Benchmarking critical technologies

Building an evidence base for an informed critical technologies strategy

Kitsch Liao, Dr Samantha Hoffman and Karly Winkler

with Baani Grewal, Cheryl Yu, Saki Kikuchi, Matthew Page, Jackson Schultz and Tilla Hoja

ASPI AUSTRALIAN STRATEGIC POLICY INSTITUTE
INTERNATIONAL CYBER POLICY CENTRE
TWENTY YEARS OF ASPI STRATEGY 2001 - 2021

Policy Brief
Report No. 53/2021

About the authors

Kitsch Liao is a contractor with ASPI's International Cyber Policy Centre and a military and cyber affairs consultant with Taiwan's Doublethink Lab.

Dr Samantha Hoffman is a senior analyst with ASPI's International Cyber Policy Centre.

Karly Winkler is a senior analyst with ASPI's International Cyber Policy Centre.

Baani Grewal is a researcher with ASPI's International Cyber Policy Centre.

Cheryl Yu is a researcher.

Saki Kikuchi is a contractor with ASPI's International Cyber Policy Centre.

Tilla Hoja is a researcher with ASPI's International Cyber Policy Centre.

Matthew Page is an intern with ASPI's International Cyber Policy Centre.

Jackson Schultz is an intern with ASPI's International Cyber Policy Centre.

Acknowledgements

We acknowledge the assistance we have received from IP Australia, the Department of the Prime Minister and Cabinet, the Department of Industry, Science, Energy and Resources, and numerous interviewees and peer reviewers in policy and industry roles across the Quad.

Thank you to ASPI ICPC researcher Albert Zhang for assistance. We are grateful for the valuable comments and assistance provided by Fergus Hanson, Michael Shoebridge and Jocelinn Kang.

This project was supported through a $150,000 grant from the Department of the Prime Minister and Cabinet.

What is ASPI?

The Australian Strategic Policy Institute was formed in 2001 as an independent, non-partisan think tank. Its core aim is to provide the Australian Government with fresh ideas on Australia's defence, security and strategic policy choices. ASPI is responsible for informing the public on a range of strategic issues, generating new thinking for government and harnessing strategic thinking internationally. ASPI's sources of funding are identified in our annual report, online at www.aspi.org.au and in the acknowledgements section of individual publications. ASPI remains independent in the content of the research and in all editorial judgements.

ASPI International Cyber Policy Centre

ASPI's International Cyber Policy Centre (ICPC) is a leading voice in global debates on cyber, emerging and critical technologies, issues related to information and foreign interference and focuses on the impact these issues have on broader strategic policy. The centre has a growing mixture of expertise and skills with teams of researchers who concentrate on policy, technical analysis, information operations and disinformation, critical and emerging technologies, cyber capacity building, satellite analysis, surveillance and China-related issues.

The ICPC informs public debate in the Indo-Pacific region and supports public policy development by producing original, empirical, data-driven research. The ICPC enriches regional debates by collaborating with research institutes from around the world and by bringing leading global experts to Australia, including through fellowships. To develop capability in Australia and across the Indo-Pacific region, the ICPC has a capacity building team that conducts workshops, training programs and large-scale exercises for the public and private sectors.

We would like to thank all of those who support and contribute to the ICPC with their time, intellect and passion for the topics we work on. If you would like to support the work of the centre please contact: icpc@aspi.org.au

Important disclaimer

ASPI

Tel +61 2 6270 5100

Email enquiries@aspi.org.au

www.aspi.org.au

www.aspistrategist.org.au

facebook.com/ASPI.org

@ASPI_ICPC

First published November 2021. ISSN 2209-9689 (online). ISSN 2209-9670 (print).
Cover image: Leslie Sharpe.

A S P I AUSTRALIAN STRATEGIC POLICY INSTITUTE

INTERNATIONAL CYBER POLICY CENTRE

Funding support for this publication was provided by the Department of the Prime Minister and Cabinet.

Benchmarking critical technologies

Building an evidence base for an informed critical technologies strategy

Kitsch Liao, Dr Samantha Hoffman and Karly Winkler

with Baani Grewal, Cheryl Yu, Saki Kikuchi, Matthew Page, Jackson Schultz and Tilla Hoja

Policy Brief
Report No. 53/2021

Contents

What's the problem?

Technology policy formulation has recently gained a renewed importance for governments in the era of strategic competition, but contextual understanding and expertise in deciding where to focus efforts are lacking. As a result, decision-makers might not understand their own national strengths and weaknesses. It's difficult to judge whether a country's R&D outputs, no matter how advanced, and its development of production capacity, no matter how significant, align with the country's intended strategic objectives or can be used effectively to achieve them.

The ability to measure the relative strengths and weaknesses of a country by weighing specific strategic objectives against technical achievements is of paramount importance for countries. This is especially true as nations seek to resolve supply-chain resilience problems underscored by the Covid-19 pandemic. China's rejection of the Quad's vision of a free and open Indo-Pacific, willingness to use economic coercion and the resulting strategic competition, call further attention to multiple technology sectors' heavy reliance on a single source. A solution must be found that can exploit synergy across multiple technology sectors among collaborating countries while ensuring supply-chain resilience.

What's the solution?

Governments' ability to ensure that strategic objectives pertaining to critical technologies are both well articulated and achievable, and researchers' and industry's ability to collaborate in meeting those objectives, would be greatly enabled by the development of an objective and repeatable methodology for measuring technical achievements against clearly defined strategic goals for the critical technology sector. The most pressing challenge should be a relatively straightforward one to resolve: standardise metadata about national objectives and R&D efforts to enable business analysis.

The Quad Critical and Emerging Technology Working Group is an important step towards building collaboration in the research, development and production of critical technologies among like-minded governments. While in nascent stages, the group is gathering momentum and working towards addressing the September 2021 objective to monitor trends in critical and emerging technologies for cooperation, with an initial focus on biotechnology. We recommend as follows:

- Conduct detailed analysis to understand current and emerging gaps in critical and emerging technologies, starting with biotechnology, among like-minded countries.
- Develop a partnership between like-minded countries with advanced technological capabilities to deliver a secure technology supply chain for critical tech. This should include a commitment to a set of core principles for technology development and delivery, including 'baking in' democratic principles to the technology and agreeing to share any civilian advances on market terms and refrain from coercion.
- Establish a Quad or Quad Plus critical technologies fund to which participating states pledge investment funds that are then disbursed to address current and emerging critical technologies gaps.

1. Introduction to the Benchmarking Critical Technologies Project

Benchmarking Critical Technologies is a pilot project at ASPI ICPC that examines the development of a handful of critical technologies in the context of strategic partnership and strategic competition. ‘Critical technologies’ broadly refers to strategically important technology areas.[1] Australia, for example, defines ‘critical technology’ as ‘technology that can significantly enhance or pose risks to Australia’s national interests, including our prosperity, social cohesion and national security’.[2] For this pilot study, we focus on the biotechnology and energy technology sectors in China and in the Quad—the quadrilateral Indo-Pacific diplomatic network consisting of Australia, India, Japan and the US. This project will be expanded over the course of 2022 to include more technology areas and countries.

During the Quad Leaders’ Summit in March 2021, the Quad Critical and Emerging Technology Working Group was announced. The communiqué from the summit said that the working group was intended to ‘ensure the way in which technology is designed, developed, governed and used is shaped by the Quad countries’ shared values and respect for universal human rights’.[3] The communiqué didn’t directly name China, but China was clearly implied in its pledge to recommit to ‘promoting the free, open, rules-based order, rooted in international law and undaunted by coercion, to bolster security and prosperity in the Indo-Pacific and beyond’.[4]

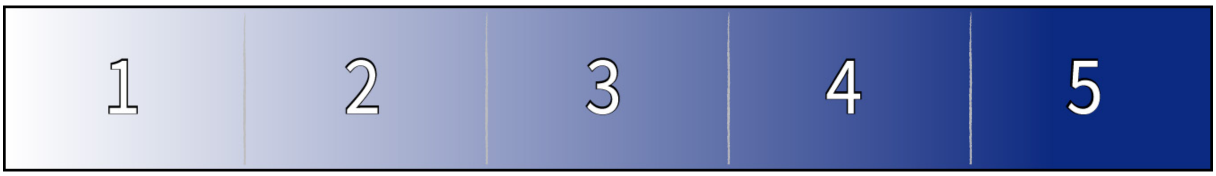
It’s clear that China is the key strategic competitor that the Quad countries are hedging against. They’re technology and manufacturing powerhouses with strong geopolitical influence in the region, which makes the competition both more important and more difficult. As the Quad works to develop capabilities in a range of critical sectors, the Quad members will need to also understand how to leverage each other’s strengths and overcome collective weaknesses to guarantee supply-chain resilience, among other strategic objectives.[5] They will also need to triangulate the effects of each nation’s digital enmeshment in Chinese supply chains and the net effects of that in particular sectors.

There’s a lack of empirical data to ground decision-makers’ advice on everything from capability gaps to priority investment areas. This project is an attempt to begin to bring additional empirical data to the decision-making process. Our intent is to offer improved clarity on each country’s strengths and weaknesses in each critical technology. After consultation with the Australian Government, we decided to focus on hydrogen energy and solar photovoltaic (solar PV) technologies from the energy sector, and genetic engineering and vaccines and medical countermeasures in the biotechnology sector. The broader technology areas that these specific technologies sit within are of clear strategic importance. The Quad Leaders’ Summit communiqué established that biotechnology would be the starting point for the Critical and Emerging Technology Working Group’s collaboration. It also highlighted, in the context of the recent COP26 conference, that the Quad would coordinate to ‘establish responsible and resilient clean-energy supply chains’.[6]

To assess national capabilities, we measured each country’s R&D and infrastructure development efforts using patent and patent impact data and academic impact data, and compared those results against the country’s technology-specific policy goals. For patents, we collected two measures for each critical technology: the quantity and quality of the patents. IP Australia provided ASPI ICPC with patent data to analyse the quantity of patents for each critical technology. Additionally, using the commercial product PatentSight developed by LexisNexis, we assessed patent quality with the Patent Asset Index (PAI).[7] The tool assesses patent quality across various measures in the overall ecosystem of a technology field. Those measures are technology relevance (TR), indicating how much future patents in the field depended upon the patent; market coverage (MC), indicating how much of the global market the patent offers protection of; and competitive impact (CI), the aggregate of TR and MC indicating the economic value of the patent. The aggregate economic value of all patents in the field then constitutes the field's PAI. For academic impact factors, we used the CiteScore (CS) methodology for measuring impact factors embedded within Elsevier's Scopus commercial database product. We also drew on background interviews with industry specialists and senior officials in relevant government departments. Budget data was more challenging to collect, normalise and assess. Consequently, it isn't treated as a separate metric, but included with general policy analysis. (For more on our methodology, see the Appendix.)

We recognise that both the policies and technologies on which we base our assessments are evolving. Technology development doesn't always move in a linear trajectory, and current capabilities aren't the only indicator of future outcomes. Moreover, the strategic interests and desired policy outcomes one country seeks might not align simply or easily with those of another. Therefore, it isn't possible to directly compare countries against each other. Rather than arbitrarily rating each country's progress against the others, we've rated each country's progress in achieving the strategic objectives that it has outlined for each technology area (Figure 1). The progress indicator's location should be interpreted as being dynamic, given that both policies and technologies will evolve.

Figure 1: Rating scale—country progress in meeting national policy objectives



Rating scale legend

1. Some high-level policy objectives specific to the technology area have been set, but there's little evidence of efforts making progress towards meeting those objectives.
2. Despite the articulation of some policy objectives pertaining to the technology area, those are still relatively unclear. The country's R&D and production capabilities don't appear to be sufficient to contribute to realising the country's stated policy objectives.
3. There's some evidence that the country is developing actionable policy in the technology area. There's clear progress in the country's ability to contribute to the R&D of the technology, or production capacity. It isn't clear, however, whether this progress aligns with the country's stated policy objectives.
4. There's evidence that stated policy objectives, research and investment are beginning to translate into aligning capabilities.
5. There's strong evidence that stated policy objectives, research and investment have already translated into aligning capabilities.

Source: Image produced by ASPI.

2. Overall assessment

- *Quantity doesn't mean quality, at least in terms of the way patents and research shift global knowledge and capabilities in the overall ecosystem of a technology field.* Our findings on patent impact—measured by how often a patent is cited or purchased—highlighted that China, with the highest number of patent applications filed, didn't have a correspondingly high impact factor. Australia and India, and to a lesser extent Japan, filed far fewer patents, but those few patents had impact more on par with US patents, which were high in both number and impact. One patent can significantly influence the evolution of a technology; others might incrementally advance knowledge or create offshoot fields. Impact factors in these types of analysis can be an objective measure for determining scientific advances or commercial success but aren't necessarily useful in indicating whether national capabilities support policy objectives. If the point of benchmarking critical technologies capabilities at a national level is to understand what makes a country capable of meeting national policy objectives, competitive in a strategic competition and well placed to work with like-minded partners, then the ability of individual researchers or organisations to advance a technology field doesn't tell us how competitive a country is in translating concepts to capabilities that align with its strategic objectives. For example, ASPI ICPC believes that in China, the disproportionately large number of patents filed internally is most likely attributable to companies patenting specific applications of technology. In the Quad, countries such as Australia and India have been more impactful for a fewer number of patent applications filed and research papers significantly advance the field.
- *Success in connecting policy objectives to outcomes isn't yet entirely measurable.* Our comparison of national policies pertaining to each critical technology we research shows that China, followed by the US, tends to have more clarity about what it seeks to achieve by investing in R&D and production capabilities, and following that up with actions that will achieve those objectives. India, Japan and Australia don't lack policy development or innovative capacity, but we believe they have been less effective at connecting concepts to capability. This assessment is no doubt at least partially because the development of policy objectives postdates most of our data.
- *Metrics don't explain the context in which innovation is taking place, including incentive structures, and how that affects a country's ability to meet specific objectives.* In China, the incentive structure is designed so that researchers are working to meet specific policy objectives. In fact, companies closely collaborate with the state in technical standards development. According to the revised 2017 Standardisation Law,[8] the Standardisation Administration of China (an agency under the State Administration for Market Regulation) is required to oversee standards initiation and implementation, and in practice technical committees for standards setting under the Standardisation Administration tend to consist of both companies and research institutes. We believe the knock-on effect of the incentive structure in China is that the R&D base is disadvantaged, while companies and researchers focus on implementing specific applications of technology that meet policy needs. China's National Patent Development Strategy (2011–2020) was designed as a 'long-term and comprehensive plan to use the patent system and patent resources to enhance the country's core competitiveness'.[9] The strategy document prioritises 'encourag[ing] and supporting[ing] enterprises to upgrade the core technologies and key technologies with patent rights in China's advantageous fields to national and international standards'.[10] We believe

companies are seeking to achieve those objectives by owning the market first, and patents support that approach. They're adding economic value by increasing the quantity of applications, and owning the market comes before efforts to refine the product. Many PRC-originated technologies are being exported globally (see ASPI ICPC's *Mapping China's Tech Giants* project), no matter what the overall quality of the product in comparison to competitors, and that proliferation is probably achieving some market power and incumbency. It's a cumulative and individual challenge for the Quad nations to move more rapidly from concept to capability in order to avoid the PRC leading in meeting strategic objectives with that technology.

3. Energy technologies

Energy forms a key pillar in the 'free and open Indo-Pacific' strategy first introduced by former Japanese Prime Minister Abe,[11] then adopted by the US[12] and subsequently by the Quad as a whole.[13] Initiatives such as the US Asia EDGE (Enhancing Development and Growth through Energy) project have placed the energy sector at the forefront of that strategic effort.[14]

3.1 Hydrogen energy

Hydrogen energy refers to the expanded hydrogen value chain. That includes the production, transportation, use and externalities associated with the use of hydrogen energy. Hydrogen represents an ideal form of energy carrier and storage for renewable energy generation because the storage capacity of hydrogen cells doesn't degrade over time or with use.

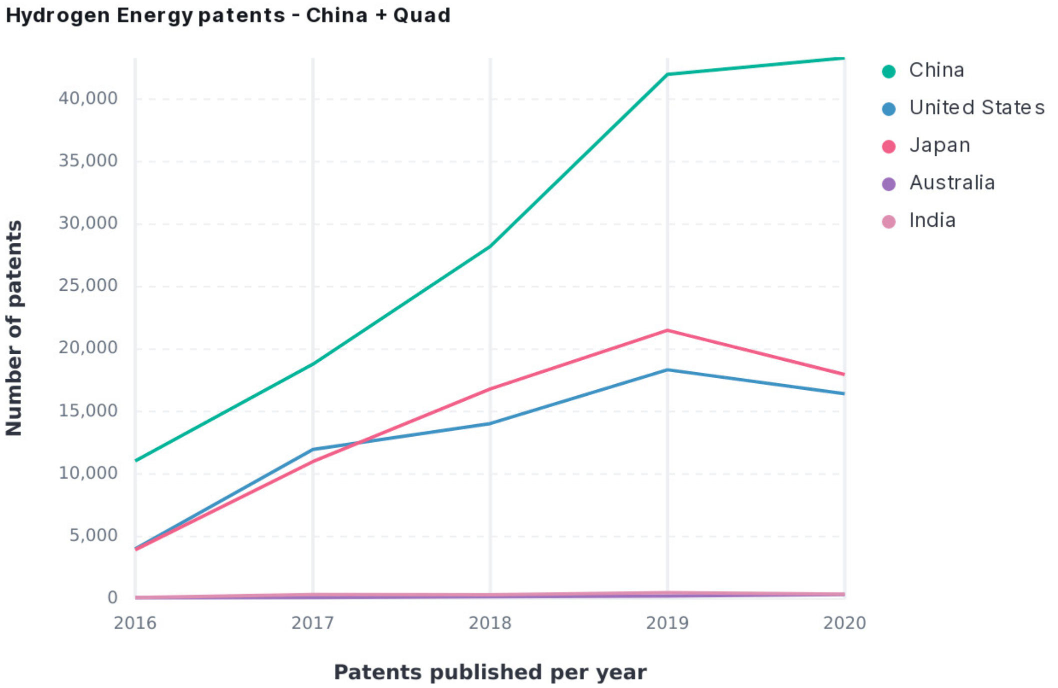
Aggressive growth in the production and application of carbon-free green hydrogen[15] and carbon-neutral blue hydrogen[16] transportation and storage, as well as the extended value chain, is a key dimension of future strategic competition in the Indo-Pacific region. The Indo-Pacific has the fastest rising regional energy demand,[17] and an estimated 420 million people still lack access to electricity.[18] Hydrogen energy is also crucial in achieving carbon neutrality—a goal aggressively pursued by the UN and individual countries including China[19] and the Quad[20] members. This is largely because of hydrogen's energy density and because it promises relatively mature energy storage methods that can be carbon free, or at the very least carbon neutral.

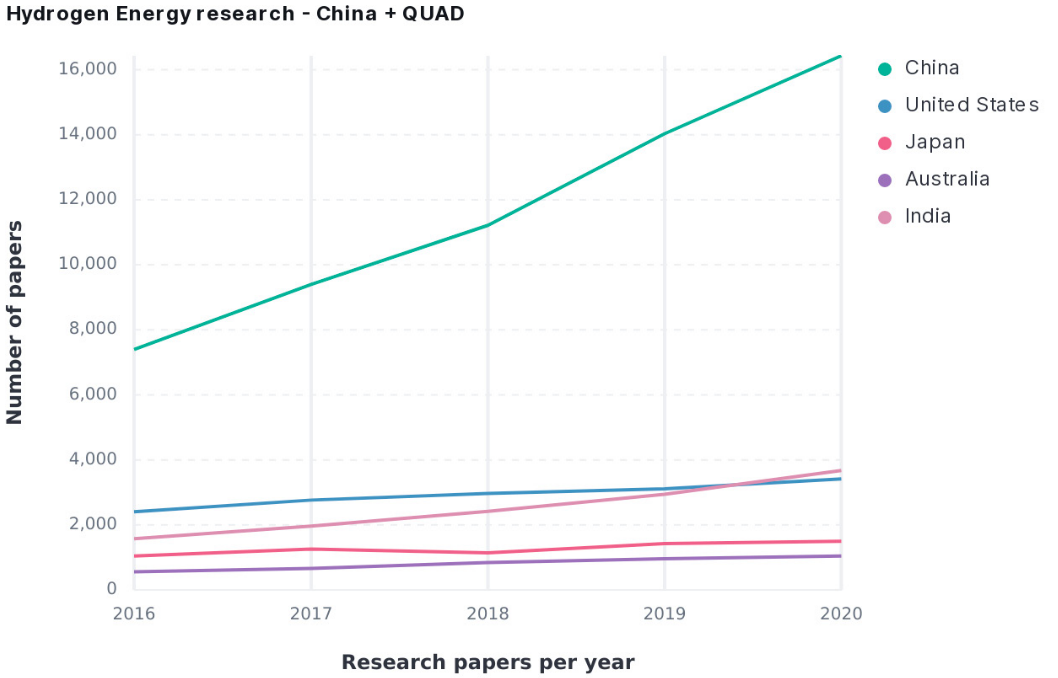
Hydrogen is an energy carrier. It doesn't exist in its exploitable gaseous form on Earth and inputting energy is needed to produce it. This contrasts with energy such as that from fossil fuels and sunlight, which are energy sources because their exploitable form can be found in the natural environment. The development of hydrogen as an energy carrier has complemented and benefited significantly from the maturation and lowering costs associated with other renewable energy technologies, such as solar panels and wind turbines, which function as energy sources from nature. To that end, many countries have established their own hydrogen strategies (Table 1). The International Energy Agency estimates that the global demand for hydrogen in a net-zero scenario will rise from 88.48 megatonnes (Mt) in 2020 to 210.56 Mt in 2030.

