2025

YEAR IN REVIEW

FUTURE ISSUES & TECHNOLOGY (FIT) CLUSTER

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Message from the Executive Deputy Chairman

Dear Readers,

The Future Issues and Technology (FIT) 2025 Year in Review brings together a wide-ranging set of analyses that reflect the growing strategic importance of emerging and disruptive technologies for Southeast Asia as well as the wider international community. As global technological competition intensifies, states and societies are increasingly confronted with complex challenges arising from quantum technologies, artificial intelligence, advanced energy systems, space-based capabilities, and other emerging and frontier technologies. These developments hold immense promise, but without anticipatory governance and informed policy choices, their potential benefits may be constrained while their risks are amplified.

Contributions in this review examine how quantum technologies are reshaping global supply chains and international security, underscoring the urgency of domain-specific, forward-looking regulatory approaches that recognise quantum's dual-use nature and commercial trajectory. A number of essays explore the transformative

potential of fusion energy as a clean, safe, and economically viable energy source, highlighting its growing relevance not only for sustainability but also for national resilience and security. The intersection of AI with space is likewise examined as a public interest technological frontier with far-reaching implications for long-term strategic stability.

This Year in Review also draws attention to the role of public trust in enabling effective governance of intrusive or high-stakes technologies such as AI. As several studies show, trust is not only foundational to policy legitimacy and adoption, but increasingly a strategic asset in a competitive global innovation landscape.

We hope that the FIT Year in Review 2025 will be a useful resource for readers seeking to better understand the risks, opportunities, and policy implications arising from future issues and technology trends in the region and beyond. Moving forward, RSIS's FIT Cluster will continue to pursue policy-oriented research on AI, space, quantum, energy, biotechnology, and their broader socio-economic impacts.

We welcome your feedback and look forward to mutually rewarding engagement.

Ambassador Ong Keng Yong

Message from the Head of FIT

Dear Readers,

The Future Issues and Technology (FIT) research cluster has been busy in 2025! Our compact team has continued to engage experts from Singapore and around the world, both in person and online, for workshops, webinars, and joint publications.

Together with these international and domestic experts, we have explored the impact of rapid technological advancement shaping our societies, economies, and security environments.

This year end compilation highlights the policy issues we have been exploring in the security, governance, and regulation of emerging technologies like artificial intelligence and quantum technologies, as well as the convergence with space, biotechnology, and advanced energy systems. We also try to identify areas where more collaboration, multi-stakeholder participation, and adaptive policymaking will be needed to navigate uncertainty.

At the FIT Cluster, we know we are just scratching the surface of the multidisciplinary issues that arise from these emerging technologies. We hope you will find our research policy-relevant and helpful for understanding of emerging technologies and their implications for society, policy, and security.

We warmly welcome your feedback, perspectives, and collaboration as we continue to explore these evolving issues.

We look forward to engaging with you in the year ahead.

Ben Ang

Benjamin Ang

THE YEAR IN AI, QUANTUM, SPACE, AND ENERGY

ARTICLE 01

MAPPING ASEAN'S UNEVEN PATH TO AI GOVERNANCE

Benjamin Ang, Karryl Kim Sagun Trajano

A version of this brief was first published by The National Bureau of Asian Research

The Association of Southeast Asian Nations (ASEAN) and its member states' innovation-friendly approach to artificial intelligence (AI) has in some measure been effective in advancing the region toward its goal of becoming a fully digital economy. The current framework seeks to ensure that no country is left behind. However, growing AI-related risks now suggest the need for more binding regulations. It may be timely to review existing guidelines and assess which countries are technologically prepared to start implementing enforceable regulations. Singapore has the potential to serve as a governance benchmark, helping pave the way for a region-wide approach through alignment of regulations across ASEAN. This could enhance the region's credibility as a technological hub, protect individuals from bad actors exploiting legal gaps, and attract global investment by reinforcing ASEAN's image as a trustworthy destination for AI development.

This brief explores ASEAN's collective approach to AI regulation, as well as the domestic efforts (or at times the lack thereof) of individual member states. It concludes that the region can contribute valuable insights to the global conversation on responsible AI development and governance.

AI Regulation: The ASEAN Way

The AI boom of recent years has aligned with ASEAN's ambition to become a digital economy and digital society by 2025. Yet its key document, the ASEAN Digital Masterplan 2025 (published in 2021), makes no mention of

AI across its 140 pages. This omission suggests that the potential of AI might not have been fully anticipated during the drafting process.

To catch up, ASEAN has since taken an innovation-friendly governance approach. Following the introduction of more compulsory regulatory frameworks around the globe, ASEAN released the non-binding Guide on AI Governance and Ethics for the entire region in February 2024. The guide articulates core principles—transparency, fairness, security, reliability, privacy, accountability, and human centricity—which seek to ensure that countries retain agency over AI-driven outcomes. Its voluntary, adaptable framework enables countries to tailor governance to their specific contexts and degrees of AI readiness. Given the varying levels of domestic AI infrastructure and capabilities across Southeast Asian nations, a nuanced approach allows for greater flexibility to preserve room for AI innovation.

Yet, if ASEAN is truly committed to ensuring that emerging technologies remain safe and human-centric, it must responsibly begin considering more binding legal frameworks, including AI regulation. According to the guide, human centricity means that AI systems are designed and used to promote human well-being, ensuring that they benefit society while protecting individuals, particularly the vulnerable, from harm or exploitation. This is a pressing issue, especially since the technology is already being used in malign ways, such as to produce deepfake content during elections.

However, even though ASEAN serves as the primary regional organization in Southeast Asia, it remains an intergovernmental body whose member states retain full sovereignty. Unlike the European Union, ASEAN lacks a parliament with legislative authority, which makes the implementation of binding laws across the region more challenging. Nonetheless, regional harmonization is not out of reach. ASEAN has previously demonstrated effective coordination in the technological sphere—for example, through the ASEAN Cybersecurity Cooperation Strategy.

Domestic AI Playbooks

Given ASEAN's overall innovation-friendly approach, it is unsurprising that no member state has enacted dedicated, binding AI legislation to date. Southeast Asian countries largely rely on "soft law" instruments, such as ethical guidelines, governance frameworks, national roadmaps, and readiness assessments to guide the responsible development and deployment of AI.

