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Harnessing Artificial Intelligence for Energy Transition

ESCAP

APCTT
Asian and Pacific Centre for Transfer of Technology

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The Economic and Social Commission for Asia and the Pacific (ESCAP) is the most inclusive intergovernmental platform in the Asia-Pacific region. The Commission promotes cooperation among its 53 member States and 9 associate members in pursuit of solutions to sustainable development challenges. ESCAP is one of the five regional commissions of the United Nations.

The ESCAP secretariat supports inclusive, resilient and sustainable development in the region by generating action-oriented knowledge, and by providing technical assistance and capacity-building services in support of national development objectives, regional agreements and the implementation of the 2030 Agenda for Sustainable Development.

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Foreword

Artificial intelligence (AI) is revolutionizing energy generation and management systems. Across the Asia-Pacific region, AI is emerging as a key enabler of a transition towards renewable and sustainable energy sources - optimizing grid operations, enhancing renewable energy forecasting, improving energy storage management and supporting smarter demand response. From wind and solar forecasting to predictive maintenance and autonomous grid management, AI-driven solutions are helping countries meet rising energy demand along-side their decarbonization goals, while maintaining system reliability and affordability.

The potential of AI in energy transition is substantial; however, significant challenges remain. Infrastructure gaps, fragmented policies, investment shortfalls, and inadequate skills, workforce capacity and availability, complicate the deployment of AI solutions at scale. Technical challenges, including data quality, interoperability, cybersecurity and AI explainability need to be addressed Ensuring equitable access to AI benefits across countries with diverse levels of development is a priority.

Addressing these challenges requires a comprehensive approach: harmonized governance frameworks, strategic investments in digital-ready grids, capacity building initiatives, and strengthened regional cooperation. With its diverse energy landscape and growing digital economy, the Aisa Pacific region stands at a pivotal juncture to harness AI's transformative potential while managing the associated risks. According to the World Bank, 98.6% of the Asia-Pacific population had electricity access as of 2023, and the region is now prioritizing energy efficiency and expanding renewable sources.

This issue of Asia-Pacific Tech Monitor is dedicated to the theme: "Harnessing Artificial Intelligence for Energy Transition." It features insightful articles exploring AI applications across energy systems. The articles examine technical innovations, policy frameworks, regional case studies, and future research directions, enriched with real-world examples from across the region. This issue also includes an AI-generated special feature to showcase AI's potential in knowledge synthesis and technical writing - offering both substantive content on AI applications for energy transition and a practical demonstration of AI capabilities.

We hope this edition serves as a useful resource, not only for information on AI's transformative role in energy systems but also for supporting informed decision-making for moving towards a cleaner, smarter and resilient energy future.

Preeti Soni
Head, APCTT

Technology Market Scan

ASIA-PACIFIC

BANGLADESH

Software to protect IP launched

The government has launched the Industrial Property Administration System (IPAS 4.0) software to protect intellectual property. IPAS is an internationally known and recognized software being successfully used in many countries across the world with the technical assistance of the World Intellectual Property Organization (WIPO).

Industries Adviser Adilur Rahman Khan today inaugurated the software for the Department of Patents, Designs and Trademarks (DPDT) at an event at the Industries Ministry conference room in the city, said a press release. Speaking on the occasion, Adilur said that with the inauguration of the Industrial Property Administration System (IPAS 4.0) software, Bangladesh has entered a fully automated era in intellectual property management.

The software will take the country's patent, design, and trademark services to a faster and international standard, he added. Among others, WIPO Representative Hisham Adel Elhosseiny Fayed and Director General of the DPDT Mohammad Jahangir Hossain were present.

https://www.bssnews.net/

CHINA

Guidelines to promote AI education

China's Ministry of Education has recently issued two guidelines to promote artificial intelligence (AI) education in primary and secondary schools by building a tiered, progressive, and spiralling general AI education system, prohibiting students from independently using open-ended content generation at primary schools and banning teachers from using generative AI as a substitute for their core teaching responsibilities.

The release of the two documents - the guidelines for AI general education in primary and secondary schools (2025) and the guidelines for the use of generative AI in primary and secondary schools (2025) - marks a significant initiative to scientifically and systematically promote AI education across all levels of schooling, further implement the cultivation of innovative talent with AI literacy and offers a Chinese solution to respond to technological transformation in the global education sector, CCTV News reported.

The guidelines for AI general education aim to establish a comprehensive, scientifically grounded AI education system, which centers on AI literacy through the adoption of a spiral curriculum designed to realize the development from cognitive enlightenment to creative practice, CCTV reported. At the primary level, the focus is on sparking interest and building foundational cognitive understanding. During the junior high school period, the AI education will reinforce students' understanding of technical principles and foundational AI applications. At the senior high level, emphasis is placed on systems thinking and innovation.

According to the AI general education guidelines, the goal is to cultivate students' core competencies for adapting to an intelligent society, the AI education system will cultivate talent with AI literacy characterized by an integrated development in terms of knowledge, skills, thinking and values which includes the development of technological innovation thinking, critical thinking, human-AI collaboration skills, AI literacy, and a strong sense of social responsibility, People's Education magazine reported on Monday.

By implementing a coordinated mechanism involving "curriculum restructuring, integrated resources, innovative assessment and empowered teacher training," this initiative aims to transition AI education from localized pilots to nationwide implementation, ultimately establishing a Chinese-style model of AI general education for primary and secondary schools, CCTV reported.

The guidelines for using generative AI focus on practical applications in primary and secondary education, clearly specifying the usage standards for each educational stage. They aim to ensure that the technology is used safely, appropriately, and effectively to support teaching, promote students' personalized learning, and advance intelligent education management, while strictly upholding data security and ethical standards, according to CCTV.

The implementation of the two guidelines is expected to enhance AI literacy among primary and secondary students, deepen the integration of AI into education, and drive innovation in teaching models. They aim to build a new AI-powered educational ecosystem that is safe, efficient, equitable, and inclusive, laying a solid foundation for cultivating innovative talent in line with the development of the era, according to People's Education.

https://www.globaltimes.cn/

INDIA

Low-interest funding for startups

India's newly approved Research Development and Innovation (RDI) scheme, with a INR 1 lakh crore corpus, is set to provide a major boost to private sector R&D and deep-tech startups by making long-term, affordable financing accessible for high-impact innovation projects, a senior government official said. The scheme, approved by the Union cabinet on July 1, is designed to ease funding constraints and foster a robust domestic innovation ecosystem. A senior government official cited by news agency PTI said that the RDI scheme is structured to help companies access long-term, low or nil-interest financing for high-risk, high-tech research projects.

The initiative will also support equity-based funding for startups and facilitate the creation of a deep-tech Fund of Funds. The corpus will be managed through a Special Purpose Fund under the Anusandhan National Research Foundation (ANRF), with INR 20,000 crore already allocated in the Union Budget for FY26. The government will provide a 50-year interest-free loan to the fund, which will further allocate capital to second-level fund managers, including AIFs, NBFCs, and Focused Research Organisations. The official further said that the aim is to help India "jumpstart its R&D ecosystem" by creating a mechanism where ministries can propose relevant technologies for inclusion under the scheme. "Any ministry that wants a technology included under the scheme can send a proposal to the Department of Science and Technology," the official added.

The Department of Science and Technology will act as the nodal agency for implementation and will issue detailed operational guidelines. These will include provisions to ensure effective capital recycling so that private sector RDI efforts continue to receive support over time. India currently spends just 0.65% of its GDP on R&D, significantly below the global average of 2.7%, and far lower than countries like Israel (6.3%) and the Republic of Korea (5%). According to officials, one of the key objectives is to change the perception in the private sector that R&D is a cost rather than an investment.

The governing board of ANRF, chaired by the Prime Minister, will provide strategic direction. An Executive Council under ANRF will approve project scopes and second-level fund managers. Launched under the broader umbrella of Startup India, the RDI scheme adds another critical layer to India's ambition to become a global innovation powerhouse by 2047

https://timesofindia.indiatimes.com/

Advanced biomanufacturing hubs

The government launched a network of advanced biomanufacturing hubs to scale up the country's bioeconomy and accelerate innovation across diverse sectors, officials said. The High Performance Biomanufacturing Platforms, an initiative of the Department of Biotechnology (DBT) and the Biotechnology Industry Research Assistance Council (BIRAC), are being rolled out under the BioE3 Policy (Biotechnology for Environment, Economy and Employment), they said.

The High Performance Biomanufacturing Platforms, an initiative of the Department of Biotechnology (DBT) and the Biotechnology Industry Research Assistance Council (BIRAC), are being rolled out under the BioE3 Policy (Biotechnology for Environment, Economy and Employment), they said. "The High Performance Biomanufacturing Platforms are a network of advanced bio-foundries and biomanufacturing hubs designed to provide state-of-the-art infrastructure, technology, and expertise for scaling up bio-based innovations from the laboratory to pilot and pre-commercial stages," an official statement said.

The platforms integrate tools such as synthetic biology, artificial intelligence, machine learning, and omics technologies to accelerate the development of sustainable solutions in health, agriculture, food systems, clean energy, industrial biotechnology, and climate resilience, it said.

Union Minister of State for Science and Technology Jitendra Singh noted that India's bioeconomy has also gone up from just $10 billion and is now set to leapfrog to the $300 billion mark by 2030. He said the biomanufacturing hubs and bio-enablers would also contribute to India's geopolitical empowerment, reducing dependence on petroleum imports and creating sustainable alternatives through biotechnology. It brings together 21 bio-enabler facilities across the country, supporting start-ups, SMEs, industries, and academia in scaling up technologies in areas ranging from cell and gene therapy to marine biotechnology, precision biotherapeutics, smart proteins, and carbon capture.

The newly launched hubs, which are also called National Bio-Enablers or Mulankur (roots of new growth), will support innovation across health, agriculture, energy, environment, industrial biotechnology, and AI-driven bio-manufacturing, Gokhale explained.

https://www.thehindu.com/

INDONESIA

National AI roadmap

Artificial Intelligence (AI) could help Indonesia achieve its vision of Golden Indonesia 2045 with the right strategy and governance, according to Minister of Communication and Digital Affairs, Meutya Hafid. Stating this in her foreword to Indonesia's National AI Roadmap White Paper, she said the AI roadmap would provide policy direction to accelerate AI ecosystem development to ensure the country was not to be left behind in a field increasingly dominated by advanced countries and global tech giants.

The White Paper, drafted by the AI Roadmap Task Force, a 443-member body representing government, academia, industry, civil society, and the media, was launched by the Ministry of Communication and Digital in early August. It has been envisaged as a strategic document that would serve as the country's reference for adopting and developing AI technology in a more focused, inclusive, and ethical manner. The document has been circulated for public consultation to gather wider input from stakeholders. This initiative builds on the National AI Strategy 2020-2045, which was an initial framework developed by the Collaborative Research and Industrial Innovation in AI (KORIKA), an organisation formed by scientists, technocrats, and industry leaders to accelerate the AI ecosystem in Indonesia.

The national AI roadmap outlines three main action plans: AI ecosystems, AI development priorities, and AI financing – all anchored in ethical guidance and regulation. This roadmap also breaks down the action plan into three time horizons: short term (2025-2027), medium term (2028-2035), and long term (2035-2045).

Indonesia's AI ecosystem development would focus on three main pillars. The first pillar was talent development. Indonesia aimed to nurture a large pool of skilled professionals who could both use and create AI innovation. The roadmap sets an ambitious target of producing 100,000 AI talents annually. Around 30 per cent would be developers, divided further into AI specialists (30 per cent) and practitioners (70 per cent), and the remaining 70 per cent would be AI end-users. The government also aimed to ensure 20 million citizens are AI-literate by 2029. The next pillar was research and industrial innovation.

The roadmap emphasised advanced, relevant, and sustainable AI research that delivered real benefits to society. To achieve this, the government would encourage agencies, universities, and industries to strengthen AI programmes in priority sectors. A cross-sectoral open sandbox platform would also be developed to support experimentation and collaboration.

The last pillar in Indonesia's AI ecosystem was infrastructure and data. To foster domestic AI innovation, the government planned to expand digital infrastructure, including high-performance computing, GPUs/TPUs, and a national cloud hosted in sovereign data centres to ensure secure and regulated data management. The white paper also outlined plans to promote the development of green data centres through public–private partnerships.

The roadmap focuses on developing AI for strategic use cases, ensuring that AI adoption delivers meaningful and sustainable impact. These priorities closely align with the country's national development agenda and President Prabowo's Asta Cita vision. The priority sectors for AI include food security, healthcare, education, economy and finance, bureaucratic reform, politics and security, energy, environment, housing, transport and logistics, as well as arts, culture, and the creative economy.

Public services were also identified as an immediate priority for the 2025–2027 term. In healthcare, AI would be applied for early disease detection, remote patient monitoring, and optimising the distribution of medicines and vaccines. In education, the focus would be on adaptive learning and digital platforms for personalised teaching materials. The government also plans to develop automated evaluation systems to ease assessment processes in schools.

In governance, AI applications would centre on intelligent chatbots for public services and data-driven policy analytics. For transport and mobility, development would be directed towards smart traffic systems, public transport management, and the optimisation of national logistics.

The roadmap outlined a phased financing strategy, combining state budget allocations, private sector contributions, and external partnerships through bilateral and multilateral collaborations. Over the next two decades, the government aimed to establish a sustainable financing ecosystem driven by industry participation and international investment. To achieve this, Indonesia will expand fiscal incentives to encourage AI-related investments. A notable feature of the roadmap was the role of Danantara, Indonesia's newly established sovereign wealth fund, which has been tasked with spearheading AI financing.

https://govinsider.asia/

ISLAMIC REPUBLIC OF IRAN

Quantum technology strategy

The National Document for the Development of Quantum Sciences and Technologies was approved with a focus on ten-year strategies for the advancement of this field and with the goal to place Iran among the leading countries in quantum technology and increase investment in this area to $50 million in the next three years.

One of the goals of this document is to increase Iran's investment volume in the quantum field to $50 million in the next three years. This document has been prepared and compiled in six main axes of value principles, vision, macro goals, strategies, priority areas, and a monitoring mechanism. The human resource in this field is set to increase. Developing higher education and attracting researchers to enhance Iran's position in scientific production and international patent registration are other goals in the quantum field.