Table 1: National policies on hydrogen energy

Country	Policy summary
Australia	Australia has committed to a national goal of net zero emissions by 2050. The Long-Term Emissions Reduction Plan[21] and the government's 2020 Technology Investment Roadmap and Low Emissions Technology Statement[22] name clean hydrogen as a priority technology. Australia's National Hydrogen Strategy (2019) said that Australia should be a globally competitive player in the renewable hydrogen export industry by 2030.[23] Prior to 2019, the Australian Government's investment in hydrogen energy was on par with investments in other renewable energy technologies, solar excluded, and several millions of dollars in research grants were awarded to universities through the Australian Renewable Energy Agency (ARENA) and the Australian Research Council. In 2018, for example, ARENA awarded a total of $22.1 million across 16 hydrogen projects expected to produce outcomes that would deliver cost reductions and efficiency gains.[24] Then, in 2019, ARENA launched the Renewable Hydrogen Development Funding Round, and in May 2021 announced that it had conditionally approved awards under the funding round of $103.3 million towards three commercial-scale hydrogen projects.[25]
India	India committed to a national goal of net zero emissions by 2070 and a target to achieve 50% of its energy requirements from renewable energy by 2030. The Indian Government has included the promotion and development of green hydrogen energy in its push to switch from fossil fuel to renewable energy. In 2021, Prime Minister Modi announced the intention to make India the 'world's largest green hydrogen hub'.[26] India announced a National Hydrogen Mission in 2021 to research and develop efficient hydrogen energy (at the time of writing, the budget had not been announced).[27] The mission is intended to be a long-term incentive and R&D strategy with the aim of developing India into a 'global hub for manufacturing of hydrogen and fuel cells technologies across the value chain'.[28] The Indian Ministry of New and Renewable Energy has classified hydrogen energy as a 'new technology' and has a focus on the development of hydrogen fuel cells for transport vehicles.[29]
Japan	Japan declared in October 2020 that it aims to achieve carbon neutrality by 2050.[30] Following the declaration, the Ministry of Economy, Trade and Industry and related ministries formulated the Green Growth Strategy through Achieving Carbon Neutrality in 2050.[31] The strategy identifies 14 growth sectors, including hydrogen, and provides policy tools to support the achievement of carbon neutrality by 2050, including budgets. A ¥2 trillion fund called the Green Innovation Fund Project supports R&D in several technology areas.[32] The first selected projects under the fund that were related to hydrogen energy totalled ¥384 billion.
United States	The US has set a national goal of net zero emissions by 2050 and a target to achieve a 50%–52% reduction in economy-wide net greenhouse gas pollution in 2030.[33] Research, development and deployment of clean hydrogen fuel cell technologies has been a priority focus area for the US's net zero emissions targets through a multi-year R&D strategy first launched in 2003.[34] The Biden administration's flagship Bipartisan Build Back Better Act and Framework is the primary legislation aiming to meet its climate target and goals.[35] Development and research in clean hydrogen energy received a major boost under the Build Back Better Act, which allocated over US$9.5 billion investment in clean hydrogen energy, including US$1.5 billion towards clean hydrogen manufacturing and advancing recycling research, development and demonstration (RD&D)[36] In 2020, separately, the US Department of Energy published its updated Hydrogen Program Plan, which provides a framework for RD&D activities for clean hydrogen energy. The 2020 Hydrogen Strategy (under the Hydrogen Program Plan) is the primary government strategic framework aimed at accelerating the R&D of hydrogen technologies.[37]
China	China's 14th Five-Year Plan outlined top-level goals that could be achieved with hydrogen energy, and under the objective of developing and growing strategic new industries listed hydrogen energy technology as one of the cutting-edge technologies that would support the modernisation of the country's industries.[38] More specific policy targets were postulated and recommended by the semi-official China Hydrogen Alliance in its 2019 *China hydrogen energy and fuel cell industry White Paper*.[39] According to the White Paper, from the technology perspective, the 2025 objective is to actively promote the scale-up of hydrogen production from renewable energy power generation, biological hydrogen production and other technology RD&Ds. That includes developing hydrogen production methods based on local conditions by using industrial by-products and renewable energy-based electrolysis and increasing storage capacity by developing low-temperature liquid, solid-state storage, and low-temperature liquid pipeline transport. In 2021, the Chinese Government allocated ¥795 million (US$124.49 million) for the development of hydrogen technology for green hydrogen production and large-scale transfer systems, hydrogen-safe storage and a rapid transportation and distribution system, and fast hydrogen reforming and high-efficiency power system.[40]

Figure 2: Hydrogen energy patent applications published in China and the Quad and relative research output, 2016 to 2020

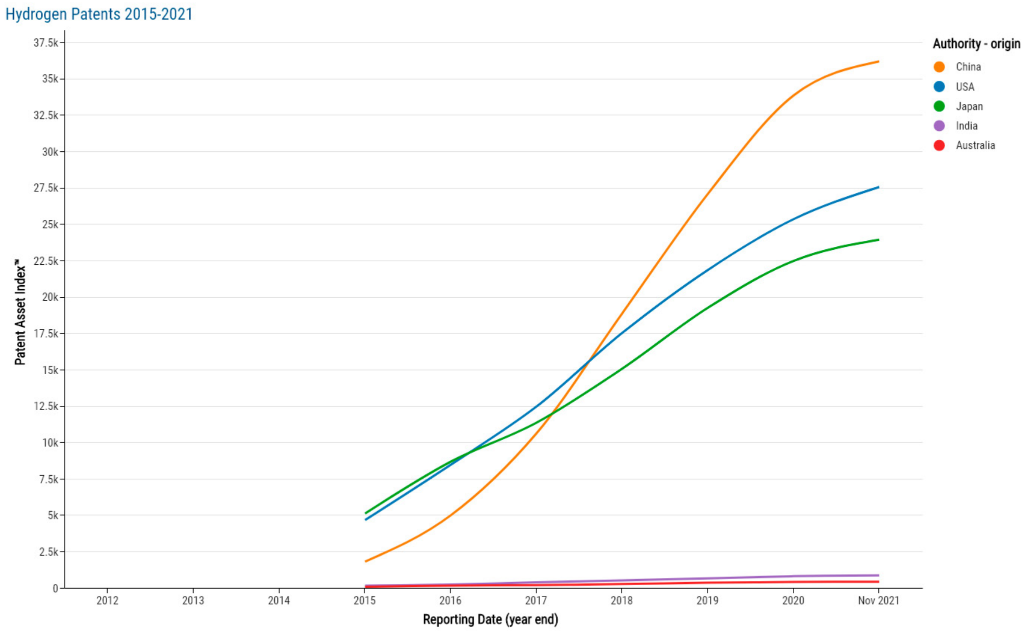


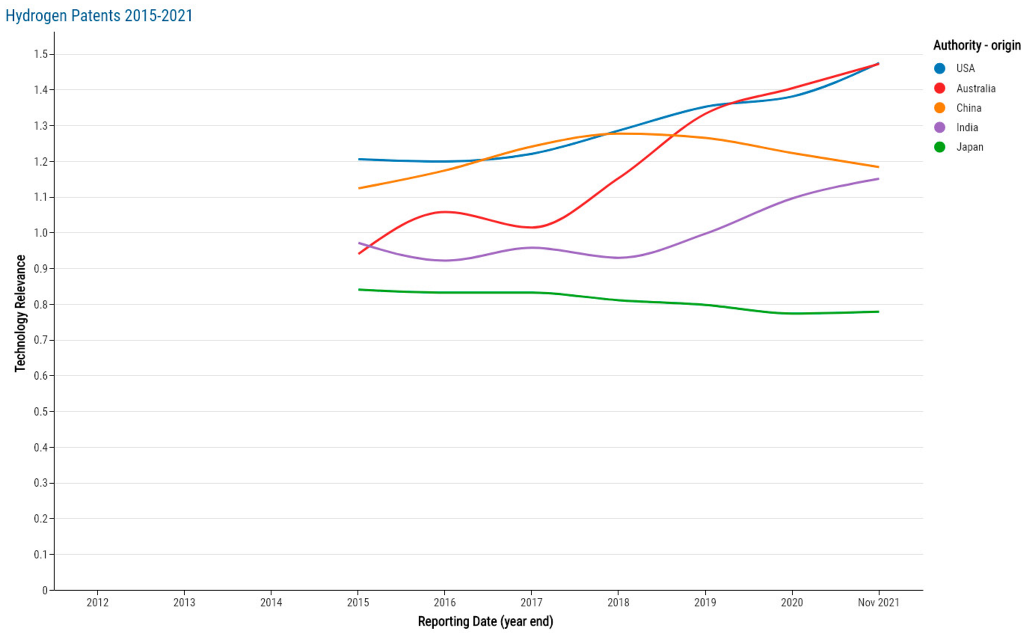


Note: While India and Australia are producing very few patents on most technologies, hydrogen energy patents are particularly low, next to the high numbers originating from China, the US and Japan. India has a far greater relative investment in hydrogen energy research than patent development and commercializing their work. The opposite is seen from Japan; they are filing large numbers of patent applications, but their research output is comparatively low, particularly relative to their research output across other fields.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.) and the Scopus research database.

Figure 3: Hydrogen energy patents outlined with Patent Asset Index and technology relevance, by country, 2015 to 2021

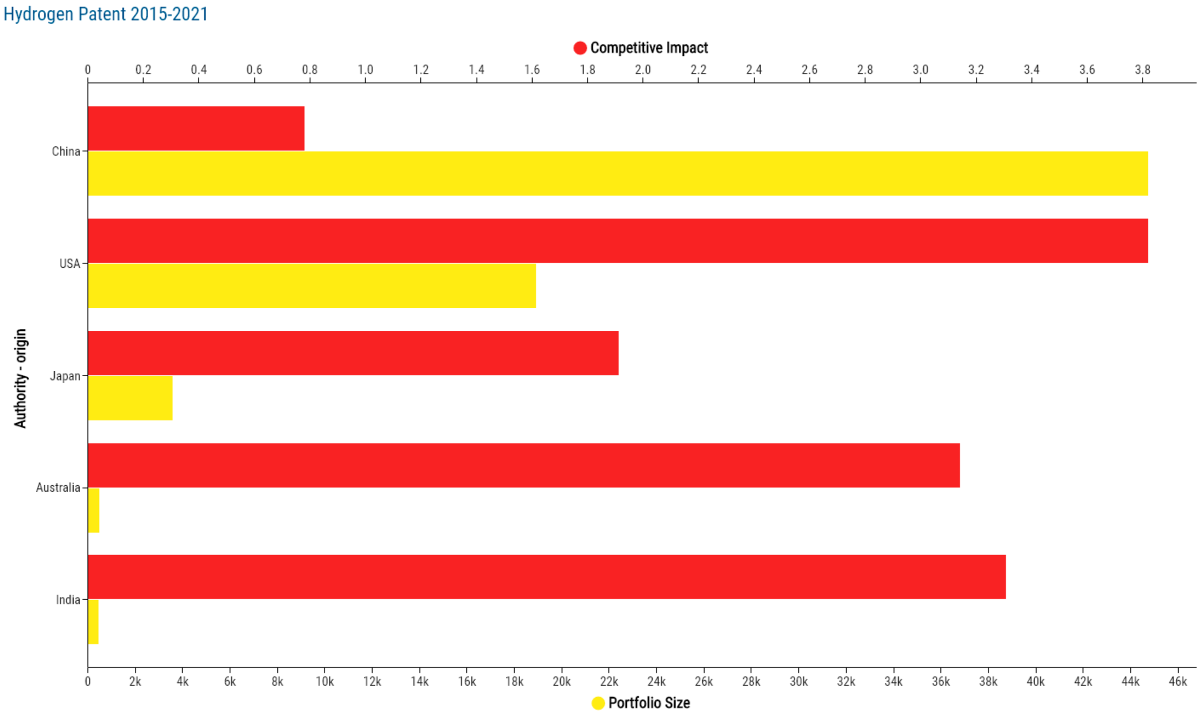




Note: The Patent Asset Index graph indicates the total economic impact of patents, while the 'technology relevance' graph reflects how the patent helps with subsequent R&D in the field. Because the PAI indicates total economic worth, both the quality and quantity of patents are factors. Technology relevance indicates, for lack of a better term, the 'quality' of the patents; this is measured by whether they're being cited to advance the field. Thus, a high PAI can be a result of a large quantity of low-quality patents or a small quantity of high-quality patents.

Source: Images produced by ASPI ICPC using PatentSight.

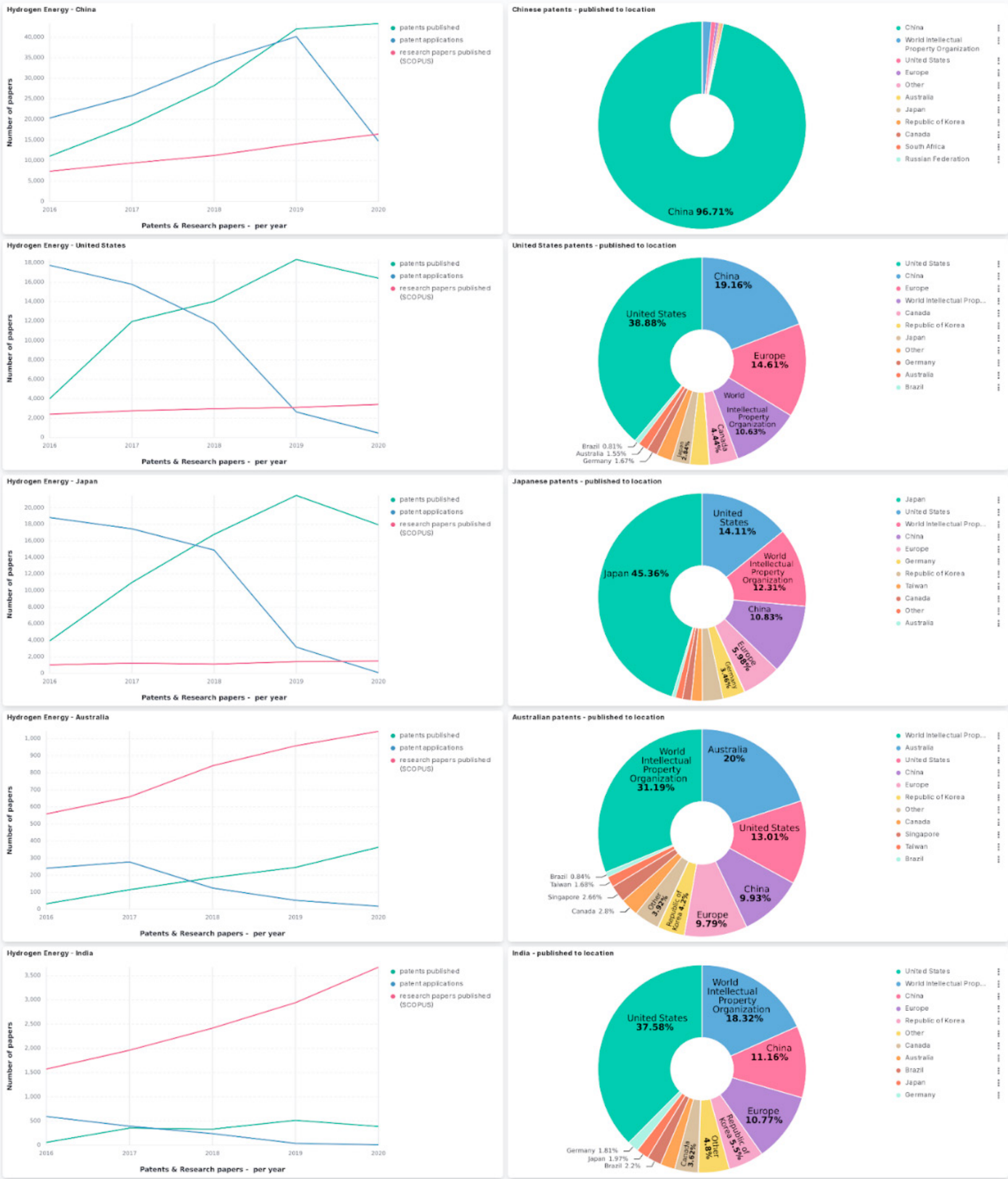
Figure 4: Hydrogen energy patents—portfolio size and competitive impact organised, by country, 2015 to 2021



Note: The yellow bar illustrates the quantity of patents through portfolio size, while the average competitive impact (the economic value of individual patents defined by both the technological relevance and the market coverage of the patent) for the country in each field is represented by the red bar. For example, China has an enormous quantity of patents but relatively low competitive impact, which means the quality and market coverage of the average patent are extremely low according to the PatentSight metric.

Source: Images produced by ASPI ICPC using PatentSight.

Figure 5: Hydrogen energy academic research, compared with to patent applications and publishing, as a measure of impact

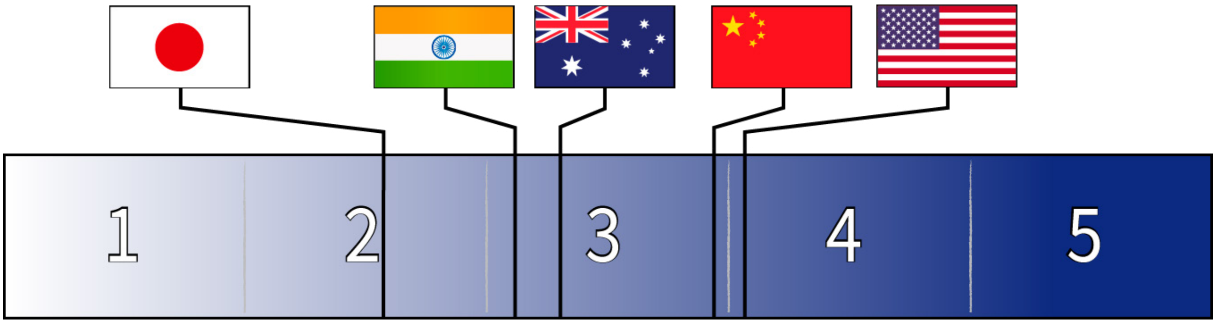


Note: The downturn on patent applications (blue line), where it crosses the still rising patents published (green line), indicates when the majority of patent applications were still filed but not yet published. The 'publication lag' from first filing can be up to two years in Australia and then there is additional time for patent application acceptance or rejection. The publishing lag depends on a variety of internal policy and legal factors that are similar across the world but can differ across jurisdictions such as China. Additionally, a longer lag time can often be desired by industry, as it gives it time to innovate and evolve its strategy before the details are made public. Combined with the fact that inventors in China primarily only file patents in China, our findings show that Chinese patents are published 2 to 3 times faster on average (0.78 years) than in the Quad countries (1.89 to 2.04 years), which enables China to commercialise its technology and transition to production more quickly. ASPI ICPC assesses that China's fast patent lifecycle, combined with a relatively smaller volume of published research, provides supporting evidence for a fast-paced and iterative approach to technology delivery in China.

Australia and India both produce significantly more research papers than patent applications, which indicates either a new or primary investment in ideas generation, or that they face challenges in commercialising those ideas themselves, unlike Japan, China and the United States.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed).

Figure 6: Hydrogen energy—country progress in meeting national policy objectives



Source: Image produced by ASPI.

Australia has outlined specific policy objectives and, despite low output in terms of innovation, the research is of high quality and is cited nearly as often as output from the larger countries, despite the enormous difference in population size. It isn't clear, however, that this progress aligns with policy objectives, which are still relatively nascent in form, or that it carries through to industry. It's likely that research is leading the policy objectives rather than the other way around.

China has clear policy objectives and a relatively high economic impact for research, but the quality isn't necessarily high. Patents are published quickly. While their individual impact on the field and economic value are relatively low, their aggregate impact may have a positive effect on Chinese companies being able to quickly seize the market and on China translating policy objectives into aligning capabilities.

India has clear policy objectives and strategy for achieving designated R&D, production capability, and quality research for hydrogen energy. However, as it currently stands, no domestic producers have significant capacity. Consequently, the country is still incapable of functioning as a production base for hydrogen energy. Several Indian companies have announced plans to establish hydrogen energy production facilities; however, those plans will take 5–10 years to be realised.[41]

The **US** has a clear strategy for hydrogen energy development, strong innovation capacity and budget allocations to build production capabilities, which will help the US translate policy objectives into aligning capabilities. However, its investment in hydrogen research falls well behind its investment in solar research.

Japan has policy objectives for the use and production of hydrogen energy, and there are new investments in achieving those objectives and signs that targets are being met, but Japan's current R&D capacity doesn't necessarily align with the objectives. Its relative research effort lags behind that of the other Quad countries, and Japan produces less than half the number of papers on hydrogen energy than on solar energy or vaccines and medical countermeasures, suggesting that this policy has yet to transition into action.

