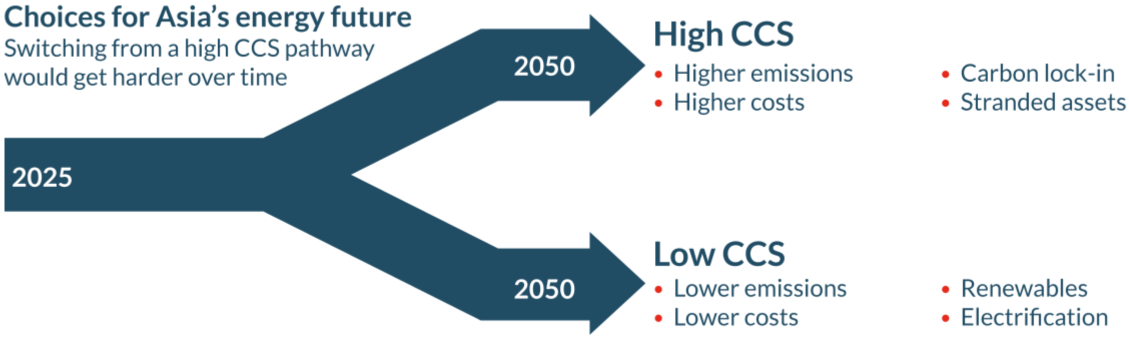

Figure 5. Asia's potential CCS pathways

Thankfully, Asia has another potential climate future. This would be a ‘deliberate low-CCS pathway’, whereby governments actively support more rapid phaseout of fossil fuels, with low to zero CCS dependence – consistent with the low-CCS scenarios we outline above. This would correspond with more rapid deployment of readily available affordable zero emissions solutions, such as electrification, batteries, wind and solar,

[76] Bacilieri et al., *Assessing the Relative Costs of High-CCS and Low-CCS Pathways to 1.5 Degrees*.

and longer-term lowering of cost and technical barriers where zero emissions solutions are not currently available.

Options for rapid, low-cost emissions abatement already exist

Asian countries have abundant opportunity to rapidly deploy technologically mature, low-cost zero emissions solutions – namely renewables, electrification, and energy efficiency – in priority sectors, led by power generation and transportation.

Power generated from unabated fossil fuels is already uncompetitive with renewable options on a global basis and in most Asian countries. Latest International Renewable Energy Agency figures show the global weighted average levelised cost of electricity (LCOE) for new capacity additions for renewables in 2023 were USD33/MWh for onshore wind, USD75/MWh for offshore wind, and USD44/MWh for utility scale solar photovoltaic (PV). This compared with the weighted average cost of new capacity additions across fossil fuels, of USD100/Mwh. [77]

Asian countries have shared in this renewable energy cost windfall. Australia was the second country in the world, behind Brazil, to see the weighted average LCOE of new utility scale solar PV fall below that of new fossil fuel capacity – a record it achieved in 2016. China, India, South Korea, and the Philippines followed in 2017 and 2018, Vietnam in 2019, Indonesia and Japan in 2021, and Malaysia in 2022.[78]

Asia accounts for more than half the estimated fuel cost savings from renewable power deployed since 2000 (USD212 billion out of USD409 billion). Asia's estimated savings from renewables were USD29 billion in 2023 alone – 3.5 times higher than in 2010.[79]

Figure 7 shows the LCOE advantage of renewables over fossil fuels in key Asian countries. This does not include integration costs (including transmission and 'firming' of intermittent renewables through storage or 'peaking' capacity such as hydropower or gas). However, research by Ember has found that techno-economic improvements tied to battery technology can allow very sunny regions to get close to 97% continuous solar generation at a cost of USD104/Mwh – outcompeting integrated fossil capacity.[80]

As opposed to common pro-CCS arguments, deploying renewables in place of fossil fuels can thus be an energy security benefit. This point is most salient in areas of sustained energy demand growth and reduced domestic fossil fuel production, which would otherwise necessitate expensive and often vulnerable import dependence. Southeast Asian countries currently face this predicament on gas. Rather than turn to volatile LNG imports, they would be better placed generating and storing more of their own renewable energy and building out cross-border transmissions infrastructure.[81]

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[77] IRENA, "Renewable Power Generation Costs in 2023."
[78] IRENA, "Renewable Power Generation Costs in 2023."
[79] IRENA, "Renewable Power Generation Costs in 2023."
[80] "Solar Electricity Every Hour of Every Day Is Here and It Changes Everything."
[81] Zero Carbon Analytics, "It Is Unclear If LNG Imports Can Guarantee Southeast Asia's Energy Security."

