Climate Change and National Security: The Potential Application of Integrated Assessment Models

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1. Introduction

In the 2023 National Defence Strategic Review the Australian government confirmed "Climate change is now a national security issue" that "has the potential to significantly increase risk in our region." It further states climate change could lead to mass migration, increased demands for peacekeeping and peace enforcement, and intrastate and interstate conflict." (Commonwealth of Australia 2023).

The implications of climate change for Australian national security were also addressed in the 2018 report from the Foreign Affairs, Defence and Trade References Committee of the Australian Senate (Foreign Affairs Defence and Trade References Committee 2018). In summarising submissions to the inquiry, the committee noted evidence that climate change will directly impact the environment across different timescales. Amongst other recommendations, the Committee proposed the National Security Agency increase its knowledge of climate security and its capability of responding to climate risks, provide additional funding for international climate adaptation and disaster risk mitigation measures to support regional stability and adaptation, and build capacity by committing the Commonwealth Government to providing ongoing funding for climate science and research organisations.

A key issue in planning how to respond to climate change for national security is uncertainty. The most recent summary of the state of the global climate released by the Intergovernmental Panel on Climate Change (IPCC) states it is unequivocal humans have warmed the atmosphere, ocean, and land, leading to widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere. Yet it also shows there remains a large range of uncertainty around possible climate futures depending on the effect of future emissions on additional warming. There is also uncertainty about low-likelihood, high-impact tipping points in which the climate system or a climate sub-system crosses a critical threshold, leading to potentially abrupt and irreversible changes in natural systems (Lee et al. 2023).

One strategy developed to assess potential future climate change impacts, and the effect policies have on future climate trajectories is Integrated Assessment Modelling. Integrated Assessment Models (IAMs) are quantitative models designed to study future change and the effect of policies on climate pathways. Broadly speaking, IAMs are used to understand the impact of climate change on different factors of interest, the economic impact of climate mitigation policies, or a combination of both, although there are substantial uncertainties in cost estimates depending on assumptions made about the future costs of technologies and how policies are designed and implemented (Weyant 2017).[1]

In this paper we address the potential application of IAMs to the practice of strategic foresight in defence planning. We propose that IAMs are a potentially useful tool for assessing the implications of potential future states of the world related to climate change for long-run defence planning. We focus particularly on IAMs as a tool for exploring the implications of climate change for the low carbon energy transition, and argue they enable analysts to test the implications of different assumptions about technology availability costs on the composition of energy supply and demand in important states in the Asia-Pacific region. IAMs also provide a way of considering the strategic implications of what will be a decades-long transition to zero carbon economies.

In the next section we discuss climate change as a national security challenge, before outlining the function, characteristics and applications of IAMs in section three. In section four we then introduce possible applications of IAMs in strategic foresight for the purposes of defence planning. We conclude by offering a number of policy recommendations.

2. National Security Implications of Climate Change

Climate-related financial risks can be categorised into direct physical risks, defined by the IPCC as the "adverse physical impact of hazards related to climate change", and transition risks, defined as "negative…adjustments in assets' values resulting directly or indirectly from the low-carbon transition" (Shukla et al. 2023). This categorisation of

[1] There are limitations of IAMs identified that potentially weaken their utility in modelling potential climate futures. For a trenchant critique see Pindyck (2017).

physical and transition risk is also useful in examining national security challenges which emerge as a result of a changing climate. Changes in national security risks can be separated into those directly caused by physical changes in the climate, and changes induced by policies implemented as part of a response to climate change which have an effect on energy-related national security risks faced by states.

In terms of physical risk, the most recent assessment of the state of the climate from the IPCC records evidence shows the “projected adverse impact and related losses and damages from climate change escalate with every increment of global warming” with very high confidence. Physical effects from climate change are myriad, including the “likelihood of abrupt an irreversible changes and their impacts increase with higher global warming levels”. As the world continues to warm, adaptation actions are likely to become more constrained and less effective, loss and damage will increase, and some human and natural systems will no longer be able to effectively adapt (Lee et al. 2023). A particularly challenging physical risk is sea level rise, which will continue for millennia, with extreme sea level events becoming 20 to 30 times more frequent by 2050, and one billion people exposed to this risk (Lee et al. 2023, 45). Consistent with these physical risks, the 2023 Australian Defence Strategic Review highlights the implications for the strategic environment in which Australia is located, stating that:

> “Climate change will increase the challenges for Australia and Defence, including increased humanitarian assistance and disaster relief tasks at home and abroad. If climate change accelerates over the coming decades it has the potential to significantly increase risk in our region. It could lead to mass migration, increased demands for peacekeeping and peace enforcement, and intrastate and interstate conflict.” (Commonwealth of Australia 2023)

Sea level rise and extreme weather events also have implications for existing energy related infrastructure. In an assessment of the implications of sea level rise and extreme events for Europe's coastal energy infrastructure, for example, Brown, Hanson, and Nicholls (2014) find there are 158 major oil/gas/LNG/tanker terminals in Europe's coastal zones, as well as 71 operating nuclear reactors, concluding that adapting coastal energy infrastructure to rising sea levels will be a crucial issue for governments and industry in the coming decades.