Like the rest of the region, **Brunei** has yet to enact dedicated AI legislation, but it is actively developing a governance framework rooted in innovation-led principles. This enables the country to drive innovation across multiple sectors and applications. Brunei published its own Guide on AI Governance and Ethics. Similar to ASEAN's approach, this guide is technology- and sector-neutral, taking a pragmatic, principles-based stance designed to keep pace with rapid technological change. A formal national AI strategy is also in progress under the country's 2025 Digital Economy

Masterplan, prioritizing infrastructure development, talent cultivation, and innovation. The strategy also emphasizes flexibility, allowing AI guidelines to be revised as technologies and societal needs evolve. Meanwhile, Brunei is finalizing the Personal Data Protection Law—a critical step for regulating data practices in AI systems and beyond.

Vietnam's AI governance resembles Brunei's in its emphasis on digital transformation policies but differs through its use of binding sector-specific regulations. The National Program for Digital Transformation promotes AI use in areas like education, public administration, and urban planning. Efforts include AI-integrated curricula, smart-city projects, and even AI-powered waste management. Initiatives like national data systems led by the Ministry of Education show Vietnam's commitment to AI readiness. Use of AI in the workplace is covered by the Labor Code, while cybersecurity laws support AI-related protections, advancing Vietnam's aim to be among the top cybersecurity leaders by 2030. While these steps allow Vietnam to ensure that innovation aligns with context-specific societal needs, challenges remain, including ethical concerns, infrastructure gaps, and fragmented governance.

Akin to the broader ASEAN approach, **Malaysia** is shaping its AI regulations through a combination of ethical, legal, and infrastructure frameworks. By combining ethics and regulation with strategy, the country is able to foster responsible AI in high-impact sectors. The National AI Roadmap (2021–25) promotes responsible AI use across five key sectors: agriculture, healthcare, smart cities, education,

and public services. Complementing this roadmap, the National Guidelines on AI Governance and Ethics set out core principles, including fairness, safety, transparency, and human benefit, to build trust and mitigate risks. Reflecting a commitment to human centricity, Malaysia's 2024 Cybersecurity Bill supports AI governance by addressing critical issues of data security. Its National Artificial Intelligence Office, established in 2024, serves as the central body for coordinating AI policy and ensuring alignment with international standards. In line with its flexible, adaptive approach, Malaysia continues to engage in open discussions with various stakeholders to address emerging AI challenges.

The approach of **Thailand** to AI governance incorporates national planning, legislative development, and sector-specific initiatives, thus driving innovation while ensuring responsible use. Its National AI Strategy and Action Plan (2022–27) is ambitious, with the goal of positioning Thailand as a regional AI hub focusing on infrastructure, workforce development, and legal readiness by 2027. The country also demonstrates a strong commitment to responsible AI. Last year, the Ministry of Digital Economy and the Electronic Transactions Development Agency issued generative AI guidelines mandating risk assessments, transparency, and data protection compliance. Additionally, a royal decree, currently under review, adopts a risk-based model inspired by the EU AI Act's risk-based approach to enhance algorithmic accountability and public safety. The legislation requires that high-risk AI applications (such as facial recognition for surveillance) be registered with the Thai

government, outlines categories of prohibited uses, and imposes penalties upon failure to comply. For a more balanced approach, Thailand is also drafting the Act on the Promotion and Support of Artificial Intelligence Innovation, aimed at lowering regulatory barriers and encouraging collaboration. By 2025, the country aims to have a dedicated framework for the public sector to further guide ethical AI use in areas such as healthcare and energy. Thailand also partners with UNESCO on AI ethics training and offers incentives—including tax breaks—to encourage responsible, human-centric AI adoption.

Indonesia primarily relies on adapting existing laws, ethical guidelines, and international standards, rather than creating entirely new regulatory frameworks for AI. Through this approach, legal clarity and stakeholder familiarity can potentially be more effectively supported. The country also appears to adopt a more consumer-friendly stance, legally defining AI as an "electronic agent" under the amended Electronic Information and Transactions Law, which holds operators liable unless user negligence can be proved. Government Regulation No. 71 of 2019 and the Personal Data Protection Law form the legal foundation of AI use in Indonesia, emphasizing security and consumer protection. AI ethics were also outlined in Circular Letter No. 9/2023, which focuses on transparency and inclusivity, with additional guidance from the Financial Services Authority for financial technology. In terms of innovation, Indonesia's National AI Strategy (2020–45) sets long-term goals across ethics, talent, and infrastructure. A draft presidential regulation is in progress, with sector-specific rules in health

and education expected. Indonesia's approach aligns with Pancasila values as well as with international frameworks like the EU AI Act and UNESCO assessments.

Whereas Indonesia leans on existing frameworks, the **Philippines** has introduced targeted regulations to steer the responsible growth and use of AI technologies. This approach benefits the country through regulatory agility and responsiveness to challenges as they come along. Targeted, sector-specific regulations also allow the Philippines to address emerging risks more efficiently. The Philippines' 2021 AI Roadmap aims to boost digital infrastructure, research, and workforce skills. The country also has the Data Privacy Act of 2012. Under the legislation, when AI systems process personal information, individuals must give their consent for automated processing, and such processing must be registered with the National Privacy Commission. Key laws, such as Republic Act No. 11927, support digital skill-building, while Republic Act No. 10175 addresses deepfake-related offenses and online harassment. In response to AI-generated deepfakes during its recent midterm elections, the Philippines enacted Resolution No. 11064 mandating transparency in AI use for electoral processes. Its Advisory No. 2024-04 further clarifies rules for AI's compliance with privacy laws. The country also aligns with UNESCO and the Bletchley Declaration on ethical AI and supports regional regulation within ASEAN.

Myanmar, **Cambodia**, and **Laos** remain in much earlier stages of AI governance relative to the rest of the region.

Currently, they do not have dedicated national AI strategies or agencies. While they participate in regional AI efforts by closely following the ASEAN guide, more coordinated action, both nationally and regionally, is urgently needed to ensure they are not left behind in AI innovation. ASEAN's preference for soft law reflects the reality that many member states are still catching up technologically. If these three countries lag further behind, it could delay the region's readiness to adopt more binding AI regulations, potentially slowing collective progress.