China, whose energy demand is now beginning to slow, has already realised energy security benefits through its rapid renewables and oil demand-avoiding EV buildout.[82]

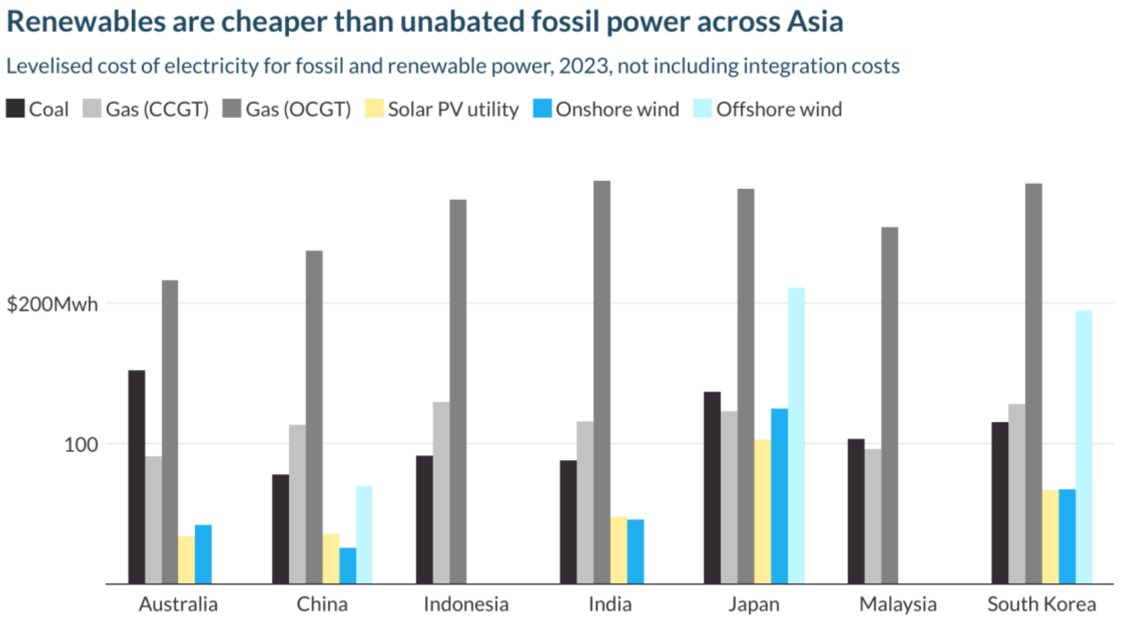

Figure 6. Levelised cost of electricity for fossil versus renewable electricity in select Asian countries. Figures in USD. Figures do not include integration costs such as transmission and firming. CCGT = combined cycle gas turbine. OGCT = open cycle gas turbine. Source: IRENA[83]

There is no comparable LCOE data for fossil power with CCS, as there is no commercial-scale CCS plant operating anywhere in the world (itself a strong contrast with record renewables deployment of recent years). But costs will only increase disparities between renewables and fossil fuels.

Renewables cost advantage can persist even as rates of penetration rises, even in relatively wind and solar-poor countries. Japan, for example – which does have poorer resources and higher costs than the likes of China, India, and virtually all other Asian countries – has been estimated able to generate 90% of its electricity with solar, wind, and battery storage by 2035, while cutting costs 6% (and, in a further energy security boost, nearly eliminating coal and LNG imports).[84]

Retrofits of existing power infrastructure with CCS can also increase costs and lower capture rates relative to new build plants.[85] This will, in many cases, require significant additional operational lifespans to cover additional costs. Ageing facilities may struggle to justify this. Some may cover additional costs by operating at higher capacity and for

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82 Jaffe, "Green Giant."
83 IRENA, "Renewable Power Generation Costs in 2023."
84 Shiraishi et al., *The 2035 Japan Report: Plummeting Costs of Solar, Wind, and Batteries Can Accelerate Japan's Clean and Independent Electricity Future*.
85 "Retrofitting CO_2 Capture to Existing Power Plants."

longer durations than originally intended. Coupled with under-performance on capture rates, this would likely negate any climate benefit.