These technologies play a strategic role in the security, communication, and economic fields of the world, and Iran should also have an effective presence in this field with long-term planning.

https://ana.ir/

NEPAL

AI policy

The government endorsed the new National AI Policy, which has invited a lot of enthusiasm and positivity. By implementing this policy, the government hopes to achieve the digital transformation envisioned by the Digital Nepal Framework (DNF), which has identified and outlined seven sectors: smart infrastructure; agriculture; health; tourism; education; finance; governance, social protection, and lifecycle protection. Given their proliferating innovation and adoption, the government's effort to strategize and regulate the use of AI and other digital technologies is not just timely but praiseworthy. However, given Nepal's pre-existing digital divide and the sluggish pace of mitigating efforts, the implementation of the new AI policy not only faces significant challenges but also risks further exacerbating the digital divide, pushing rural and marginalised groups to further exclusion.

Before assessing their implementational feasibility, it is essential to recognise how Nepal's AI policy addresses inclusion. Notably, the policy's vision explicitly emphasises "inclusive" use of AI systems to "build a prosperous Nepal", signalling that the government acknowledges the importance of equitable access. To promote inclusion, the policy outlines targeted measures such as awareness, orientation, literacy, skill development, and capacity-building programmes at the federal, provincial, and local levels. These initiatives aim to accelerate AI adoption across diverse populations. Special focus on women and marginalised communities through training and workshops could help prevent the benefits of AI from being confined to urban, English-speaking groups.

The policy also promotes inclusive sectoral adoption. In education, it plans to introduce AI-related subjects in school curricula, support personalised and adaptive learning, and build skilled human resources through varied training programmes. Importantly, it encourages the use of local languages in AI development, making tools more accessible to non-English speakers. In agriculture, the policy envisions AI-driven innovations such as weather-based farming, smart irrigation, and e-agriculture markets. In healthcare, it aims to improve access and quality of services in remote areas. Furthermore, the policy seeks to enhance public service delivery through AI-enabled digitisation, which could increase transparency, improve grievance redressal, and simplify access to government services.

To its credit, the policy does acknowledge key implementation challenges, including low digital and AI literacy, limited data availability and accessibility, poor digital infrastructure, and a shortage of skilled human resources. However, it falls short in incorporating these ground realities into its strategic planning and fails to propose context-specific, tailored solutions.

https://thehimalayantimes.com/

THE PHILIPPINES

Zero-interest loans for patent commercialization

Filipino inventors can now access zero-percent interest loans to commercialize their patented inventions through an enhanced government lending program launched recently. The Department of Science and Technology-Technology Application and Promotion Institute, in partnership with the Land Bank of the Philippines (Landbank), officially launched the improved Innovation and Technology lending program during the Philippines' International Exposition of Technologies at Okada Manila, Parañaque City.

The enhanced i-TECH 2.0 program removes the previous P12.5 million loan ceiling and eliminates interest charges entirely, allowing eligible borrowers to access funding up to 85% of their total project cost based on requirements.

DOST-TAPI, Landbank, and the Philippine Economic Zone Authority (PEZA) signed a renewed partnership agreement to support more local inventors in commercializing their technology products. The original i-TECH program, launched in September 2017, offered low-interest funding at 5% annually with a complex loan-sharing structure. Under the previous system, 40% came from TAPI's Invention Guarantee Fund at zero interest, 45% from Landbank at 5% interest, and borrowers provided 15% equity.

Eligible applicants include registered Filipino-owned corporations or partnerships with active intellectual property rights for patents, utility models, or industrial designs. Filipino inventors must be major stockholders or managing partners, and IP rights must have at least one year of remaining validity. According to Javate, DOST-TAPI and Landbank have assisted six Filipino inventors through the program as of this year.

The lending program supports DOST's strategic pillars of human well-being, wealth creation, wealth protection, and sustainability under the "OneDOST4U: Solutions, Opportunities for All" initiative.

https://pia.gov.ph/

THE REPUBLIC OF KOREA

R&D allocation in 2026

The government has unveiled a plan to allocate a record-breaking 35.3 trillion won (US$25.1 billion) for research and development (R&D) projects in 2026 in a move to enhance productivity and develop new growth engines. The decision was reached at a meeting of the Presidential Advisory Council on Science & Technology, chaired by President Lee Jae Myung, with details set to be submitted to the National Assembly in the near future. The amount, the highest of its kind, marks a 19.3 percent spike from this year's 29.6 trillion-won R&D budget, according to the Ministry of Science and ICT.

Of the total, 2.3 trillion won will be spent on pursuing "transformation of the economy and society through artificial intelligence (AI) technology," which is more than double from 2025.

The government aims to apply AI across various industries and expand adoption in the public sector, including administration, health care, and defense. The government will also spend 2.6 trillion won on the development of renewable energy technologies, up 19.1 percent from this year. In detail, the government will seek to speed up the transformation of the energy sector led by renewable sources, such as solar and wind power, supporting the development of related homegrown technologies.

A total of 8.5 trillion won will be earmarked for fostering cutting-edge industries, marking a 29.9 percent increase from 2025. The government said it will focus on securing core technologies in areas with great potential, such as quantum computing and synthetic biology.

The Republic of Korea will also make efforts to make early progress in areas with strong public demand, including self-driving and robotics technologies. The budget for defense-related R&D projects will rise 25.3 percent on-year to 3.9 trillion won to support efforts to secure omnidirectional deterrence capabilities in all domains, including space and cyber.

The government will promote research in basic science by spending 3.4 trillion won, up 14.6 percent from this year, offering scholars a more liberal, sustainable, and stable research environment. An additional 1.3 trillion won will be allocated to attract competitive experts from overseas, along with 4 trillion won to enhance the capabilities of state-funded research institutes, the ministry added.

https://qazinform.com/

Development blueprint for an AI powerhouse

The new Lee Jae Myung administration aims to integrate private firms and the public sector, as well as all other sectors of society, with artificial intelligence (AI) to achieve what it calls a "super-innovation economy," the government said. Unveiling its five-year economic development blueprint, the government said private companies will spearhead AI development, supported by comprehensive policy measures to build a nationwide AI ecosystem.

The government will focus on developing a sovereign AI model that is accessible to the general public and enhances daily life, along with customized AI models for key industries to drive innovation and accelerate AI adoption across all sectors. As part of the plan, the government will launch 30 projects centred around AI, including the development of humanoid robots, initially for logistics and later expanding to manufacturing, construction, and services. Other major goals include fully commercializing autonomous vehicles by 2027 and completing the development of unmanned autonomous ships by 2030, the government said.

The government also aims to expand AI-based smart factories in key manufacturing sectors, such as automobiles, with the goal of raising AI adoption in manufacturing to over 40 percent by 2030. In addition, AI-powered drones will be developed and deployed in five specialized sectors, including firefighting and aviation, to enhance operational efficiency and support fieldwork.

In the pharmaceutical sector, the government plans to introduce AI into the drug approval process, automating tasks such as data analysis and drafting review reports, to shorten the time required for reviews. In the public sector, AI will be applied throughout the administrative process, starting with welfare and employment services, and later expanded to tax administration.

The government first plans to introduce AI-based tax consultation services by 2026 and overhaul the national taxation system by 2027, using AI to help detect potential tax evasion. To nurture a skilled workforce, the government will introduce customized AI education programs tailored to various groups, including elementary and secondary students. The government will also establish a national AI training data cluster that integrates AI training datasets from both public and private sectors.

https://en.yna.co.kr/

SRI LANKA

National R&D policy

Sri Lanka's new national research and development (R&D) policy has been finalised and is set to be implemented from 2025, a strategic move by the government to pivot the nation towards a production-based economy, driven by value-added products and services. Joining a panel discussion at the Asian Development Bank's Serendipity Knowledge event in Colombo last week, Senior Advisor to the President on Science and Technology Prof. Gomika Udugamasooriya announced that the proposed new policy has been drafted and is currently undergoing an evaluation process and will be implemented within this year.

The new policy aims to create a centralised and cohesive R&D ecosystem, addressing the long-standing issues of fragmented research efforts and a disconnect between the research outcomes and the national economy. The government plans to establish a powerful centralised commission and administrative institute to govern the entire R&D system.

The proposed centralised R&D commission will be structured into six interconnected divisions to address systemic flaws. These divisions include policy development tasked with creating and updating national R&D policies, research prioritisation aimed at aligning research with national economic and social development needs, targeted funding, which will direct financial resources to prioritised research areas to prevent wastage, and facilitation and monitoring, responsible for regulating and overseeing all funded research projects.

Additionally, a commercialisation division will support intellectual property protection and connect the researchers with the private sector investors, while knowledge dissemination will focus on sharing research findings and integrating the lessons learned back into the policy cycle.

This initiative will focus on providing the "gap-filling" funding for the nearly completed research with high commercial value, matching the finished projects with the investors, and resolving the legal or bureaucratic hurdles for the researchers.

https://www.dailymirror.lk/

Committee for R&D

Sri Lanka has established a national ad-hoc committee for the first time to identify and prioritize research and development (R&D) needs based on the country's development goals. Formed on July 7, the committee aims to categorize ongoing research efforts across the country by priority and align them with national requirements. This is the first time such a body has been formed to coordinate and classify ongoing research initiatives nationwide based on strategic national priorities.

The committee is co-chaired by Professor Gomika Udugamasooriya, Senior Advisor to the President on Science and Technology, and Professor Rohan Fernando, Chairman of the National Science and Technology Commission (NASTEC), under the Ministry of Science and Technology. It includes 20 experts from various disciplines.

Key responsibilities of the committee include aligning R&D policies across universities, research institutions, industries, and government agencies with national objectives. It also seeks to guide the allocation of national budget funds toward prioritized research areas to ensure more efficient use of public resources.

Sri Lanka's R&D sector has long been characterized by fragmentation and a lack of coordinated strategy, limiting its impact on economic and social development, the PMD said. The committee aims to address this by integrating input from grassroots to national levels through stakeholder reports and surveys. The initiative also promotes data-driven decision-making and financial accountability in the R&D sector, marking a shift toward more strategic and outcome-focused investment in science and innovation.

https://www.newswire.lk/

VIET NAM

R&D for a tech-driven future

With a landmark resolution, Viet Nam aims to lead innovation and digital transformation through major investments in science and technology. On December 22, 2024, General Secretary To Lam signed Resolution No. 57-NQ/TW of the Politburo, focusing on breakthroughs in science, technology, innovation, and national digital transformation.

Science, technology, innovation, and digitalization are now seen as prerequisites for achieving Viet Nam's ambitious goals: ranking in the global top 30 for innovation and digital transformation by 2045, with a digital economy contributing at least 30% of GDP by 2030 and 50% by 2045. Notably, Resolution 57 prioritizes R&D with clearly defined metrics. The science and innovation system is being restructured to integrate research, application, and education more effectively.

Achieving Resolution 57's goals will be challenging given the current fragmented and underfunded state of R&D in Viet Nam. The country must act decisively to improve labor productivity, master core technologies, boost global competitiveness, and accelerate national progress.

Resolution 57 targets include making Viet Nam a leader in science and innovation among upper-middle-income countries by 2030. Goals include having at least 40-50 science and technology organizations ranked regionally or globally, increasing international publications by 10% annually, patent applications by 16-18%, and achieving a tech commercialization rate of 8-10%. The resolution also aims to attract at least three major global tech firms to invest in R&D in Viet Nam.

https://vietnamnet.vn/

Technology training networks

The Ministry of Education and Training, on August 8, announced the establishment of six networks of excellent training and talent centres in key 4.0 technology fields, aiming to boost high-quality training, research, and innovation through nationwide and international collaboration.

They include the network of artificial intelligence (AI) and semiconductors in the southern region, led by the University of Technology under Vietnam National University-Ho Chi Minh City; the network of AI and semiconductors in the central region, led by the University of Technology under the University of Da Nang; the network of agricultural biotechnology in the southern region, led by Can Tho University; the network of agricultural biotechnology in the central region, led by Hue University; the network of renewable energy and hydrogen energy, led by HCM City University of Technology and Education; and the network of educational technology, led by HCM City Open University.

The networks bring together universities, research institutes, and domestic and foreign businesses. Members will work closely in training, research, and technology transfer by sharing curricula, improving faculty capacity, providing access to laboratories and research facilities, and jointly implementing science and technology projects. Through joint training programmes and university–industry research projects, students and researchers will gain the latest knowledge, develop interdisciplinary skills, and tackle real-world technological challenges.

This network model marks a strategic shift in higher education reform - from single institutional development to cooperative, resource-sharing alliances. Strategic partnerships between universities and businesses in specific 4.0 technology fields will create combined strength to deliver the highest quality training and research. By linking training and research with the needs of businesses and the economy, research outcomes can be applied in production and business instead of remaining on paper, he said.

https://en.vietnamplus.vn/

PPP framework for STI projects

In a move to encourage stronger private sector engagement in scientific research and technological development, the Government has issued a legal framework and special incentives designed to attract investment into science, innovation, and digital transformation. On July 1, the Government issued rules and policies for public-private partnerships (PPPs) in science, technology, innovation, and digital transformation. It explains how partners can work together and which areas are covered, such as technology, digital infrastructure, and workforce training.

The decree outlines different ways to cooperate, such as PPP partnerships, using public assets for joint ventures, and other legal forms. PPPs can be used in areas like high technology, key technologies, digital infrastructure, shared digital platforms, digital skills training, and services for digital transformation.

According to the decree, enterprises participating in PPP projects will enjoy a range of prominent incentives. Notably, actual expenditure on research and development (R&D) will be calculated at double (200 per cent) when determining deductible expenses for corporate income tax purposes.

In addition, enterprises will benefit from exemptions or reductions in land use fees and land rents and other investment incentives in line with current legislation. Regarding ownership rights, participating parties will be recognised as owners of products, technological platforms, data, and software in accordance with their agreements and subject to intellectual property and technology laws.

The decree also introduces a risk acceptance process for scientific and technological work, with clear rules for assessing risks and protecting those carrying out the work, based on relevant specialised regulations. The State can also place orders or directly award contracts to buy scientific and technological products and services from PPP projects to meet special public needs.

For original data directly created by State agencies, ownership will rest with the State unless otherwise agreed. Post-tax profits from commercial exploitation of products and services must be shared transparently, fairly, and in proportion to each party's contributions.

https://vietnamnews.vn/

Technology Scan

Focus: Artificial intelligence for energy transition

ASIA-PACIFIC

AUSTRALIA

AI to make green ammonia greener

To find the best catalyst for green ammonia, researchers were staring down 8000 lab experiments. With AI, they only needed 28. Scientists and engineers at the University of New South Wales (UNSW) Sydney, who previously developed a method for making green ammonia, have now turned to artificial intelligence and machine learning to make the process even more efficient.