The effects of climate change extend beyond physical risk to include a complex set of interactions between transition policies being put in place by governments in response to climate change, and the energy-related national security risks faced by states. Energy security has been a core concern of states since industrialisation. In the Indo Pacific region energy security risks have historically been dominated by the dependence of many states on imports of fossil fuels, for example, including Australia’s major trading partners.

The low carbon energy transition will have an increasingly large impact on the structure and volume of trade in energy-related commodities. Policies supporting energy transition such as the electrification of transport and industrial and other processes that currently use liquid and gaseous fuels, for example, coupled with the decarbonisation of electricity systems through the deployment of renewable energy, should “make energy supply, energy mix, and energy trade less dependent upon assumptions of fossil resource availability” (Cherp et al. 2016). The potential of hydrogen as an energy carrier will also have important geopolitical consequences as new patterns of trade and investment emerge (International Renewable Energy Agency 2022).

Geopolitical leverage conferred on exporters of energy commodities will also change as a result of the energy transition (Downie 2022). A core concern historically for governments has been potential vulnerability to politically-induced shocks in oil production, as occurred in the 1970s (Hughes and Long 2015). Reflecting this, Bordoff and O’Sullivan Meghan (2022, 69) argue that “the transition will reconfigure many elements of international politics that have shaped the global system since at least World War II”. Under the International Energy Agency's Net Zero emissions scenario for the energy sector fossil fuel use falls as a share of total energy supply from 80% in 2020 to just over 20% in 2050. Oil demand falls from 90 million barrels a day in 2020, to 72 million barrels a day in 2030, and 24 million barrels a day in 2050 (International Energy Agency 2021, 57), with enormous implications for major trading partners of Australia such as China and Japan.

A core challenge in analysing these changes is uncertainty. In addition to uncertainties around the nature and extent of physical climate risks, there are also large uncertainties about the mix of technologies different countries will decarbonise their economies. There is also uncertainty about the pace of transition. While many governments have committed to Net Zero targets, for example, the policies being used in the near to medium term to support transition continue to be developed. There is also the risk of an implementation gap emerging, in which governments make long-term commitments but do not put in place the policy is required to meet those commitments. The longer that governments delay the low carbon energy transition, the longer risks associated with traditional fossil fuels will continue to be an important part of their energy security concern.

A potential solution to understanding this uncertainty for national security and defence planning is the use of IAMs. IAMs incorporate both economic and natural processes contributing to greenhouse gas emissions, and allow for the characterization and analysis of future uncertainty (Morgan and Dowlatabadi 1996). In the next section we discussed the function characteristics and applications of IAMs. We then move on to discuss possible applications of IAMs for national security planning.

3. The Function, Characteristics and Applications of IAMs

There are numerous quantitative models that have been developed to study the links between emissions from a range of sectors of the economy, the concentration of Greenhouse Gases (GHGs), the impact of these emissions on temperature/climate change, and the effect of technological change and/or the impact of various types of public policies. If a model has most of these elements, then they are conducting “integrated assessment of climate change” and are typically referred to as IAMs. There are over 20 global scale models that can be classified as either detailed process (DP) IAMs and benefit–cost (BC) IAMs (Weyant 2017).

The pioneering work and initial development of an IAM, led by William Nordhaus, led to the award of the 2018 Nobel Memorial Prize in Economic Sciences and is the classic example of a benefit–cost (BC) IAM. The DICE (Dynamic Integrated Climate and Economy) model developed by Nordhaus is a relatively simple model that was developed to compare the optimal climate mitigation policy trajectory using an assessment of abatement costs and climate change damages (Nordhaus 1994). A key question was whether emissions reductions should occur in the near future based on the present value of future damages from climate change. Other examples of BC IAMs are the Framework for Uncertainty, Negotiation, and Distribution (FUND) and Policy Analysis of the Greenhouse Effect (PAGE) models (Narita, Tol, and Anthoff 2010).