3.2 Solar PV

Solar PV refers to electrical power systems that reply on solar power by means of photovoltaic cells. Photovoltaic cells are made with semiconductor materials, such as silicon and cadmium telluride.[42] The PV cells enable the conversion of light into electricity through the photoelectric effect.

According to research by GlobalData, the Indo-Pacific region's cumulative capacity in the global solar PV market is leading at 58.9%.[43] China occupies the largest share of the market, followed by Quad members US, Japan and India.[44] Australia is much further behind. With carbon neutrality squarely in its sight, the Indo-Pacific region is looking at reaching 1,500 gigawatt hours (GWh) per year by 2030.[45]

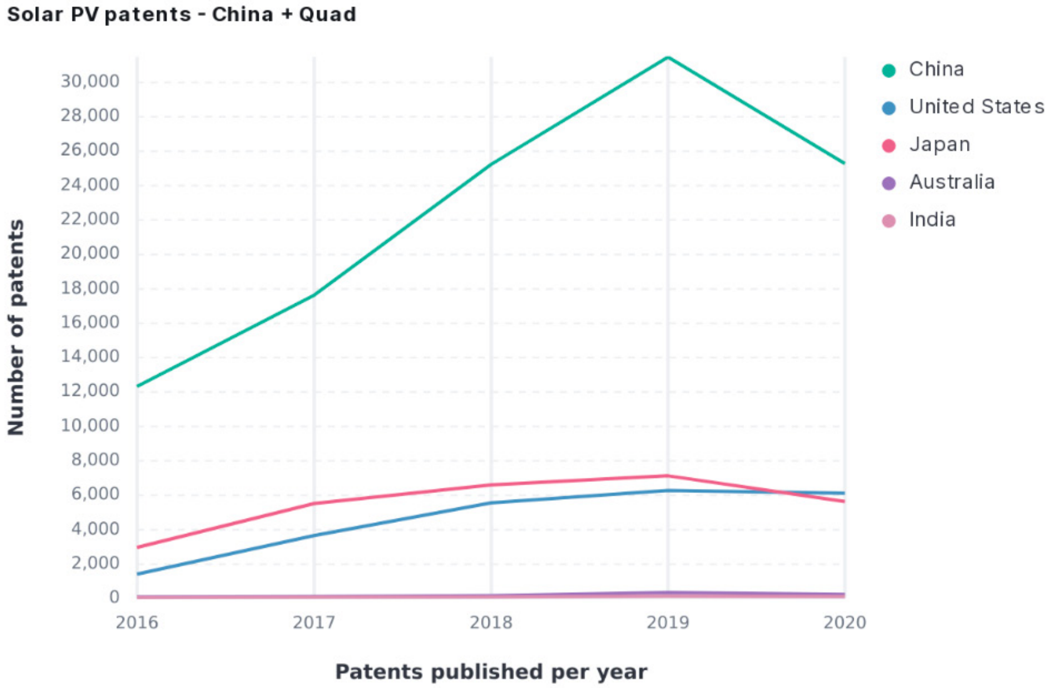
Solar power is one of the most mature renewable energy sources, and under ideal scenarios solar power schemes now offer the cheapest electricity in human history.[46] The two major power-generation schemes using solar power are concentrating solar power (CSP), which uses mirrors to focus sunlight and store the heat generated for later use, and solar PV, which uses the photoelectric effect to convert sunlight directly into electricity.[47] CSP has a higher rate of energy conversion and can be done on a larger scale to be 'dispatchable', the energy industry's power output can be adjusted as needed without using batteries, but CSP has higher costs per kilowatt under current technology. Solar PV has lower efficiency and can't generate power without continuous sunlight,[48] but the cost of utility-scale solar PV generation has dropped by 85% since 2010.[49] Consequently, solar PV is one of the fastest growing sources of renewable electricity generation and is expected to increase by 145 terawatt hours, or 18%, in 2021.[50]

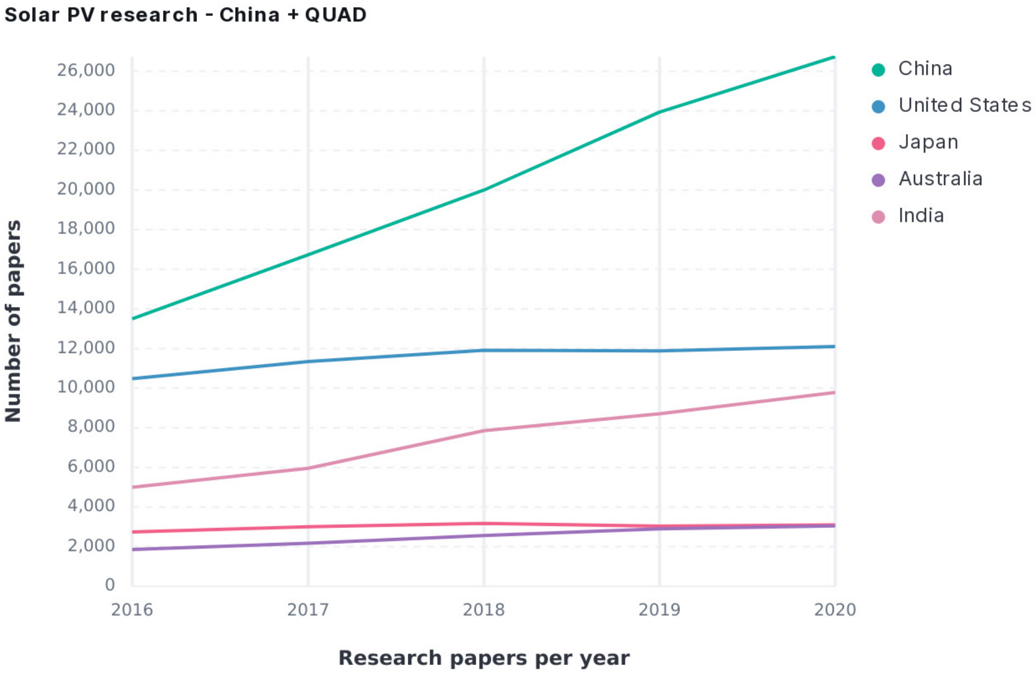
Table 2: National policies on solar PV

Country	Policy summary
Australia	The solar PV household installation rate in Australia is high, and solar generated about 10% of Australia's electricity in 2020.[51] But high adoption rates aren't necessarily matched by a clear research priority. Solar PV isn't a listed 'priority technology' in the Australian Government's 2020 Technology Investment Roadmap and Low Emissions Technology Statement,[52] but solar energy was identified as a key supporting technology for other innovations, such as clean hydrogen production.[53] The government's documents identified a stretch goal of lowering the cost of solar energy production to $15/MWh as a pathway to powering low-cost clean hydrogen production, manufacturing low-emissions steel and aluminium, and other emerging technologies. More recently, in 2021, Australia committed to a national goal of net zero emissions by 2050 ahead of the 2021 UN Climate Change Conference (COP26) in Glasgow, releasing a corresponding Long-Term Emissions Reduction Plan. In the plan, 'ultra-low-cost solar' was reiterated as a key technology in reducing Australia's carbon emissions. Since ARENA and the Clean Energy Finance Corporation were established by the Australian Government in 2012, more than a billion dollars in funding has been directed towards solar PV energy technology.[54] In 2013, the Australian Centre for Advanced Photovoltaics was established through ARENA funding with a focus on solar PV R&D and forming national and international relationships with academic institutions and industry partners.[55] Since 2012, ARENA has provided over $230 million towards about 130 solar R&D projects, of which about $80 million has been allocated to the Australian Centre for Advanced Photovoltaics.[56] Since 2016, most solar PV funding has been directed through competitive grants administered through ARENA's Large-Scale Solar (LSS) Funding Round, complemented by funding through long-term debt financing by the Clean Energy Finance Corporation.[57]
India	India has committed to a national goal of net zero emissions by 2070 and a target to achieve 50% of its energy requirements from renewable energy by 2030.[58] Solar energy is the core driver of India's renewable energy push. India has set an ambitious target of installing 450 GW of mixed-source renewable energy capacity by 2030, of which 280 GW (over 60%) will be from installed solar,[59] with a mid-term goal of achieving 175 GW installed renewable energy capacity by 2022,[60] again with the majority from solar energy. The National Solar Mission, initiated in 2010, aims to establish India as a global leader in solar energy.[61] The mission is a multiyear, multiphase project—with differing targets for each phase—using a mixture of government subsidies and incentives. In 2020, the Indian Government launched a solar PV research and manufacturing scheme to establish a domestic high-efficiency solar module industry through an investment of approximately US$600 million (45 billion rupees) over five years.[62] India has also made solar energy a focal part of its international climate change policy through the creation of the International Solar Alliance.[63]
Japan	In October 2020, Japan declared that it aims to achieve carbon neutrality by 2050.[64] Following the declaration, the Ministry of Economy, Trade and Industry and the other related ministries formulated the Green Growth Strategy through Achieving Carbon Neutrality in 2050.[65] The strategy identifies 14 growth sectors, including solar, and provides policy tools to support the achievement of carbon neutrality by 2050, including budgets. As a mid-term goal, Japan aims to increase the proportion of renewable energy to 22%–24% of its total energy mix by 2030.[66] Thanks to the Feed-In Tariff Scheme implemented in July 2012, the progress rate for solar power was 87% in 2018.[67] To maximise the introduction of renewable energy, the government will optimise the feed-in system to reduce power-generation costs.[68] A ¥2 trillion fund called the Green Innovation Fund Project supports R&D in several technology areas.[69] Under the fund, there's currently an open call for solar PV projects, for which a total of ¥49.8 billion is to be allocated.[70]
United States	The US has set a national goal of net zero emissions by 2050 and a target to achieve 100% carbon pollution-free electricity by 2035.[71] Most of this push towards clean energy is proposed to be through solar energy; in its Clean Energy Blueprint, the US Department of Energy expects more than 40% of US electricity to be solar powered by 2035.[72] The RD&D of solar energy infrastructure is a national priority under the Biden administration's flagship Bipartisan Infrastructure Deal and Build Back Better Agenda, which aims to significantly accelerate solar deployment by 2030 through large-scale investment in 'infrastructure, manufacturing, innovation, and incentives' for solar energy.[73] The Department of Energy has a dedicated solar PV R&D support program under its Solar Energy Technologies Office.[74] Solar energy is also a core part of the Biden administration's climate-change foreign policy in the Indo-Pacific.[75]

China	In December 2020, Xi Jinping proposed at the Climate Ambition Summit that China plans to 'bring its total installed capacity of wind and solar power to over 1.2 billion kilowatts' by 2030.[76] Following his speech, the National Energy Administration established a goal to have wind and solar power account for about 11% of the country's electricity consumption by the end of 2021.[77] China's solar energy strategy has been outlined in specific five-year plan policy documents since 2011.[78] The 13th Five-Year Plan for Solar Energy Development, covering 2016 to 2020, called for enhancing capacity, lowering costs and advancing technology.[79] It called for China's installed capacity of solar power generation to reach 110 million kilowatts, of which PV power-generation capacity should reach 105 million kilowatts. It also said that the installed capacity of solar thermal power generation should reach 5 million kilowatts, the solar heat collectors should cover 800 million square metres, and the annual utilisation of solar energy should reach more than 140 million equivalent tonnes of standard coal. Although the official 14th Five-Year Plan for solar energy hasn't been published yet, Ren Yuzhi, who is Deputy Director in the New Energy Department at the National Energy Administration, stated that the scale of the installed PV power generation will be a lot higher than that specified in the 13th Five-Year Plan.[80] He also stated that, during the 14th Five-Year Plan period, new industries and new formats such as PV + energy storage, PV hydrogen production and photovoltaic direct supply will be initiated.[81] China also faces severe challenges in sunsetting its ubiquitous subsidies for the PV industry: the total subsidy for solar power in 2021 was set at ¥3.38 billion (US$530 million),[82] and the goal for 2022 is set at ¥2.28 billion (US$357.2 million).[83] From 2016 to 2020, a total of ¥137.337 billion (US$21.51 billion) was spent on solar power subsidies.[84]

Figure 7: Solar PV patent applications published in China and the Quad and relative research output, 2016 to 2020

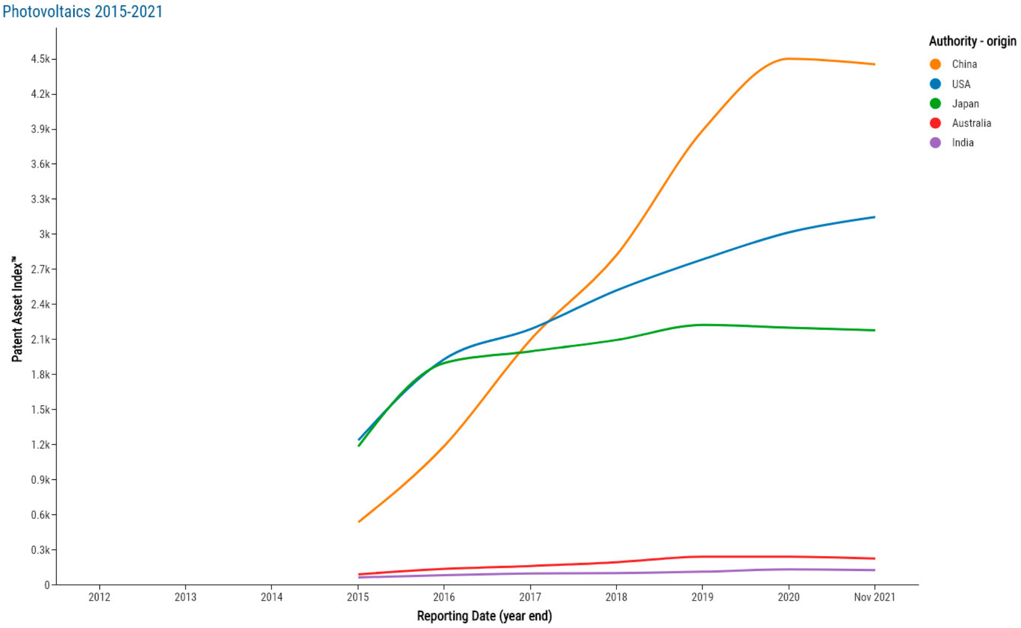


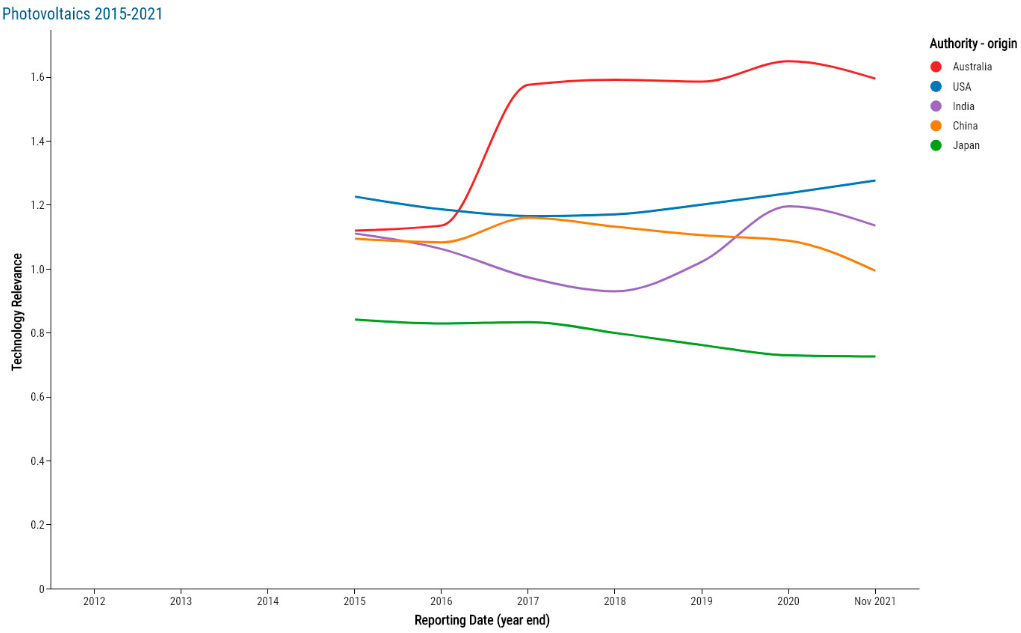


Note: Solar PV research either matches or significantly outstrips patent publishing across the board, except Japan. The dip in patent publishing for all technologies and countries in 2020—probably related to Covid-19—is particularly significant in China's case for solar PV, although the specific cause is unclear.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.) and the Scopus research database.

Figure 8: Solar PV patents outlined with Patent Asset Index and technology relevance, by country, 2015 to 2021

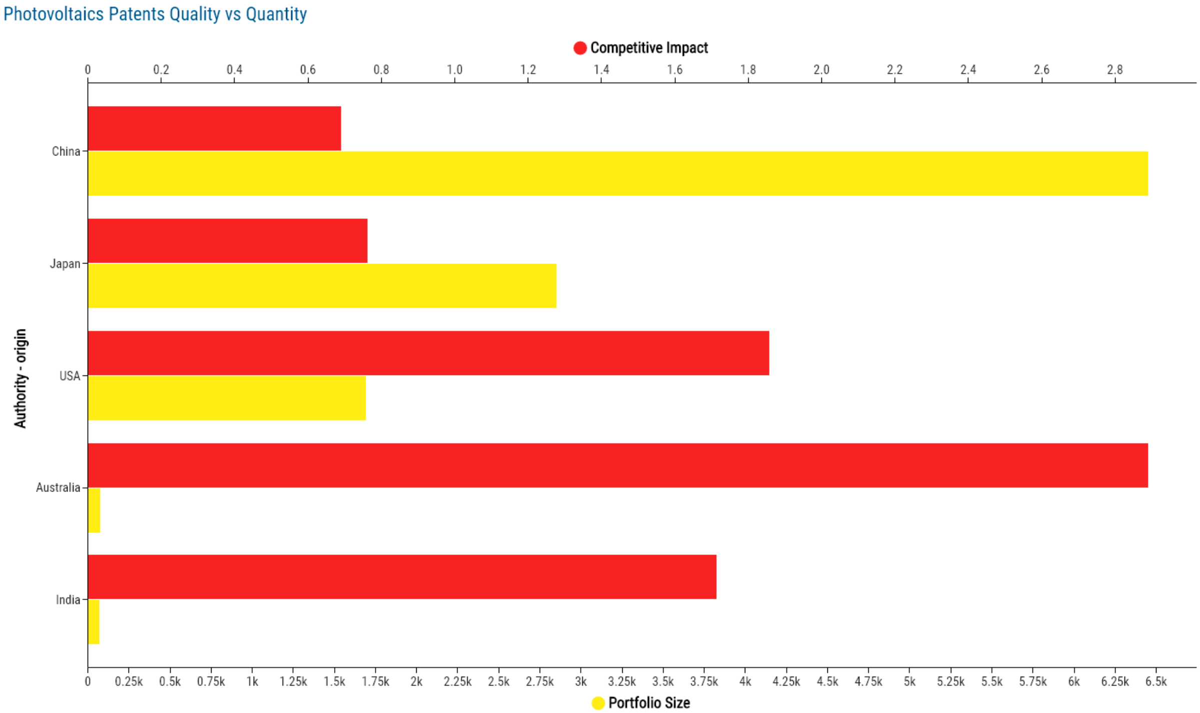




Note: The Patent Asset Index graph indicates the total economic impact of patents, while the 'technology relevance' graph reflects how the patent helps with subsequent R&D in the field. Because the PAI indicates total economic worth, both the quality and quantity of patents are factors. Technology relevance indicates, for lack of a better term, the 'quality' of the patents, which is measured by whether they're being cited to advance the field. Thus, a high PAI can be a result of a large quantity of low-quality patents or a small quantity of high-quality patents (see Appendix: Methodology).

Source: Images produced by ASPI ICPC using PatentSight.