Myanmar's Cybersecurity Law No. 1/2025 indirectly touches on AI, focusing on digital platforms and national security, while its e-Governance Master Plan 2030 reflects the country's overall vision of building a digital government that is efficient, transparent, citizen-centric, and inclusive, affecting AI development. High-level coordination meetings are also being held to craft a future national AI strategy and policy. However, weak infrastructure, censorship, and the absence of AI-specific laws continue to limit progress in Myanmar.

Cambodia's secretary of state Keo Sothie stressed that the country will "regulate, not strangulate" AI in its approach to oversight. In June 2025, public consultations were launched on a draft national AI strategy, a key step in shaping policy. Cambodia's approach to AI is based on its wider Digital Government Policy (2022–35) and tailored for AI as guided by its Ministry of Industry, Science, Technology and Innovation's AI Landscape Report (2023). These steps mark

key progress in Cambodia's AI strategy and regulation efforts.

While no specific AI law exists in Laos, its government adopted a twenty-year vision (2021–40) augmented by shorter-term plans to guide digital policy, including AI. Legal frameworks under development aim to align with national priorities, ensuring transparency, accountability, data privacy, and protection of public interest and reflecting the ASEAN way.

The Curious Case of Singapore

Singapore is often lauded as Asia's smartest city, with its leadership in innovation, including in AI, setting the country apart from its Southeast Asian peers. Given its strong technological foundation, Singapore is well-positioned to take the lead in shaping more binding AI regulations. However, like much of the region, its current approach to AI governance remains flexible and principles-based, aiming to balance innovation and ethical use.

This measured strategy can be a double-edged sword. On the one hand, it keeps Singapore ahead within the region and positions the country competitively on the global stage, even among more advanced economies—economies typically with more stringent laws. It likewise enables the country to have bilateral agreements and collaboration on AI development outside the region with minimal restrictions. For example, Singapore built on its 2020 Digital Economy Agreement with Australia to deepen AI

cooperation focused on maximizing benefits and mitigating risks. In 2024, it also partnered with Rwanda to launch the AI Playbook for Small States, highlighting how geographically distant nations can face similar challenges in AI policy implementation.

On the other hand, Singapore might be missing a valuable opportunity to take the lead in shaping binding AI regulation in the region. The country has already demonstrated its regulatory capabilities through the effective implementation of its Cybersecurity Act. It certainly holds much potential to play a similar role in shaping AI governance. A robust approach to advancing both strategy and ethics through policy and implementation measures can already be observed in the country. Singapore launched its National AI Strategy in 2019, well ahead of its regional peers, with the goal of positioning itself as a global leader in AI, especially in high-value sectors, by 2030. In the same year, the Model AI Governance Framework (later updated in 2020) was launched, providing detailed guidance for private-sector organizations, emphasizing transparency, fairness, explainability, and accountability. The AI Verify Toolkit, launched in 2022, helps assess AI systems for trustworthiness and aligns with Singapore's "smart nation" goals. The following year, in 2023, Singapore released the National AI Strategy 2.0. The updated strategy outlines long-term goals, reinforcing a soft-law approach that remains agile yet principled in response to evolving technologies.

Consistent with ASEAN's principles-based approach, Singapore supports responsible AI development through frameworks like the Advisory Guidelines for Personal Data in AI Systems, which ensure alignment with the country's Personal Data Protection Act. To further promote safe innovation, the Model AI Governance Framework for Generative AI (2024) emphasizes transparency, risk assessment, and safeguards against harmful outputs. Singapore has also expanded the Privacy Enhancing Technologies Sandbox to test privacy-preserving technologies in generative-AI contexts. Although the country does not yet have comprehensive, AI-specific legislation, regulators like the Monetary Authority of Singapore have issued sector-specific guidelines to address emerging risks.

While Singapore leaps toward a proactive and flexible governance model, other ASEAN states take incremental but meaningful steps toward AI policies. Together, these efforts form a regional approach favoring readiness over coercion. However, if global trends are followed, once states are sufficiently equipped with a baseline level of technological and governance capacity, the next logical step is to move toward more formal and binding regulation. This is crucial, as the rapid pace of AI development not only brings new opportunities but also poses significant risks that demand a stronger regulatory response.

Singapore, being technologically ready for governance, risks setting a negative example in the region if it does not lead in establishing binding AI regulations. The country has

the capacity to set a regional benchmark for responsible AI governance, encouraging regulatory alignment and accelerating progress across ASEAN. Adopting binding laws would also signal to the global community that the region takes AI safety seriously, enhancing its reputation as a trustworthy technological hub and attracting more international investment. Clear legal frameworks promote accountability and mitigate risk, while the absence of binding laws creates gaps that bad actors can exploit, potentially leading to unfair practices and user harm. Regulatory ambiguity also weakens the region's ability to resolve legal disputes involving AI. Establishing firm legal standards could provide essential guidance for the public, private, and academic sectors, helping Singapore and the rest of the region stay resilient amid rapid technological change.

Conclusion

Southeast Asia's AI governance may seem uneven, but it reflects a region attempting to adapt regulation to its diverse political, economic, and developmental realities. ASEAN's use of soft law through voluntary guidelines, strategic frameworks, and ethics-based principles shows a pragmatic, innovation-friendly approach. Rather than treating innovation and regulation as opposing forces, the region promotes a flexible, inclusive model that enables countries at different stages of development to participate in AI development. Most are crafting adaptable national playbooks aligned with regional norms, prioritizing innovation over inflexible rules. As seen in the case of

Singapore, this approach is a deliberate choice to balance opportunity with responsibility while considering infrastructure capabilities and evolving digital ecosystems. However, once readiness is in place, bolder steps toward binding regulation to address risks should follow.

Overall, the ASEAN region's approach to AI governance demonstrates that the development and implementation of responsible AI do not always require sweeping laws at the onset. Instead, regulation can be built on a foundation of trust, ethics, and flexibility that adapts to technological progress.

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ARTICLE 02

CAN ASEAN SECURE A QUANTUM FUTURE?