Detailed process IAMs tend to disaggregate key factors and assess key issues using detailed regional and sectoral representations. This tends to be motivated by informing conversations on the optimal emissions pathway and associated policies to achieve them. Topics include the assessment of the impacts of delayed policy action (Riahi et al. 2015) and how technological change will impact sectoral emissions (Eom et al. 2015). Other DP IAMs utilise projections of the physical impacts of climate change, such as changes in crop growth, and temperature-related mortality (Weyant 2017).

DP IAMs have also been used to set renewable energy and/or emission targets. The European Commission has a suite of models that inform policy development with analysis of environmental, economic and social impacts, including cost-effectiveness analysis. These include the POLES-JRC, PRIMES and PRIMES-TREMOVE models, which are a global energy model, a EU energy system model, and a transport model, respectively (European Commission 2023). The results from these models have informed the 2020 and 2030 emissions targets. The Global Change Assessment Model (GCAM) and Office of Policy – National Energy Modelling System (OP-NEMS) were used to assess the possible pathways to Net Zero emissions in the US by 2050. A key contribution of GCAM was to illustrate how the pathways may differ based on assumptions that include lower industrial emissions, lower CO2 removal technologies and land use change, and lower non-CO2 reductions (United States Department of State and United States Executive Office of the President 2021).

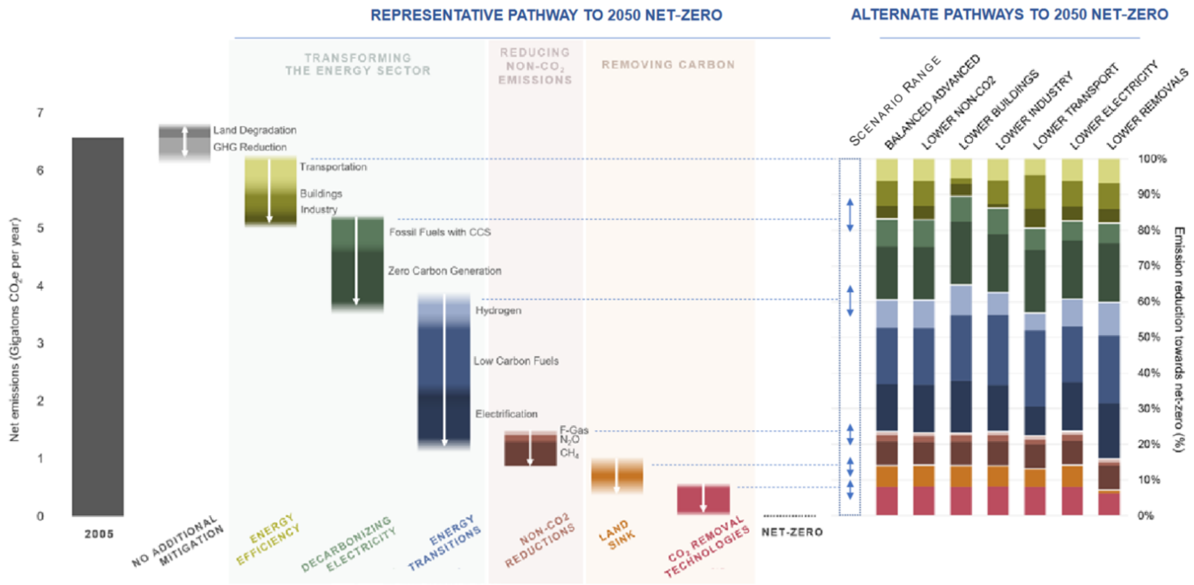

Figure 1 - Emissions Reductions Pathways to Achieve 2050 Net-Zero Emissions in the United States, source: (United States Department of State and United States Executive Office of the President 2021)

IAMs have had an important role as part of the Intergovernmental Panel on Climate Change reports, which is reflected in IAMs being the subject of a whole chapter in each report (Intergovernmental Panel on Climate Change 2007, 2014, 2022). These chapters contain a model comparison where numerous scenarios are compared to summarise the literature on how IAMs have modelled climate policy and technology assumption sensitivity analyses (Weyant 2017). However, it has been the case that researchers and the IPCC have been criticised for not highlighting the complexities and uncertainties associated with the underlying model formulations, key model inputs and parameters, such as the impact of assumptions on economic growth and technological change (Fisher-Vanden and Weyant 2020). This led to a literature that focuses on model diagnostics, which can be based on hindcasting or model comparison exercises (Schwanitz 2013).

Often, IAMs are calibrated to aggregated national or regional data, such as the International Energy Agency's World Energy Outlook (WEO). Some modelling initiatives have focused on improving the representation of key segments of a sector using facility level data. Examples include a focus on the number of coal electricity generation facilities that are in planning, permitting, or construction and the possible need for early retirement of these facilities to achieve climate policy targets (Cui et al. 2019; Cui, Hultman, Cui, McJeon, Yu, Edwards, Sen, Song, Bowman, and Clarke 2021; Edwards et al. 2022).