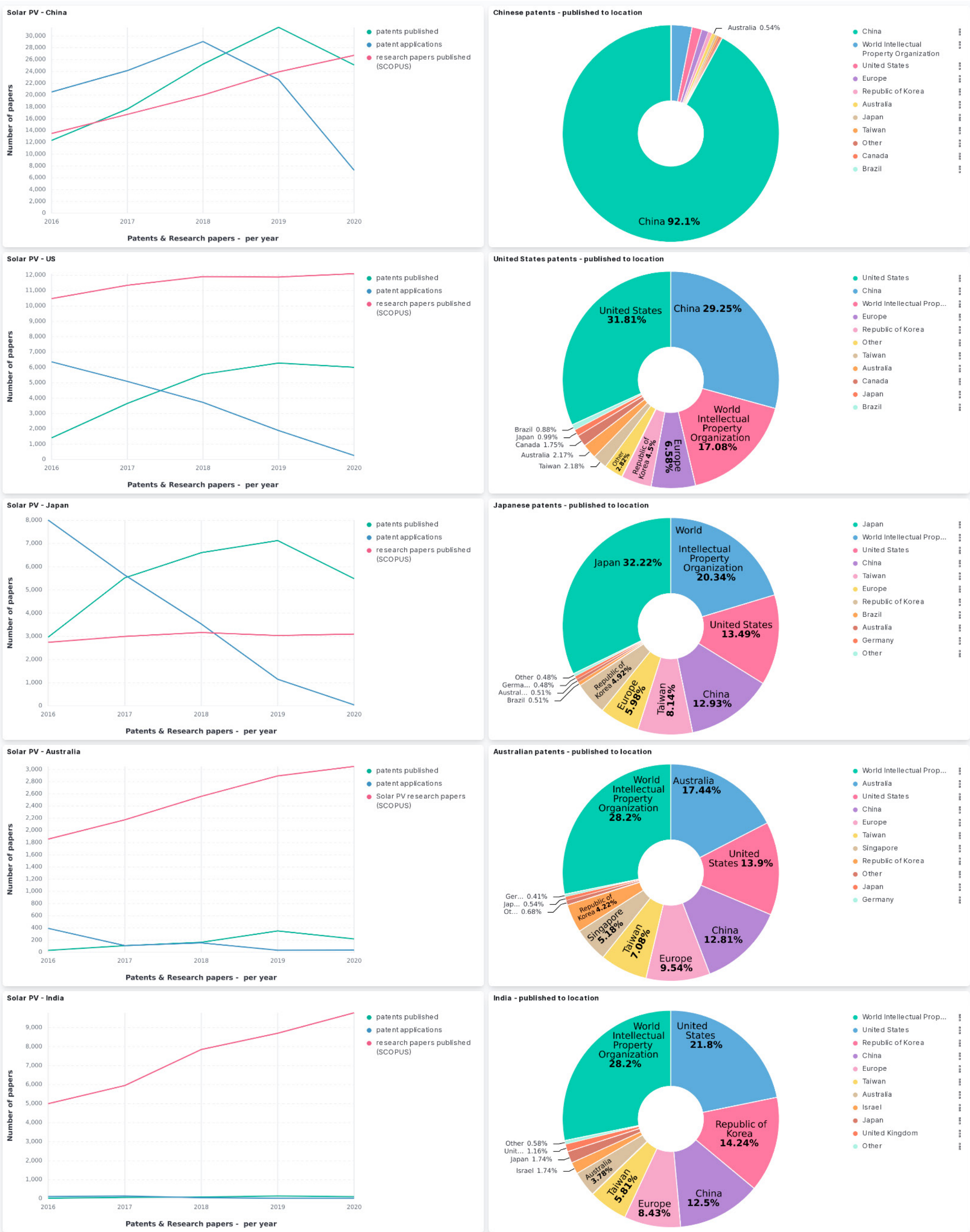
Figure 9: Solar PV patents—portfolio size and competitive impact, by country, 2015 to 2021



Note: The yellow bar illustrates the quantity of patents through portfolio size, while the average competitive impact (the economic value of individual patents defined by both the technological relevance and the market coverage of the patents) of the country in each field is represented by the red bar. For example, China has an enormous quantity of patents but relatively low competitive impact, which means the quality and market coverage of the average patent are extremely low according to the PatentSight metric.

Source: Image produced by ASPI ICPC using PatentSight.

Figure 10: Solar PV academic research, compared with patent applications and publishing, as a measure of Impact

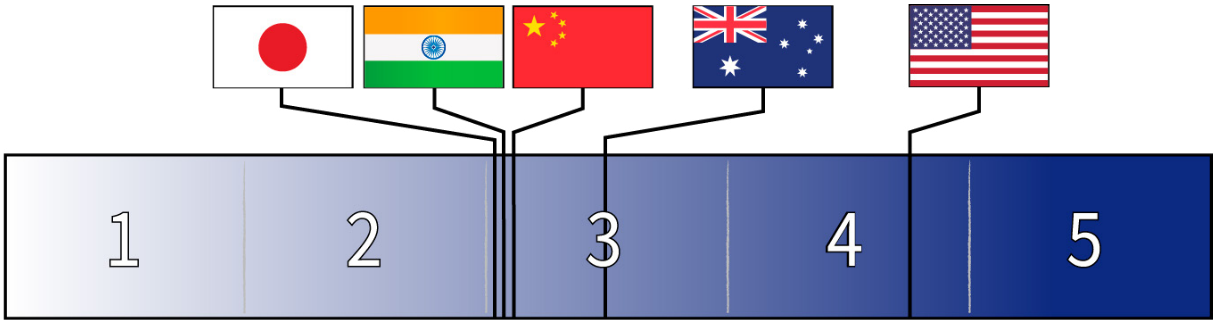


Note: The downturn on patent applications (blue line), where it crosses the still rising patents published (green line), indicates when the majority of patent applications were still filed but not yet published. The 'publication lag' from first filing can be up to two years in Australia and then there is additional time for patent application acceptance or rejection. The publishing lag depends on a variety of internal policy and legal factors that are similar across the world but can differ across jurisdictions such as in the case for China. Additionally, a longer lag time can often be desired by industry, as it gives it time to innovate and evolve its strategy before the details are made public. Combined with the fact that inventors in China primarily file patents only in China, our findings show that Chinese patents are published 2–3 times faster on average (0.8 years) than those of the Quad countries (1.85 to 2.06 years), which enables China to commercialise its technology and transition to production more quickly. ASPI ICPC assesses that China's fast patent lifecycle, combined with a relatively smaller volume of published research, provides supporting evidence for a fast-paced, iterative approach to technology delivery in China.

Australia and India both produce significantly more research papers than patent applications, which indicates either a new or primary investment in ideas generation or that they face challenges in commercialising those ideas themselves, unlike Japan, China and the US.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.).

Figure 11: Solar PV—country progress in meeting national policy objectives



Source: Image produced by ASPI.

Australia has outlined specific policy objectives and high-impact research outputs, but, while Australia has the world's highest per capita installed solar capacity, the domestic solar industry is behind in terms of investment and Australian installed capacity uses offshore suppliers, not from Quad partners, and primarily from Chinese suppliers.

China has clear policy objectives and a relatively high economic impact for research, but the quality is declining. Patents are published quickly, but with diminishing returns on relevance and economic value. However, changing policy in China on phasing out solar PV subsidies may affect future alignment. A phasing out of solar subsidies may affect deployment plans, as well as the quantitative advantage that holds up the total economic impact of China's solar PV patent portfolios.

India has clear policy objectives and an existing strong domestic private solar energy industry in mixed use (commercial and residential) solar installation, on- and off-grid solar installation and the development of solar energy plants and parks. It isn't clear that progress in those areas is on track for meeting the policy objectives.

The **US** has a clear strategy for solar power implementation, strong innovation capacity and budget allocations to build production capabilities. There's evidence that will help the US translate policy objectives into aligning capabilities. Patent growth isn't as dramatic as in other countries in solar energy, which is probably due to it being a well-established technology in the US, and strong, consistent research investment continues.

Japan has policy objectives for the use and production of solar PV, and there are new investments into achieving those objectives and signs that targets are being met, but Japan's current R&D capacity isn't necessarily sufficient in the longer term.

4. Biotechnologies

The outbreak of Covid-19 in Wuhan, China, in 2019 had significant geopolitical implications for the Indo-Pacific region and the globe.[85] The rapid adoption and maturation of techniques such as the polymerase chain reaction screening methods and mRNA vaccines has made them household terms. Amid these developments, a gene-editing method, CRISPR-Cas9, pioneered by US and French scientists, won the Nobel Prize in Chemistry in 2020,[86] while a Chinese biophysicist who used that technique to create gene-edited babies was sentenced to prison for 'illegal medical practice' over that research.[87] Biotechnologies have applications for human health as well as across agriculture and the wider plant and animal world, and involve positive and negative security and ethical issues along with the science and applications.

4.1 Genetic engineering

Genetic engineering refers to the tools and techniques for directly modifying one or more of an organism's genes. Applications for genetic engineering include making crops that are more nutritious or require less water or pesticides, treating genetic diseases by replacing faulty genes with working copies, and cell therapies that treat diseases by extracting, modifying and reimplanting patients' own cells.

Genetic engineering has been a controversial issue since the first recombinant DNA was created in the 1970s.[88] Genetic engineering promises to eradicate disease, develop resilient food crops and advance research on the human genome. Unrestricted use of genetic engineering, however, would threaten ecological disasters, and risk weaponisation to create genetically engineered bioweapons.[89]

The CRISPR-Cas9 gene editing method significantly altered the landscape by allowing scientists to cut and insert DNA wherever desired, but also introduces powerful negative potentials such as the ability to edit out genes deemed undesirable by less than scrupulous individuals, groups or even, potentially, nations.[90] Those concerns, and more specific ones such as germline editing that may lead to heritable traits in humans, have precipitated the UN Declaration on the Human Genome and Human Rights in 1997,[91] the Cartagena Protocol on Biosafety (a supplement to the Convention on Biological Diversity) in 2000, and the follow-up Nagoya Protocol in 2010. As of 2020, the Cartagena Protocol had been signed by 173 parties,[92] highlighting the universal concern over the potential negative implications of genetic engineering.

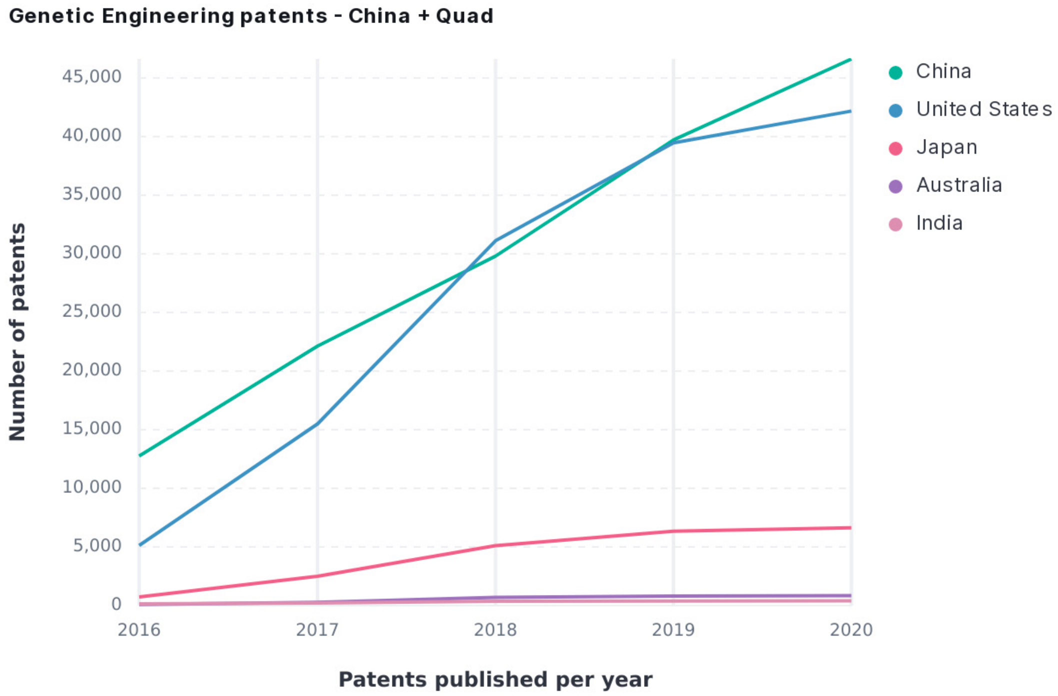
The Indo-Pacific region contains many isolated islands and infectious animal and human diseases that provide a unique mix of opportunities for genetic engineering.[93] Furthermore, China's use of genomic data for biosurveillance programs that violate human rights[94] shows that its intended use cases for genetic engineering technologies could undermine the interests of the Quad and like-minded countries.[95] And the lack of transparency involved with the combination of research and government action that has played out in understanding the beginnings of the Covid global pandemic makes those uncertainties not simply hypothetical. Consequently, a closer look at the technology is of paramount importance for the future of Indo-Pacific and the Quad.

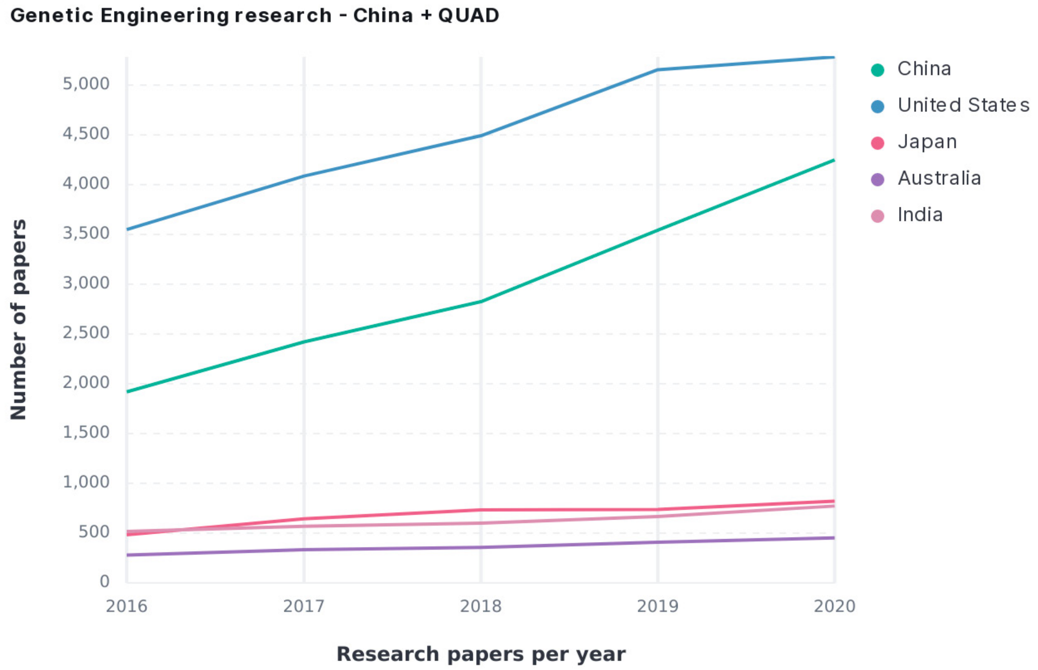
Table 3: National policies on genetic engineering

Country	Policy summary
Australia	Australia defines critical technologies as 'current and emerging technologies with the capacity to significantly enhance or pose risk to Australia's national interest'.[96] The newly established Australian Government Critical Technologies Policy Coordination Office has identified gene technology, which includes genetic engineering and genome sequencing, as one of nine priority critical technologies in the health sector that are 'likely to have a major impact on Australia's national interest in the next decade'.[97] The Australian Government's research commitment for genetic engineering and gene therapies is predominantly through the Medical Research Future Fund (MRFF) initiative managed by the Department of Health.[98] A subprogram of the MRFF, the Genomics Health Futures Mission, is a 10-year, $500 million investment introduced in the 2017–18 Budget for research into genomics.[99] The Genomics Health Futures Mission has said that it aims to position Australia as a global leader in genomics, citing the transformative effect that this research would have in medicine. Additionally, the Department of Defence's Next Generation Technologies Fund (NGTF) lists 'enhanced human performance' as one of its nine priority technology investment areas,[100] which potentially includes research in genetics. NGTF funding is distributed to university partners, the defence industry and publicly funded research organisations such as the CSIRO.
India	India's latest National Biotechnology Strategy (2021–2025) aims to develop India as an advanced bioeconomy and a 'global biomanufacturing hub' through an industry growth target of US$150 billion by 2025.[101] The strategy identifies gene editing, gene therapies and CRISPR-Cas technology as being among multiple new and emerging technologies that require government support in capacity building and infrastructure to meet the needs of the growing biotechnology sector.[102] The Department of Biotechnology, under the Ministry of Science and Technology, is the premier government body developing a genetic engineering policy framework and has a research focus on genetic disorders and Indian genome sequencing. Multiple government departments, subdepartmental organisations and research institutions have research programs in genetic engineering technologies, both agricultural and biomedical, under guidelines set in 1989 under the *Environment Protection Act 1986*. Government-funded R&D programs for genetically engineered crops and livestock exist, but the use of genetically modified crops in India is a controversial domestic political issue.[103] To regulate a growing genetic editing and testing industry—including research and practices by private labs and companies—draft national guidelines on genetic engineering were written in 2020.[104]
Japan	Japan's 2019 Bioeconomy Strategy[105] aims to establish Japan as the 'world's most advanced bioeconomy society by 2030' through an expansion of its domestic biotechnologies industry, including biopharmaceuticals, regenerative medicine, cell therapy and gene-therapy-related industries worth US$837 billion (¥92 trillion).[106] The strategy identifies agriculture and human genetic engineering in its nine priority market areas; each market area has a specific road map to achieve the goal.[107] The Bioeconomy Strategy will be updated annually in order to respond quickly to domestic and international situations involving biotechnology.
United States	The National Institutes of Health (NIH) and their reporting institutes, notably the National Human Genome Research Institute (NHGRI, famous for its sequencing of the human genome in 2003) are the premier genetic engineering organisations in the US. In its 2020 Strategic Vision, NHGRI emphasised 'responsible stewardship [as] a central aspect of being at (and pushing forward) the forefront of genomics'.[108] NHGRI receives approximately US$500 million per year for research across its subdivisions of genome science, genome medicine and genomics and society.[109] NHGRI's recent work has included compiling datasets used for studying common diseases in all patient populations, with a focus on 'ethnic minority populations, underserved populations, or populations who experience poorer medical outcomes'.[110] The Population Architecture using Genetics and Epidemiology Consortium is also 'analysing the relationship between genomic variants and a range of common diseases and traits, with a special focus on non-European ancestry populations'.[111] NHGRI is further building off its incipient human genome project with ENCODE (*The encyclopedia of DNA elements*) in an effort to identify the parts of the human genome that are functional, with nearly 900 publications thus far.[112]

China	The PRC's biotechnology strategy is outlined in the Outline of the National Medium and Long-term Science and Technology Development Plan (2006–2020),[113] the 13th Five-Year Special Plan for Biotechnology Innovation,[114] the 13th Five-Year Plan for Biotechnology Industry Development, and the 14th Five-Year Plan and the Long-Range Objectives Through the Year 2035.[115] The most recent of those, the 14th Five-Year Plan and the Long-Range Objectives Through the Year 2035, specified that biotechnology is one of nine strategic emerging technologies that it plans to develop and expand during the period, and genetics and biotechnology are listed as one of seven cutting-edge scientific and technological fields.[116] This includes establishing biotech and pharmaceutical national laboratories, promoting the integration and innovation of biotechnology and information technology, accelerating the development of biomedicine, biobreeding, biomaterials, bioenergy and other industries, and expanding and strengthening the bioeconomy. More specific R&D spending on genetic engineering has included ¥240 million (US$37.58 million) on stem cell and stem cell transformation research for 2020[117] and ¥37.7721 million (US$5.91 million) on safety evaluations of genetically modified food and animal feed between 2016 and 2020.[118]

Figure 12: Genetic engineering—patent applications published in China and the Quad and relative research output, 2016 to 2020

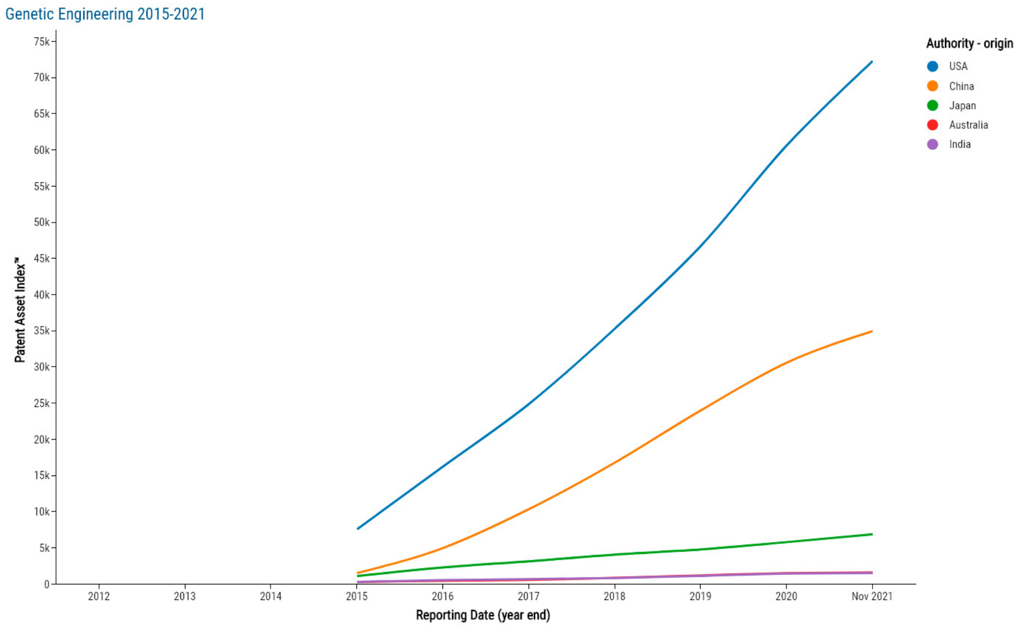


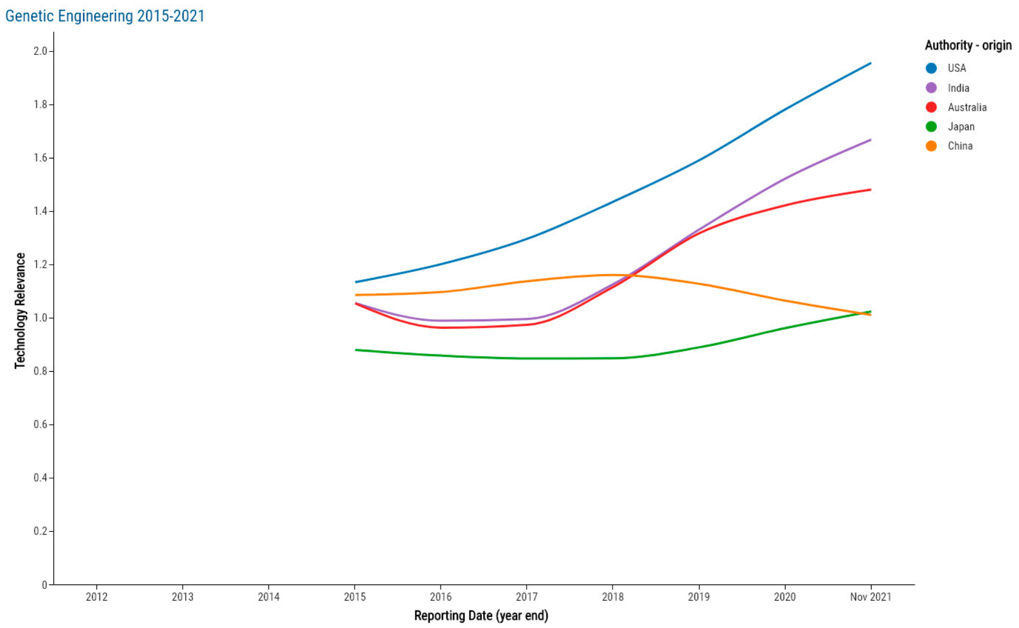


Note: The United States is dominant in this field, in both research and patent applications filed. In both biotechnology fields, there was no notable drop in patent applications or research from 2019 to 2020 around the time of the COVID-19 pandemic.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.) and SCOPUS research database