The UNSW team discovered a way to make ammonia from air and water using renewable energy, at about the same temperature as a warm summer's day. Dr Ali Jalili, with UNSW's School of Chemistry, says while the original proof-of-concept demonstrated that ammonia could be created entirely from renewable energy, at low temperatures and without emitting carbon, there was still room for improvement. For example, could it be produced more efficiently, using lower energy, less wasted energy, and producing more ammonia?

To answer these questions, the team needed to find the right catalyst – a substance that speeds up the chemical reaction without being consumed by it. But the best catalyst would need a combination of these metals, and if you do the maths, that turns out to be more than 8000 different combinations. The researchers fed a machine learning system information about how each metal behaves and trained it to spot the best combinations. That way, instead of having to run more than 8000 experiments in the lab, they only had to run 28. The winning combo was a mix of iron, bismuth, nickel, tin, and zinc. While the researchers were expecting some improvement in the process of producing green ammonia, this new five-metal catalyst exceeded even their most optimistic expectations.

Known as Faradaic efficiency, high efficiency scores mean the process is more sustainable, cost-effective, and scalable, which is crucial for making green ammonia a viable alternative to fossil-fuel-based methods. Dr Jalili says his team was able to make ammonia this way at an ambient 25°C, less than 10% of the temperature required to make ammonia the conventional way via the Haber-Bosch method.

This low-temperature, high-efficiency approach makes green ammonia production viable and scalable. We believe it can compete directly with electrified Haber–Bosch and even fossil-based routes, creating a realistic pathway for truly green ammonia. The goal is that one day soon, farmers will be able to produce ammonia for fertilisers onsite, at low cost and low energy, eliminating the need for delivery via transport routes, further reducing the carbon footprint of ammonia production.

https://www.unsw.edu.au/

CHINA

AI improves fusion reactor safety and performance

A research team led by Prof. Sun Youwen at the Hefei Institutes of Physical Science of the Chinese Academy of Sciences has unveiled two artificial intelligence systems designed to enhance the stability and efficiency of fusion experiments. Their results appear in the journals *Nuclear Fusion and Plasma Physics and Controlled Fusion*.

Fusion energy promises clean, virtually inexhaustible power, but future reactors must operate reliably to prevent damaging disruptions and maintain precise plasma confinement. Disruptions are sudden, intense events that threaten reactor integrity, while maintaining high-performance confinement states is critical for sustained operation.

To address these issues, the team built two specialized AI platforms. The first, a disruption predictor, employs decision tree models to identify early warning signals of disruptions triggered by locked modes, a common plasma instability. Unlike opaque black-box algorithms, this model is interpretable, pointing to the physical causes behind its predictions. In trials, it successfully issued warnings 94 percent of the time, with alerts arriving 137 milliseconds before the disruption-leaving enough time for countermeasures.

The second AI system focuses on real-time plasma monitoring. Instead of relying on separate models to classify confinement states such as L-mode and H-mode and to detect edge-localized modes (ELMs), the researchers developed a multi-task learning framework that performs both simultaneously. This approach increased both accuracy and resilience, achieving a 96.7 percent success rate in recognizing plasma conditions.

Together, these innovations advance the prospects of next-generation fusion reactors by boosting safety, improving performance, and contributing to deeper insights into plasma dynamics.

https://www.spacedaily.com/

INDIA

AI-powered solar manufacturing line

Pralhad Joshi, Union Minister of New and Renewable Energy, launched India's first AI-powered solar manufacturing line at Goldi Solar's newly built, state-of-the-art facility in Kosamba, Surat, Gujarat. This landmark achievement marks a major leap in India's renewable energy sector, integrating cutting-edge AI-driven processes to revolutionize solar PV module production. The AI-powered facility enhances precision, scalability, and efficiency, redefining solar manufacturing and strengthening India's transition toward a net zero future.

The AI-powered facility, with an impressive 14 GW planned production capacity, integrates several industry-first innovations designed to redefine solar manufacturing. These include high-speed stringers leveraging AI-driven automation to achieve a remarkable production capacity of 10,000 cells per hour, ensuring consistency and precision, minimizing errors, and reducing material wastage. The facility also features AI-powered AOI (Automated Optical Inspection) systems for real-time quality control, using computer vision to detect and eliminate defects at a microscopic level.

The facility further incorporates a fully integrated pre-lamination section with an auto EVA laying robot, which optimizes the placement of encapsulation layers with minimal human intervention, reducing inconsistencies compared to traditional manual processes. Additionally, it includes AI-powered 3-Display EL and visual (front and back) inspection systems, which ensure that only the highest quality solar modules reach the market, enhancing reliability and durability.

Advanced automation is further demonstrated through a 3-stage auto laminator with double-side heating (electric and oil-based) that enhances panel strength and longevity, an auto ICB elevate-lifting system with Teflon removal to optimize efficiency, and an inline double-layer HI POT tester to ensure superior insulation and electrical safety. Additionally, the facility incorporates an intelligent 8-bin auto sorting system for precise module classification, leveraging AI for real-time adjustments, and a state-of-the-art MES system for live module monitoring and tracking, ensuring complete transparency and operational efficiency.

Capt. Ishver Dholakiya, Founder and Managing Director of Goldi Solar, commented on the milestone, saying, "Goldi Solar is proud to be the first solar company in India to integrate Artificial Intelligence into PV module manufacturing. Our planned 14 GW advanced facility is a testament to our vision of a net-zero India and reflects our unwavering commitment to innovation, sustainability, and excellence.

https://constructiontimes.co.in/

JAPAN

ML to enhance nickel catalysts for CO2-to-methane conversion

Researchers at Tohoku University have utilized explainable machine learning to uncover critical factors that enhance the performance of nickel-based catalysts in the conversion of carbon dioxide into methane. The study highlights how data-driven approaches can inform catalyst design, contributing to advancements in carbon recycling and sustainable energy solutions.

The team applied machine learning techniques to analyze the properties of nickel catalysts used in CO_2 methanation, a process that transforms carbon dioxide into methane—a potential renewable energy source. By leveraging explainable AI, researchers identified specific characteristics and conditions that optimize the catalytic activity. This approach not only provides insights into improving existing catalysts but also offers a framework for developing new materials tailored for efficient carbon recycling applications. The findings underscore the role of artificial intelligence in addressing environmental challenges through innovative material design.

https://www.geneonline.com/

THE REPUBLIC OF KOREA

Energy-efficient NPU technology

Researchers at the Korea Advanced Institute of Science and Technology (KAIST) have developed energy-efficient neural processing units (NPU) technology that demonstrates substantial performance improvements in laboratory testing. Their specialised AI chip ran AI models 60% faster while using 44% less electricity than the graphics cards currently powering most AI systems, based on results from controlled experiments.

To put it simply, the research, led by Professor Jongse Park from KAIST's School of Computing in collaboration with HyperAccel Inc., addresses one of the most pressing challenges in modern AI infrastructure: the enormous energy and hardware requirements of large-scale generative AI models.

Current systems such as OpenAI's ChatGPT-4 and Google's Gemini 2.5 demand not only high memory bandwidth but also substantial memory capacity, driving companies like Microsoft and Google to purchase hundreds of thousands of NVIDIA GPUs.

The core innovation lies in the team's approach to solving memory bottleneck issues that plague existing AI infrastructure. Their energy-efficient NPU technology focuses on "lightweight" the inference process while minimising accuracy loss—a critical balance that has proven challenging for previous solutions. The technology centres on KV cache quantisation, which the researchers identify as accounting for most memory usage in generative AI systems. By optimising this component, the team enables the same level of AI infrastructure performance using fewer NPU devices compared to traditional GPU-based systems.

The KAIST team's energy-efficient NPU technology employs a three-pronged quantisation algorithm: threshold-based online-offline hybrid quantisation, group-shift quantisation, and fused dense-and-sparse encoding. This approach allows the system to integrate with existing memory interfaces without requiring changes to operational logic in current NPU architectures.

The hardware architecture incorporates page-level memory management techniques for efficient utilisation of limited memory bandwidth and capacity. Additionally, the team introduced new encoding techniques specifically optimised for quantised KV cache, addressing the unique requirements of their approach.

"Through this technology, we implemented an NPU with over 60% improved performance compared to the latest GPUs by combining quantisation techniques that reduce memory requirements while maintaining inference accuracy."

The energy-efficient NPU technology developed by KAIST offers a potential path toward more sustainable AI operations. With 44% lower power consumption compared to current GPU solutions, widespread adoption could significantly reduce the carbon footprint of AI cloud services. However, the technology's real-world impact will depend on several factors, including manufacturing scalability, cost-effectiveness, and industry adoption rates.

The timing of this energy-efficient NPU technology breakthrough is particularly relevant as AI companies face increasing pressure to balance performance with sustainability. The current GPU-dominated market has created supply chain constraints and elevated costs, making alternative solutions increasingly attractive.

Professor Park noted that the technology "has demonstrated the possibility of implementing high-performance, low-power infrastructure specialised for generative AI, and is expected to play a key role not only in AI cloud data centres but also in the AI transformation (AX) environment represented by dynamic, executable AI such as agentic AI."

https://www.cloudcomputing-news.net/

Wind turbine blade to capture energy

Researchers have developed a new design platform and a staggering 12-megawatt-class blade to match in an effort to put wind beneath the sails of its domestic production of wind power. The Wind Energy Research Department at the Korea Institute of Energy Research (KIER) set out to increase localization rates for wind turbine components, which stood at around 34%, according to WindTech International. The priority was particularly for larger capacity wind turbines, as Korea still heavily relies on imports to make them.

What resulted was BladeFORGE, a design platform that utilizes both advanced optimization algorithms and artificial intelligence techniques to face the complex technical challenges of building 10-megawatt-plus capacity wind turbines.

The integrated aero structural design system aims to increase design efficiency by addressing aerodynamic and structural factors simultaneously, rather than individually, like in previous manual methods. With this strategy, BladeFORGE cuts optimization time by more than 50%, and the methods have already received approval in principle from the Korean Register. To match the efficiency of their cutting-edge platform, KIER has also created a research facility at Jeju Global Research Center that will house wind blade design, fabrication, and structural testing all under one roof.

This system and facility are substantial steps in the Republic of Korea's renewable energy efforts, as they both cut manufacturing times domestically and reduce outsourcing of necessary parts. By reducing the need for shipping, in particular, the program reduces the excess use of energy in production that causes the rapid overheating of our planet.

Using BladeFORGE in tandem with this new infrastructure, researchers created a 107-meter (351-foot), 12-megawatt-class wind turbine blade — the first of its size and capacity from Korea to receive Des Norske Veritas design verification. To receive approval from DNV is a major credit to the program, as the provider sets quality and safety standards globally for wind turbine components.

This focus on localizing manufacturing thanks to KIER puts the country's renewable industry at a new level, as it reflects a commitment to the environment at all stages of production, not just in energy production.

https://www.yahoo.com/

UNITED ARAB EMIRATES

AI-powered digital twins for clean energy

Researchers at the University of Sharjah have recently conducted an in-depth study looking into how AI-powered digital twins could reshape the future of clean energy. Their findings reveal both the strong potential and ongoing challenges of applying this advanced technology to real-world energy systems.

Digital twins simulate physical systems in real time, allowing engineers to monitor performance, detect issues, and optimise operations without interrupting energy production. In industries like manufacturing and transportation, they've already improved efficiency and reduced costs.

In renewable energy, digital twins can be used to model complicated systems like wind farms, solar arrays, geothermal wells, hydroelectric dams, and biomass supply chains. These simulations can help operators fine-tune performance, predict maintenance needs, and design more intelligent infrastructure.

The researchers conducted a complete review of scientific literature using AI-driven text mining techniques. This allowed them to analyse large amounts of data and identify gaps in existing digital twin applications across renewable energy systems.

Their findings suggest that there is still a need for better data collection methods, more sophisticated modelling techniques, and expanded computational resources. These improvements could improve the accuracy, adaptability, and usefulness of digital twins in energy production and management.

To guide future innovation, the team has proposed a roadmap for overcoming current limitations. Their recommendations hope to strengthen the reliability of digital twins and make them a cornerstone technology in the global effort to reduce carbon emissions.

https://www.openaccessgovernment.org/

EUROPE

GERMANY

Method to reduce AI energy consumption

AI applications such as large language models (LLMs) have become an integral part of our everyday lives. The required computing, storage, and transmission capacities are provided by data centers that consume vast amounts of energy. In Germany alone, this amounted to around 16 billion kWh in 2020, or around 1% of the country's total energy consumption. For 2025, this figure is expected to increase to 22 billion kWh.

The arrival of more complex AI applications in the coming years will substantially increase the demands on data center capacity. To counteract this trend, researchers have developed a training method that is 100 times faster while achieving accuracy comparable to existing procedures.

The functioning of neural networks, which are used in AI for such tasks as image recognition or language processing, is inspired by the way the human brain works. These networks consist of interconnected nodes called artificial neurons. The input signals are weighted with certain parameters and then summed up. If a defined threshold is exceeded, the signal is passed on to the next node.

Felix Dietrich, a professor of Physics-enhanced Machine Learning, and his team have developed a new method. Instead of iteratively determining the parameters between the nodes, their approach uses probabilities. Their probabilistic method is based on the targeted use of values at critical locations in the training data where large and rapid changes in values are taking place. The objective of the current study is to use this approach to acquire energy-conserving dynamic systems from the data. Such systems change over the course of time in accordance with certain rules and are found in climate models and in financial markets, for example.

https://www.tum.de/

SWITZERLAND

AI writing climate-friendly cement recipes

When cement is mixed with water, sand, and gravel, it becomes concrete, the most widely used building material in the world. However, the production of cement releases large amounts of carbon dioxide. Researchers at the Paul Scherrer Institute PSI are using artificial intelligence and computational modelling to develop alternative formulations that should be more climate friendly. The Researchers have developed an AI-based model that helps to accelerate the discovery of new cement formulations that could yield the same material quality with a better carbon footprint.

One promising strategy for reducing emissions is to modify the cement recipe itself - replacing some of the clinker with alternative cementitious materials. That is exactly what an interdisciplinary team in the Laboratory for Waste Management in PSI's Center for Nuclear Engineering and Sciences has been investigating. Instead of relying solely on time-consuming experiments or complex simulations, the researchers developed a modelling approach based on machine learning. "This allows us to simulate and optimise cement formulations so that they emit significantly less CO2 while maintaining the same high level of mechanical performance," explains mathematician Romana Boiger, first author of the study. "Instead of testing thousands of variations in the lab, we can use our model to generate practical recipe suggestions within seconds - it's like having a digital cookbook for climate-friendly cement." With their novel approach, the researchers were able to selectively filter out those cement formulations that could meet the desired criteria.