A key advantage in using IAMs is they can place bounds on the range of estimated costs, even where substantial uncertainties remain (Weyant 2017). IAMs also have a useful role through "what if" assessments of potential future economic and climatic environments, while taking into account this uncertainty. While transitioning away from coal is a common finding of the modelling of emission reduction policies (Cui et al. 2019; Cui, Hultman, Cui, McJeon, Yu, Edwards, Sen, Song, Bowman, and Clarke 2021; Edwards et al. 2022), the mix of fuels that a country transitions towards is uncertain and modelling is needed to understand the potential shares of gas, biomass, solar, wind and nuclear. Future fuel mixes will be determined by technological costs, available resources, and trade. Modelling the dynamics of these factors is also a key strength of IAMs.

The Global Change Analysis Model (GCAM) which we focus on in this paper, is an IAM developed at the Pacific Northwest National Laboratory in the United States that incorporates the interaction of five systems: the economy, the energy system, the climate system, water, and agriculture and land use. As such, it allows for analysis of physical and socio- economic systems to address interactions between these in a single computational platform that is not highly demanding of computational power. Key outputs from scenario analyses using GCAM are:

- Energy: energy demand and flows, technology deployment, energy prices.
- Agriculture and Land Use: prices and supply of all agricultural and forest products, land use and land use change.
- Water: demand and supply for agricultural, energy, and household water use
- Greenhouse Gas (GHG) Emissions: 24 GHG and short-lived species: CO2, CH4, N2O, halocarbons, carbonaceous aerosols, reactive gases, and sulphur dioxide.

In climate research, GCAM has been used to address a wide variety of research questions about human-climate interactions from the global to the national in scope, including issues such as the future impact of climate on global agricultural yields, water demands associated with long-term electricity plans under different developmental pathways in India, and the implication of uncertainty about the renewable energy resource base for projections of the global role of wind and solar power projections globally.

The key characteristics of GCAM are as follows:

- Transparency and Open Access: A key issue with IAMs as analytic tools is the importance of assumptions in determining model outcomes. GCAM is fully documented and available online, supporting transparency and open access.
- Wide Coverage of Fuels and Sectors: As noted above, GCAM models demand and supply of coal, gas, bioenergy, nuclear, solar, wind and hydroelectricity.
- Traded fuels: Fossil-fuels (i.e. coal, gas, and oil) are traded across regions in the model, allowing modelling of import demands of fuels under different scenarios.
- Policy-based Scenarios: GCAM allows the modelling of different "what if" policy scenarios, such as emission reduction targets, technological subsidies or restrictions.
- Uncertainty Analysis: The model runs using a dynamic recursive process, which approximates a decision maker that is unable to foresee future changes. This contrasts with another class of IAMs called intertemporal optimization models, which assume agents in the model have full information about the future when they make decisions.

GCAM offers a potentially useful tool for long-term defence-related scenario analysis as it enables the flexible assessment of future scenarios concerning key areas of interest to Australia's interests related to energy, land, water, climate, and socio-economic factors in the Indo-Pacific region, including the potential role of feedback loops and compounding effects.

The open-source nature of the GCAM IAM also allows for the development of additional modules to increase resolution of assessments In the Asia-Pacific region. At present, geographic and sectoral coverage of the model in the Asia-Pacific is as follows:

- Australia/NZ
- China
- India
- Indonesia
- Japan

- South Korea
- Taiwan, and
- Rest of Southeast Asia and Pacific.

4. Possible Use of IAMs in Long-run Strategic Planning

Uncertainty and complexity are hallmarks of strategic planning. A key tool developed to assist in defence planning is the use of strategic foresight tools. In a report on the design and implementation of scenario analysis in defence planning by the Australian Defence Science and Technology Organisation of the Department of Defence, Nguyen and Dunn (2009) describe procedures for identifying a problem for analysis and synthesising a range of possible scenarios for analysis. Leigh (2003) notes that strategic foresight processes would lead to a more “focused, innovative and creative government” in Australia. Elsewhere, Durst et al. (2015) document the foresight processes used by the German Federal Armed Forces, which included environmental planning, impact uncertainty analysis, and explorative scenario construction. Davis (2016) recommends strategic planning in the United States should prioritise capabilities attuned to a proper treatment of uncertainty, and make clear key assumptions for use in analyses. Dreyer and Stang (2013) review practices used by governments in foresight activities, recommending proper identification of target audiences, maintaining close ties with senior decision makers, establishing programmes rather than single projects, and using scenario-based analysis. In a review for the Swiss Federal Commission for Nuclear, Biological and Chemical Protection and the Federal Office for Civil Protection, Kohler (2021) summarizes different forecasting techniques, and notes that “foresight can help to prioritize which areas would profit from more data collection and resilience.”