Figure 13: Genetic engineering patents outlined with Patent Asset Index and technology relevance, by country, 2015 to 2021

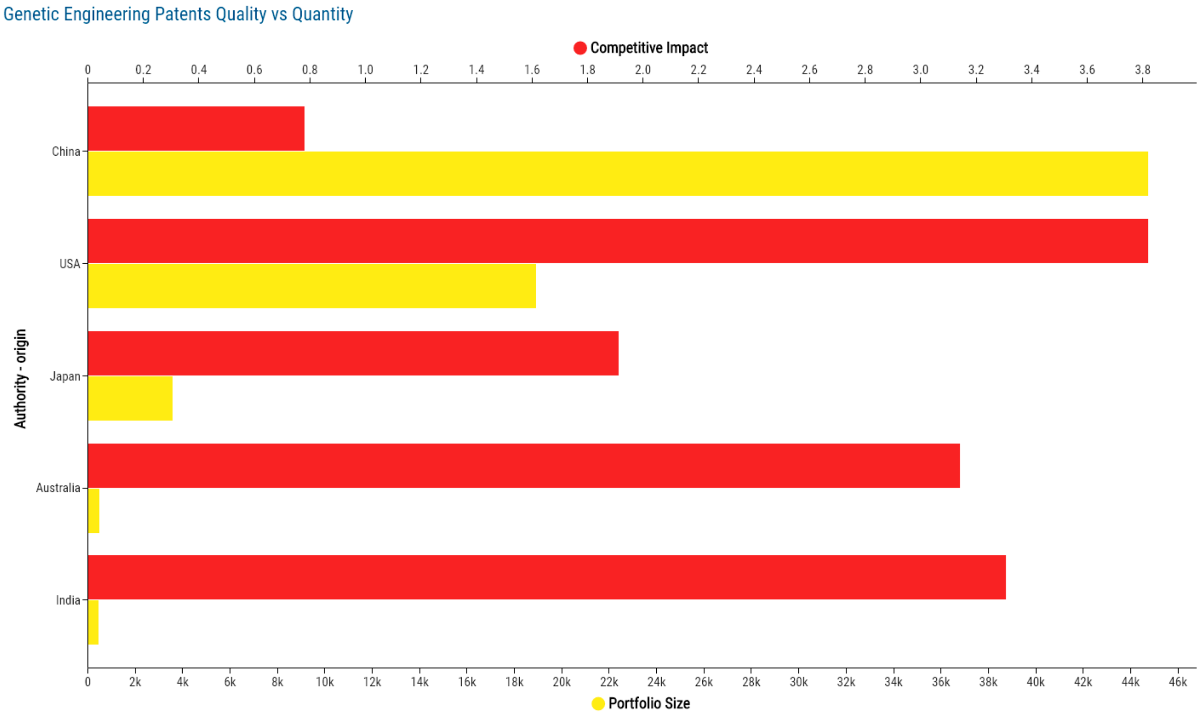




Note: The Patent Asset Index graph indicates the total economic impact of patents, while the 'technology relevance' graph reflects how the patent helps with subsequent R&D in the field. Because the PAI indicates total economic worth, both the quality and quantity of patents are factors. Technology relevance indicates, for lack of a better term, the 'quality' of the patents; this is measured by whether they're being cited to advance the field. Thus, a high PAI can be a result of a large quantity of low-quality patents or a small quantity of high-quality patents.

Source: Image produced by ASPI ICPC using PatentSight.

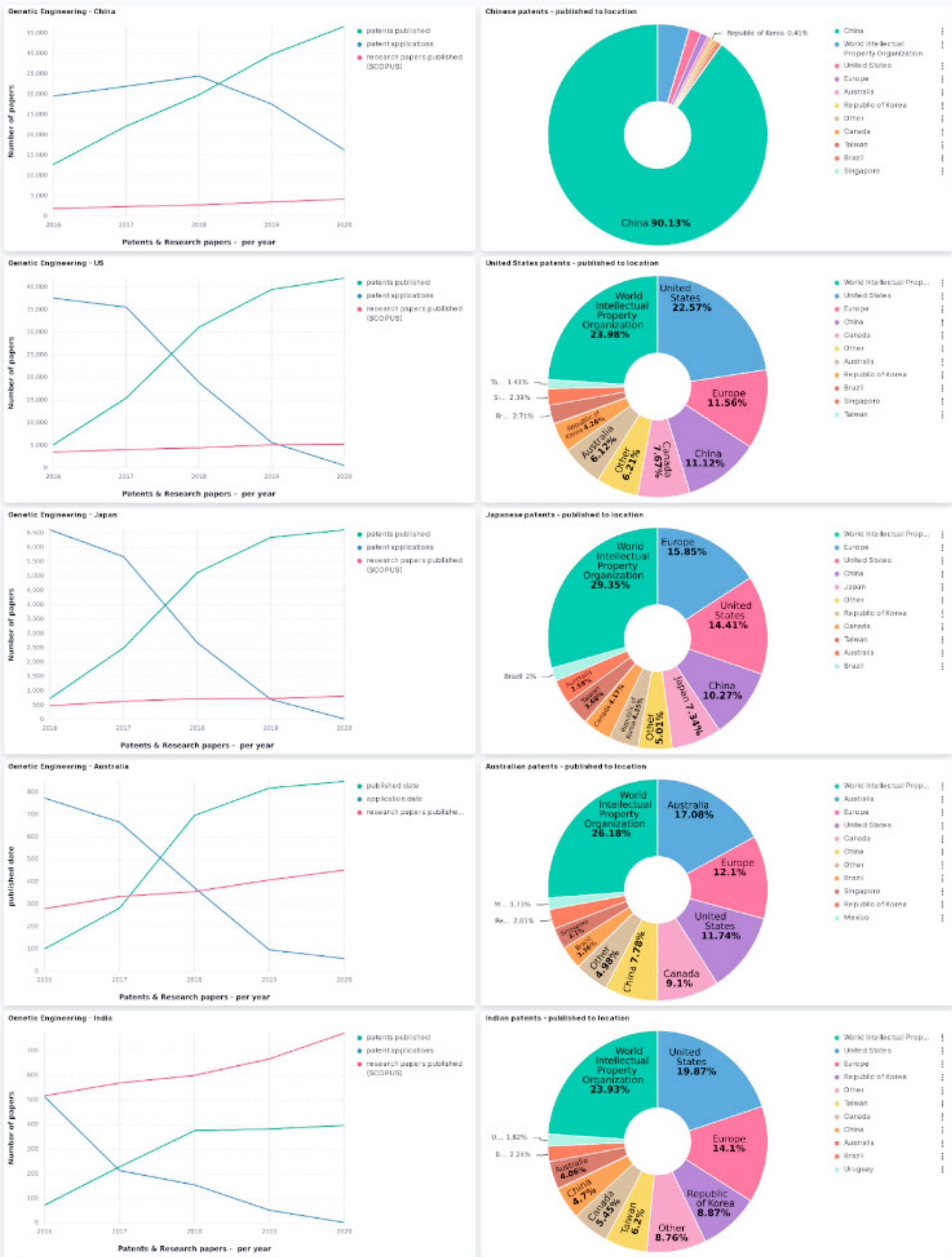
Figure 14: Genetic engineering patents—portfolio size and competitive impact, by country, 2015 to 2021



Note: The yellow bar illustrates the quantity of patents through portfolio size, while the average competitive impact (the economic value of individual patents defined by both the technological relevance and the market coverage of the patents) of the country in each field is represented by the red bar. For example, China has an enormous quantity of patents but relatively low competitive impact, which means the quality and market coverage of the average patent are extremely low according to the PatentSight metric.

Source: Image produced by ASPI ICPC using PatentSight.

Figure 15: Genetic engineering— academic research, compared with patent applications and publishing, as a measure of impact

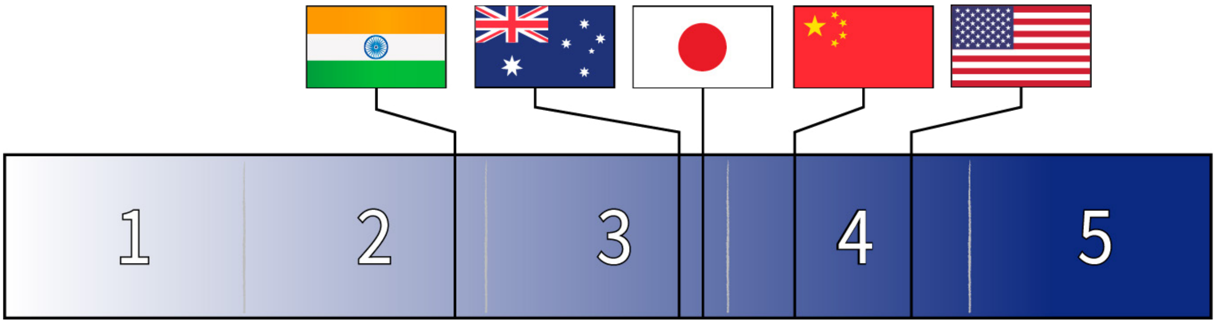


Note: The downturn on patent applications (blue line), where it crosses the still rising patents published (green line), indicates when the majority of patent applications were still filed but not yet published—the 'publication lag' from first filing can be up to two years in Australia and then there is additional time for patent application acceptance or rejection. The publishing lag depends on a variety of internal policy and legal factors that are similar across the world but can differ across jurisdictions such as in the case for China. Additionally, a longer lag time can often be desired by industry, as it gives it time to innovate and evolve its strategy before the details are made public. Combined with the fact that inventors in China primarily file patents in only China, our findings show that Chinese patents are published 2to 3 times faster on average (0.92 years) than those of Quad countries (2.26 to 2.49 years), which enables China to commercialise its technology and transition to production more quickly. ASPI ICPC assesses that China's fast patent lifecycle, combined with a relatively smaller volume of published research, provides supporting evidence for a fast-paced, iterative approach to technology delivery in China.

All countries have demonstrated slow and steady research progress over the period. Australia has been significantly more successful in bridging research output with patent applications than in other technologies, as has India though research papers still dominate.

Source: Image produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed).

Figure 16: Genetic engineering— Country progress in meeting national policy objectives



Source: Image produced by ASPI.

Australia has outlined specific policy objectives and high-impact research outputs. We believe there's a clearly forming alignment of policy objectives to the development of capabilities.

China has clear policy objectives and a relatively high economic impact for research, but the quality isn't necessarily high. Patents are published quickly, with high volume and low technology relevance, but in this case the economic impact, while rising, suffers from low market coverage, meaning that they may have less international impact when compared with other critical technology patents China is a part of. It's also hard to know whether this is having the intended policy impact.

India doesn't yet have a clearly articulated policy, although the research contributions from specific activities are resulting in some high-impact patents.

US research is a clear leader in genetic engineering, as US papers are being cited significantly more often by other researchers around the world. The US's policy approach to genetic engineering largely conforms to its academic approach, so alignment is relatively high, but outside of this it isn't clear that the US has a clear strategic direction in its genetic engineering research.

Japan has a concrete strategy and targets, but research impact is still relatively low. There's evidence that Japan is developing capabilities, but it isn't clear how closely those will align with achieving policy objectives.

4.2 Vaccines and medical countermeasures

Vaccines and medical countermeasures (MCMs) are the tools and techniques to quickly develop and manufacture vaccines, drugs, biological products and devices used to diagnose and treat emerging infectious diseases and medical conditions caused by exposure to harmful chemical, biological, radiological or nuclear substances. Applications for vaccines and MCMs include public health emergencies, industrial accidents and defence.

As the location for the initial Covid-19 outbreak and subsequent controversy,[119] China and its surrounding Indo-Pacific region have been engulfed in the development, production and dissemination of vaccines and MCMs since the pandemic began.

The pandemic has brought the importance of vaccines and MCMs to the forefront of the biological sciences. While records in vaccine development time frames have been achieved and more records are planned,[120] major powers, including China, the US, Russia and India, are also awakening to the realisation that vaccine development and production are potent geopolitical levers.[121] China's Health Silk Road,[122] Xi's 'People's War' against the virus,[123] the Trump administration's executive order mandating the inclusion of vaccine and MCM production under the Defence Production Act[124] and the subsequent 'vaccine diplomacy'[125] all but ensured the category's place within the strategic competition framework for all countries involved.

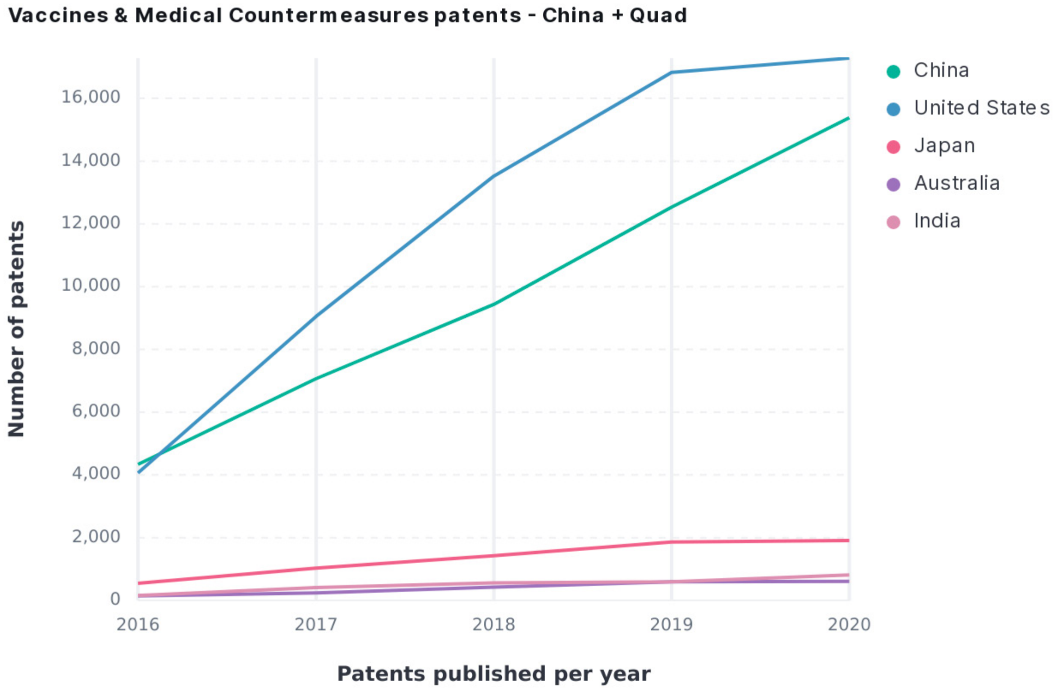
Table 4: National policies on vaccines and medical countermeasures

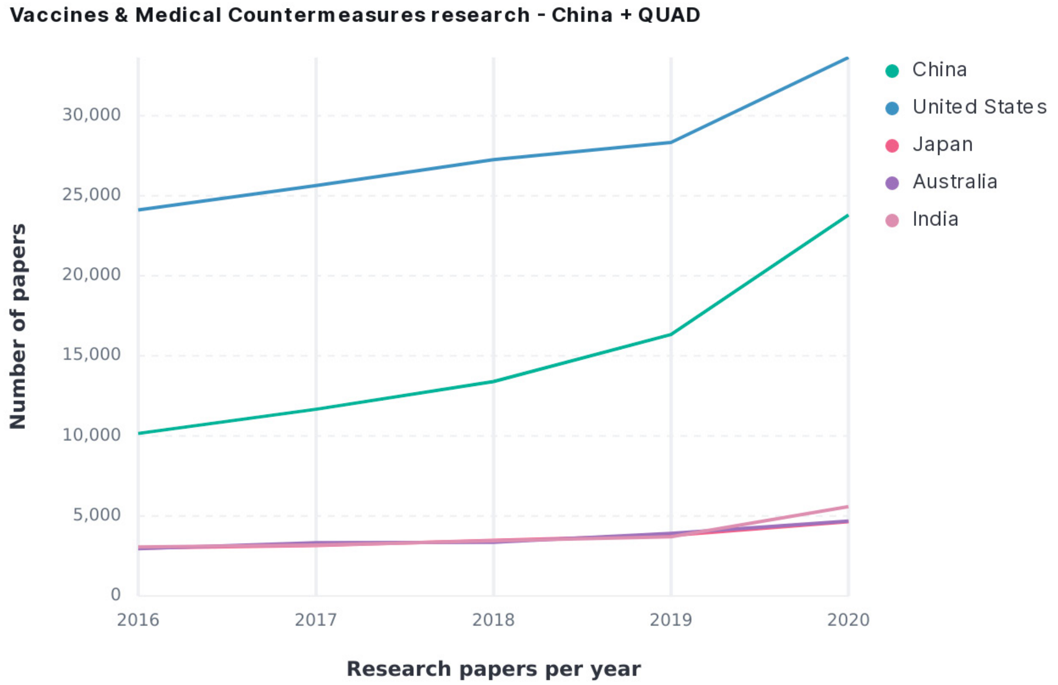
Country	Policy summary
Australia	Australia defines critical technologies as 'current and emerging technologies with the capacity to significantly enhance or pose risk to Australia's national interest'.[126] The 2021 Australian Government Blueprint for Critical Technologies recognises vaccine R&D as a critical technology opportunity to improve health and social outcomes.[127] The newly established Australian Government Critical Technologies Policy Coordination Office has identified MCM products, which include vaccine R&D, as one of nine priority critical technologies in the health sector that are 'likely to have a major impact on Australia's national interest in the next decade'.[128] Prior to Covid-19, vaccine research was already a critical part of the Department of Health's $20 billion[129] ongoing Medical Research Future Fund (MRFF) initiative's investment priorities,[130] particularly in the area of combating antimicrobial resistance developed through Australia's relatively high rates of antibiotic use.[131] That priority was included in both the 2018–2020 and 2020–2022 versions of the MRFF strategies.[132] Since 2016, the MRFF has released three iterations of its two-yearly Medical research and innovation priorities documents, as well as a five-year strategy and 10-year investment plan. In addition to the MRFF, research into medical countermeasures is also supported by the Australian Government through the Medical Countermeasures Consortium, which began in late 2012. It's a four-nation partnership between the health and defence departments of Australia, the UK, Canada and the US, coordinated at Australia's end by the Defence Department's Defence, Science and Technology (DST) Group.[133] DST Group also directs funding to this research through its Next Generation Technologies Fund (NGTF), which is a $1.2 billion fund with a 10-year 'forward-looking' mandate on R&D in nine priority technology areas, one of which includes 'medical countermeasure products'. NGTF funding is distributed to university partners, the defence industry and publicly funded research organisations such as the CSIRO.[134] In March 2021, Prime Minister Morrison announced that Australia would contribute $100 million to the Quad Vaccine Partnership.[135]
India	India's latest National Biotechnology Strategy (2021–2025) aims to develop India as an advanced bioeconomy and a 'global biomanufacturing hub' through an industry growth target of US$150 billion by 2025.[136] Before Covid-19, government-funded vaccine and MCM research was aimed at developing and funding efficient low-cost vaccines and measures to manage traditional disease burdens in India. Most government R&D funding is provided through the Department of Biotechnology, its flagship programs such as the National Biopharma Mission and international cooperation programs such as the Indo-US Vaccine Action Program and Ind-CEPI Mission.[137] Since the advent of Covid-19, the Indian Government has increased R&D support for multiple Covid-19 vaccines and MCMs and committed to supporting scaling up Covid-19 vaccine production under the Indian Covid-19 Vaccine Development Mission through a US$120 million (9 billion rupees) fund.[138] Covid-19 vaccine R&D was listed as a priority area in the latest National Biotechnology Development Strategy (2021–2025),[139] which recommended a dedicated biotechnology policy mission for the development of vaccines and biosimilars as a national priority. Government funding for biotechnology and health science research received a significant 25% boost in the 2021 budget.[140] In March 2021, as part of the Quad Vaccine Partnership, the four Quad members committed to donating 1.2 billion doses of Covid-19 vaccine to developing countries, of which 1 billion doses were to be manufactured in India by the end of 2022.[141] India is a world leader in vaccine manufacturing and meets over 50% of global immunisation needs.