The researchers at PSI also made use of an artificial neural network. They themselves generated the data required for training: "With the help of the open-source thermodynamic modelling software GEMS, developed at PSI, we calculated - for various cement formulations - which minerals form during hardening and which geochemical processes take place," explains Nikolaos Prasianakis. By combining these results with experimental data and mechanical models, the researchers were able to derive a reliable indicator for mechanical properties - and thus for the material quality of the cement. For each component used, they also applied a corresponding CO2 factor, a specific emission value that made it possible to determine the total CO2 emissions. "That was a very complex and computationally intensive modelling exercise," the scientist says.

"Instead of seconds or minutes, the trained neural network can now calculate mechanical properties for an arbitrary cement recipe in milliseconds - that is, around a thousand times faster than with traditional modelling," Boiger explains.

To find the solution, the team integrated in the workflow an additional AI technology, the so-called genetic algorithms - computer-assisted methods inspired by natural selection. This enabled them to selectively identify formulations that ideally combine the two target variables. The advantage of this "reverse approach": You no longer have to blindly test countless recipes and then evaluate their resulting properties; instead, you can specifically search for those that meet specific desired criteria - in this case, maximum mechanical properties with minimum CO2 emissions.

https://www.sciencedaily.com/

THE NETHERLANDS

AI to face fusion challenges

Experiments produce massive amounts of data. The behavior of plasma, an extremely hot, electrically charged gas, is notoriously difficult to predict. This complexity makes it hard to run experiments efficiently, interpret results, or prevent sudden failures that can damage equipment. To help tackle this problem, PhD researcher Yoeri Poels developed smart data-driven tools that assist scientists in analyzing and controlling fusion experiments. His work supports the safe and efficient development of fusion energy, a clean and potentially limitless power source for the future.

Fusion experiments often use a device called a tokamak, which uses powerful magnetic fields to hold extremely hot plasma in place and allow fusion reactions to happen safely. By analyzing large amounts of data from tokamak fusion experiments, Poels used machine learning to create faster simulation models that save time. He developed more robust monitoring systems capable of detecting subtle changes in the plasma as they happen.

Additionally, he introduced new methods to recognize and study dangerous plasma instabilities, helping scientists prevent equipment damage and improve control within the tokamak. These innovations combined support safer and more efficient fusion energy research.

In his thesis, Poels explored how artificial intelligence, specifically machine learning, can support fusion research.

He developed new methods to address three important challenges:

- **Faster plasma simulations**
  Fusion experiments often rely on detailed computer simulations, but these can take a long time to run. Poels created fast data-based simulation tools that learn from past results. These tools are not meant to fully replace traditional simulations, but they can support quicker studies when time or computing power is limited.
- **Monitoring energy performance**
  Keeping energy well confined inside the plasma is essential for good fusion results. Poels built a tool that automatically detects how well the plasma is performing, even if some measurements are missing or faulty. It also tells scientists how confident it is in its predictions, which is important for real-time decision making.
- **Understanding disruptions**
  Sometimes fusion experiments end in sudden disruptions that can damage equipment. These events are still not well understood. Poels used machine learning to find simplified patterns in large datasets, helping researchers better spot warning signs and analyze past disruptions.

https://www.tue.nl/

UK

AI to predict solar energy output

Researchers at the University of Nottingham have created an AI model that allows them to accurately predict the amount of solar energy that can be created in different climates, making grid integration easier in the UK. Solar forecasting, and the ability to predict how much sunlight a certain area might receive, has therefore become more important, prompting researchers in the Faculty of Engineering to find new ways of making this process more reliable.

As a novel approach, researchers have used very-short-term (VST) solar energy forecasting, using ground-based fisheye images, which has proven effective in predicting rapid and accurate changes in solar irradiance, especially for fast-changing local cloud movements. To address varied geographical and climatic conditions, the researchers showed that a model initially trained in California's sunny climate can effectively predict solar output in Nottingham, known for its humid and rainy conditions. The approach significantly cut down the amount of local data needed to make accurate forecasts — from four months' worth to just two weeks.

https://www.russellgroup.ac.uk/

NORTH AMERICA

USA

AI to improve the efficiency of battery diagnostics

National Renewable Energy Laboratory (NREL) researchers have developed and demonstrated a groundbreaking physics-informed neural network (PINN) model that can predict battery health nearly 1,000 times faster than traditional models.

NREL's PINN replaces the traditional, resource-intensive battery physics model with a powerful artificial intelligence approach that mimics the interconnected neurons of our brains to analyze nonlinear, complex datasets. This deep learning process can enhance battery health diagnostics by quantifying physical degradation mechanisms and pave the way for more efficient, scalable approaches to manage battery aging.

NREL researchers have created a vast array of battery lifespan models to diagnose battery health, predict battery degradation, and optimize battery designs. For years, the team has been on the cutting edge of physics-based machine learning techniques to optimize predictive modelling for advanced battery research.

Two such models, the Single-Particle Model (SPM) and the Pseudo-2D Model (P2D), are widely used and accepted approaches to providing a window into how a battery's internal health parameters—such as electrode inventory and kinetics, Li-ion inventory, and Li transport paths—evolve over time. However, directly using these models is an intensive process that requires massive amounts of computation and limits their ability to offer rapid diagnostics.

The NREL-developed PINN surrogate combines the predictive power of artificial intelligence with the rigor of physics-based modelling. The resulting two-part study published in the Journal of Energy Storage demonstrates how researchers trained and tested the PINN surrogate using conventional SPM and P2D models. This multifaceted approach allowed NREL researchers to train the PINN surrogate on a wide range of internal battery properties. The resulting open-source model offers critical insights into changes that occur during battery aging, helping quickly estimate how long a battery might last in a different setting.

What makes this development especially revolutionary in battery research is the integration of physics-informed principles into neural networks. Traditional neural networks are data-driven models that excel at pattern recognition but often lack the ability to enforce physical laws, which are crucial for accurately simulating battery behaviour.

The success of NREL's PINN surrogate offers wide-ranging implications. For battery diagnostics, the PINN surrogate can provide rapid state-of-health predictions, allowing for faster decision-making across battery applications. By drastically lowering the computational barriers to battery diagnostics, the PINN surrogate model paves the way for widespread, scalable, and efficient energy storage management—helping ensure energy is available when and where it is needed.

Currently, researchers are working to transition the PINN surrogate from controlled simulations to real-world data validation, using batteries cycled within NREL's laboratories. By bridging this gap, researchers hope to deploy PINN-based diagnostics across a wide range of battery systems, enhancing battery performance monitoring and extending lifespans. Future research will focus on refining the PINN model to handle highly dimensional problems, allowing it to predict a broader array of internal battery parameters with increased precision. This means creating models that can both respond to diverse current loads and scale effectively to future battery designs and usage patterns.

https://www.nrel.gov/

AI framework to optimize battery electrolytes

Identifying new, high-performance electrolytes remains a major challenge in developing next-generation batteries for electric vehicles, consumer electronics, and grid-scale energy storage. The most stable electrolytes are not always the most conductive, and the most efficient batteries are not always the most stable, highlighting the complex trade-offs involved.

By analyzing data from 250 research papers covering the history of lithium-ion battery research, the team used AI to calculate an "eScore" for different molecules. This score balances three key properties—ionic conductivity, oxidative stability, and Coulombic efficiency—to highlight top-performing candidates. The researchers validated their AI-driven method by identifying a molecule with performance comparable to today's leading electrolytes. This achievement represents a significant step forward in a field that has traditionally relied on trial and error.

Artificial intelligence is helping scientists streamline the search for better battery materials by identifying the most promising candidates for lab testing, saving time, energy, and resources. At the University of Chicago's Pritzker School of Molecular Engineering (PME), researchers are already applying AI to speed up advances in cancer therapies, water purification, quantum materials, and more.

When it comes to battery research, the challenge is immense. The number of possible electrolyte molecules is estimated to be as high as 10^{60}, which is far too many to explore through traditional methods. AI offers a way to narrow this vast field to the most likely candidates.

Amanchukwu compares the use of AI in battery research to how streaming services recommend music. Think of each person's music taste as their own "eScore." The current AI can scan a playlist and predict which songs someone might like. The next step is building AI that can generate an entirely new playlist based on those preferences.

Ultimately, Amanchukwu's lab is aiming for something even more advanced: AI that cannot just select or predict, but actually design new molecules from scratch that meet all the required performance criteria, like composing new music instead of just recommending it. To support this work, Amanchukwu received a Google Research Scholar Award last year to help move closer to that goal of truly generative electrolyte AI. The team found that the AI performed well when predicting molecules similar to those it had already encountered. However, it was less effective when presented with unfamiliar compounds—a limitation they now aim to overcome in the next phase of their work.

https://www.azom.com/

Protecting the grid with AI

The electric grid powers everything from traffic lights to pharmacy fridges. However, it regularly faces threats from severe storms and advanced attackers. Sandia researchers have developed brain-inspired AI algorithms that detect physical problems and cyberattacks both at the same time within the grid. And this neural-network AI can run on inexpensive single-board computers or existing smart grid devices.

As the nation adds more smart controls and devices to the grid, it becomes more flexible and autonomous, but also more vulnerable to cyberattacks and cyber-physical attacks. Cyber-physical attacks use communications networks or other cyber systems to disrupt or control a physical system such as the electric grid. Potentially vulnerable equipment includes smart inverters that turn the direct current produced by solar panels and wind turbines into the alternating current used by the grid, and network switches that provide secure communication for grid operators, said Adrian Chavez, a cybersecurity expert involved in the project.

Because the neural network can run on single-board computers or existing smart grid devices, it can protect older equipment as well as the latest equipment that lacks only cyber-physical coordination, Shamina said. "To make the technology more accessible and feasible to deploy, we wanted to make sure our solution was scalable, portable, and cost-efficient," Adrian said.

The Sandia team collaborated with experts at Texas A&M University to create secure communication methods, particularly between grids owned by different companies, Shamina said. The biggest challenge in detecting cyber-physical attacks is combining the constant stream of physical data with intermittent packets of cyber data, said Logan Blakely, a computer science expert who led development of the AI components.

Physical data, such as the frequency, voltage, and current of the grid, is reported 60 times a second, while cyber data, such as other traffic on the network, is more sporadic, Logan said. The team used data fusion to extract the important signals in the two different kinds of data. The collaborators from Texas A&M University were key to this effort, he added.

Then the team used an autoencoder neural network, which classifies the combined data to determine whether it fits with the pattern of normal behaviour or if there are abnormalities with the cyber data, physical data, or both, Shamina said. For example, an increase in network traffic could indicate a denial-of-service attack, while a false-data-injection attack could include atypical physical and cyber data, Adrian said.

Unlike many other kinds of AI, autoencoder neural networks do not need to be trained on data labelled with every type of issue that may show up, Logan said. Instead, the network only needs copious amounts of data from normal operations for training. The use of an autoencoder neural network makes the package pretty much plug and play, Shamina added.

Once the team constructed the autoencoder neural network, they put it to the test in three different ways. First, they tested the autoencoder in an emulation environment, which includes computer models of the communication-and-control system used to monitor the grid and a physics-based model of the grid itself, Shamina said. The team used this environment to model a variety of cyber-attacks or physical disruptions, and to provide normal operational data for the AI to train on. The collaborators from Texas A&M University assisted with the emulation testing.

Then the team incorporated the autoencoder onto single-board computer prototypes that were tested in a hardware-in-the-loop environment, Shamina said. In hardware-in-the-loop testing, researchers connect a real piece of hardware to software that simulates various attack scenarios or disruptions. When the autoencoder is on a single-board computer, it can read the data and implement the algorithms faster than a virtual implementation of the autoencoder can in an emulation environment, Adrian said. Generally, hardware implementations are a hundred or thousand times faster than software implementations, he added.

The team is working with Sierra Nevada Corp. to test how Sandia's autoencoder AI works on the company's existing cybersecurity device called Binary Armor, Shamina said. The team is testing both formats — single-board prototypes interfaced with the grid and the AI package on existing devices — in the real world at the Public Service Co. of New Mexico's Prosperity solar farm as part of a Cooperative Research and Development Agreement, Shamina said. These tests began last summer, Adrian said.

The team also worked with PNM early in the project to learn what AI design might be most useful for grid operators. It was during conversations with PNM staff that the Sandia team identified the need to connect cyber-defenders with system operators rapidly and automatically.

This project built off and expanded upon a previous R&D 100 Award-winning project called the Proactive Intrusion Detection and Mitigation System, which focused on detecting and responding to cyber intrusions in smart inverters on solar panels, Shamina said. The team is also expanding upon the autoencoder AI in similar projects, she added.

The team filed a patent on the autoencoder AI and is looking for corporate partners to deploy and hone the technology in the real world, Shamina said. With a bit more work, the autoencoder could be used to protect other critical infrastructure systems such as water and natural gas distribution systems, factories, and even data centers, Adrian said.

The project is funded by Sandia's Laboratory Directed Research and Development program.

https://www.sandia.gov/

Harnessing Artificial Intelligence for Energy Transition

Artificial Intelligence in ASEAN's Energy Transition

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ABSTRACT

Southeast Asia is currently experiencing a rapid increase in electricity demand, which is fueled by rapid urbanization, industrial growth, and the expansion of the digital economy. The surge in data centers and computational demand from AI processing has further exacerbated energy demand. At the same time, AI technologies are emerging as power enablers for cleaner, smarter, and more resilient energy systems. This poses an important challenge for ASEAN nations, which comprises of Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam, to balance rising energy demand with the advancement of decarbonization targets, while simultaneously prioritizing the development of smarter grids. Uneven infrastructure, fragmented policy frameworks, and investment gaps complicate this task. With greater cooperation and stronger investment, AI could be an important catalyst that drives ASEAN's secure, sustainable energy transition.