Factor relevant to climate risk	How can be addressed with IAMs?
Displaced population, migration	IAMs typically use population as a key assumption, and population change due to climate change and transition risks can be reflected to the model. Additionally, most IAMs allow users to choose a pathways or define a new pathways with different population and urbanization projections (Jiang and O'Neill 2017; Kc and Lutz 2017). IAMs covers several world regions depending on their complexity. Most IAMs have the flexibility to allow creation of a new region by disaggregating a combined area. Most IAMs also allow users to re-design a region to include detailed subnational representation. For instance, the GCAM-USA model was created to represent U.S. economic, energy, and water systems for 51 state-level regions (50 states plus the District of Columbia) and to explore the impacts on subnational level (Binsted et al. 2022; Shi et al. 2017).
Food, agriculture, land use	Land use is another essential input for IAMs to define land area and land type. Depending on the complexity of the model, land use can be modelled to understand the future changes in a specific land of a region for agriculture, water and energy use (Calvin et al. 2022). Furthermore, changes in agriculture sector and food security could be examined by IAMs to understand the impact of climate change and transition related security risks (Edmonds et al. 2017; Hasegawa et al. 2020).
Energy, infrastructure	Energy is a broad and significant topic for national security as well as IAMs. Most IAMs include energy sectors demand-supply representation including residential, industry, transport, agriculture, etc. When generally more broader energy related questions could be answered by using IAMs, the role of specific technologies (such as wind technology) (Eurek et al. 2017) or the impact of climate change and transition related security risks on a particular sectors (such as steel and cement) can be studied (Van Ruijven et al. 2016).
Natural resources	Natural resources are a core energy security concern of governments. IAMs are widely used models for developing scenarios of the future of resources including phasing out fossil fuels (Cui et al. 2022; Cui, Hultman, Cui, McJeon, Yu, Edwards, Sen, Song, Bowman, Clarke, et al. 2021; Muttitt et al. 2023), stranded assets (Mercure et al. 2018), renewable energy integration and low carbon transition (Fragkos et al. 2021; Kumar 2016) , innovative technology substitution,

	even the effect of shocks (such as Russia-Ukraine war) (Liu et al. 2023; Rudakov 2022).
Water	Water is a significant topic for national security as well as energy and food. Not only including residential and industrial usage in the models, but also modelling water resources in the energy context (hydro energy, hydrogen etc) gained importance to develop successful strategies and prioritize water use in case of scarcity (Cui et al. 2018; Khan et al. 2023).
Climate transition policies	To address climate change and its risks, several global, regional and sectoral strategies including different policy portfolios are studied since the Paris Agreement. IAMs are useful tools for decision makers to see the future impacts of policies, including understanding the synergies and trade-offs between different policies in terms of national security, (Browning et al. 2023; Lam and Mercure 2021; Moreno et al. 2023).

To date IAMs have been used to examine the implications of climate change for energy security, with a particular focus on Europe. Guivarch and Monjon (2017), for example, find a nonlinear relationship between energy transition and energy security, and also suggest low cost and wide availability of low carbon power generation technologies will rapidly reduce European reliance on the import of fuels for power generation while increasing the robustness of the energy system. In an assessment of the energy security implications of long-term climate scenarios for China, India, the European Union, and the United States, Jewell et al. (2014) compare results from six different IAMs and find climate policies lower energy trade globally and reduce energy related imports of major economies, suggesting there are energy security co-benefits from the introduction of more stringent policies. Related, McCollum et al. (2014) find across multiple IAMs that energy system resilience increases along with a reduction in oil imports as climate change mitigation policies increase in stringency. They also find, however, that energy efficiency policies are unlikely to improve energy independence, and that there may be an increased concentration in regions exporting oil and gas as countries decarbonize, with negative implications for energy security.

Taken together, these results suggest national security concerns associated with fossil fuel import dependence may fall in the long-run, however there are potential nonlinearities and complexities emerging from the substitution of coal for gas in the short to medium term, coupled with the potential for increased market concentration in fossil fuel markets. Supply chains in the energy sector will grow in complexity as the range of technologies used to supply energy services increase.