There is a similar need for the power sector to avoid any fuel shifts which CCS might facilitate. These, such as partially abated fossil hydrogen and ammonia, also typically result in higher cost, lower mitigation potential than zero emissions alternatives.[86]

The same logic applies to transport. Some Asian carmakers contend that hydrogen fuel cell vehicles can be a cost-competitive, low emissions transportation option, using CCS-abated fossil hydrogen, or, in the longer-term, green hydrogen produced from renewable electricity. Fuel cell vehicles have, however, been progressively outcompeted by battery EVs in various road vehicle classes.[87]

Even in longer distance transport, where low-carbon fuels such as hydrogen have long been seen as essential, a wide range of options can now compete with CCS-derived fuels. Rapidly declining cost of batteries will enable partial electrification of shipping and aviation[88], and CCS-abated fossil hydrogen would need to compete with alternatives such as green hydrogen or methanol for remaining fuel-consuming applications.

Some options for partially CCS-abated hydrogen or other fuels theoretically still exist in more challenging transport segments. This will, however, remain contingent on maintaining emissions abatement performance and cost advantages sufficient to crowd out emerging zero emissions alternatives, which is far from certain.

Avoiding CCS in harder-to-abate sectors is increasingly possible

There is even growing confidence that zero emission technologies can outcompete CCS-enabled production in sectors most commonly claimed to be hard-to-abate.

To be assured of 1.5°C alignment, CCS might only be justified where abated fossil fuels are less technically mature and cost-competitive than unabated fossil fuels, but more technically mature and cost-competitive than zero emissions alternatives. This has historically appeared the case for emissions tied to industrial sectors such as steel, cement, and fertiliser production.

Asia is at the global heart of these sectors. China accounted for approximately half of global steel and cement production and consumption in recent decades.[89] China's steel and cement output is now slowing but, alongside a similarly declining Japan and South Korea, will likely remain strong for several decades. Other Asian countries are also rising in steel and cement. India is already second in global steel consumption and expected to see annual growth of 6.3% in demand between 2025-2030, while Association of Southeast Asian Nations (ASEAN) countries could see steel production grow at 3.7%

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[86] Henze, *Japan's Ammonia-Coal Co-Firing Strategy a Costly Approach to Decarbonization, Renewables Present More Economic Alternative*.
[87] Plötz, "Hydrogen Technology Is Unlikely to Play a Major Role in Sustainable Road Transport."
[88] Kersey et al., "Rapid Battery Cost Declines Accelerate the Prospects of All-Electric Interregional Container Shipping."
[89] IEA, "Cement – Analysis"; World Steel Association, "World Steel in Figures 2025."

per annum.[90] India and other South Asian cement consumption could grow more than 40% during 2025- 2035, while ASEAN could see 14% growth.[91] Led by China and India, Asia also accounts for more than half of global fertiliser consumption, which is particularly important to national and regional development priorities.[92]

Asian policy documents have often stated the importance of CCS in hard-to-abate sectors. But current project plans mostly help sustain fossil fuel use in relatively easy-to-abate sectors. Regional countries would ideally abandon CCS plans in these sectors. But it would still be advisable to avoid pivoting to CCS for hard-to-abate emissions.

There has been significant global progress on technologies for eliminating fossil fuels from industry in in recent years. For example, a 2020 European-centric study found 78% of energy demand in 11 industrial sectors (accounting for more than 92% of European industrial CO_2) could already be electrified with established technologies, and 99% with technologies now in development.[93] This would allow for progressive abatement of emissions from heat as power supplies are decarbonised.

Avoiding process emissions could prove more difficult. Even here, however, CCS support might come at the cost of supporting techno-economic transformations that reduce CCS need.

CCS is often the most expensive abatement option in purported hard-to-abate sectors, including for capturing process emissions. In cement, for example, a combination of four existing levers (efficient design in construction and concrete production; decarbonised cement and binders; fuel switching; and energy efficiency) with estimated combined abatement costs of less than USD20/tCO_2 could deliver up to 70% of emissions savings.[94] This compares with estimated USD60-120/tCO_2 abatement costs for cement-applied CCS.[95] Some zero, and potentially net CO_2–absorbing, negative emissions cements are also in development. Though expensive and technologically immature at present, they could become comparatively less so with further policy support, such as carbon pricing and subsidies.[96]

In steel, current plans for CCS applied to carbon-intensive blast furnaces could be avoided by more rapidly scaling viable production technologies that eliminate both process and energy emissions. Green hydrogen-based direct reduced iron, coupled with renewably powered electric arc furnace (EAF)-based steelmaking, is commercially viable