Japan	Japan launched some projects to counter novel infectious diseases in the 2000s and early 2010s in response to the pandemics of SARS, MERS and novel influenza,[142] but the projects were short term due to the relatively low number of cases in Japan, the high standard of public health, a lack of economic rationality, and vaccine avoidance by the public.[143] On 1 June 2021, against the backdrop of the Covid-19 pandemic, the Cabinet Office decided on the Strategy to Strengthen Vaccine Development and Production System.[144] The strategy confirms that having the ability to develop and produce vaccines domestically is extremely important not only for public health but also for diplomacy and national security. In the strategy, the Japanese Government aims to clarify the factors that have delayed vaccine development in Japan and rebuild the necessary systems and a long-term, continuous strategy to resolve the issues. In 2019, the government published its Bioeconomy Strategy 2019.[145] The strategy defines biotechnology as a core solution for Japanese society's challenges, such as climate change, environmental conservation and an ageing population. To realise the world's most advanced bioeconomy society by 2030, the government identifies nine market areas as measures for a back-casting approach in the strategy. The sixth area is for MCMs (biopharmaceuticals, regenerative medicine, cell therapy and gene-therapy-related industries). The Bioeconomy Strategy will be updated annually to respond quickly to domestic and international situations involving biotechnology. Each market area has a specific road map to achieve the goal. While the Cabinet Office manages the grand strategy, the road maps are under the jurisdiction of the ministries in charge.[146] In March 2021, the Japanese Government announced that it would provide US$41 million in grant aid and provide new concessional loans as part of the Quad Vaccine Partnership to developing countries to assist in their vaccination efforts.[147]
United States	In 2004, the US Congress established Project BioShield to help create incentives for the private sector to develop MCMs against high-priority chemical, biological, radiological and nuclear threats by 'providing multi-year funding to support advanced research, clinical development, manufacture and procurement'.[148] Two years later, in 2006, the Congress established the Biomedical Advanced Research and Development Authority (BARDA) to procure and develop MCMs primarily against bioterrorism as well as pandemics and emerging diseases. In the context of the Covid-19 pandemic, BARDA has also been responsible for strengthening MCM manufacturing capacity of ancillary supplies in order to secure national supply chains. Project BioShield's 2021 projects include 'late stage development and procurement of a next-generation anthrax vaccine, new antibacterial drugs, chemical agent MCMs, a product to temporise burn injuries resulting from chemical agents, MCMs to detect and treat acute exposure to ionising radiation and making available intravenous formulations of stockpiled smallpox antiviral drugs for special populations and those who are severely ill.' Congress also provided the Office of the Assistant Secretary for Preparedness and Response (ASPR) with an additional US$535 million to support ongoing Ebola efforts.[149] Both agencies report to ASPR and are involved with the procurement of drugs and materials (such as PPE) for the Strategic National Stockpile. In 2019, the Congress increased the authorisation for Project BioShield from US$2.8 billion over five years to US$7.1 billion over ten.[150] ASPR's FY 2021 budget request is for US$2.6 billion, divided between: • US$1.4 billion for BARDA, including US$562 million for advanced R&D, US$535 million for Project BioShield and US$306 million for pandemic influenza research • US$705 million for the Strategic National Stockpile • US$258 million for the Hospital Preparedness Program • US$92 million for the National Disaster Medical System and the Civilian Volunteer Medical Reserve Corps • US$15 million for a new Preparedness and Response Innovation program.[151] The Congressional Budget Office has further estimated that 'BARDA alone has spent US$19.3 billion on Covid-19 vaccine development' as part of 'Operation Warp Speed'.[152] The US Department of State is another important actor in the MCM space, with an annual budget of between US$6 billion and US$9 billion for its Global Health Program.[153] The department's FY 2020 funding request for the program states its 'support for programs to control the HIV/AIDS epidemic, prevent child and maternal deaths, and combat infectious disease threats and to build healthier, stronger, more self-sufficient nations'.[154] In March 2021, the US announced that it would commit at least an additional US$100 million to regional immunisation efforts.[155]

China	In March 2020, General Secretary Xi Jinping emphasised that major scientific and technological achievements in the fields of life safety and biosafety are the country's important pillars. The epidemic prevention and control and public health emergency systems are important parts of the state's strategic systems.[156] The 14th Five-Year Plan and the Long-Range Objectives Through the Year 2035, published in March 2021, emphasised the importance of strengthening the state's strategic technology power by strengthening original and leading scientific and technological research. The PRC would concentrate superior resources to research key and core technologies in fields including the prevention and control of emerging infectious diseases and biosafety risks, and pharmaceuticals and medical equipment. In addition, the plan also mentioned the promotion of the construction of a 'healthy China', including setting up a strong public health system that strengthens the monitoring and early-warning capability of the disease prevention and control system. Prior to Covid-19, the PRC stated that it would improve the high-level biosafety laboratory system in the 13th Five-Year Plan for Biotechnology Industry Development. This includes constructing and improving the high-level biosafety laboratory system, consolidating the basic conditions for the prevention and control of severe and major infectious diseases, biological prevention, the development of the biological industry in China and enhancing the ability of independent innovation in biosafety technology. In the 13th Five-Year Plan for National Technology Innovation, new drug creation is one of the national science and technology major projects. Measures include strengthening the R&D of vaccines and antibodies, supporting the development of drugs with industrialisation prospects, and building the country's ability in critical technology and basic research. The 13th Five-Year Plan also devoted ¥7.092 billion (US$1.11 billion) to 704 line items concerning new pharmaceuticals[157] and ¥3.373 billion (US$530 million) to 115 line items concerning commutable diseases.[158]

Figure 17: Vaccines and medical countermeasures patent applications published in China and the Quad and relative research output, 2016 to 2020

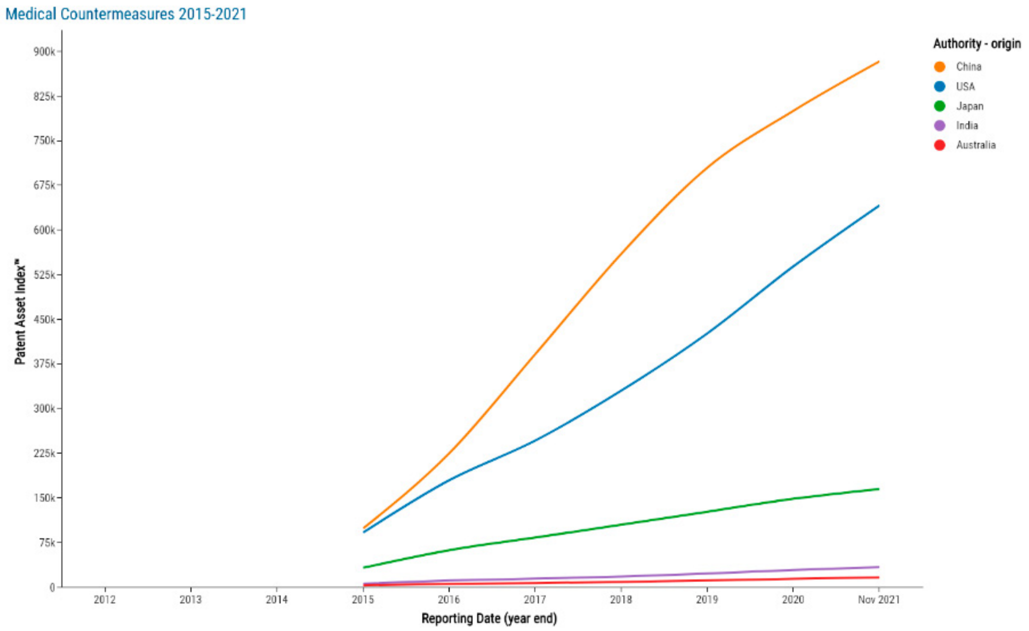


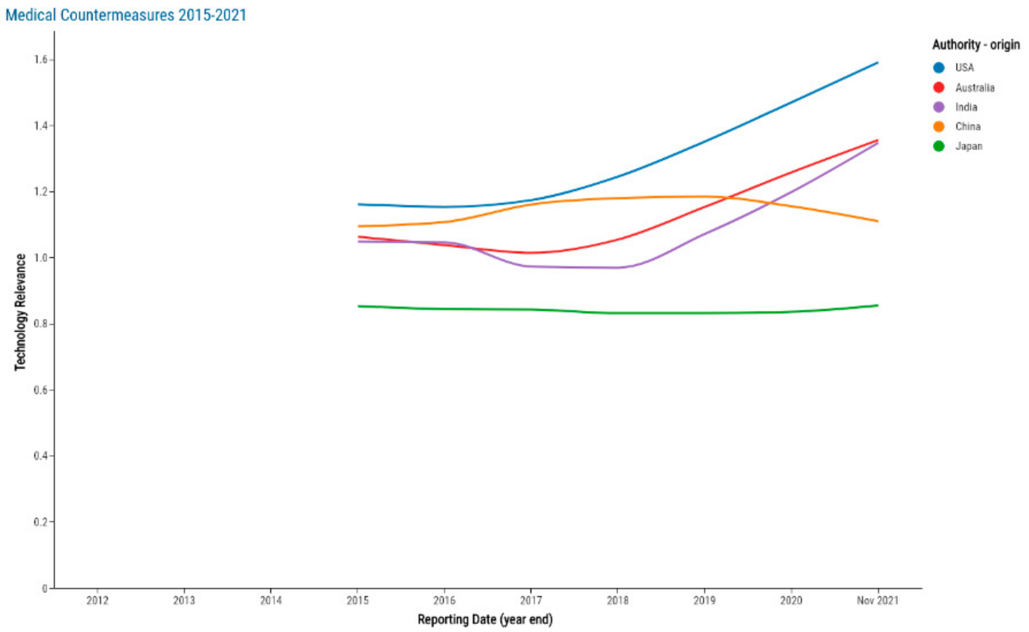


Note: Unlike the other critical technologies assessed in this project, there is no drop in patent applications or research from 2019 to 2020, due to the reprioritisation of global medical resources towards COVID-19 vaccine development. Australia's contribution to vaccine and medical countermeasure research matches the efforts by Japan and India, countries with approximately 5 and 50 times Australia's population, which indicates an extremely impressive per capita contribution, particularly when paired with high citation scores.

Source: Images produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.) and SCOPUS research database

Figure 18: Vaccines and medical countermeasures patents outlined with Patent Asset Index and technology relevance, by country, 2015 to 2021

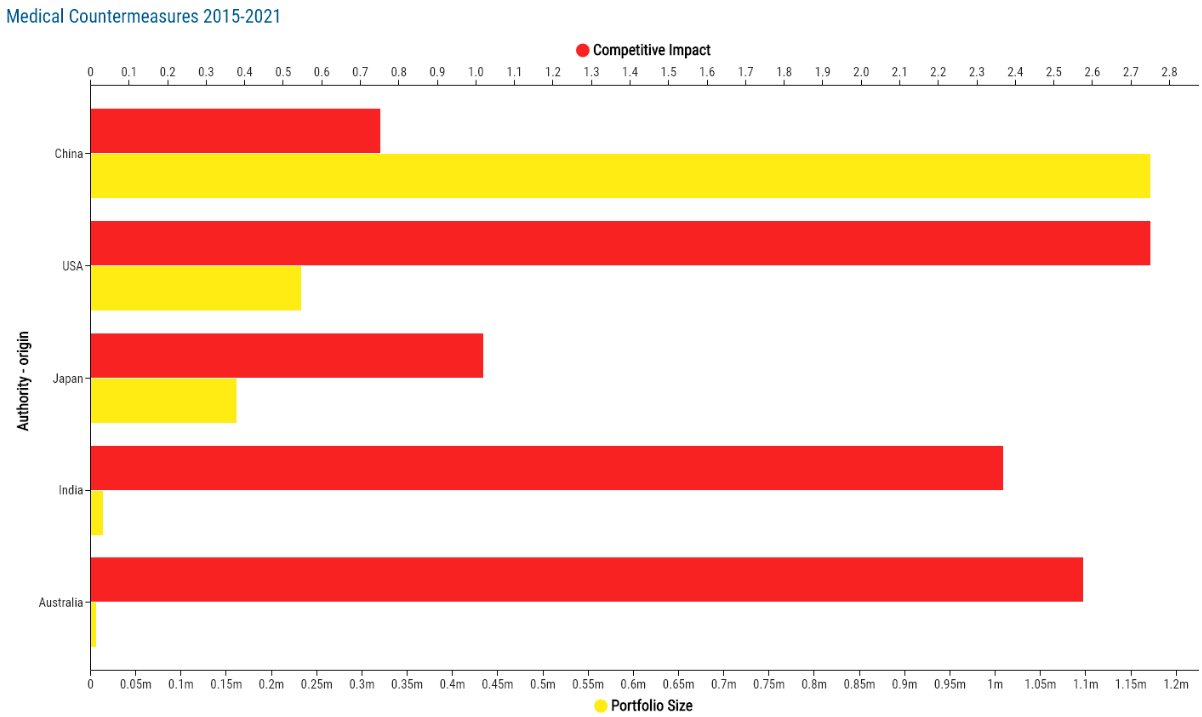




Note: The Patent Asset Index graph indicates the total economic impact of patents, while the 'technology relevance' graph reflects how the patent helps with subsequent R&D in the field. Because the PAI indicates total economic worth, both the quality and quantity of patents are factors. Technology relevance indicates, for lack of a better term, the 'quality' of the patents; this is measured by whether they're being cited to advance the field. Thus, a high PAI can be a result of a large quantity of low-quality patents or a small quantity of high-quality patents.

Source: Images produced by ASPI ICPC using PatentSight.

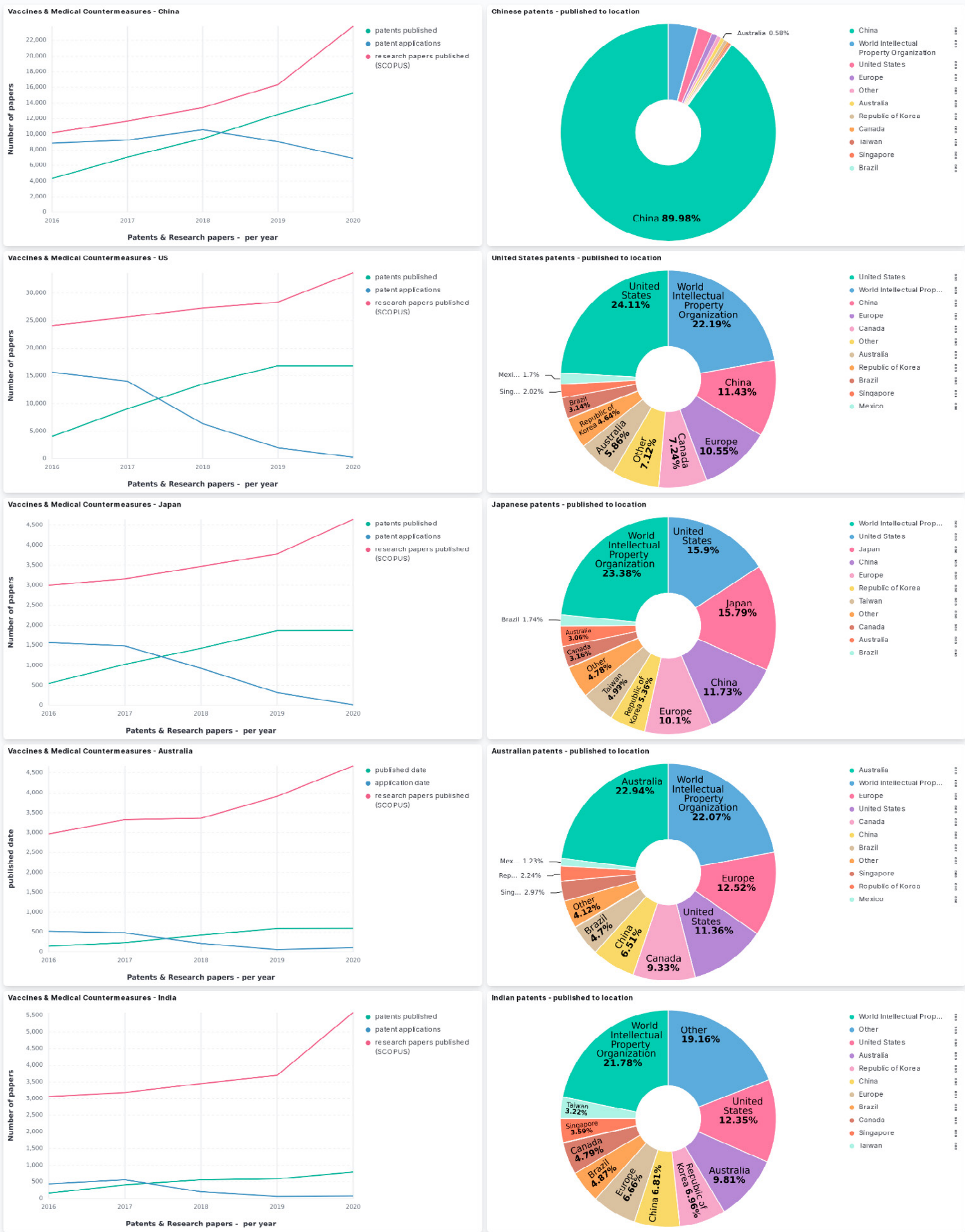
Figure 19: Vaccines and medical countermeasures patents—portfolio size and competitive impact, by country, 2015 to 2021



Note: The yellow bar illustrates the quantity of patents through portfolio size, while the average competitive impact (the economic value of individual patents defined by both the technological relevance and the market coverage of the patents) of the country in each field is represented by the red bar. For example, China has an enormous quantity of patents but relatively low competitive impact, which means the quality and market coverage of the average patent are extremely low according to the PatentSight metric.

Source: Image produced by ASPI ICPC using PatentSight.

Figure 20: Vaccines and medical countermeasures—academic research, compared with patent applications and publishing, as a measure of impact

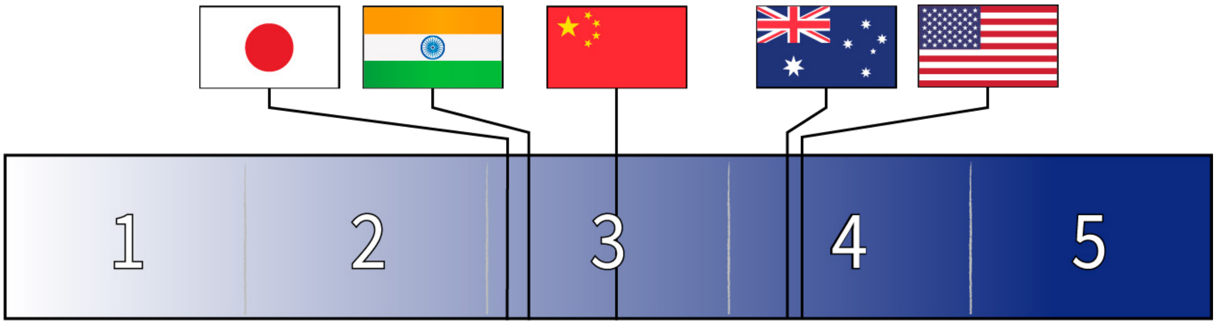


Note: The downturn on patent applications (blue line), where it crosses the still rising patents published (green line), indicates when the majority of patent applications were still filed but not yet published—the 'publication lag' from first filing can be up to two years in Australia and then there is additional time for patent application acceptance or rejection. The publishing lag depends on a variety of internal policy and legal factors that are similar across the world but can differ across jurisdictions such as in the case for China. Additionally, a longer lag time can often be desired by industry, as it gives it time to innovate and evolve its strategy before the details are made public. Combined with the fact that inventors in China primarily file patents only in China, our findings show that Chinese patents are published 2 to 3 times faster on average (0.99 years) than those of the Quad countries (2.35 to 2.58 years), which enables China to commercialise its technology and transition to production more quickly. ASPI ICPC assesses that China's fast patent lifecycle, combined with a relatively smaller volume of published research, provides supporting evidence for a fast-paced, iterative approach to technology delivery in China.

Vaccine and medical countermeasure research has been a steady investment of effort over many years, with a clear increase in resourcing and publishing papers as the global Covid-19 pandemic struck, though it's still too soon to see how China's results have been realised in patent applications. Publishing lag is slightly longer for these patent applications across the board. While all countries produced far more research papers than patent applications, Australia made its greatest contribution of research papers in this space, particularly when considered on a per capita basis, yet without an equivalent increase in patent applications.

Source: Image produced by ASPI ICPC using data generously provided by IP Australia (PATSTAT Spring 2021 ed.).