IAMs can be used to assess how decarbonization trajectories affect the energy security risks faced by states in the Asia-Pacific region, including Australia. In the case of Australia and the Asia Pacific, the pace and direction of decarbonization will also have a substantial effect on the energy security related risks faced by governments. It is possible, for example, that if thermal coal rapidly exits power generation systems and is replaced buy gas, this will increase energy security risks for governments in the region. In addition, coal, gas, and oil will continue to be used as countries chart trajectories towards Net Zero, however the range of technologies that are available to support decarbonization are likely to influence the pace with which these fuels exit the market. Furthermore, regional governments will use increasing amounts of low carbon technologies to support broad electrification, as well as the decarbonization of their electricity systems, leading to greater complexity in supply chains used to support the provision of energy services to populations. Analysis of scenarios using IAMs could be used to support foresight analysis focused on how the strategic behaviour of states in the Indo-Pacific are likely to change in response to such shifts in the structure of supply chains supporting energy systems regionally.

A second example is the implications of China's economic and military rise for the future trajectory of climate change regionally and globally. China is the largest global emitter of GHG emissions globally, and has committed to achieving carbon neutrality by 2060, and peaking CO_2 emissions by 2030. In addition to being a large emitter of greenhouse gases, China also dominates the supply chains for key technologies involved in the low carbon energy transition. The International Energy Agency, for example, records that China held 79% of the world's polysilicon production capacity in 2021, 97% of global production capacity for solar wafer manufacturing, and 85% of so cell production. China also holds an important share of production for raw materials used in solar manufacturing (International Energy Agency 2022). Strategic competition between China and the United States has potential implications not only for climate policies, but also for the costs of kilo carbon technologies relative to more emissions intensive substitutes. The implications of restrictions on trade in low carbon technologies because of increased geostrategic competition thus has implications for the ability of the world to decarbonize. Assessing the implications of a more fragmented world for trade and investment in key low carbon technologies aligns with the capabilities of IAMs.

5. Conclusion and Discussion

IAMs are an important tool climate scientists used to assess the future impacts of climate change, and the impact of public policies - including but not limited to - those designed to transition to low carbon economies, on climate futures and other important factors such as the structure of energy supply and demand within countries, regionally, or globally. A benefit of IAMs is their ability to conduct “if-then” analysis, in which the effect of climate transition policies can be assessed in terms of their future implications for energy supply and demand using a robust quantitative framework. A second benefit of IAMs is the ability to address future uncertainty using scenario-based analyses.

In the European and North American contexts, IAMs have been used to assess issues such as the energy security implications of low carbon energy transition. Yet their application to analysing future scenarios in the Asia Pacific related to national security issues is limited. IAMs thus represents a potentially useful tool for use in strategic foresight exercises, complementing other approaches such as the use of horizon scanning, trend analysis, the use of the Delphi method or expert surveys in forecasting, and other approaches (Kohler 2021). Carrying out assessments using IAMs requires an investment in human capital to enable capabilities development, including through working with the research sector. Understanding the future implications of climate change, and the effect of strategic issues such as the economic and military rise of China for the future of climate change mitigation in the Indo Pacific, warrants consideration of such an approach in order to inform long-term decision-making.

References

Binsted, Matthew et al. 2022. "GCAM-USA v5.3_water_dispatch: Integrated Modeling of Subnational US Energy, Water, and Land Systems within a Global Framework." *Geoscientific Model Development* 15(6): 2533–59.

Bordoff, Jason, and L. O'Sullivan Meghan. 2022. "Green Upheaval: The New Geopolitics of Energy." *Foreign Aff.* 101: 68.

Brown, Sally, Susan Hanson, and Robert J. Nicholls. 2014. "Implications of Sea-Level Rise and Extreme Events around Europe: A Review of Coastal Energy Infrastructure." *Climatic Change* 122(1): 81–95.

Browning, Morgan et al. 2023. "Net-Zero CO2 by 2050 Scenarios for the United States in the Energy Modeling Forum 37 Study." *Energy and Climate Change* 4: 100104.

Calvin, Katherine V., Abigail Snyder, Xin Zhao, and Marshall Wise. 2022. "Modeling Land Use and Land Cover Change: Using a Hindcast to Estimate Economic Parameters in Gcamland v2.0." *Geoscientific Model Development* 15(2): 429–47.

Cherp, Aleh et al. 2016. "Global Energy Security under Different Climate Policies, GDP Growth Rates and Fossil Resource Availabilities." *Climatic Change* 136: 83–94.

Commonwealth of Australia. 2023. *National Defence: Defence Strategic Review*. Canberra: Commonwealth of Australia.

Cui, Ryna Yiyun et al. 2018. "Regional Responses to Future, Demand-Driven Water Scarcity." *Environmental Research Letters* 13(9): 094006.

———. 2019. "Quantifying Operational Lifetimes for Coal Power Plants under the Paris Goals." *Nature communications* 10(1): 4759.