Karryl Kim Sagun Trajano

A version of this commentary was first published by Lowy Institute's The Interpreter

Quantinuum, the world's largest quantum company, is planting its flag in Singapore through a new collaboration with the country's National Quantum Office. This, together with a robust National Quantum Strategy (2024), signals the city-state's growing weight in the global quantum race. However, while Singapore gets ready for further participation in the quantum economy, the rest of the region risks falling behind.

As quantum technologies are no longer a far-off scientific dream, they are fast becoming a strategic reality poised to reshape the global order. In 2025's International Year of Quantum Science and Technology, Southeast Asia faces an important question: Can it secure its own quantum future, or will it be shaped by forces beyond its control?

What if Southeast Asia Falls Behind?

For a region juggling economic growth, technological sovereignty, and geopolitical pressure, falling behind in the quantum race is a serious risk. Unlike AI, which excels at processing huge volumes of data, quantum computing tackles deep, complex problems in simulation, optimisation, and secure communication. It is the backbone of what scientists call "Quantum 2.0", the next leap after Quantum 1.0 which brought us semiconductors, lasers, transistors, MRI, and atomic clocks. Governments will increasingly need experts to identify critical problems and apply quantum computing, with AI and quantum likely converging to complement each other.

But the promise of quantum arrives in a fractured geopolitical landscape. In contrast with the space race, which evolved from competition to cooperation through shared projects, the quantum race is moving in the opposite direction: closed, proprietary, and increasingly politicised. Export controls on even low-performance quantum devices by the United States and other major powers, restrictions on research collaboration, and the nationalisation of technological standards are constraining global knowledge flows and raising the cost of innovation.

For Southeast Asia, this fragmentation narrows the path forward. Most ASEAN member states still lack the local expertise, infrastructure, and research capabilities needed to develop their own quantum technologies. Malaysian policymakers, for instance, are beginning to recognise quantum's strategic dimensions. Yet the country's approach remains largely vendor-supplier based with it acquiring access to quantum computing infrastructure through partnerships rather than domestic capability building. This model can enable participation but also risks long-term dependency and shallow capability-building if not paired with domestic capacity-building and broader investment.

The region also urgently needs to adopt new encryption protocols, including post-quantum cryptography and quantum key distribution, to safeguard trust in its critical systems such as banking. Lagging in this domain could erode confidence, deter investment, and threaten regional economic stability. More broadly, falling behind in quantum technologies could impose a significant economic loss, one

that Southeast Asian nations cannot afford, given that the global quantum industry is projected to reach around US$97 billion by 2035.

The quantum supply chain is likewise intricate and specialised, reliant on rare-earth materials, with geopolitical rivalries already disrupting access. Technological fragmentation, where incompatible systems proliferate, could undermine interoperability and deepen inequalities, leaving smaller countries and newer players, including ASEAN states, vulnerable to alignment pressures from major powers.

This dynamic is particularly relevant to Southeast Asia, whose economies depend on open trade and diversified partnerships. A fragmented quantum ecosystem could expose the region to coercive dependencies. While ASEAN could, in theory, serve as a neutral convening space for quantum research, governance, and standards, this remains aspirational without a dedicated regional policy framework, technical expertise, and alignment among member states. The gap is significant, as the ASEAN Digital Masterplan 2025 notably makes no mention of quantum across its 140 pages.

This is not to suggest that quantum ambitions are absent in the region. Singapore has built Southeast Asia's first quantum-safe network infrastructure, Thailand has introduced a national quantum roadmap, while Indonesia has established a research centre for quantum physics, among other national-level initiatives. At the

regional level, efforts such as the ad hoc ASEAN Quantum Committee and the SEA Quantum Network reflect growing recognition of quantum's importance.

Way Forward

But, while momentum is slowly building, Southeast Asia must address three interlinked priorities to secure a meaningful quantum future.

First, it must formalise regional coordination. ASEAN must move beyond ad hoc working groups and establish a dedicated mechanism to harmonise standards, technical definitions, and security protocols. A coordinated approach can preserve strategic autonomy while avoiding fragmented national efforts.

Second, broaden capacity-building. Quantum cannot remain confined to elite institutions and single counties. It requires region-wide investment in education, local talent pipelines, and industry partnerships that build hands-on capability, and not just procurement.

Third, integrate quantum into strategic planning. Quantum (among other emerging technologies) should be reflected in the next iteration of its Digital Masterplan. Early applications such as quantum machine learning for disaster early warning, for instance, can offer immediate benefits for a region highly exposed to natural hazards, while laying the foundation for more advanced uses in agriculture, genomics, and data security.

Conclusion

Quantum will not transform Southeast Asia overnight. But its cumulative impact on security, economic competitiveness, and technological sovereignty will certainly refine if not redefine the region's strategic future. Treating quantum as a distant science experiment, rather than a here-and-now priority, risks leaving the region dependent on external powers. A coordinated, forward-looking approach can instead position ASEAN as an active shaper of its own quantum landscape.

As quantum technologies prompt new forms of cooperation, ASEAN's long tradition of consensus-building can be a strategic asset. The real question is whether the region can move quickly, and collectively, to secure its place in the quantum future.

Recommended Citation
Trajano, K.K.S., 2025, "Can ASEAN Secure a Quantum Future?" In *Future Issues and Technology 2025: Year in Review*, Singapore: S. Rajaratnam School of International Studies, Nanyang Technological University.

ARTICLE 03

SPACE AND AI: SHAPING THE FUTURE OF FOOD SECURITY IN ASEAN

Ysa Marie Cayabyab

This article first appeared as an RSIS commentary

Food security remains one of the most urgent global challenges of the 21st century, with many nations struggling to secure stable access to safe, nutritious, and affordable food. Climate change is a key driver of this crisis, increasingly undermining agricultural productivity, as demonstrated in last year's drought in Thailand and severe flooding in Vietnam.

These events caused food supply shortages not only in the region but also in global markets, further exposing vulnerabilities in international food systems. Looking ahead, this crisis is likely to worsen as the world's population is projected to reach 9.1 billion by 2050, necessitating a 70 per cent increase in overall food production to meet global demand.