Introduction

ASEAN's energy landscape stands at a pivotal juncture, driven by rising energy demand and rapid digitalization across its economic sectors. Electricity consumption across ASEAN, as reported in *(IEA, Southeast Asia Energy Outlook, 2024)*, is projected to rise by nearly 4% each year, fuelled by economic expansion, rapid urbanization, and surging cooling needs amid intensifying heatwaves. Simultaneously, the advent of digitalization from cloud services to generative AI is driving a sharp increase in energy demand from data centers. The International Energy Agency (IEA) forecast that electricity demand from data centers in Southeast Asia will almost double by 2030 compared to 2024, driven by its emergence as a regional hub, especially in Singapore and southern Malaysia. From 2024 to 2030, based on a report published by (IEA, Energy and AI, 2025) Energy and AI – Analysis - IEA electricity consumption for data centers is projected to grow at approximately 15% per year which is more than four times faster than the growth rate of total electricity consumption from all other sectors (IEA, Energy and AI, 2025). In order to meet this rising demand, renewable energy sources such as wind, solar, modern bioenergy, and geothermal are projected to contribute to more than one-third of the increase in energy demand across Southeast Asia by 2035 (IEA, Southeast Asia Energy Outlook, 2024). However, this is still insufficient to meet energy energy-related CO2 emission targets. Due to this, the energy-related CO_2 emissions are expected to climb by 35% between now and mid-century *(IEA, Southeast Asia Energy Outlook, 2024)*. Carrying forward COP28's commitments and strengthened by COP29's outcomes, Southeast Asia must significantly hasten the transition to clean energy to meet COP28 goals and support the net-zero pledges. AI-driven tools and smart-grid technologies can play a key role in boosting renewable energy uptake and improving energy efficiency while supporting the region's digital growth.

The surge in data center development across ASEAN is forecast to increase electricity demand up to 30% of national consumption in certain countries by 2030, requiring an estimated USD 45–75 billion in solar and wind investment to power facilities sustainably and minimize continued dependence in fossil fuels (Ember, From AI to Emissions: Aligning ASEAN's Digital Growth with Energy Transition Goals, 2025). Current renewable targets and grid decarbonization trajectories remain too slow to match energy demand growth. For example, Indonesia's JAMALI (Jawa-Madura-Bali) grid and Singapore's grid are expected to cut emission intensity by only 9.4% and 4.9% respectively by 2030. To align AI-driven digitalization with ASEAN's net-zero commitments, ASEAN must expedite its energy transition by scaling renewable capacity, enhancing grid flexibility, and adopting a stronger regulatory framework. ASEAN's electricity generation reached a record 1,263 TWh in 2022, with fossil fuels such as coal, oil, and gas still dominating. However, the fossil fuel share of ASEAN electricity generation declined from 85.8% in 2005 to 71.2% in 2022. During the same period, renewable energy expanded to 29.2% of the generation mix, led by hydro, solar PV, and bioenergy, reflecting a structural shift as RE progressively offsets coal and gas in ASEAN's power sector (Ember, From AI to Emissions: Aligning ASEAN's Digital Growth with Energy Transition Goals, 2025). This momentum must be further intensified, as the current share of renewables remains insufficient to drive a significant energy transition.

The 8th ASEAN Energy Outlook (AEO8) reported in (ASEAN Centre for Energy, 8th ASEAN Energy Outlook, 2024) outlines four distinct scenarios, which are Baseline (BAS), AMS Targets (ATS), Regional Aspiration (RAS), and Carbon Neutrality (CNS). This allows ASEAN to explore its energy prospects from

2023 to 2050 with each scenario reflecting different levels of policy ambition and technological adoption in shaping the region's energy transition. Bridging these scenarios with real-world action demands accelerated technology adoption and digital innovation to ensure ASEAN's transition keeps pace with rising energy demand. Accelerated deployment of RE sources, AI-enabled forecasting, smart grid initiatives, and smart demand response are critical enablers to balance rising digitalization-driven electricity demand with ASEAN's decarbonization goals.

Significance of AI in ASEAN energy systems

ASEAN's energy demand is intensifying with Total Final Energy Consumption (TFEC) projected to rise by nearly 73% by 2050, driven by rapid industrialization, urbanization, and expanding mobility needs. The industrial sector is set to dominate, increasing its share from 44% in 2023 to 52% by 2050. Transportation remains the second-largest sector, which is mainly contributed by electric vehicle penetration. The residential sector's share is projected to decline, while the commercial sector remains stable at 6–8% of TFEC, and the agriculture sector contributes a minor share of the TFEC (ASEAN Centre for Energy, ASEAN Energy Investment, 2024).

Currently, Southeast Asia is rapidly emerging as a global hub for data centers, with ASEAN's major economies leading the charge. Malaysia, Singapore, and Indonesia are experiencing some of the fastest growth in capacity, with Malaysia projected to be the region's fastest-expanding market. Its data center electricity demand is expected to surge from just 9 TWh in 2024 to 68 TWh by 2030 (Ember, From AI to Emissions: Aligning ASEAN's Digital Growth with Energy Transition Goals, 2025), which marks a dramatic leap in regional digital infrastructure needs.

Singapore, which is ASEAN's largest hub with 1 GW capacity, has tightened approvals to prioritize projects powered by green energy and advanced efficiency standards. Malaysia is supporting data center growth through solar mega-farms and cross-border clean energy initiatives. With Jakarta as its primary hub, Indonesia is seeking to reduce coal dependence through RE adoption, whereas Thailand is centred on co-location investment. The Philippines pursues sustainability in new hyperscale projects, and Vietnam is scaling up through its Digital Transformation Programme. The rapid expansion of data centers positions Southeast Asia as a leading digital hub, but without accelerated RE adoption and efficiency improvements, rising digital demand could increase reliance on fossil fuels and drive significant emissions growth (Ember, From AI to Emissions: Aligning ASEAN's Digital Growth with Energy Transition Goals, 2025).

The energy transition is accelerating as countries seek to decarbonize power systems, and AI is emerging as a key enabler by enhancing RE integration, improving forecasting accuracy, and optimizing grid operation. This is crucial for ASEAN, where renewable capacity is rising and grids must handle intermittent supply efficiently. AI leverages massive streams of sensor and weather data to enhance RE generation forecasts and optimize dispatch, which outperforms the accuracy of traditional models. Beyond operational optimization, AI is accelerating energy technology innovation by expediting the discovery of advanced battery chemistries, CO_2 capture materials, and catalysts for synthetic fuels. This is made possible by consolidating R&D cycles that would otherwise span decades into far more manageable timeframes. At the grid level, AI can support ASEAN's energy transition through predictive maintenance, congestion management, and dynamic line rating, further optimizing transmission and distribution network operation. The IEA notes that transmission lines can typically carry 20–30% additional capacity above their maximum rating for about 90% of the year and that DLR could unlock 115–175 GW of global capacity at far lower cost than new lines (IEA, Energy and AI, 2025). For Southeast Asia, these applications are important as rising digital demand and growing RE integration further stress the power grid. AI-enabled forecasting can optimize dispatch and reduce RE curtailment, while advanced fault detection and automation enhance system reliability, especially during power outages.

In summary, Southeast Asia is undergoing rapid digital and energy transformation, with rising electricity demand from both economic growth and expanding digital infrastructure. At the same time, countries are pushing to decarbonize their power systems through large-scale RE integration and smarter grid management. AI stands at the core of this transition, providing the innovation needed to balance reliability with sustainability while accelerating the shift towards a low-carbon future.

ASEAN case studies on AI integration in power grid

To further analyze the integration of AI in ASEAN power grid, six national case studies are considered. Although each country faces distinct challenges, ranging from Malaysia's rapid data center expansion to Vietnam's smart grid initiatives, a common theme can be observed in the growing reliance on AI as a catalyst in supporting the region's energy transition. These case studies highlight AI integration in renewable infrastructure, advanced grid management, and regional interconnection.

Malaysia

Malaysia is positioning itself as a leader in ASEAN's AI and clean energy transition by coupling its fast-growing data center sector with renewable investments. The AI infrastructure will be located at the YTL Green Data Center Park in Kulai, Johor. The 500 MW facility will be developed by YTL and fully powered by an equivalent capacity of onsite solar energy. The project positions Malaysia as a regional hub for green AI, which enables energy-intensive AI workloads to be powered by RE (YTL Power International, 2023). Malaysia's utility company Tenaga Nasional Berhad (TNB) has committed RM43 billion ($10.1 billion) to modernize the national grid, enabling higher AI computing loads and large-scale battery energy storage integration (Reuters, 16 June 2025). At the same time, Petronas is developing three offshore carbon-capture and storage facilities with over 10 international partners to position CCS as both a decarbonization mechanism and a regional revenue stream. Furthering its energy transition initiatives, in 2024, Malaysia introduced the Energy Exchange Malaysia (ENEGEM) to drive structured cross-border green electricity trading. The platform's inaugural deal enables Sembcorp Power Pte Ltd to purchase 50 MW of renewable power from TNB for delivery into Singapore over a two-year period starting December 2024 (Regional Power Grids, EMA).

Singapore

Singapore, constrained by limited land for large-scale renewables, is leveraging AI-driven grid management and regional power trading to decarbonize its power grid. AI is being deployed to strengthen grid stability, forecast electricity demand, and optimize solar generation, enabling more efficient energy distribution and reducing reliance on domestic sources. Since 2022, Singapore has been importing renewable hydropower under the Lao–Thailand–Malaysia–Singapore Power Integration Project (LTMS-PIP). This represents ASEAN's first multilateral electricity trade, starting with 100 MW of Lao hydropower delivered to Singapore and expanding to 200 MW through multidirectional flows that include RE supply from Malaysia (Regional Power Grids, EMA). Singapore has progressively expanded its electricity import programme, with the Energy Market Authority (EMA) raising its target from 4 GW to 6 GW of low-carbon imports by 2035. Recent conditional licenses include the 1 GW project by Singa Renewables with RGE and TotalEnergies, focusing on regional power integration to secure cleaner and more diversified supply sources. By harnessing AI for smart meters, predictive analytics, and real-time optimization across facilities like shipyards, airports, and campuses, Singapore is proving how AI-based energy management can cut grid reliance and make regional power imports more efficient (How Singapore Uses AI to Cut Electricity Use, 2020).

Indonesia

Indonesia is advancing its Nusantara Super Grid, an inter-island electricity transmission network using High Voltage Direct Current (HVDC) technology. This initiative aims to transport vast renewable potential, such as the 13 GW of hydropower in Kalimantan, toward major load demand centers in Java and Sulawesi. The Super Grid is positioned as a backbone of Indonesia's energy transition, enabling large-scale integration of solar, wind, and hydropower into the national mix while supporting the country's net-zero emissions target for 2060 (Chandak, 2023). To enhance its energy transition, Indonesia is applying AI for predictive maintenance, demand forecasting, and real-time grid optimization, enabling more reliable integration of solar, wind, and hydropower into the power grid. On islands like Sumba, AI-managed microgrids have already achieved up to 95% renewable penetration by adapting to monsoon patterns, while predictive algorithms deliver 97% demand forecast accuracy and extend battery lifespans by 40% (Challenge, 2025). Beyond transmission and microgrids, Indonesia's geothermal sector is integrating generative AI through platforms like Kyndryl Bridge (Cariaga et al., 2024), which provide real-time insights on system performance and proactive solutions to increase reliability by predicting failures before they occur.

Thailand

Thailand's Power Development Plan (PDP2015) emphasized smart grid development to strengthen reliability and enable large-scale renewable integration, laying the groundwork for future adoption of AI-driven solutions in energy management and grid operations. Among the main initiatives are large-scale transmission upgrades, energy efficiency measures targeting 89,672 GWh of savings by 2036, and the Alternative Energy Development Plan (AEDP) that sets a 19,634 MW RE capacity target (Lauradmin, 2025). Thailand has since launched a $1.8 billion smart grid and AI-powered energy transformation programme, which focuses on modernizing power distribution, enhancing grid security, and optimizing energy efficiency nationwide. The initiative integrates AI-driven grid management, predictive analytics, and real-time cybersecurity, creating a smarter and more resilient energy ecosystem. Continuing this initiative. the Thai government is advancing its National AI Action Plan by incorporating smart grid upgrades and AI deployment across utility networks, as part of a broader strategy to become a regional AI hub by 2027 (Sayson, 2025).

Viet Nam

Vietnam is relatively new to the AI landscape, introducing its first national strategy in 2021 that identifies artificial intelligence as a core pillar of the Fourth Industrial Revolution. The strategy sets targets through 2030, including the establishment of national AI innovation centers, supercomputing facilities, and applications extending into key sectors such as RE and power systems (Pham et al., 2024). At Son La Hydropower Plant, AI-integrated robotic systems equipped with environmental sensors and image-processing algorithms are applied to monitor electrical cabinets and provide accurate information to power system operators. Vietnam Electricity (EVN) is applying AI across its operations, which includes an AI-based power transmission line management system with automated UAV inspections to optimize grid monitoring and fault detection. In customer services, EVN also deploys AI chatbots and virtual assistants to handle requests and provide information, improving efficiency and service quality (Artificial Intelligence Application Become Driving Force for Comprehensive Innovation in EVN's Operations).

The Philippines

The Philippines is advancing AI in its power sector through Meralco's 4-I strategy, which integrates artificial intelligence to grid operations for real-time monitoring, forecasting, and improved reliability. With distributed energy resources expanding across the Philippines, Meralco is harnessing AI, battery storage, and interoperability tools for a decentralized and clean energy future (Meralco Prepares for Decentralized Grid With AI, BESS and Interoperability Tools). Similarly, Aboitiz Power Corporation is implementing "Project Arkanghel," a digital twin initiative that creates real-time replicas of its coal-fired plants to strengthen predictive maintenance and operational decision-making. At the distribution level, the Institute for Climate and Sustainable Cities has developed the SPECTRUM platform, which applies machine learning and satellite imagery to map rooftop solar systems nationwide and forecast their generation potential (Albay, 2025). As industrial demand grows, artificial intelligence platforms like SPECTRUM are set to drive the Philippines' energy transition by applying machine learning to expand rooftop solar coverage, improve forecasting accuracy, and track solar deployment over time.

AI tools in energy systems

The modern power grid is continuously adopting AI technologies to strengthen reliability and efficiency. Machine learning models are applied to vast historical and real-time datasets to predict equipment failures and potential outages. At the same time, IoT-enabled smart meters and sensors provide detailed information on load consumption patterns and grid performance to detect system anomalies. AI-based self-healing grids are also deployed to autonomously detect and repair faults while rerouting electricity to prevent outages.

Emerging AI technologies are expected to significantly advance grid planning and power system operations. Ongoing research focuses on the application of generative AI and large-scale foundation models specifically designed for power systems. ASEAN power systems are increasingly adopting AI, particularly in predictive analytics to strengthen grid resilience and mitigate potential failures (How AI-driven Cable Management Can Boost Southeast Asian Power Networks). Current AI applications in power systems focus on predictive analytics for demand forecasting, fault detection and maintenance, while future advancements are expected to utilize generative AI and integrated digital platforms to enable autonomous, resilient and decentralized grid operations across ASEAN.