Figure 21: Vaccines and medical countermeasures— country progress in meting national policy objectives



Australia has outlined specific policy objectives and has highly impactful research outputs, but more investment is needed to carry these successes through to industry. There is a need for the government to work collaboratively with industry to capitalise on high quality Australian research, to ensure commercial viability and remain aligned with strategic objectives.

China has clear policy objectives and a relatively high economic impact for research, but the quality of research outputs isn't correspondingly high.

India has low government research and funding into emerging infectious diseases, and that funding isn't currently a part of the national security apparatus (interviewees said this could change soon due to Covid-19).

The **US** has all the component parts for a successful realization of policy objectives in the vaccines and medical countermeasures field, but, to date, success in connecting capabilities to policy outcomes is not necessarily correspondingly high. US research is world-leading and US papers are cited far more often than those of the other countries, in part due to the successful commercialisation of the medical sector by the US's mighty pharmaceutical industry. However, in some cases policy objectives have been left behind as they diverged from the commercial drivers.

Japan has a strategy for strengthening vaccine development and production that's still very new. Its R&D capabilities are less advanced, although where that capability does exist, it's more impactful. The component parts exist for the successful realisation of policy objectives in the long term.

5. Conclusion and recommendations

The race to develop critical and emerging technologies is becoming increasingly geopolitical and is an acknowledgement by states that technological capability translates to both economic and strategic advantage. The stakes for states are high. If they lack indigenous capability, there's the prospect of having access to key technologies arbitrarily cut off, and, regardless of local capacity, the risk of having new technologies used maliciously against them. Other than the superpowers, and even then not always, no state has the capability to create stand-alone, world-leading capability in all critical and emerging technologies, so deep partnerships—as we see beginning to emerge between the Quad partners through government leadership—have obvious utility. In this milieu, it's more important than ever to understand relative capabilities that individual states possess and to regularly assess where gaps exist or are emerging, as well as whether supply can be assured through the complementary activities of a network of reliable and like-minded nations.

There is not enough clarity in existing data holdings to build effective business intelligence on how the R&D ecosystem is performing in response to policy requirements. We assess, for example, that the 'low quality' patent indicator for China across the four technologies does not necessarily mean capabilities do not align with its policy objectives. We think this is instead due to Chinese companies patenting specific applications of technology, indicating a fast-paced and iterative approach to technology delivery in China. As Chinese companies export their products globally, they are probably achieving some market power and incumbency even if the product quality is by objective metrics inferior. This pattern might be more pronounced across the other critical technologies ASPI ICPC will examine as the Benchmarking Critical Technologies project evolves in 2022, such as artificial intelligence and data science and storage technologies. This will be a challenge for the Quad nations as they seek to move more rapidly from concept to capability.

Meanwhile, for the Quad, research outputs (patents and academic publications) pre-date most policy documents on strategic objectives, while any new patent or academic data aligning more closely with strategic objectives wouldn't necessarily be published yet. For government officials tasked within governments to advise on these matters a tough job lies ahead. Rotated into position, they don't necessarily have technology backgrounds and certainly not across all of them.

On the international stage, as we build collaborative relationships such as the Quad, there is a critical need for specialist 'technology diplomacy' support to foreign policy organisations to enable them to identify key issues as they engage with foreign technology industries. Critical technologies are increasingly intersecting with economics, national security, democratic values and geopolitical issues, and key to navigating these issues and leveraging the Quad partnership effectively will be an understanding of the technology, the state-of-play of key R&D and commercial sectors and their critical dependencies, such as supply chains.

With this in mind, we recommend as follows:

1. For governments to ensure that strategic objectives pertaining to critical technologies are both well articulated and possible to meet, and for researchers and industry to collaborate in meeting those objectives, they must first develop an objective and repeatable methodology for quantifying technical achievements within each clearly defined critical technology sector. This includes the

development of a common language or lexicon of keywords for published research, keywords in patent documents, and the high-level language used in policy documents. This will provide the connective tissue to create alignment and a level of orchestration by policymakers and the response by academia, resulting in possible practical technology applications through patents.

2. The Quad Critical and Emerging Technology Working Group is an important step towards building collaboration in the R&D and production of critical technologies by like-minded governments. During the formative stages of the working group, we recommend that it consider the following:
    - Identify key indicators of capability and develop and clear methodology for assessing the capability of each nation to understand current and emerging promising and complementary capabilities and strengths, along with gaps among like-minded countries, in critical and emerging technologies.
    - One aim should be to develop a network of like-minded countries with advanced technological capabilities that connect to the Quad nations and their research communities. The network should commit to a set of core principles, including 'baking' democratic principles into the technology and agreeing to share any civilian advances on market terms and to refrain from coercion. This will build on strong existing partnerships that each Quad nation has with other partners.
    - Understanding the impact of Quad nation's partnerships, and partnerships within their research and corporate communities, in critical technology will be essential in considering competitive advantage, complementarity and where Quad resilience may need to be strengthened when considered from the perspective of strategic technological competition.
    - The partners should establish a Quad or Quad Plus critical technologies fund to which participating states pledge investment funds that are then disbursed to address current and emerging critical technologies gaps. Co-investment approaches between Quad government agencies and private investors should be considered in order to leverage government funding more effectively than simply through grants or incentives.

3. The ability to measure relative strengths and weaknesses among collaborating countries will enable the measurement of the comparative advantages of each country in 'on-shoring' certain parts of the technology supply chain. Such individual country assessments could then support policy focuses where particular national strengths compensate for or augment other Quad nations' vulnerabilities or weaknesses and build the resilience of the network.

Appendix: Methodology

While considering Australian national interests, we settled on the four technologies for this pilot program through consultation with experts and officials from the public and private sectors. Innovation begins with R&D for a given technology sector, and individuals or companies will patent the parts with potential practical implications. Should the application of the particular technology have sufficiently far-reaching benefits and consequences, that would incentivise the government and private sector to devote additional resources to that technology. Therefore, in assessing national capabilities, we collected data from four categories: policy, high-level budget allocations, patents, and academic publications.

Policy summaries and budget allocations

For policy documents, we focused on collecting central and national-level strategic and planning documents concerning the given critical technology and how they fit into the overall strategic goal of the country. Part of our policy analysis included investigations into each country's high-level budgetary allocations for the critical technologies, so we collected budgetary data from central government ministries and departments, including for R&D, infrastructure and subsidies, where appropriate. However, we ultimately decided against isolating budgetary allocations as a distinct category of analysis. The principle methodological issues concern the fact that not only does private investment in various sectors constitute a significant portion of investment, but that each country has different approaches and levels of influence and regulation over how private investment may be directed; for example, Chinese private investment is highly regulated, especially in key sectors such as energy and telecommunications. We also recognise that, even for government budgets, line items rarely fall neatly within the definitions of each critical technology, and occasionally subjective judgement is required on the inclusion or exclusion of line items. This issue may introduce a certain degree of uncertainty into the final aggregated figure for each technology and country. Also, significant funding may be missing because we couldn't include very general funds that could be applied to many technology areas outside the scope of our research (for instance, funds marked for 'general medical research').

Patents

We collected two measures for each critical technology: the quantity and quality of the patents. They were organised by the country of origin of the applicant or inventor where the patent was originally filed. For the quantitative data on patents, IP Australia provided ASPI ICPC with carefully curated extracts from PATSTAT Spring 2021 to analyse the quantity of patents for each critical technology.

Using the commercial product PatentSight developed by LexisNexis, we broke down patent data across the same categories to assess patent quality with the Patent Asset Index (PAI),[159] employing proprietary measures of technology relevance, market coverage and competitive impact.

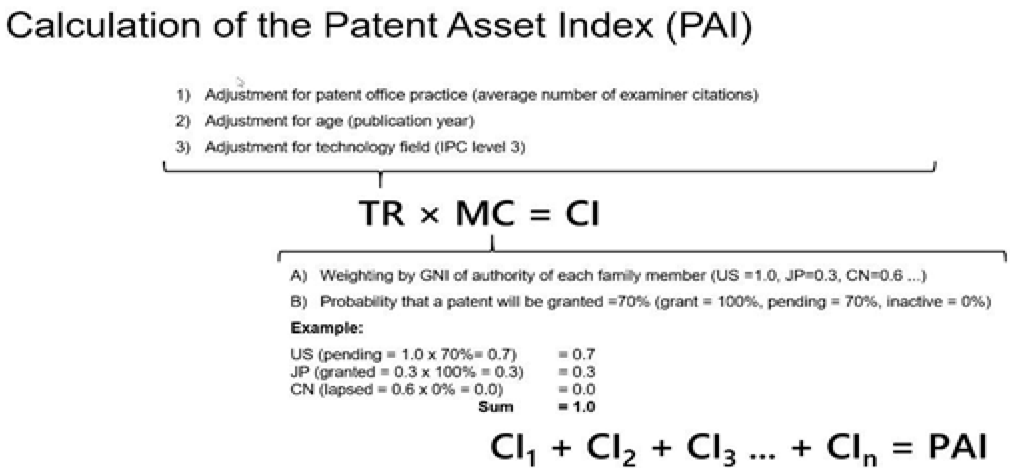
The technology relevance (TR) of a patent represents how much future development in the field is built upon that patent. TR calculates how often it's been cited in the same field compared to all other patents and is adjusted for the patent's age, since older patents usually receive more citations than new ones.

Market coverage (MC) of a patent represents how much of the global market within this field is protected by this patent. MC calculates coverage based on the size of the US market as defined by gross national income (GNI).

Competitive impact (CI) is derived from both TR and MC and represents the total economic impact of a given patent. The PAI represents the aggregate of CI within a given field—in our case, a rigorously defined set of classifications delineating each critical technology.

Figure 22 shows the calculation of the PAI.

Figure 22: Calculation of the Patent Asset Index



Academic publications

We used CiteScore (CS) methodology for measuring impact factors embedded within Elsevier's commercial database product Scopus. Compared with the more widely used journal citation reports impact factor, CS indexes more journals but has a longer evaluation interval (four versus two years), while evaluating a wider range of materials:[160]

$$\mathrm{CS}_y = \frac{\mathrm{Citations}_y + \mathrm{Citations}_{y-1} + \mathrm{Citations}_{y-2} + \mathrm{Citations}_{y-3}}{\mathrm{Publications}_y + \mathrm{Publications}_{y-1} + \mathrm{Publications}_{y-2} + \mathrm{Publications}_{y-3}}$$

Patent search strategy

For the full patent search strategy, see online.

Notes

1 ‘What is a “critical technology”?’, in ‘Appendix A: National Critical Technologies List’, Clinton White House archives, online.
2 Marise Payne, ‘Launch of the International Cyber and Critical Technology Engagement Strategy’, speech, 21 April 2021, online.
3 Scott Morrison, ‘Quad Leaders’ Summit communique’, 24 September 2021, online.
4 Morrison, ‘Quad Leaders’ Summit communique’.
5 See, for instance, the Biden administration’s memorandum, ‘Multi-agency research and development priorities for the FY 2023 Budget’, August 2021, online; and the former Trump administration’s October 2020 list of critical and emerging technologies, online.
6 Morrison, ‘Quad Leaders’ Summit communique’.
7 For a more comprehensive definition and explanation of the methodology behind the Patent Asset Index, consult the product website, online.
8 Standardisation Law of the People’s Republic of China, Standardisation Administration of China, 23 March 2018, online. The Standardisation Law was revised and adopted at a meeting of the Standing Committee of the National People’s Congress in November 2017 and came into force on 1 January 2018.
9 ‘National Patent Development Strategy (2011–2020)’ [‘全国专利事业发展战略(2011—2020年)’], China National Intellectual Property Administration, 18 November 2010, online.
10 ‘National Patent Development Strategy (2011–2020)’.
11 Hiroyuki Suzuki, *Japan’s leadership role in a multipolar Indo-Pacific*, Center for Strategic and International Studies, 23 October 2020, online.
12 State Department, *A free and open Indo-Pacific: advancing a shared vision*, US Government, 4 November 2019, online.
13 ‘Quad Leaders’ joint statement: “The spirit of the Quad”‘, The White House, 12 March 2021, online.
14 Bureau of Energy Resources, ‘Asia EDGE—Enhancing development and growth through energy’, US Government, 2021, online.
15 ‘Carbon-free’ = green hydrogen produced through electrolysis using energy supplied from renewable sources; ‘Carbon neutral’ = blue hydrogen produced from natural gasses while using carbon capture technologies to eliminate or reduce carbon emissions in the process, Noé van Hulst, *The clean hydrogen future has already begun*, International Energy Agency, 23 April 2019, online.
16 van Hulst, *The clean hydrogen future has already begun*.
17 UNESCAP, ‘Achieving SDG7 in Asia and the Pacific’, UN, 12 February 2018, online.
18 UNESCAP, *Asia–Pacific progress in sustainable energy: a global tracking framework 2017 regional assessment report*, UN, 16 March 2018, online.
19 ‘How China plans to become carbon-neutral by 2060’, *Bloomberg*, 10 August 2021, online.
20 The Quad announced a ‘Clean-Hydrogen Partnership’ in September 2021 to ‘strengthen and reduce costs across all elements of the clean-hydrogen value chain.’ See ‘Fact sheet: Quad Leaders’ Summit’, The White House, 24 September 2021, online.
21 Australian Government, *Australia’s Long-Term Emissions Reduction Plan: a whole-of-economy plan to achieve net zero emissions by 2050*, 26 October 2021, online.
22 This document established the long-term goal of producing hydrogen at under A$2 (US$1.46) per kilogram and A$1.2 billion (US$875.6 million) in investment into hydrogen technologies. See Department of Industry, Science, Energy and Resources (DISER), *Technology Investment Roadmap discussion paper: a framework to accelerate low emissions technologies*, Australian Government, 21 May 2020, online; DISER, *Technology Investment Roadmap: first low emissions technology statement—2020*, Australian Government, 22 September 2020, online.
23 The strategy focused on investment in technology R&D, country-to-country agreements and infrastructure development in ‘hydrogen hubs’ (concentrations of industrial hydrogen users) to spur domestic demand. See Council of Australian Governments (COAG) Energy Council, *Australia’s National Hydrogen Strategy*, 22 November 2019, online.
24 Australian Renewable Energy Agency (ARENA), ‘Hydrogen energy’, Australian Government, 23 November 2021, online.
25 ARENA, ‘Over $100 million to build Australia’s first large-scale hydrogen plants’, media release, Australian Government, 5 May 2021, online.
26 Scott Morrison, ‘Prime Minister’s address at the 76th session of the United Nations General Assembly’, Indian Government, 25 September 2021, online.
27 ‘English rendering of the text of PM’s address from the Red Fort on 75th Independence Day’, Indian Government, 15 August 2021, online.
28 Ministry of New and Renewable Energy (MNRE), ‘National Hydrogen Mission proposed’, Indian Government, 9 February 2021, online.
29 MNRE, ‘Hydrogen energy’, Indian Government, no date, online.
30 Ministry of Economy, Trade and Industry (METI), ‘Green growth strategy through achieving carbon neutrality in 2050’, Japanese Government, online.
31 METI, ‘Green growth strategy through achieving carbon neutrality in 2050’.
32 METI, ‘グリーンイノベーション基金事業の基本方針（概要）’ [Basic Policy for Green Innovation Fund Project (Summary)], Japanese Government, 12 March 2021, online.
33 ‘Fact sheet: President Biden sets 2030 greenhouse gas pollution reduction target aimed at creating good-paying union jobs and securing US leadership on clean energy technologies’, news release, The White House, 22 April 2021, online.
34 Hydrogen and Fuel Cell Technologies Office, *Hydrogen and Fuel Cell Technologies Office multi-year research, development, and demonstration plan*, Department of Energy, US Government, December 2014, online.
35 ’President Biden announces the Build Back Better Framework’, news release, The White House, 28 October 2021, online.
36 Department of Energy, ‘Fact sheet: The bipartisan infrastructure deal will deliver for American workers, families and usher in the clean energy future’, US Government, 9 November 2021, online.
37 Department of Energy, *Hydrogen Strategy: enabling a low-carbon economy*, US Government, July 2020, online.
38 ‘中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要’ [The 14th Five-Year Plan and the long-range objectives through the year 2035], PRC Government, 13 March 2021, online.
39 中国氢能源及燃料电池产业白皮书 [*China hydrogen energy and fuel cell industry White Paper*], China Hydrogen Alliance, *Sohu*, 2019, online.
40 Ministry of Science and Technology, ‘氢能技术’重点专项2021年度项目申报指南’ [Hydrogen Energy Technology key special project 2021: Project application guidelines], PRC Government, no date, online.
41 Indian conglomerates Adani and Reliance, and state-owned Indian Oil Corporation have announced intentions to establish clean hydrogen facilities in India. See: Indian Oil Corporation Limited, ‘IndianOil to build India’s first green hydrogen plant at Mathura refinery’, 23 July 2021, online; The Print, ‘Why Ambani and Adani’s hydrogen fight will decide if India can contribute to saving the planet’, 2 November 2021, online.
42 Solar Energy Technologies Office, ‘Solar Photovoltaic Cell Basics’, Department of Energy, US Government, no date, online.
43 ‘Global solar photovoltaic (PV) market, update 2021: market size, market share, major trends, and key country analysis to 2030’, *GlobalData*, 30 September 2021, online.
44 ‘Global solar photovoltaic (PV) market, update 2021: market size, market share, major trends, and key country analysis to 2030’, 3.
45 Nicholas Nhede, ‘Net-zero targets to triple Asia Pacific’s solar PV capacity by 2030’, *Power Engineering International*, 19 July 2021, online.