These interlinked challenges highlight the pressing need for innovative, resilient, and sustainable solutions that go beyond traditional agricultural practices. The recent advances in space technologies and artificial intelligence (AI) are stepping into this role, opening new frontiers for strengthening food security through smarter monitoring and more accurate predictive insights.

Space and AI: Advancing Innovation

A key strategy for managing the impacts of agricultural disruptions is climate forecasting. Climate forecasting relies on satellite observations, remote sensing technology, and

climate models to project long-term climate trends, thus enabling strategic crop planning, efficient resource allocation, and better mitigation of risks from extreme weather events.

The first significant use of satellites for climate forecasting began in 1972 with the launch of the Earth Resources Technology Satellite (ERTS), later renamed Landsat 1, by the United States' National Aeronautics and Space Administration (NASA). Launched as the first satellite dedicated to monitoring Earth's landmasses, Landsat 1 provided multispectral imagery that enabled scientists to assess vegetation health, soil moisture, and land use changes – critical information for agricultural planning and climate forecasting.

Since then, satellite observations and remote sensing have become essential tools for crop monitoring, yield prediction, disaster management, and resource management. The precision and scope of these capabilities have also expanded substantially with technological advancements and the increasing number of orbiting satellites. For instance, in July 2025, NASA and the Indian Space Research Organisation (ISRO) jointly launched the NASA-ISRO Synthetic Aperture Radar (NISAR) satellite, which was built to monitor Earth's surface movements with centimetre-level precision.

NISAR is expected to deliver data on farming patterns, climate shifts, and sea levels, as well as natural hazards such as earthquakes, landslides, and floods. These insights

provide unprecedented visibility into environmental and agricultural conditions, supporting both resilient farming practices and timely disaster response.

In parallel, advances in AI have transformed the way satellite datasets are analysed. Machine learning (ML), a subset of AI, now enables real-time analysis of vast and complex data streams that were previously difficult to interpret. Although ML's initial application in agriculture during the 1990s was primarily on soil analysis, it has expanded considerably over the past decade, driving innovations in domains such as plant breeding and robot-assisted harvesting.

With recent advances in computing power, data storage, and access to agricultural datasets, these technologies can now deliver more accurate forecasts and enable more proactive, efficient agricultural planning. Together, space and AI technologies form a powerful system that strengthens food security and enhances climate resilience.

Strengthening Regional Cooperation

In modern agriculture, the integration of satellite imagery and AI-driven machine learning has proven to be a game-changer. These technologies generate valuable insights that enable farmers, researchers, and industry professionals to make data-driven decisions, enhancing agricultural planning and productivity.

At the regional level, their impact can be amplified through stronger cooperation. In particular, by fostering partnerships in climate data sharing, research, and policy alignment, ASEAN countries can collectively enhance forecasting accuracy and develop more effective climate adaptation strategies, ultimately building more resilient food supply chains.

Several ASEAN countries, including Singapore, Malaysia, Vietnam, Thailand, Indonesia, and the Philippines, have already developed notable space and AI capabilities through national space agencies, satellite programmes, national AI strategies, and digital infrastructures. With growing technological capabilities and strong regional partnerships, ASEAN is well-positioned to leverage space and AI to strengthen food security, reinforce climate resilience, and advance sustainable agricultural development throughout the region.

Challenges to the Use of Space and AI Technologies

However, harnessing the full potential of space and AI technologies also brings a range of challenges that must be carefully addressed, especially as the world races towards the 2030 Agenda for Sustainable Development.

Lack of Technical Capacity

The first challenge is that the vast majority of farmers, who are the main stakeholders, are not experts in these emerging technologies. This knowledge gap prevents them

from accessing or interpreting satellite data and from understanding how ML algorithms can be applied to make informed decisions.

To bridge this knowledge gap, governments, academia, and industry must collaborate to implement capacity-building programmes that equip farmers with the digital literacy and practical skills necessary to effectively integrate these tools into their agricultural practices. Such initiatives would not only promote adoption but also foster greater trust in the accuracy and usefulness of these advanced forecasting systems.

At the same time, user-friendly systems should be developed to reduce technical barriers. For example, intuitive visualisation tools can enable non-specialists to interpret forecasts accurately without requiring advanced data science expertise.

Lack of Expertise and Infrastructure

The second challenge is that many countries, particularly in Southeast Asia, where the effects of climate change are often most severe, lack the technical expertise and infrastructure needed to develop and implement these technologies. Building and applying ML algorithms to quickly process satellite-derived datasets require highly skilled professionals and scalable computing resources that are often concentrated in wealthier nations.

Addressing this gap requires the development of educational and training programmes that can cultivate local expertise in AI, remote sensing, and data analytics. Given the transboundary nature of climate change, regional collaboration is also beneficial. Neighbouring countries would greatly benefit from pooling resources, expanding satellite coverage, and sharing data and best practices through knowledge exchange networks and public-private partnerships (PPPs).

High Cost

The third challenge, closely related to the previous one, is the high cost of infrastructure, data acquisition, and system maintenance. This is particularly problematic in low- and middle-income countries where financial resources are limited.

To address this, bilateral and multilateral agreements should prioritise shared technological infrastructure and open-access data exchange, making satellite and AI tools more affordable and widely accessible. Jointly funded, collaborative research initiatives can also further enhance the use of regional satellite data and AI models, maximising their impact while strengthening cross-border forecasting, disaster preparedness, and agricultural resilience. In addition, PPPs can co-invest in scalable infrastructures, ensuring that both costs and benefits are shared equitably.

Going Forward

Beyond these measures, policies must also address equity and governance concerns in the application of satellite and AI for climate forecasting and agricultural development. Issues of data ownership, privacy, and equitable access to digital tools should be governed by transparent regulatory frameworks that protect small-scale farmers from exclusion or exploitation.

Governments and regional organisations must facilitate the creation of platforms for open dialogue to establish common grounds for information exchange, with particular emphasis on supporting vulnerable groups. Ensuring that marginalised communities in the region have equal access to climate-smart technologies will not only strengthen agricultural resilience but also enhance systemic food security.

In the long term, integrating these emerging technologies into agricultural and climate policies should be framed as part of a broader sustainability agenda, one that aligns technological innovation with inclusivity, equity, and regional cooperation.