To fully realize AI integration in the power grid, ASEAN must adopt a harmonized AI governance framework that ensures interoperability, transparency, and accountability. This will ensure that member nations are able to coordinate effectively and accelerate the integration of region-wide AI-enabled infrastructure. Investment in interoperable digital infrastructure and robust data platforms is essential to unlock additional grid capacity without reliance on new transmission expansion. ASEAN countries can

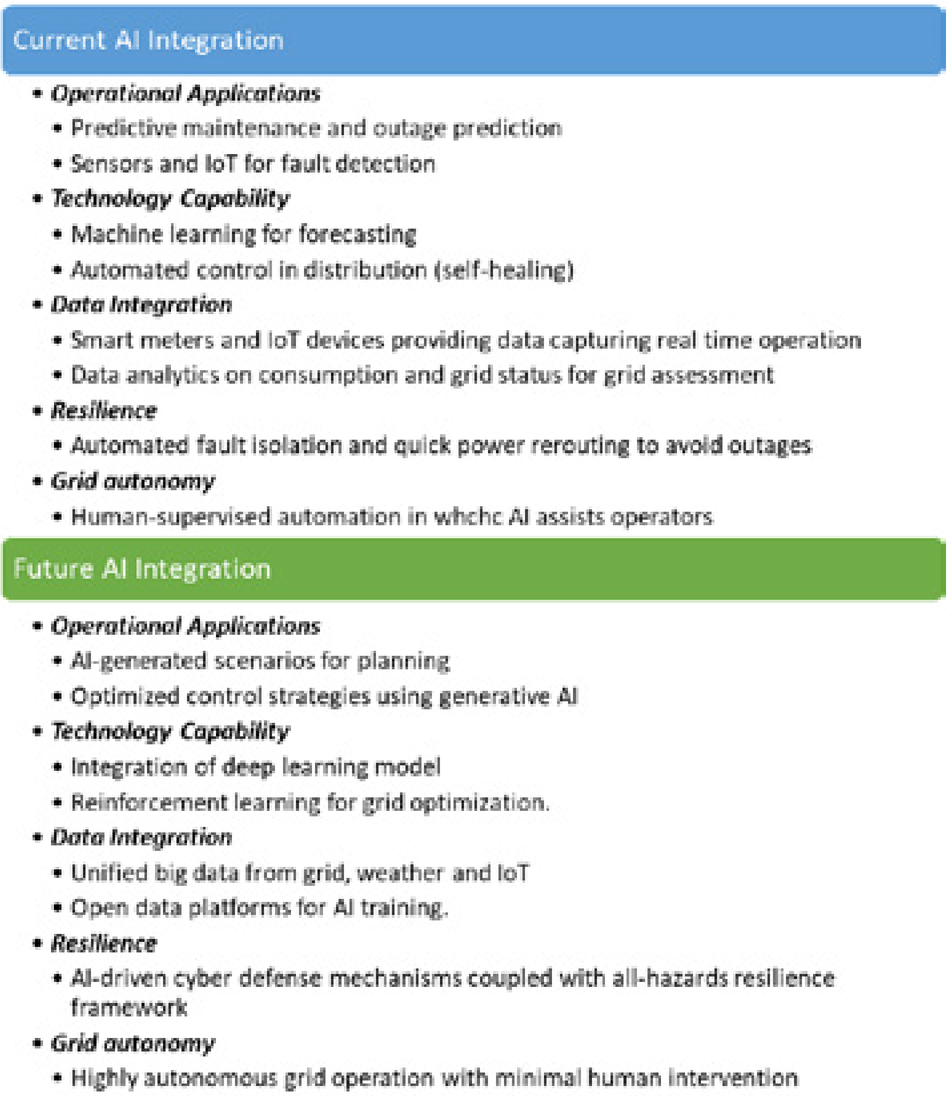

Figure 1: Current and future AI integration in power grid

further advance AI adoption through coordinated pilot programs and regulatory sandboxes that test applications under real-world grid conditions for regional deployment.

Presently, ASEAN's AI adoption in its energy transition is gradual. It mostly emerges through localized initiatives such as predictive analysis for demand forecasting and smart grid projects. Looking ahead, ASEAN's long-term vision is to embed AI comprehensively, enabling decentralized, real-time grid management, predictive maintenance, renewable energy integration, and cross-border power trading through a unified ASEAN Power Grid.

AI integration in power grid can be classified into categories such as operational applications, grid autonomy, predictive maintenance, renewable integration, and cross-border trading. Figure 1 shows how current AI influences these areas at a localized level, while future AI is expected to advance them towards a comprehensive, autonomous, and region-wide deployment.

Challenges and enablers in ASEAN

Integrating an AI solution across ASEAN's energy sectors faces significant challenges. This stems from the region's diversity, which contributes to uneven progress in infrastructure maturity, governance, human capital, and investment capacity. These challenges present an opportunity for ASEAN countries to address to develop a smarter power grid and accelerate the region's energy transition.

Infrastructure and technical capacity gaps

With modernized power grids, high connectivity, and strong human capital, Singapore and Malaysia are better positioned than most ASEAN peers to adopt AI in their energy sectors. Digitalizing the power grid required high investment costs, interoperability issues, data privacy and security, and the necessity for a competent workforce. A key technical gap remains in achieving seamless interoperability across various electrical equipment and vendor software. The integration of diverse devices and platforms poses a significant challenge for achieving real-time synchronization (Fernandez et al., 2024). Closing these gaps will require equipment upgrades such as advanced metering infrastructure (AMI), sensors, and reliable high-speed communication networks to improve data quality and system visibility. ASEAN is actively pursuing this through the integration of smart grid technologies, including phasor measurement units (PMUs), virtual power plants (VPPs), and emerging digital twin systems across the region. The United Nations Office for Project Services (UNOPS) supports ASEAN's grid modernization through the Southeast Asia Energy Transition Partnership (ETP), a multi-donor initiative that provides technical expertise and resources to countries such as Indonesia, the Philippines, and Vietnam to facilitate a just energy *transition* ('Smart Grid' Helps Accelerate Energy Transition in Indonesia).

Policy fragmentation and investment gaps

A major challenge lies in ASEAN's fragmented policy landscape, where difference in national energy regulations, data standards, and AI guidelines hinders region-wide coordination and implementation. ASEAN practices voluntary AI guidelines, unlike the EU's binding risk-based AI Act, due to its members' diverse national policies and varying levels of socioeconomic development (Labrecque, 2024). In early 2024, at the 4th ASEAN Digital Ministers' Meeting, the 10 ASEAN members released the ASEAN Guide to AI Governance and Ethics. This is a non-binding governance model highlighting seven core principles comprising of transparency, fairness, security, reliability, human-centricity, privacy, and accountability. This initiative marks ASEAN's effort to align governance and paves the way for greater regional coordination on AI regulation. The modernization of ASEAN's grids is constrained by investment disparity between the member nations, with Singapore attracting USD 141 billion in FDI and Indonesia receiving USD 22 billion. Malaysia has committed USD 10.1 billion specifically for upgrading its national grid infrastructure (ASEAN Centre for Energy, ASEAN Energy Investment, 2024). Despite these national efforts, regional financing remains insufficient, as green investment rose to only USD 6.3 billion in 2023, which is well below the USD 1.5 trillion required to support Southeast Asia's transition by 2030 (Kear Tian Seng, Southeast Asia's Green Economy 2024 Report: Moving the Needle). Closing this financial gap is critical for ASEAN as it requires blended-finance solutions that combine grants, concessional loans, and private capital to modernize grids, expand storage, and enable AI-driven efficiency in the power grids.

Public acceptance and workforce readiness

Public perception of AI remains a major challenge. Conservative industries such as electricity supply may resist adoption, as grid operators remain cautious about trusting AI decisions over human judgment due to risks associated with cybersecurity, privacy, autonomy, and unequal access to technological resources. Data privacy risks increase as AI-driven smart grids may expose sensitive household behaviours, creating opportunities for misuse or surveillance. Building public acceptance of AI-driven smart grids requires transparent data policies, strong privacy protections, and clear accountability to foster trust between the service providers, vendors, operators, and customers. Digital competency gaps in the ASEAN region results in many graduates lacking the skills required for AI-related roles in the power sector. Critical lack of qualified technical personnel in the energy sector, compounded by an aging workforce and insufficient training systems, poses a challenge to the implementation of grid modernization. Strengthening and modernizing Technical and Vocational Education and Training (TVET) with regional mobility mechanisms and industry-led apprenticeships is important to upskill/reskill an AI-ready workforce for power grid modernization.

Conclusion

AI is an important catalyst in enabling ASEAN's energy transition with applications ranging from RE forecasting to decentralized grid management and cross-border power trading. Despite this immense potential, there are some challenges that the member nations face, such as uneven infrastructure, fragmented policy frameworks, an AI-ready workforce shortage, and investment gaps for large-scale adoption. Addressing these challenges is crucial for a successful energy transition process. This requires harmonized governance frameworks, significant digital infrastructure investment, and human capital building to ensure equitable deployment across the region. With the right approach, AI integration can advance ASEAN's power system into a resilient and efficient low-carbon network to ensure regional energy security and sustainability goals.

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Harnessing AI for Energy Transitions

Role of Big Data, Large Language Models, and Agentic Intelligence

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Abstract

Climate change is causing unprecedented global warming, rising sea levels, and extreme weather events that threaten ecosystems and human societies worldwide. To combat this and mitigate its impacts, the world is striving for an energy transition towards 100% renewable energy systems and net-zero communities. For this transition, several challenges, such as infrastructure requirements or costs, exist. One of the solutions to cover these challenges is to make the most of digital technologies, especially Artificial Intelligence (AI). AI-driven technologies can improve the design and operation of renewable farms, streamline energy storage solutions, and enable smarter urban planning to lower carbon footprints. Additionally, AI can analyze large amounts of data to identify sustainable practices and support decisions, driving faster progress toward net-zero emissions. However, the more the data increases and becomes larger big data, these classical AI models face challenges in their analytics, especially in real-time operations. To this end, the importance of big data in power systems, and the more advanced AI strategies, known as Large Language Models (LLMs) and agentic AI, are taken into consideration. For both LLMs and agentic AI strategies, one case study is analyzed for each, with several recent literature and recent developments. Then, the challenges and future research directions are presented, supported by the complementary descriptions of these technologies with the United Nations Sustainable Development Goals (UN-SDGs). Harnessing AI's potential in the energy transition through optimized renewables, intelligent grids, and sustainable data centers (to process these AI strategies) can be considerably beneficial for a resilient, net-zero future.

Introduction

The global energy transition, driven by the urgent imperative to mitigate climate change, is affecting the world's energy sector through innovative solutions addressing technical, economic, and social challenges of decarbonization (Li et al., 2025). As rising global temperatures and extreme weather events highlight the consequences of greenhouse gas emissions, nations are accelerating the shift from fossil fuels to fully Renewable Energy Sources (RES) and a net-zero community. Following this urgency, several organizations provided sustainability goals to achieve a net-zero community. One of these organizations is the United Nations (UN), which presented the Sustainable Development Goals (SDG) (Fund, 2015). The other important regulatory agreement is the Paris Agreement. The Paris Agreement, adopted in 2015 under the UN Framework Convention on Climate Change (UNFCCC), is a landmark global treaty aimed at combating climate change by limiting global warming to well below 2°C, ideally 1.5°C, above pre-industrial levels (Bodansky, 2016; Mudhee et al., 2025). Although the RES have proved that they accelerate the transition process to a fully net-zero community, several challenges remain, including the electrification infrastructure and the associated costs (Heuberger & Mac Dowell, 2018; Al-Shetwi et al., 2024; Heptonstall & Gross, 2021). In order to provide solutions for those challenges, Artificial Intelligence (AI) is the strategy that is being focused on (Salman et al., 2024). The reason for this is AI's potential. AI can optimize renewable energy production by predicting weather patterns for solar and wind, improving grid efficiency, and managing energy storage to balance supply and demand (Sankarananth et al., 2023). Additionally, it enhances energy efficiency in industries, buildings, and transportation through predictive maintenance and smart systems (Farzaneh et al., 2021). Moreover, AI accelerates research into new materials for batteries and carbon capture technologies (Priya et al., 2023). By processing vast datasets and enabling real-time decision-making, AI helps reduce costs, lower emissions, and scale clean energy solutions, making it a cornerstone for achieving global climate goals efficiently and effectively (Ukoba et al., 2024). Following this potential, AI in the renewable energy market is considerably increasing, as shown in Fig. 1.

The global AI in renewable energy market is projected to reach approximately USD 78.2 billion by 2034, up from USD 8 billion in 2024, with a Compound Annual Growth Rate (CAGR) of 25.60% from 2025 to 2034. In 2024, the Asia-Pacific region is anticipated to dominate the market, holding over 35% of the market share and generating $2.8 billion in revenue (Market.us, 2025). As mentioned, one of the important applications of AI is in the materials for batteries and carbon capture technologies. Accordingly, Fig. 2 shows the Sankey diagram of the critical minerals in clean energy transitions, which is gathered from (IEA, n.d.).

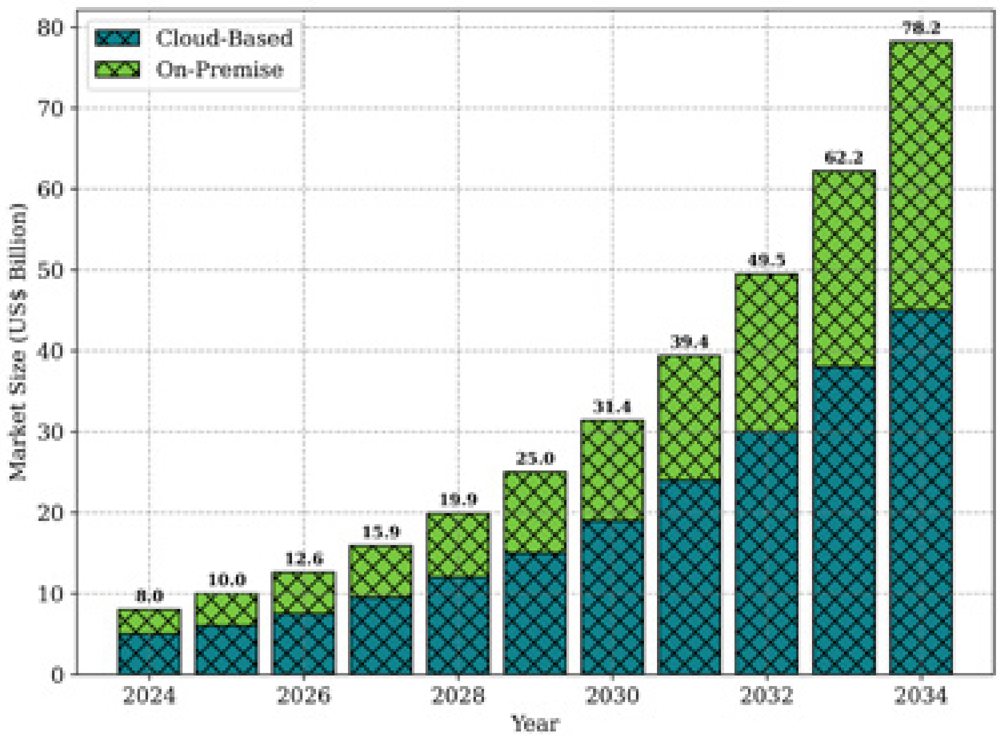

Figure 1: Artificial intelligence in the renewable energy market statistics, based on the data from (Source: Market.us, 2025).