46 Simon Evans, ‘Solar is now “cheapest electricity in history”, confirms IEA’, *Carbon Brief*, 13 October 2020, online.
47 Solar Energy Technologies Office, ‘How does solar work?’, Department of Energy, US Government, no date, online.
48 ‘Concentrated solar power (CSP) vs photovoltaic (PV): an in-depth comparison’, *Solar Feeds*, 4 October 2021, online.
49 *Renewable 2021 global status report*, REN21, June 2021, 30, online.
50 ‘Renewable energy’, Center for Climate and Energy Solutions, no date, online.
51 ARENA, ‘Solar energy’, Australian Government, 11 November 2021, online.
52 DISER, *Technology Investment Roadmap discussion paper: a framework to accelerate low emissions technologies*, Australian Government, 21 May 2020, online; DISER, *Technology Investment Roadmap: first low emissions technology statement—2020*, Australian Government, 22 September 2020, online.
53 DISER, *Technology Investment Roadmap discussion paper: a framework to accelerate low emissions technologies*, 27.
54 ARENA, ‘Solar energy’; Clean Energy Finance Corporation, ‘Solar’, 30 June 2020, online.
55 Australian Centre for Advanced Photovoltaics, ‘Keeping Australia at the forefront of solar energy research and development’, 23 October 2021, online.
56 ARENA, ‘Solar energy’.
57 The Large-scale Solar (LSS) Funding Round was principally an infrastructure investment, focusing on mitigating the costs of the development, construction and financing of large-scale solar projects. The overall goal of LSS funding, and solar PV development in the first instance, was to reduce the carbon emissions of Australia’s energy sector. ARENA, *Insights from the first wave of large-scale solar projects in Australia*, Australian Government, January 2020, online.
58 Ministry of External Affairs, ‘National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow’, Indian Government, 2 November 2021, online.
59 ‘Statement by Prime Minister Modi at COP 21 plenary’, UN Framework Convention on Climate Change, 30 November 2015, online.
60 MNRE, *Year end review 2017*, Government of India, 27 December 2017, online.
61 Solar Energy Corporation of India, ‘National Solar Mission document’, Indian Government, online.
62 MNRE, *Production linked incentive scheme ‘National Programme on High Efficiency Solar PV Modules’*, Indian Government, 28 April 2021, online.
63 International Solar Alliance, ‘Framework agreement on the establishment of the International Solar Alliance’, November 2016, online.
64 METI, *Green growth strategy through achieving carbon neutrality in 2050*, Japanese Government, online.
65 METI, *Green growth strategy through achieving carbon neutrality in 2050*.
66 Trade and Industry Agency for Natural Resources and Energy, *Strategic Energy Plan*, METI, Japanese Government, July 2018, online.
67 Agency for Natural Resources and Energy, ‘国内外の再生可能エネルギーの現状と今年度の調達価格等算定委員会の論点案’ [Current status of renewable energies in Japan and abroad and draft of issues for the current fiscal year’s Procurement Price Calculation Committee], METI, Japanese Government September 2020, online.
68 Trade and Industry Agency for Natural Resources and Energy, *Strategic Energy Plan*.
69 METI, ‘グリーンイノベーション基金事業の基本方針 (概要) ’ [Basic Policy for Green Innovation Fund Project (Summary)], Japanese Government, 12 March 2021, online.
70 METI, ‘次世代型太陽電池の開発」プロジェクトに関する研究開発・社会実装計画’ [R&D and social implementation plan for the ‘Development of Next Generation Solar Cells’ project], Japanese Government, 1 October 2021, online.
71 ‘Fact sheet: President Biden sets 2030 greenhouse gas pollution reduction target aimed at creating good-paying union jobs and securing US leadership on clean energy technologies’, The White House, 22 April 2021, online.
72 Office of Energy Efficiency and Renewable Energy, *Solar futures study*, Department of Energy, US Government, September 2021, online. This study, which is considered emblematic of the Biden administration’s vision for solar and clean energy in combating climate change, modelled three solar scenarios:
1. A ‘reference scenario’, or business as usual, in which existing state and federal clean-energy policies are implemented while ‘lacking a comprehensive effort to decarbonize the grid’.
2. A decarbonisation (Decarb) scenario, which ‘assumes policies drive a 95% reduction (from 2005 levels) in the grid’s carbon dioxide emissions by 2035 and a 100% reduction by 2050’, with standard predictions for future energy demand.
3. A decarbonisation with electrification (Decarb+E) scenario, which includes ‘large-scale electrification of end uses [and] envisions decarbonization of the broader US energy system through large-scale electrification of buildings, transportation, and industry’.
The study found that, even under the reference scenario (in which concerted policy effort doesn’t eventuate), grid emissions will decline by 45% by 2035 and 61% by 2050 relative to 2005 levels based on market forces and technology advances alone. While solar deployment will need to increase fourfold to reach those rates in conjunction with implementing the other recommendations of the study, it shows that despite previous policy inertia US solar is beginning to move in the right direction.
73 ‘Fact sheet: Bipartisan infrastructure deal and Build Back Better agenda present bright future for solar power, good jobs, and more affordable energy’, The White House, 17 August 2021, online.
74 Department of Energy, ‘About the Solar Energy Technologies Office’, US Government, no date, online.
75 In 2021, the US hosted a Leaders Climate Summit, joined the India-led International Solar Alliance and agreed to cooperate on solar energy with China.
76 ‘Full text: Remarks by Chinese President Xi Jinping at Climate Ambition Summit’, *Xinhua*, 12 December 2020, online.
77 ‘国家能源局关于印发《2021年能源工作指导意见》的通知’ [Notice by the National Energy Administration of the Guiding Opinions on Energy Work in 2021], PRC Government, 19 April 2021, online.
78 National Energy Administration, ‘太阳能发电发展“十二五”规划‘ [The 12th Five-Year Plan on Solar Power Development], PRC Government,13 September 2012, online.
79 National Energy Administration, ‘国家能源局关于印发《太阳能发电发展“十三五”规划》的通知’ [Notice from the National Energy Administration on issuing the ‘13th Five-Year Plan on Solar Power Development’], PRC Government, 8 December 2016, online.
80 ‘光伏“十四五”迎倍速增长 诸多难题待破解’ [PV ‘14th Five-Year Plan’ ushered in double-speed growth, many problems to be solved], *Xinhua*, 15 December 2020, online.
81 ‘光伏“十四五”迎倍速增长 诸多难题待破解’ [PV ‘14th Five-Year Plan’ ushered in double-speed growth, many problems to be solved].
82 Muyu Xu, Tom Daly, ‘Update 2: China lifts renewable power subsidy for 2021 by nearly 5% y/y’, *Reuters*, 20 November 2020, online.
83 Liam Stoker, ‘China sets initial 2022 solar subsidy pot at US$357.2m’, *PV Tech*, 17 November 2021, online.
84 Ministry of Finance, ‘2016年中央本级政府性基金支出决算表’ [2016 central level government-managed funds expenditure], PRC Government, 13 July 2017, online; Ministry of Finance, ‘2017年中央本级政府性基金支出决算表’ [2017 central level government-managed funds expenditure], PRC Government, 12 July 2018, online; Ministry of Finance, ‘2018年中央本级政府性基金支出决算表’ [2018 central level government-managed funds expenditure], PRC Government, 18 July 2019, online; Ministry of Finance, ‘2019年中央本级政府性基金支出决算表’ [2019 central level government-managed funds expenditure], PRC Government, 6 July 2020, online; Ministry of Finance, ‘2020年中央本级政府性基金支出决算表’ [2020 central level government-managed funds expenditure], PRC Government, 29 June 2021, online.

85 Dali L Yang, ‘Wuhan officials tried to cover up Covid-19—and sent it careening outward’, *Washington Post*, 10 March 2020, online.

86 Heidi Ledford, Ewen Callaway, ‘Pioneers of revolutionary CRISPR gene editing win chemistry Nobel’, *Nature*, 7 October 2020, online.

87 David Cyranoski, ‘What CRISPR-baby prison sentences mean for research’, *Nature*, 3 January 2020, online.

88 ‘Herbert W Boyer and Stanley N Cohen’, Science History Institute, 1 December 2017, online.

89 Kirsten Gronlund, *Genome editing and the future of biowarfare: a conversation with Dr Piers Millett*, Future of Life Institute, 12 October 2018, online.

90 Sandy Sufian, Rosemarie Garland-Thomson, ‘The dark side of CRISPR’, *Scientific American*, 16 February 2021, online.

91 UNESCO, *Universal Declaration on the Human Genome and Human Rights*, UN, 11 November 1997, online.

92 ‘Cartagena Protocol on Biosafety to the Convention on Biological Diversity’, *United Nations Treaty Collection*, status as at 15 November 2021, online.

93 Floyd A Reed, *Evolutionary genetic engineering in the Indo-Pacific: conservation, humanitarian, and social issues*, Department of Biology, University of Hawaii at Manoa, 4 July 2018, online.

94 Emile Dirks, James Leibold, *Genomic surveillance*, ASPI, Canberra, 17 June 2020, online.

95 Mercy A Kuo, ‘Hacking Darwin: Genetic engineering and the future of humanity: insights from Jamie Metzl’, *The Diplomat*, 9 October 2019, online.

96 Critical Technologies Policy Coordination Office (CTPCO), *Blueprint for critical technologies*, Australian Government, 2021, online.

97 CTPCO, *Critical technologies discussion paper: health*, Australian Government, no date, online.

98 Department of Health, *Medical Research Future Fund 10-year Plan*, Australian Government, 29 October 2019, online.

99 Department of Health, *MRFF Genomics Health Futures Mission roadmap*, Australian Government, 1 October 2021, online; Department of Health, *MRFF Genomics Health Futures Mission implementation plan*, Australian Government, 1 October 2021, online.

100 Defence Science and Technology Group, ‘Next Generation Technologies Fund’, Department of Defence, Australian Government, 2021, online; Department of Defence, *Defence industry and capability innovation programs annual report 2019–2020*, Australian Government, 2020, online.

101 Department of Biotechnology, *National Biotechnology Development Strategy 2021–25*, Ministry of Health, Indian Government, no date, online.

102 Department of Biotechnology, *National Biotechnology Development Strategy 2021–25*, 20.

103 ‘Inside India’s genetic crop battlefield’, *Mint*, 20 June 2019, online.

104 Department of Biotechnology, *Draft document on genome edited organisms: regulatory framework and guidelines for risk assessment*, Ministry of Health, Indian Government, online.

105 Council for Science, Technology and Innovation, ‘バイオ戦略 2019’ [Bioeconomy Strategy 2019], Cabinet Office, Japanese Government, 11 June 2019, online.

106 Cabinet Office, ‘バイオ戦略フォローアップ (概要) ’ [Bioeconomy Strategy follow-up (summary)], Japanese Government, June 2021, online.

107 Issues relating to genetically modified organism appear mainly in the third area (Sustainable primary production system). Genetic engineering appears mainly in the sixth area (Biopharmaceuticals, regenerative medicine, cell therapy and gene-therapy-related industries).

108 National Institutes of Health (,NIH), *National Human Genome Research Institute: congressional justification FY 2022*, Department of Health and Human Services, US Government, May 2021, online.

109 NIH, *National Human Genome Research Institute: congressional justification FY 2022*.

110 NIH, *National Human Genome Research Institute: congressional justification FY 2022*.

111 NIH, *National Human Genome Research Institute: congressional justification FY 2022*.

112 NIH, *National Human Genome Research Institute: congressional justification FY 2022*.

113 State Council, ‘国家中长期科学和技术发展规划纲要 2006–2020’ [Outline of the National Medium and Long-term Science and Technology Development Plan], PRC Government, online.

114 Ministry of Science and Technology, ‘“十三五”生物技术创新专项规划’ [Thirteenth Five-Year Plan: Biotechnology Innovation Special Plan], PRC Government, online.

115 ‘中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要’ [The Fourteenth Five-Year Plan for the National Economic and Social Development of the People’s Republic of China and the Outline of Long-term Goals for 2035], PRC Government, online.

116 ‘中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要’ [The Fourteenth Five-Year Plan for the National Economic and Social Development of the People’s Republic of China and the Outline of Long-term Goals for 2035]; 聚焦新一代信息技术、生物技术、新能源、新材料、高端装备、新能源汽车、绿色环保以及航空航天、海洋装备等战略性新兴产业，加快关键核心技术创新应用，增强要素保障能力，培育壮大产业发展新动能。推动生物技术和信息技术融合创新，加快发展生物医药、生物育种、生物材料、生物能源等产业，做大做强生物经济。[Focus on the new generation of information technology, biotechnology, new energy, new materials, high-end equipment, new energy vehicles, green environmental protection, aerospace, marine equipment and other strategic emerging industries, accelerate the innovation and application of key core technologies, enhance the ability to guarantee elements, and foster growth. New momentum for industrial development. Promote the integration and innovation of biotechnology and information technology, accelerate the development of biomedicine, biobreeding, biomaterials, bioenergy and other industries, and expand and strengthen the bioeconomy.]

117 Hefei Institute of Physical Sciences, ‘Stem cell and stem cell transformation pilot items: 2020 application guide’ [干细胞及转化研究’试点专项 2020 年度项目申报指南], Chinese Academy of Sciences, no date, online.

118 Chinese Centre for Disease Control and Prevention, ‘Genetic modification: Important Items in the 13th Five-Year Plan discussed in Beijing meeting’ [转基因重大专项’十三五’课题启动会在京召开], 30 May 2016, online.

119 Jane McMullen, ‘Covid-19: Five days that shaped the outbreak’, *BBC News*, 26 January 2021, online.

120 Eliza Mackintosh, Gianluca Mexxofiore, Katie Polglase, ‘Inside the multibillion dollar race for a Covid-19 vaccine’, *CNN*, 14 August 2020, online.

121 China attempted to manipulate Taiwan through refusal to supply vaccine to Paraguay unless Paraguay cut diplomatic ties. The attempt was thwarted by India at Taiwan’s request. Simon Frankel Pratt, Jamie Levin, ‘Vaccines will shape the new geopolitical order’, *Foreign Policy*, 29 April 2021, online.

122 State Council Information Office, ‘中国驻乌兹别克斯坦大使 : 合作抗击疫情 共建健康丝路’ [Chinese Ambassador to Uzbekistan: Work together to fight the epidemic to build a Health Silk Road], PRC Governnent, 15 May 2020, online.

123 Chen Zhaoming, ‘制胜人民战争呼唤’大动员观’ [Winning the people’s war, calling for ‘the perspective of great mobilization’], *China Military Online*, 13 March 2020, online.

124 ‘Executive order on ensuring essential medicines, medical countermeasures, and critical inputs are made in the United States’, The White House, 6 August 2020, online.

125 Grady McGregor, Yvonne Lau, ‘The US’s first shot at vaccine diplomacy in Asia failed to deliver. Can a second do the trick?’, *Fortune*, 16 September 2021, online.

126 CTPCO, *Blueprint for critical technologies*.

127 CTPCO, *Blueprint for critical technologies*.

128 CTPCO, *Critical technologies discussion paper: health*.

129 Department of Health, ‘Medical Research Future Fund’, Australian Government, 2021, online.

130 Department of Health, *Australian Medical Research and Innovation Strategy 2016–2021*, Australian Government, 9 November 2016, online; Department of Health, *Medical Research Future Fund 10-year Plan*, Australian Government, 29 October 2019, online; Department of Health, *Medical Research Future Fund: Australian medical research and innovation priorities 2016–2018*, Australian Government, November 2016, online; Department of Health, *Medical Research Fund: Australian medical research and innovation priorities 2018–2020*, Australian Government, 8 November 2018, online; Department of Health, *Medical Research Future Fund: Australian medical research and innovation priorities 2020–2022*, Australian Government, 10 November 2020, online. MRFF research funding is distributed yearly in the form of grant payments to academic and medical research institutions. Tens of millions of dollars is directed to vaccine and biomedical countermeasures research.

131 Department of Health, Department of Agriculture, Water and the Environment, *Australia's National Antimicrobial Resistance Strategy—2020 and beyond*, Australian Government, 13 March 2020, online; Australian Commission on Safety and Quality in Health Care, 'Antimicrobials report reveals consistently high use areas in major cities', Australian Government, 23 September 2020, online.

132 Department of Health, *Medical Research Fund: Australian medical research and innovation priorities 2018–2020*; Department of Health, *Medical Research Future Fund: Australian medical research and innovation priorities 2020–2022*.

133 Defence Science and Technology Group, 'Medical Countermeasures Consortium', Department of Defence, Australian Government, 2021, online; Department of Defence, *Defence industry and capability innovation programs annual report 2019–2020*, Australian Government, 2020, online.

134 Defence Science and Technology Group, 'Next Generation Technologies Fund', Department of Defence, Australian Government, 2021, online; Department of Defence, *Defence industry and capability innovation programs annual report 2019–2020*

135 Department of Foreign Affairs and Trade, 'Quad initiative, Indo-Pacific Centre for Health Security', Australian Government, March 2021, online.

136 Department of Biotechnology, *National Biotechnology Development Strategy 2021–25*.

137 The Indian Council of Medical Research, Ministry of Science and Technology and Ministry of Health also participate in vaccine R&D and fund multiple state-owned research institutes that investigate emerging and existing biothreats such as the SARS, Nipah, Zika and coronaviruses.

138 Department of Biotechnology, 'Vaccine research and development', Ministry of Science and Technology, Indian Government, no date, online.

139 Department of Biotechnology, *National Biotechnology Development Strategy 2021–25*, online.

140 KV Venkatasubramanian, 'India prioritizes new research foundation, biotech, and health in new budget', *C&EN,* 29 March 2021, online.

141 'Fact sheet: Quad Summit', The White House, 12 March 2021, online.

142 Ministry of Health, Labour and Welfare, '新型インフルエンザワクチン開発・生産体制整備事業' [Development and production system improvement project for new influenza vaccines], Japanese Government, February 2010, online.

143 Cabinet decision, 'ワクチン開発・生産体制強化戦略' [Strategy to Strengthen Vaccine Development and Production System], Cabinet Secretariat, Office of Healthcare Policy, Japanese Government, 1 June 2021, online.

144 Cabinet decision, 'ワクチン開発・生産体制強化戦略' [Strategy to Strengthen Vaccine Development and Production System].

145 Council for Science, Technology and Innovation (CSTI), 'バイオ戦略 2019' [Bioeconomy Strategy 2019], Cabinet Office, Japanese Government, 11 June 2019, online.

146 CSTI, 'バイオ戦略 2019' [Bioeconomy Strategy 2019].

147 'Fact sheet: Quad Summit'.

148 Office of the Assistant Secretary for Preparedness and Response (OASPR), 'Project Bioshield', Department of Health and Human Services, US Government, 19 May 2021, online.

149 OASPR, 'Fiscal year 2021 budget-in-brief', Department of Health and Human Services, US Government, 28 June 2021, online.

150 OASPR, 'Project Bioshield'.

151 OASPR, 'Fiscal year 2021 budget-in-brief'.

152 Richard G Frank, Leslie Dach, Nicole Lurie, 'It was the government that produced COVID-19 vaccine success', *HealthAffairs*, 14 May 2021, online; Congressional Budget Office, 'Research and development in the pharmaceutical industry', US Congress, April 2021, 10, online.

153 'Congressional Budget Justification: Department of State, foreign operations, and related programs fiscal year 2020', 19 March 2019, 65, online.

154 'Congressional Budget Justification Department of State, foreign operations, and related programs fiscal year 2020', 65.

155 'Fact sheet: Quad Summit'.

156 '习近平在北京考察新冠肺炎防控科研攻关工作时强调 协同推进新冠肺炎防控科研攻关 为打赢疫情防控阻击战提供科技支撑' [When Xi Jinping inspected scientific research on the prevention and control of new coronary pneumonia in Beijing, he emphasised the coordinated promotion of scientific research on the prevention and control of new coronary pneumonia to provide scientific and technological support for winning the battle for epidemic prevention and control], *Xinhuanet*, 2 March 2020, online; '习近平在北京考察新冠肺炎防控科研攻关工作时强调 协同推进新冠肺炎防控科研攻关 为打赢疫情防控阻击战提供科技支撑' [Xi Jinping emphasised coordinated advancement when inspecting scientific research on the prevention and control of new coronary pneumonia in Beijing. Scientific research on new coronary pneumonia prevention and control provides scientific and technological support to win the battle for epidemic prevention and control], *Xinhuanet*, 13 March 2021, online.

157 Tsou Mun-tien, 'Technological innovation lending itself to the long-term effectiveness of public health industry's development' [科技创新引领卫生健康事业长效发展], *China Daily*, 5 December 2020, online.

158 Tsou Mun-tien, 'Technological innovation lending itself to the long-term effectiveness of public health industry's development' [科技创新引领卫生健康事业长效发展].

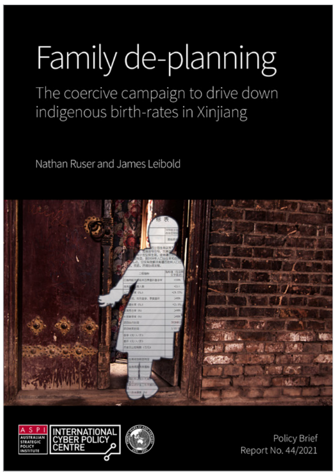
159 For a more comprehensive definition and explanation of the methodology behind the Patent Asset Index, consult the product website, online.

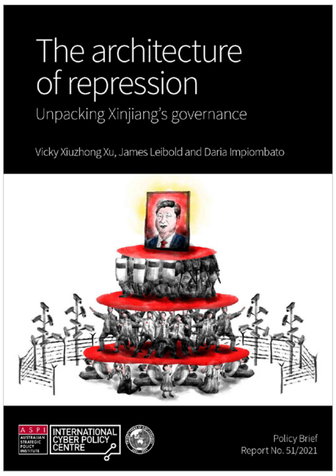
160 For more information on CiteScore, consult Elsevier's website, online.

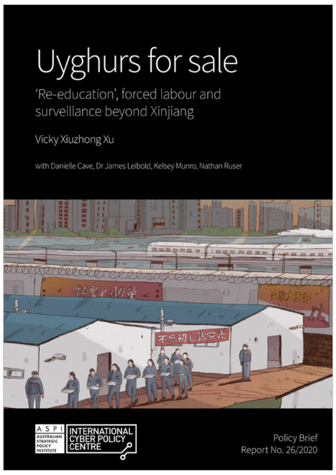
Acronyms and abbreviations

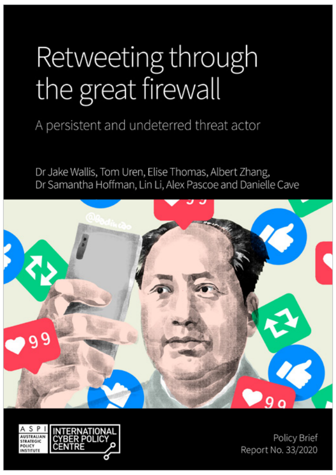
ASPR	Assistant Secretary for Preparedness and Response (US)
BARDA	Biomedical Advanced Research and Development Authority (US)
CI	competitive impact
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	concentrating solar power
DST Group	Defence Science and Technology Group
GWh	gigawatt hour
LSS	large-scale solar
MC	market coverage
MCM	medical countermeasure
MRFF	Medical Research Future Fund
Mt	megatonne
NGTF	Next Generation Technologies Fund
NHGRI	National Human Genome Research Institute (US)
NIH	National Institutes of Health (US)
PAI	Patent Asset Index
PPE	personal protective equipment
PRC	People's Republic of China
PV	photovoltaic
R&D	research and development
TR	technology relevance
RD&D	research, development and demonstration
IP	intellectual property
UN	United Nations

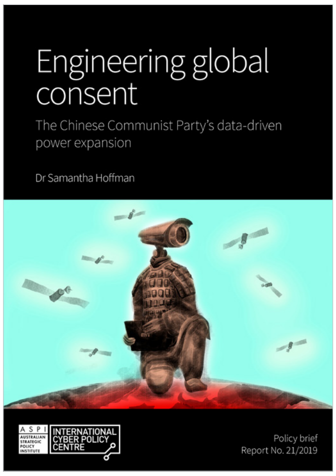
Some previous ICPC publications

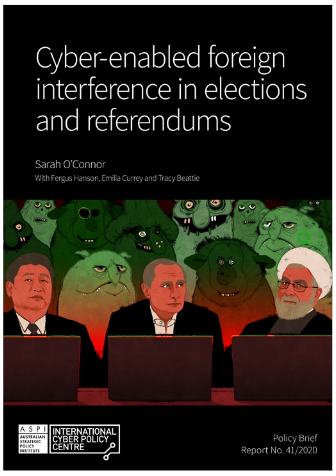












ASPI
AUSTRALIAN STRATEGIC POLICY INSTITUTE

INTERNATIONAL CYBER POLICY CENTRE

TWENTY YEARS OF ASPI STRATEGY 2001 - 2021