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[90] OECD, *OECD Steel Outlook 2025*.
[91] Riley, "Cement Demand Forecast 2050."
[92] Food and Agriculture Organization of the United States, "FAOSTAT: Fertilizers by Product."
[93] Madeddu et al., "The CO_2 Reduction Potential for the European Industry via Direct Electrification of Heat Supply (Power-to-Heat)."
[94] Council of Engineers for the Energy Transition, *Overview of Strategies for Reducing CO2 Emissions in China's Cement Industry*.
[95] IEA, *Is Carbon Capture Too Expensive?*
[96] Alliance for Low-Carbon Cement and Concrete, "Fast-Tracking Cement Decarbonisation: From Underperforming to Performance-Based Standards."

alongside EAF-based recycled steel.[97] Sustained government support is again critical to scaling up output and lowering costs, so that such options become dominant

It is possible to produce the major fertiliser input, ammonia, with renewable energy instead of current fossil gas (which might be coupled with CCS).[98] The current CCS-linked practice of using CO_2 from ammonia plants to produce urea must also be avoided, as carbon is almost immediately re-released once fertiliser is applied.[99] End-use fertiliser emissions from nitrous oxide remain a major challenge, even with fully decarbonised production.[100] But the fertiliser sector is not locked into a high emissions future; production can be decarbonised through green ammonia and end-use emissions can be curbed with better application and product innovation.

Technological breakthroughs may still not eliminate all emissions from all sectors in a Paris-aligned timeframe. Therefore, CCS may a role to play in limited and specific use-cases. But overly production-centric perspectives can still overemphasise its utility here.

Where significantly reducing use of emissions-intensive goods is considered, alongside accelerated deployment of breakthrough technologies, CCS dependence can be dramatically lowered. Edelenbosch et al. (2024), for example, find that economy-wide demand reduction could limit peak annual carbon capture (here applying BECCS) to 0.5–2.2 GtCO2e, relative to 10.3 GtCO2e/yr in a default 1.5 °C scenario. This compares with 1.9–7.0 GtCO2e/yr that could be reduced via production measures alone.[101]

A deliberate low-CCS pathway is Asia's most economically sensible plan

Despite what regional governments and industry often claim, a high-CCS pathway to net zero emissions is unlikely to be in Asia's best climate or economic interests. The great expense it would add is already unnecessary in sectors such as power and transportation, where low cost zero emissions solutions are already available.

Fast-emerging solutions also question CCS dependence in supposedly hard-to-abate sectors. While some mitigation solutions in these areas may be currently expensive and unproven, the same can be said of CCS. CCS, moreover, has unproven ability for achieving the performance and cost improvements necessary to make it a viable climate solution, despite decades of investigation. Options for demand reduction in hard-to-abate sectors have also been underexplored in Asia and beyond. If better prioritised, these would also often be a more cost-effective alternative to CCS.

Asian countries have a long history of innovating and scaling-up technology, including in the climate space. Leveraging this in the right areas could remove even more CCS use

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[97] Agora Industry, *15 Insights on the Global Steel Transformation 15 Insights on the Global Steel Transformation*.
[98] Ribeiro and Santos, "Transitioning Ammonia Production."
[99] Kayalıoğlu, "Green Approach to the Fertiliser Industry."
[100] Oukhalfan et al., "Toward Net-Zero Emission Fertilizers Industry."
[101] Edelenbosch et al., "Reducing Sectoral Hard-to-Abate Emissions to Limit Reliance on Carbon Dioxide Removal."

cases. Economic opportunities tied to these could also often be more lucrative than fossil fuel sustainment. Clean energy sectors such as solar and EV manufacturing are already a more important driver of economic growth than fossil fuels, or any other sector, in China.[102] Other Asian countries could see similar benefits. The IEA has estimated Indonesia could see USD30 billion value tied to critical mineral-linked production by 2060, for example – larger than its greatest ever coal returns.[103]

Asian countries have abundant policy potential to harness in supporting deliberate low-CCS pathways. Strong public-private integration of economic interests – including high regional presence of state-owned enterprises – could, for example, be directed towards creating demand for genuine zero emissions industrial production. Many of the tools Asian governments deploy in service of CCS, including international finance and partnerships, could be directed at the more logical avoidance of CCS avoidance.

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[102] Myllyvirta, "Analysis," January 25, 2024.

[103] IEA, *An Energy Sector Roadmap to Net Zero Emissions in Indonesia*.

Conclusion

Asia exerts considerable influence on global climate action. The pathways which regional decision-makers choose will heavily influence whether the world can realise the Paris Agreement's climate goals. Asia's expansive CCS plans create considerable, but unnecessary, risk in this regard.