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ARTICLE 04

UNLOCKING TRITIUM FOR FUSION ENERGY

Alvin Chew

FIT has supported Dr Chew's attendance to the second ministerial meeting on Fusion Energy held in Chengdu, China

The research and development in fusion energy have accelerated in recent years. Touted as "30 years away – and always will be," the "holy grail" of power has, in the past few years, achieved significant developmental milestones. In 2021, researchers at the Massachusetts Institute of Technology (MIT) built high-temperature superconducting magnets that could be deployed in future commercial fusion reactors. In 2025, France set a record for sustaining a fusion plasma in a tokamak for 22 minutes. In terms of net energy gain, the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL) in California, United States, managed to yield more than twice the energy input when it experimented with the inertial confinement method.

Despite these breakthroughs, Pietro Barabaschi, Director-General of the International Thermonuclear Experimental Reactor (ITER) project, commented that fusion is still a long way from full commercialisation. The ITER project, initially scheduled to start in 2025, has been pushed back to 2035. From that point, the experimental reactor will still need another twenty years of testing to serve as a blueprint for future commercial reactors to be connected to the grid. This means that fusion energy will most likely be available after 2055, which is still 30 years away. But the timeline is more definite now.

Despite the lengthy timeline, investors have been pouring massive funds into fusion research. The global fusion industry has attracted more than 50 start-ups, all pursuing parallel tracks of development to commercialise fusion

energy by the next decade. However, the industry will face a problem in fuelling its reactors – the availability of tritium.

Dwindling Global Stockpiles of Tritium

The deuterium-tritium combination has been identified as the most efficient fuel for fusion. Deuterium is abundant in seawater and can be extracted easily. Tritium, on the other hand, is scarce in nature and forms only when gases in the upper atmosphere interact with cosmic rays. Hence, the global inventory of tritium is a by-product of nuclear fission in Canada Deuterium-Uranium (CANDU) heavy-water reactors.

There are currently 17 CANDU reactors operating in Canada, which, in total, can produce up to 2 kg of tritium annually and sell it to the world at US$30,000 per gram. Their capacity to produce tritium will decline over time as several ageing CANDU reactors will be replaced by smaller light-water reactors. The Republic of Korea (ROK) and Romania also operate heavy-water reactors, which can add to the global tritium stockpile.

The current global stockpile of tritium is about 20 kg. The ITER project is expected to consume about 12 kg of tritium throughout its operational lifespan. Assuming Canada, ROK and Romania continue to produce tritium at a moderate rate, it is estimated that by 2055 (after ITER has ceased operation), the global tritium stockpile could dwindle to 14 kg, which would be insufficient for any fusion reactor to

begin operating then. Studies estimate that a 1 GW fusion reactor will require about 55 kg of tritium annually.

A commercial fusion reactor is designed to breed tritium, but this will only occur when the reactor is running in a steady-state condition, in which sufficient neutrons bombarding with lithium inside the reactor can produce tritium to sustain the operation. Therefore, breeding tritium in a fusion reactor remains hypothetical. The reactor will still require a considerable amount of tritium to ignite the fusion process.

Tritium and Nuclear Weapons

Tritium has also been produced with conventional light-water reactors in the US. The Tennessee Valley Authority (TVA) Watts Bar plant produces tritium by coating control rods with boron to capture neutrons. However, tritium production is tightly regulated by the National Nuclear Security Administration (NNSA) in the US because the stockpile is used primarily to boost the yield of its nuclear weapons.

In 2000, TVA entered into an agreement with NNSA to provide tritium production services from its reactors until 2035. While tritium stockpiling is small in the US due to its limited use in nuclear weapons, the US should consider scaling up its proven supply chain of tritium and play a leadership role in the future deployment of fusion reactors.

Tritium Production from Nuclear Waste

Spent nuclear fuel can be reprocessed for use as fuel in fission reactors. However, the reprocessing of spent fuel raises international concerns about proliferation, and it has also been proven uneconomical. Therefore, spent fuel is disposed of as nuclear waste and temporarily stored in on-site metal casks. Nevertheless, nuclear wastes still pose a significant issue, as improper management can lead to environmental contamination.

Researchers at the Los Alamos National Laboratory (LANL) in the US are investigating the use of particle accelerators to produce tritium from nuclear waste. Computer simulations are performed to study the feasibility of firing proton beams onto spent fuel rods coated with molten lithium salt, which would initiate a fission process that converts lithium into tritium. In short, it is reigniting the fission process on the waste using an accelerator rather than in a reactor pressure vessel.

The production of tritium via this method has three benefits: i) The use of accelerators provides a more controlled environment for the fission process; ii) Operational output of the nuclear plant will not be compromised, as it is performed on wastes that have been taken out of the reactors; iii) There will be less waste to manage.

If viable, nuclear waste could become a gem, triggering a sea change in policies for radioactive waste management.

Upcycling nuclear waste into tritium for use in fusion reactors is turning a problem into an opportunity. While it will ease the management of nuclear waste, it will also increase the supply of tritium, lowering the potential commercial cost of fusion energy.

Conclusion

Production of tritium will still be tightly regulated internationally due to its potential use in nuclear weapons. Therefore, not every country will have access to the technology and tritium production supply chain. Countries with the capability to manufacture tritium, such as Canada, South Korea, and Romania, which operate heavy-water reactors, should consider ramping up their tritium production to prepare for the large-scale deployment of fusion energy globally. Furthermore, if the extraction of tritium from nuclear waste proves viable, it will certainly offer more options for waste management.

Unlike rare earth materials, which are mined, tritium must be produced by nuclear fission. Despite the current geopolitical climate, it is unlikely that rivalry will surface in the tritium economy, as the major players researching on fusion are contributing to the development of the ITER project. There will be no problems for ITER operations, as Canada has agreed to supply tritium. The problem of tritium supply only arises after the commercialisation of fusion.

Timing is critical. As the half-life of tritium is about 12 years, there is no need to rush into tritium production if fusion

energy will be commercialised in 30 years. However, policymakers need to start thinking of strategies to shore up the fission fuel cycle for tritium production, such as extending the operation of heavy-water reactors or taking back spent fuel and nuclear waste for upcycling. The world needs the nuclear fission industry to realise fusion energy in the future.