Cui, Ryna Yiyun, Nathan Hultman, Diyang Cui, Haewon McJeon, Sha Yu, Morgan R Edwards, Arijit Sen, Kaihui Song, Christina Bowman, and Leon Clarke. 2021. "A Plant-by-Plant Strategy for High-Ambition Coal Power Phaseout in China." *Nature communications* 12(1): 1468.

Cui, Ryna Yiyun, Nathan Hultman, Diyang Cui, Haewon McJeon, Sha Yu, Morgan R. Edwards, Arijit Sen, Kaihui Song, Christina Bowman, Leon Clarke, et al. 2021. "A Plant-by-Plant Strategy for High-Ambition Coal Power Phaseout in China." *Nature Communications* 12(1): 1468.

Cui, Ryna Yiyun et al. 2022. "A U.S.–China Coal Power Transition and the Global 1.5 °C Pathway." *Advances in Climate Change Research* 13(2): 179–86.

Davis, Paul. 2016. *Capabilities for Joint Analysis in the Department of Defense: Rethinking Support for Strategic Analysis*. RAND Corporation. http://www.rand.org/pubs/research_reports/RR1469.html (August 22, 2022).

Downie, Christian. 2022. "Geopolitical Leverage in the Energy Transition: A Framework for Analysis and the Case of Australia."

Dreyer, Iana, and Gerald Stang. 2013. "Foresight in Governments – Practices and Trends around the World."

Durst, Carolin et al. 2015. "A Holistic Approach to Strategic Foresight: A Foresight Support System for the German Federal Armed Forces." *Technological Forecasting and Social Change* 97: 91–104.

Edmonds, James A., Robert Link, Stephanie T. Waldhoff, and Ryna Cui. 2017. "A Global Food Demand Model For The Assessment of Complex Human-Earth Systems." *Climate Change Economics* 08(04): 1750012.

Edwards, Morgan R et al. 2022. "Quantifying the Regional Stranded Asset Risks from New Coal Plants under 1.5° C." *Environmental Research Letters* 17(2): 024029.

Eom, Jiyong et al. 2015. "The Impact of Near-Term Climate Policy Choices on Technology and Emission Transition Pathways." *Technological Forecasting and Social Change* 90: 73–88.

Eurek, Kelly et al. 2017. "An Improved Global Wind Resource Estimate for Integrated Assessment Models." *Energy Economics* 64: 552–67.

European Commission. 2023. *Modelling Tools for EU Analysis*. https://climate.ec.europa.eu/eu-action/climate-strategies-targets/economic-analysis/modelling-tools-eu-analysis_en.

Fisher-Vanden, Karen, and John Weyant. 2020. “The Evolution of Integrated Assessment: Developing the next Generation of Use-Inspired Integrated Assessment Tools.” *Annual Review of Resource Economics* 12: 471–87.

Fragkos, Panagiotis et al. 2021. “Energy System Transitions and Low-Carbon Pathways in Australia, Brazil, Canada, China, EU-28, India, Indonesia, Japan, Republic of Korea, Russia and the United States.” *Energy* 216: 119385.

Guivarch, Céline, and Stéphanie Monjon. 2017. “Identifying the Main Uncertainty Drivers of Energy Security in a Low-Carbon World: The Case of Europe.” *Energy Economics* 64: 530–41.

Hasegawa, Tomoko et al. 2020. “Food Security under High Bioenergy Demand toward Long-Term Climate Goals.” *Climatic Change* 163(3): 1587–1601.

Hughes, Llewelyn, and Austin Long. 2015. “Is There an Oil Weapon?: Security Implications of Changes in the Structure of the International Oil Market.” *International Security* 39(3): 152–89.

Intergovernmental Panel on Climate Change. 2007. *AR4 Climate Change 2007: Mitigation of Climate Change*. https://www.ipcc.ch/report/ar4/wg3/.

———. 2014. *AR5 Climate Change 2014: Mitigation of Climate Change*. https://www.ipcc.ch/report/ar5/wg3/.

———. 2022. *AR6 Climate Change 2022: Mitigation of Climate Change*. https://www.ipcc.ch/report/ar6/wg3/.

International Energy Agency. 2021. *Net Zero by 2050 - A Roadmap for the Global Energy Sector*. Paris: International Energy Agency.

International Renewable Energy Agency. 2022. *Geopolitics of the Energy Transformation The Hydrogen Factor*. Abu Dhabi: International Renewable Energy Agency.

Jewell, Jessica et al. 2014. “Energy Security of China, India, the E.U. and the U.S. under Long-Term Scenarios: Results from Six IAMs.” *Climate Change Economics*: 54.