We have shown that Asia achieving a high-CCS pathway to net zero emissions, combined with poor capture rates – which is likely based on current observation – could lead to almost 25 GtCO_2-e of emissions by 2050. Asia supporting, but failing to achieve, a high-CCS pathway would also have damaging, and potentially larger repercussions. Either or some combination of an underperforming and underachieved high-CCS pathway for Asia would put the 1.5°C warming limit far out of reach.

Asia's CCS drive is not only incompatible with necessary climate action but needlessly expensive. Regional countries could rapidly deploy readily available low-cost emissions abatement solutions in priority sectors. There are also emerging options to decarbonise so-called hard-to-abate sectors, many of which Asia dominates, including through additional policy support to scale up solutions.

Whether a combination of zero emissions energy and industrial production and supportive demand reduction can avoid significant residual emissions in evert sector by mid-century remains in doubt. Based on this, there is some utility in continued investigation of potential CCS applicability in an Asian context, so long as it does not detract from fossil fuel phaseout.

The continued inability of CCS to live up to its promise is a warning to Asian policymakers. Keeping the Paris Agreement goals in sight means CCS should be considered a last resort emissions abatement tool. Regional government would be better placed allocating most resources and attention to supporting a deliberate low-CCS pathway, which carries the lowest emissions and economic risk.

Appendix

Methodology for calculating additional emissions risk from 'underperforming high-CCS' pathway for Asia

To calculate the emissions risk of Asia embarking on a high-CCS energy system transition, but with CCS failing to perform to the levels required, we first identified an appropriate scenario from the IPCC's AR6 database to act as an illustrative pathway.

The scenario selected was produced by the IMAGE model and is the SSP2_SPA1_19I_D_LB scenario.[104] This scenario is a default mitigation scenario from the IMAGE model, which follows a middle-of-the-road socio-economic setup from SSP2, in which population and GDP growth follows historical trends.[105]

We calculated the level of carbon sequestration from fossil CCS by applying emissions factors for coal, oil, and gas to scenario data on the use of these fuels with CCS. We then assumed that 95% of these emissions are captured, and methane abatement rates are 80%. This arises from IPCC authors definition of what "abated" fossil fuels would entail.[106] This produced an estimate of fossil CO_2 captured by CCS, rather than taking a direct datapoint from the scenario itself.

To calculate the additional emissions risk, we then explored the level of emissions at risk under a 50% CO_2 capture rate and 30% methane abatement rate. Given the current very limited portfolio of CCS deployment projects, determining what a likely 'underperformance rate' is for the Asian CCS portfolio is difficult. However, existing CCS demonstration projects often display capture rates that are close to or even below 50% (with wide variance across different projects).[107]

For the regional focus, we used the R5ASIA region from the IMAGE model, which captures the whole Asia region. This can then be broken down into the R10CHINA+, R10INDIA+ and R10REST_ASIA regions, which contain China/India and neighbouring countries, and then the remaining countries, which are all located in Southeast Asia. Japan is not included in any of these regions, as it is instead included in the R10PAC_OECD (Pacific OECD) region in IMAGE, alongside Australia and New Zealand.

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[104] Van Vuuren *et al* (2021): The 2021 SSP scenarios of the IMAGE 3.2 model https://eartharxiv.org/repository/view/2759/

[105] Fricko et al., "The Marker Quantification of the Shared Socioeconomic Pathway 2: A Middle-of-the-Road Scenario for the 21st Century."

[106] Bataille et al., "Defining 'Abated' Fossil Fuel and Industrial Process Emissions." A 0.2% leakage rate for methane would (using GWP_{100} potentials) equate to an emissions factor of ~1 gCO_2e/MJ of gas extracted, which is an 85% reduction from the current global average emissions factor of 7.6 gCO_2e/MJ. Hence an 80% abatement factor is broadly aligned with the insights of this paper.

[107] Stockman et al., *Funding Failure: Carbon Capture and Fossil Hydrogen Subsidies Revealed*; Robertson and Mousavian, *The Carbon Capture Crux*.

This means calculations in this report do not quantify the emissions at risk from CCS underperformance in Japan, but this would increase the scale of emissions at risk.

Low-CCS scenarios also considered in this report

We also considered two low-CCS scenarios in the AR6 database, for means of comparison with the high-CCS scenario. We identified these by seeking scenarios with the lowest fossil CCS deployment in Asia. These were both produced by the REMIND-MAgPIE modelling framework and were the EMF33_1.5C_nofuel and DeepElec_SSP2_HighRE_Budg900 scenarios.

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