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Chew, A., 2025, "Unlocking Tritium for Fusion Energy" in *Future Issues and Technology 2025: Year in Review*, Singapore: S. Rajaratnam School of International Studies, Nanyang Technological University.

2025 ROUNDUP

PUBLICATIONS

Policy Reports

Karryl Kim Sagun Trajano, Ysa Marie Cayabyab, Seth Seet Kai, Edson Tandoc Jr., "Trust as a Strategic Asset: AI and Domestic Confidence in Singapore amid US-China Dynamics," RSIS Policy Report, 21 November 2025.

Karryl Kim Sagun Trajano, Seth Seet Kai, Ysa Marie Cayabyab, Edson Tandoc Jr., "Navigating Public Opinion on AI in Singapore: Awareness, Perceptions, and Vulnerabilities," RSIS Policy Report, 18 September 2025.

Karryl Kim Sagun Trajano, "Charting ASEAN's Path to AI Governance: Uneven Yet Gaining Ground," The National Bureau of Asian Research, 4 September 2025

Karryl Kim Sagun Trajano and Benjamin Ang, "Soft but Ethical: The ASEAN Way to Data Protection and AI Governance," Safer Internet Lab, 21 August 2025.

Commentaries

Karryl Kim Sagun Trajano, "SpaceAI for Sustainability: Opportunities and Challenges for Southeast Asia," RSIS Commentary, 22 December 2025.

Karryl Kim Sagun Trajano , "Can ASEAN secure a quantum future?" The Interpreter, 19 November 2025.

Ysa Marie Cayabyab, "Space and AI: Shaping the Future of Food Security in ASEAN Space and AI: Shaping the Future of Food Security in ASEAN," RSIS Commentary, 29 August 2025.

Keith Paolo Catibog Landicho and Karryl Kim Sagun Trajano, "Disasters and Disinformation: AI and the Myanmar 7.7 Magnitude Earthquake," IDSS Paper, 1 May 2025

Karryl Kim Sagun Trajano and Adhi Priamarizki, "Southeast Asia faces AI influence on elections," The Strategist, 2 April 2025.

Chapters in Edited Books

Karryl Kim Sagun Trajano, Iuna Tsyrulneva, Chee Yong Sean Chua, "AI in Space Technologies: A Singapore Case Study," in Wiring the Domains: Research on Cyber, Digital, Science and Technology. World Scientific, January 2026, pp. 217-234.

Alvin Chew and Karryl Kim Sagun Trajano, "Red Hydrogen for a More Sustainable Future" in Wiring the Domains: Research on Cyber, Digital, Science and Technology. World Scientific, January 2026, pp. 211-216.

Benjamin Ang and Teck Boon Tan, "Chapter 26: Singapore's Digital Defence" in Singapore Unveiled Volume 1: Insights and Reflections on Politics and Society in the Lion City, July 2025, pp. 309-315.

Benjamin Ang and Tan E Guang Eugene, “Cyber Diplomacy in Singapore and ASEAN” in Andrea Salvi, Heli Tiirmaa-Klaar, James Andrew Lewis (eds.), A Handbook for the Practice of Cyber Diplomacy. Europe: Publications Office of the European Union, January 2025, pp. 119-128.

Bulletin

Karryl Kim Sagun Trajano, Ysa Marie Cayabyab, Dongyoun Cho, Clarissa Ai Ling Lee, and Alexander Ling Euk Jin, “Science, Technology and Security: Quantum,” Future Issues, 14 April 2025.

Conference Papers

Karryl Kim Sagun Trajano, Antara Chakraborthy, Yasmine Wong, “From Crisis to Capacity Building: AI Pedagogies and Social Resilience in Singapore,” BISA-ISA Conference, 10 October 2025.

Karryl Kim Sagun Trajano, Antara Chakraborthy, Vincent Kyle Parada, Juan Cui Ying, Ysa Marie Cayabyab, “Building Social Resilience in the Age of AI,” Technology, Knowledge, and Society Conference, 26 April 2025.

Karryl Kim Sagun Trajano, Banjamin Ang, “In Us We Trust? Singapore’s Public Opinion on AI amid US-China Dynamics” International Studies Association (ISA) Conference, 03 March 2025.

EVENTS

In 2025, FIT organised three seminars: (1) Anticipating the Quantum–AI Continuum in Southeast Asia (Dr Clarissa Lee, Monash University Malaysia); (2) Sharing the Vision for Nuclear Energy in the New AI Era (Dr Hwang Yongsoo, KEPCO International Nuclear Graduate School); and (3) Trust by Design: Public Opinion and the Future of AI Policy (Merve Hickok, Center for AI & Digital Policy).

FIT also collaborated with the RSIS Digital Impact Research (DIR) team to host a tabletop exercise titled AI-Enabled Cybercrime: Exploring Risks, Building Awareness, and Guiding Policy Responses, featuring Dr Gil Baram (Department of Political Studies, Bar-Ilan University) and Mr Derek Manky (Fortinet). The exercise brought together cybercrime experts and practitioners from across Singapore.

ACHIEVEMENTS

The FIT team, in collaboration with full professors from NTU, won the competitive Social Science and Humanities Research (SSHR) Seed Grant in 2025. That year, Karryl Trajano was recognised as a space expert at the International Space Challenge organised by Space Faculty in Singapore. Dr Trajano also graduated with distinction from the Center for AI and Digital Policy's (CAIDP) AI Policy Clinic.

ENGAGEMENTS

Benjamin Ang spoke at the EU–Indo-Pacific Digital Partnership Conference 2025, organised by the National University of Singapore and the Singapore Academy of Engineering. He also served as a speaker on several panels at the Singapore International Cyber Week.

Benjamin Ang, together with Ysa Cayabyab, participated in a closed-door roundtable on governing AI, held at the Czech Embassy in Singapore (above). Ms Cayabyab also participated in the IAPP Asia 2025: Privacy Forum + AI Governance Global Conference (below).

Karryl Trajano went live on BBC News to discuss artificial intelligence and elections in Southeast Asia (above). She also represented RSIS at the International Astronautical Federation–UNOOSA event on "Resilient Coasts, Resilient Earth: Innovative Space Solutions for Coastal Resilience and Emergency Management," held in Sydney, Australia (below), and at the British International Studies Association Conference in Newcastle, United Kingdom, where she presented a paper on "AI as a Social Good in Singapore."