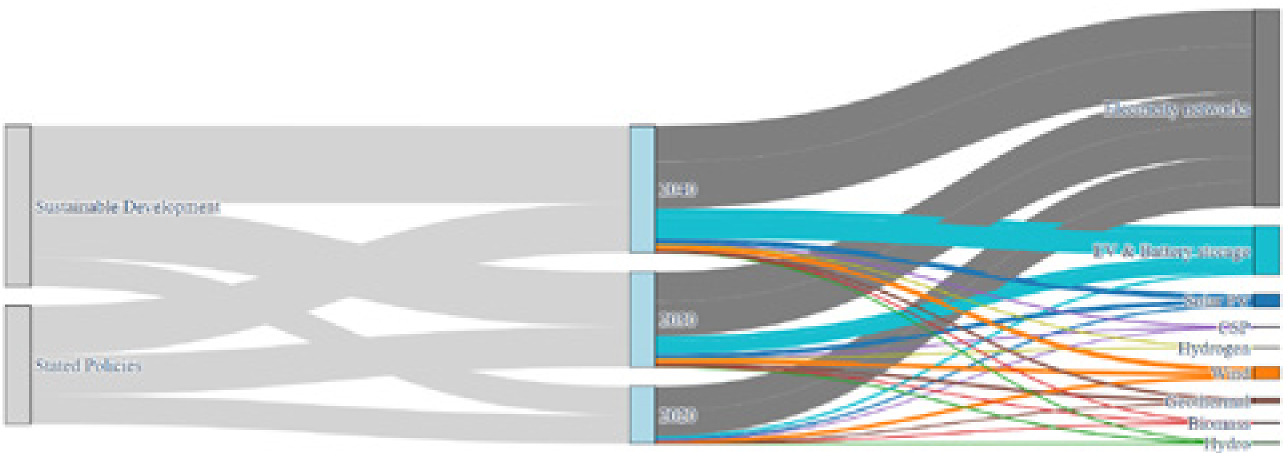

Figure 2: Sankey diagram of critical minerals in different energy technologies, considering sustainable development and policies, based on the data from Source (IEA, n.d.). A Sankey diagram is a flow diagram that visualizes the magnitude of flows between nodes, with arrow widths proportional to the flow quantity.

As reported in (IEA, n.d., IEA, 2021), the types of mineral resources required differ depending on the technology. Lithium, nickel, cobalt, manganese, and graphite are essential for battery performance, durability, and energy density. Rare earth elements are critical for permanent magnets used in wind turbines and Electric Vehicle (EV) motors. Electricity grids rely heavily on copper and aluminium, with copper being a key component in all electricity-related technologies. The transition to a clean energy system is expected to increase the demand for these minerals, positioning the energy sector as a major player in mineral markets. As clean energy transitions accelerate, clean energy technologies are now the fastest-growing source of demand. In a scenario aligned with the Paris Agreement goals, the share of total demand for these minerals is projected to rise sharply over the next two decades: over 40% for copper and rare earth elements, 60-70% for nickel and cobalt, and nearly 90% for lithium. EVs and battery storage have surpassed consumer electronics as the largest consumers of lithium and are expected to overtake stainless steel as the primary end user of nickel by 2040 (IEA, n.d., IEA, 2021). The world is on pace to double the demand for minerals used in clean energy technologies by 2040, according to the IEA's Stated Policies Scenario (STEPS). This surge is driven by the rapid expansion of clean energy systems, with technologies of EVs, battery storage, and renewable energy infrastructure requiring substantial amounts of minerals such as lithium, nickel, cobalt, copper, and rare earth elements. Consequently, AI applications in those economies, environments, and energy, such as Deep Learning (DL), and Machine Learning (ML) strategies, find importance, as reviewed in (Sarwar et al., 2024).

To this end, in this article, we have emphasized the role of harnessing AI in energy transition by presenting the importance, applications, and use cases of big data, Large Language Models (LLMs), and agentic AI in power systems. Firstly, the big data and its different usage strategies in power systems are presented in Section 2. Then, LLMs are described and one of their case studies in power systems, and several literatures in that field (Section 3). As the LLMs and their insights are presented, Section 4 describes the agentic AI concept, a case study, and the relevant literature. Next, the challenges, associated future works, and the alignment with UN SDGs are given in Section 5. Finally, the conclusion is drawn in Section 6.

Big data in power systems

The power sector generates vast amounts of data from sources, such as smart meters (Wen et al., 2018, Alemazkoor et al., 2022), sensors (Rani et al., 2017, Marinakis et al., 2020) on grid infrastructure (Munshi & Yasser, 2017), renewable energy systems (Mostafa et al., 2022, Ejiyi et al., 2025), and consumer devices (Al-Ali et al., 2018, Hu & Vasilakos, 2016), characterized by high volume, velocity, and variety (which are the three Vs of big data). This data is important for real-time monitoring and predictive maintenance, allowing utilities to detect equipment failures before they occur, thus reducing outages and maintenance costs. Big data analytics also facilitates the integration of renewable energy sources, such as solar and wind, by analyzing weather patterns and consumption trends to balance supply and demand, optimizing grid stability (Safari et al., 2024). Furthermore, it supports demand-side management through insights from consumer usage patterns, enabling dynamic pricing and energy-saving recommendations. By extracting information from complex datasets, big data empowers power systems to meet growing energy demands, reduce carbon footprints, and transition toward a more sustainable and intelligent energy ecosystem. Following this importance, big data can be used in different aspects of power systems. These aspects are presented in Fig. 3 (Guo et al., 2018).

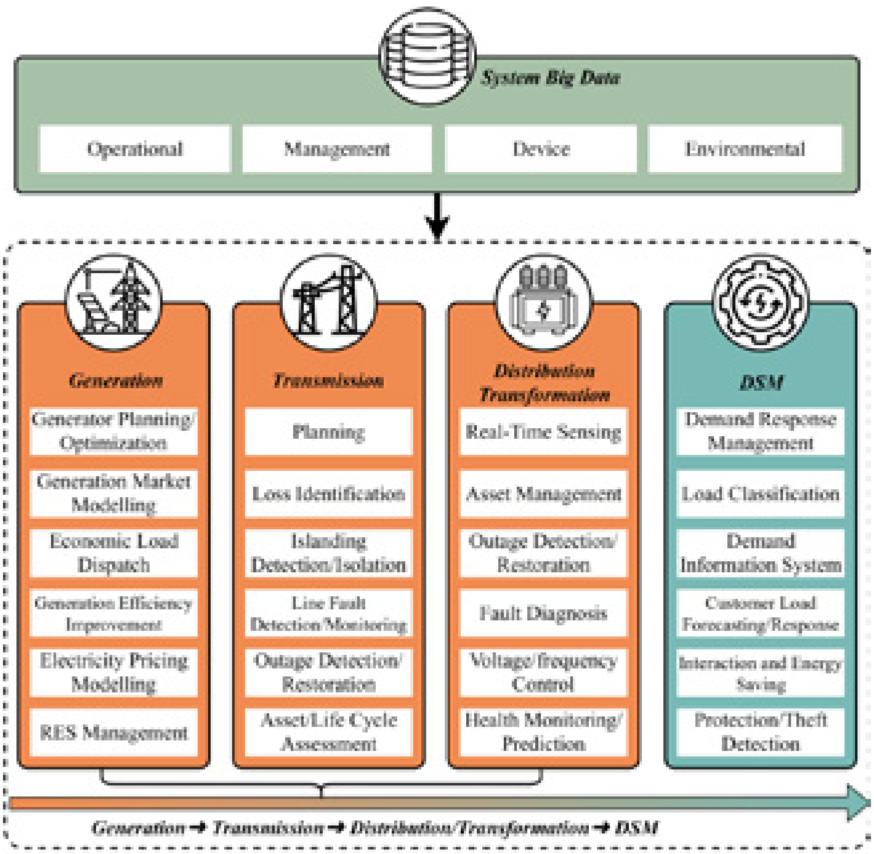

Figure 3: Big data application in power systems different sections: From Generation to Demand Side Management (DSM) (Source: Guo et al., 2018)

Based on (Guo et al., 2018), power system big data is categorized into four dimensions: operational, management, device, and environmental. In power generation, big data can be used for optimizing resources and achieving cost efficiency. It supports applications such as generator planning and optimization, market modeling, and economic load dispatch, helping utilities balance supply and demand effectively. Additionally, big data-based analytics can improve generation efficiency, electricity pricing models, and RES management. In the transmission sector, big data enhances both planning and real-time operations. It enables applications such as loss identification, islanding detection and isolation, and line fault detection and monitoring, ensuring stable power transmission over long distances. Additionally, big data supports outage detection and restoration, bolstered by asset and lifecycle assessments, allowing operators to maintain grid reliability while minimizing downtime and service disruptions. On the side of the distribution/transformation, big data can support localized, customer-focused applications. Real-time sensing and asset management deliver detailed operational information, enabling efficient outage detection and restoration. Big data-based fault diagnosis, voltage and frequency control, and health monitoring/prediction improve the reliability and adaptability of distribution systems. In DSM, big data enables consumer-focused strategies to balance demand with available supply. Applications such as demand response management, load classification, and demand information systems provide actionable insights for both consumers and utilities. Tools, including customer load forecasting, energy-saving interactions, and protection/theft detection, enhance efficiency and security on the demand side. By utilizing these tools, DSM empowers consumers to actively participate in energy markets while supporting overall system stability.

Overall, big data and its analytics are the foundation and most important part of harnessing AI for the energy transition. In the following sections, LLMs and agentic AI strategies in power systems presented are fully dependent on big data.

Large language models in power systems

Large language models are advanced AI systems designed to process, understand, and generate human-like information by using vast amounts of data and advanced computational techniques (Chang et al., 2024; Naveed et al., 2025). Built on DL architecture, typically Transformer-based neural networks (Bouschery et al., 2023; Su et al., 2025), LLMs consist of vast amounts of parameters that enable them to capture intricate patterns. These models are trained on diverse datasets, including books, articles, websites, and other textual sources, allowing them to develop a broad knowledge base and the ability to perform different tasks. The training process involves unsupervised learning, where the model predicts the token in a sequence, and sometimes fine-tuning with supervised or Reinforcement Learning (RL) to align outputs with specific tasks. Power systems are also among these sectors in which LLMs can be used in different ways. As a case study of LLMs integration in the power systems, an example is manifested in Fig. 4.

The architecture of LLMs, in Fig. 4, is tied to the hardware they operate on, particularly in Transformer-based models running on a Personal Computer (PC) with Graphical Processing Unit (GPU) acceleration (Li, R et al., 2024; Koilia & Kachris, 2024). The computational pipeline starts with the Central Processing Unit (CPU) handling lightweight input processing by tokenizing text, followed by the transfer of tokenized data from Random Accessible Memory (RAM) to GPU memory through the Peripheral Component Interconnect Express (PCIe) bus (Saber & Jiang, 2025,

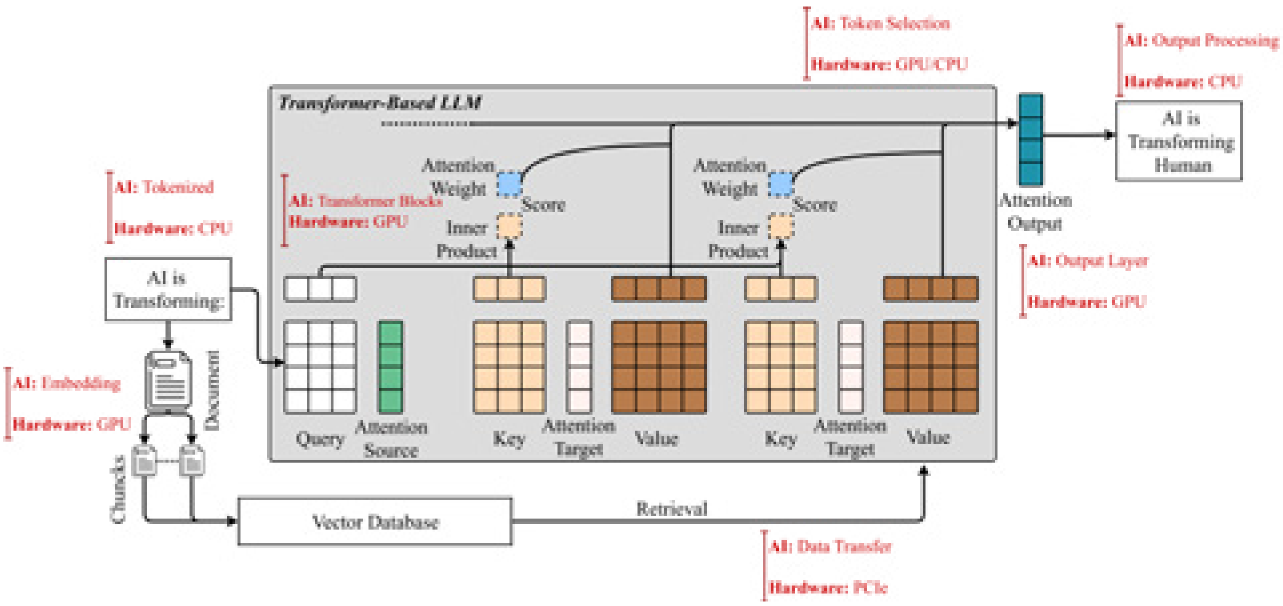

Figure 4: A case study of LLM integration in a power system, conceptualized from (Li, Y et al., 2024). This case study shows the LLM pipelines and the hardware process relationships.