Jiang, Leiwen, and Brian C. O’Neill. 2017. “Global Urbanization Projections for the Shared Socioeconomic Pathways.” *Global Environmental Change* 42: 193–99.

Kc, Samir, and Wolfgang Lutz. 2017. “The Human Core of the Shared Socioeconomic Pathways: Population Scenarios by Age, Sex and Level of Education for All Countries to 2100.” *Global Environmental Change* 42: 181–92.

Khan, Zarrar et al. 2023. “Global Monthly Sectoral Water Use for 2010–2100 at 0.5° Resolution across Alternative Futures.” *Scientific Data* 10(1): 201.

Kohler, Kevin. 2021. *Strategic Foresight: Knowledge, Tools, and Methods for the Future*. ETH Zurich. http://hdl.handle.net/20.500.11850/505468 (May 17, 2023).

Kumar, Subhash. 2016. “Assessment of Renewables for Energy Security and Carbon Mitigation in Southeast Asia: The Case of Indonesia and Thailand.” *Applied Energy* 163: 63–70.

Lam, Aileen, and Jean-Francois Mercure. 2021. “Which Policy Mixes Are Best for Decarbonising Passenger Cars? Simulating Interactions among Taxes, Subsidies and Regulations for the United Kingdom, the United States, Japan, China, and India.” *Energy Research & Social Science* 75: 101951.

Lee, H. et al. 2023. “Synthesis Report of the IPCC Sixth Assessment Report (AR6).”

Leigh, Andrew. 2003. “Thinking Ahead: Strategic Foresight and Government.” *Australian Journal of Public Administration* 62(2): 3–10.

Liu, Li-Jing et al. 2023. “Carbon Emissions and Economic Impacts of an EU Embargo on Russian Fossil Fuels.” *Nature Climate Change* 13(3): 290–96.

McCollum, David et al. 2014. “Fossil Resource and Energy Security Dynamics in Conventional and Carbon-Constrained Worlds.” *Climatic Change* 123(3): 413–26.

Mercure, J.-F. et al. 2018. “Macroeconomic Impact of Stranded Fossil Fuel Assets.” *Nature Climate Change* 8(7): 588–93.

Moreno, Jorge et al. 2023. “Assessing Synergies and Trade-Offs of Diverging Paris-Compliant Mitigation Strategies with Long-Term SDG Objectives.” *Global Environmental Change* 78: 102624.

Muttitt, Greg, James Price, Steve Pye, and Dan Welsby. 2023. “Socio-Political Feasibility of Coal Power Phase-out and Its Role in Mitigation Pathways.” *Nature Climate Change* 13(2): 140–47.

Narita, Daiju, Richard SJ Tol, and David Anthoff. 2010. “Economic Costs of Extratropical Storms under Climate Change: An Application of FUND.” *Journal of Environmental Planning and Management* 53(3): 371–84.

Nguyen, Minh-Tuan, and Madeleine Dunn. 2009. *Some Methods for Scenario Analysis in Defence Strategic Planning*. Defence Science and Technology Organisation.

Nordhaus, William D. 1994. 31 *Managing the Global Commons: The Economics of Climate Change*. MIT press Cambridge, MA.

Pindyck, Robert S. 2017. “The Use and Misuse of Models for Climate Policy.” *Review of Environmental Economics and Policy* 11(1): 100–114.

Riahi, Keywan et al. 2015. “Locked into Copenhagen Pledges—Implications of Short-Term Emission Targets for the Cost and Feasibility of Long-Term Climate Goals.” *Technological Forecasting and Social Change* 90: 8–23.

Rudakov, Andrey. 2022. “European Union Can Break Free from Russia’s Fossil Fuels.” *Nature* 604.

Schwanitz, Valeria Jana. 2013. “Evaluating Integrated Assessment Models of Global Climate Change.” *Environmental modelling & software* 50: 120–31.

Shi, Wenjing et al. 2017. “Projecting State-Level Air Pollutant Emissions Using an Integrated Assessment Model: GCAM-USA.” *Applied Energy* 208: 511–21.

Shukla, Priyadarshi R, Jim Skea, Andy Reisinger, and Raphael Slade. 2023. *Climate Change 2022: Mitigation of Climate Change*. Geneva: Intergovernmental Panel on Climate Change.

United States Department of State and United States Executive Office of the President. 2021. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf.

Van Ruijven, Bas J. et al. 2016. “Long-Term Model-Based Projections of Energy Use and CO2 Emissions from the Global Steel and Cement Industries.” *Resources, Conservation and Recycling* 112: 15–36.

Weyant, John. 2017. “Some Contributions of Integrated Assessment Models of Global Climate Change.” *Review of Environmental Economics and Policy* 11(1): 115–37.