Benjamin Ang was a speaker at GovWare 2025 on the panel "Cyber, Conflict and Critical Infrastructure: Securing the Modern State" (above), and also spoke at the AI and Cybersecurity Lab event organised by Cyber Security World (below).

Ysa Marie Cayabyab and Benjamin Ang participated in the ISEAS–CIIS Joint Symposium on China–ASEAN AI Cooperation (above). Ms Cayabyab also attended the ISEAS–Yusof Ishak Institute Workshop on National Space Laws in Europe and Asia, featuring OSTin and the International Institute of Space Law, held at the Konrad-Adenauer-Stiftung Singapore Office (below).

The paper, "Soft but Ethical: the ASEAN Way to Data Protection and AI Governance," co-authored by Benjamin Ang and Karryl Trajano, was presented during the Information Resilience and Integrity Symposium (IRIS 2025) in Yokyakarta, Indonesia.

Dr Trajano also spoke at the Asian Development Bank's Insight Thursday event on "SpaceAI for a Greener Earth and Space."

Benjamin Ang served as a panel speaker on "Regional Governance of AI in ASEAN" at the 17th ASEAN–Australia–New Zealand Dialogue in Kuala Lumpur, Malaysia (above), and as a keynote speaker at the IMDA–CyberSG TIG Collaboration Centre event in Singapore titled "AI, Deepfakes and the Cyber Frontier" (below).

In 2025, Karryl Trajano participated in the ASEAN Quantum Summit in Johor, Malaysia (top left), presented a paper titled “Balancing Trust: Singapore’s Public Opinion on AI amid US–China Dynamics” at the International Studies Association Conference in Chicago, USA (top right), and spoke at Satellite Asia at ATxSingapore on a panel on “Space AI: Automation, Predictive Analytics, and Mission Optimization,” sponsored by the Singapore Space & Technology Think Tank (below).

Benjamin Ang participated in a closed-door cybersecurity side event at the Asia Pacific Foundation of Canada's 2025 Canada in Asia Conference in Singapore, where he joined Julia Voo and Gaurav Keerthi on a panel discussing "The Future of Cybersecurity: Challenges and Opportunities" (above). He also presented a proposal on enabling non-state stakeholder participation in the UN OEWG on Cyber's future permanent mechanism beyond 2025 (below).

ABOUT US

The Future Issues and Technology Cluster

The Future Issues and Technology (FIT) research cluster supports the development of RSIS' research agenda on emerging issues where science and technology intersect with national security. FIT works collaboratively with a wide range of RSIS stakeholders to explore and incubate topics that could become new research areas and builds up RSIS' networks with science and technology experts and researchers working on ideas yet to enter the mainstream. FIT's current focus areas include: (1) AI & Data, (2) Technology & Geopolitics, (3) Science & Technology's Evolving Relationship with National Security, (4) Space, (5) Biotechnology, and (6) Quantum technologies.

S Rajaratnam School of International Studies

The S. Rajaratnam School of International Studies (RSIS) is a global graduate school and think tank focusing on strategic studies and security affairs. Its five Research Centres and three Research Programmes, led by the Office of the Executive Deputy Chairman, and assisted by the Dean on the academic side, drive the School's research, education and networking activities.

The graduate school offers Master of Science Programmes in Strategic Studies, International Relations, International Political Economy and Asian Studies. As a school, RSIS fosters a nurturing environment to develop students into first-class scholars and practitioners.

As a think tank, RSIS conducts policy-relevant and forward-looking research in both national and international security, science and technology, society and economic and environmental sustainability. RSIS also produces academic research on security and international affairs. It publishes scholarly research in top-tier academic journals and leading university presses, and distributes policy research in a timely manner to a wide range of readers. Relevant RSIS research contributes to rule-making and norm-setting in cyber domain and digitalisation. RSIS works closely with other academic institutions and partners including international and regional organisations, global think tanks as well as national agencies to conduct policy relevant research in various areas of interest.

Our Team

Mr Benjamin Ang is Senior Fellow and Head of FIT, the Centre of Excellence for National Security and Digital Impact Research at RSIS. He graduated from Law School at the National University of Singapore and has an MBA and MS-MIS (Management Information Systems) from Boston University. He has given expert testimony at the UN Open Ended Working Group on Cyber, testified before Singapore's Parliamentary Select Committee on Deliberate Online Falsehoods, and lectures at the UN-Singapore Cyber Fellowship. He is Co-Chief Data Officer of AI.Singapore and Co-Editor of *Science, Technology & Security Bulletin*.

Dr Karryl Kim Sagun Trajano is a Research Fellow focusing on emerging technologies (AI, space, quantum, energy, and

biotech) relating to strategy, policy, and national security. She holds a PhD in Information Studies from NTU Singapore and a Master's in Technology Management from the University of the Philippines Diliman. Dr Trajano serves as Co-Editor of the *Science, Technology & Security Bulletin* and sits on the editorial board of *LIBRES e-journal*. Her work has appeared on BBC World, Channel News Asia, Straits Times, National Bureau of Asian Research, The Council of Councils, Lowy Institute, The Australian Strategic Policy Institute, as well as various edited books and peer-reviewed academic journals.

Ms Ysa Marie Cayabyab is an Associate Research Fellow with FIT. Her research focuses on the intersection of technology and society, examining the governance, public communication, and societal implications of emerging technologies. She holds a Bachelor's in Communication Research from the University of the Philippines Diliman and a Master's in Communication Studies from NTU. Her work has been published in peer-reviewed journals including the *International Journal of Advertising*, *BMC Public Health*, *Journalism Studies*, and the *International Journal of Communication*, among others.

We also thank and acknowledge our collaborators in 2025: Iuna Tsyrulneva, Adhi Priamarizki, Keith Paolo Landicho, Alvin Chew, Alexander Ling, Lynette Tan, Nicolette Yeo, Helena Huang, Edson Tandoc Jr, Chew Lock Yue, Juan Cui Ying, Vincent Kyle Parada, Yasmine Wong, and Antara Chakraborthy.