Huang et al., 2025), which can become a challenge for large datasets. On the GPU, tokens are transformed into vector representations with positional encodings during the embedding phase, a task of moderate computational intensity. The core of the LLM's workload occurs in the Transformer blocks, where the GPU's parallel processing excels in executing multi-head self-attention, layer normalization, and Feed-Forward Neural Network (FFNN) operations, leading to the resource-intensive stage and highlighting the critical role of GPU acceleration. Subsequently, the GPU performs a final linear transformation and Softmax operation (Zimerman et al., 2024; Jha & Reagen, 2024; Rakka et al., 2025) in the output layer to generate token probabilities, after which token selection involves both GPU and CPU to choose the next token based on these probabilities. The CPU then converts the selected token back into text during output processing, with steps including data transfer, embedding, Transformer block computations, output layer processing, token selection, and output processing repeating iteratively for multi-token generation. The computational demands of LLMs scale with model size and hardware capabilities, which can run on mid-range GPUs, while larger models necessitate high-end or multiple GPUs. This interdependence presents the GPU's important effect on handling the extensive matrix operations within Transformer blocks, forming the computational foundation of modern LLMs (Li, Y et al., 2024), being used in different power system applications. Additionally, an overview of recent works presented LLMs integration in power systems is given in Table 1.

Table 1: Some of the works considered agentic AI strategies in power systems

Strategy	System	Insights	Ref.
Fine-Tuned LLM	Power System Load Profile	Fine-tuned LLMs to reduce data needs in power system load profile analysis by restoring missing data. It proposes a two-stage fine-tuning strategy, demonstrating that the fine-tuned model matches the performance of specialized models. Key insights emphasized the role of prompt engineering and few-shot learning for efficient knowledge transfer.	(Hu et al., 2025)
Pre-Trained LLM	Building	Black-box tuning inductive adapter based on pre-trained LLMs, designed for short-term building-level load forecasting to enhance power grid stability and efficiency. Addressing the challenge of limited or unavailable historical load data, it used LLMs' generalization capabilities without requiring domain-specific pre-training or fine-tuning. It considered spatial correlations among nearby buildings to improve forecast accuracy and adapt to varying building sizes.	(Zhou & Wang, 2025)
Prompting LLM	Wind Turbine	A hard-soft hybrid prompt learning method to enhance wind power forecasting (WPF) using an LLM, addressing two key challenges: inflexible forecasting horizons and prediction errors due to chaotic wind speed mutations under varying geographic and atmospheric conditions. A hard prompt generator redefines WPF as a language modeling task, leveraging the LLM's representation learning to capture temporal features and detect mutations in wind power data. A soft-prompt adapter with gated attention aligns the LLM to the WPF context through parameter-efficient tuning, capturing spatial-temporal characteristics across wind farms.	(Duan et al., 2025)
LLM-SUC	Wind Energy System	A hybrid method integrating LLMs with a multi-scenario stochastic unit commitment (SUC) framework to boost efficiency and reliability in power systems amid high wind uncertainties. In 10 trials, LLM-SUC cut average total costs by 1.1–2.7% ($185.58M vs. $187.68M for traditional SUC) and load curtailment by 26.3% (2.24 ± 0.31 GWh vs. 3.04 GWh), with zero wind curtailment.	(Ren et al., 2025)
LLM-DRL	Distribution Networks	A regional voltage control approach for distribution grids featuring extensive Distributed Energy Resources (DERs), tackling issues of voltage breaches and grid losses. It fuses Deep Reinforcement Learning (DRL) with LLM tools by prompt engineering to create tailored datasets for DRL agent training.	(Yan & Cheng, 2025)

Continue (Table 1)

Strategy	System	Insights	Ref.
Fine-Tuned LLM	Distribution Networks	A DL method employing a fine-tuned LLM to solve the distribution network reconfiguration challenge in power grids with DER and heightened customer involvement. Through engineered prompts and a bespoke loss function, the LLM learns from bus, line, voltage, and loss data to forecast optimal setups that reduce losses while satisfying operational limits.	(Christou et al., 2025)
LLMs	Smart Grids	Review of LLMs in power systems, evaluating 30 practical implementations in key areas: Grid Operations and Management, Energy Markets and Trading, Personalized Energy Management and Customer Engagement, Grid Planning and Education, Grid Security and Compliance, Advanced Data Analysis and Knowledge Discovery, Emerging Applications and Societal Impact, and LLM-Enhanced RL. By fusing live grid information, market fluctuations, and user patterns, LLMs facilitated dynamic operations, anticipatory protection, and tailored energy offerings. The analysis tackles hurdles in data privacy and model dependability, offering strategies for ethical and fair implementation.	(Madani et al., 2025)
LLM	Industrial Control System	A strategy merging data-driven and design-driven techniques to create attack sequences for assessing ML resilience in Industrial Control Systems (ICS) by LLMs. Countering issues of limited testing environments, expensive expert input, and sparse attack datasets, this approach employs LLMs to yield superior and more plentiful attack patterns compared to human-generated ones.	(Ahmed, 2025)
LLM-Multi-Task Learning	Integrated Energy Systems	A zero-shot forecasting model for energy loads powered by LLMs to handle growing complexity and variability in integrated energy setups incorporating renewables. The model features a preprocessing unit for multi-source load data, a prompt creation module employing multi-task learning and similarity matching to close semantic divides, and a forecasting unit leveraging pre-trained LLMs.	(Li et al., 2025)
LLM	Power System	An LLM-powered autonomous research system that applies a reflection-evolution technique to autonomously tackle intricate power system research problems without human oversight. It manages devices, collects data, devises approaches, and refines algorithms for tasks in parameter prediction, power optimization, and state estimation.	(Liu et al., 2025)
Multi-Agent-LLM-CGAN	EV Charging System	An EV charging platform employing multi-agent LLMs to streamline integration of EV charging with grid scheduling. It incorporates a user agent delivering customized charging advice from past records and a station agent that dynamically sets prices via fine-tuned LLMs, linked through a negotiation hub for protected data exchange. A Conditional Generative Adversarial Network (CGAN) produces synthetic user habits and pricing info to boost LLM refinement.	(Niu et al., 2025)
Feedback-Based Multi-Agent LLM	Power System Simulations	A feedback-guided, multi-agent architecture that combines LLMs with experimental tools to advance power system modeling, surmounting LLMs' gaps in specialized expertise, logical processing, and parameter management. The architecture comprises an upgraded Retrieval-Augmented Generation (RAG) component, a refined reasoning unit, and an adaptive interaction module featuring error-feedback mechanisms.	(Jia et al., 2025)

Continue (Table 1)

Strategy	System	Insights	Ref.
LLM	Power Grid Graph Embedding	A framework crafted to tackle Optimal Power Flow (OPF) challenges in power systems via LLMs. It merges graph-based and tabular depictions of grids to adeptly query LLMs, capturing intricate interdependencies and limits. The system applies customized in-context learning and fine-tuning methods for LLMs.	(Bernier et al., 2025)
LLM & Power AI	Urban Distribution Network	A system fusing an LLM with a versatile power AI engine to support interactive and dependable dispatching in city distribution grids. To overcome LLMs' weaknesses in precise numerical calculations and adherence to rigid power rules, it employs a dispatcher-tool structure for concurrent cooperation via formatted data exchanges. It further integrates stepwise chain-of-thought logic, rejection sampling, and guided fine-tuning to guarantee rule conformity and elevate effectiveness.	(Zhu et al., 2025)
Optimized LLM	Distribution Power Grid Insulators	A hybrid DL system for forecasting surges in leakage current on high-voltage insulators from surface pollutants, which may trigger discharges and system failures. The system integrates multi-objective tuning via tree-structured Parzen estimation, a noise-suppression input filter, and an LLM for sequential forecasting to track and curb fault escalation.	(Matos-Carvalho et al., 2025)
LLM	Power System Dispatch	An LLM presented to advance power dispatch processes by overcoming traditional approaches' shortcomings in managing the magnitude, intricacy, and multitasking needs of contemporary power grids. It aids in operational adjustments, oversight, and black start situations via an innovative dataset assembly method that merges varied data origins for fine-tuning, plus targeted prompt tactics to maximize input-output performance.	(Cheng et al., 2025)
LLM	Urban Power Grid	An LLM-based system for building a specialized lexicon in urban power grid engineering, countering issues of outdated terms, meaning vagueness, and narrow word scope in conventional approaches. It assembles a structured dataset from official and sector standards, applying an advanced Term Frequency–Inverse Document Frequency (TF-IDF) method incorporating mutual information and adjacency entropy to derive 3426 premium initial terms. Hierarchical prompt designs and LLM self-correction facilitate synonym extraction, yielding 10745 equivalents with a mean cosine similarity of 0.86 and 89.3% precision.	(Xu et al., 2025)

Following Table 1, LLMs' applications are increasing in power systems by addressing complex challenges across diverse aspects, including load forecasting, wind power prediction, grid optimization, and security. Through advanced strategies, such as fine-tuning, prompt engineering, and multi-agent frameworks, LLMs enhance forecasting accuracy, optimize resource allocation, and improve operational resilience in scenarios with limited data or high uncertainty. By integrating real-time data, using generalization capabilities, and supporting tasks of network reconfiguration and anomaly detection, LLMs enable scalable, efficient, and adaptive solutions, significantly advancing smart grid technologies, urban power systems, and renewable energy integration, which manifests LLMs' increasing importance. Consequently, the much-advanced form of LLMs, known as agentic AI, is considered in the next section, and its applications in power systems are taken into consideration.

Agentic artificial intelligence in power systems

Agentic AI refers to AI systems designed with a high degree of autonomy, decision-making capability, and goal-oriented behavior, enabling them to act independently in dynamic environments to achieve specific objectives (Acharya et al., 2025; Bandi et al., 2025). Unlike traditional AI, which often relies on

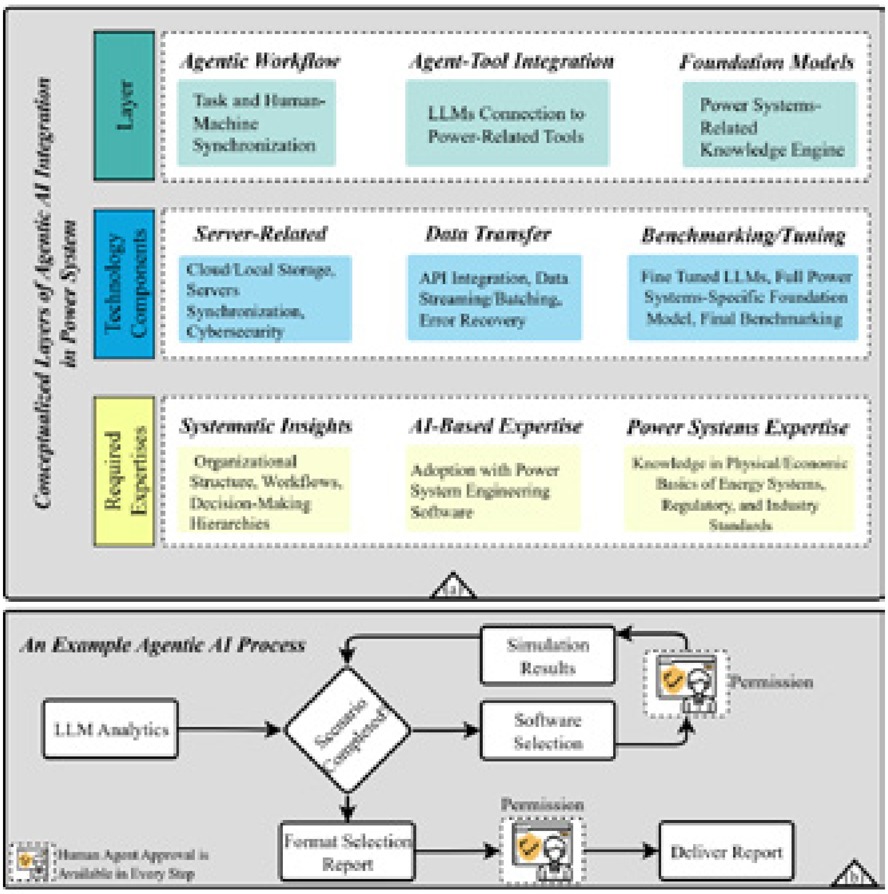

Figure 5: Agentic AI strategy for power systems: (1) Overall layers of its integration, and (b) Example utilized agentic AI, known as PowerAgent (Conceptualized from Zhang & Xie, 2025)

predefined rules or human oversight, agentic AI models use advanced techniques, such as RL (Zhang et al., 2025), LLMs, and contextual reasoning (Singh et al., 2025, Ren et al., 2025, Biswas & Talukdar, 2025), to perceive their surroundings, reason about complex scenarios, and execute actions with minimal human intervention. These systems are characterized by their ability to adapt to new information, learn from experience, and make decisions aligned with long-term goals, often in unpredictable or partially observable environments. An example of an agentic AI model, utilized for power systems, is shown in Fig. 5.

As the case study of agentic AI in power systems, the PowerAgent framework is presented (Zhang & Xie, 2025), built on three essential layers: (1) Foundation models that deliver broad intelligence capabilities, (2) Model Context Protocols (MCPs) that connect models with tools, and (3) Agentic workflows that facilitate real-world task execution through coordinated, modular AI behaviors. This modular structure enhances implementation clarity and aligns with evolving AI development trends, enabling the power sector to efficiently adapt and scale agentic intelligence. At the main center of PowerAgent lies a three-layered ecosystem comprising workflow automation, tool integration, and domain-specific foundation models (Fig. 5 (a)). These layers collectively provide a flexible and scalable foundation for agentic AI applications. The proposed agentic AI strategy, in Fig. 5 (b), integrates a domain-tailored LLM with MCPs and predefined workflows, enabling it to function as a virtual agent. When a user submits a query, such as evaluating potential power load demand growth in a specific region, the LLM processes the request and independently selects an appropriate analysis workflow. For instance, this workflow might include performing contingency analyses to assess how different load growth scenarios could impact transmission line congestion or voltage issues. Instead of directly resolving the query, the LLM uses MCP to interface with external tools, such as professional-grade simulation software, to handle technical computations. This separation of roles is advantageous in precision and reliability by using trusted industry-standard platforms. A defining feature of this agentic workflow is its adaptable human-in-the-loop approach. For sensitive tasks, including running simulations or altering system settings, the LLM may seek user approval before proceeding. For instance, after conducting scenario analyses, the LLM presents the results to the user for review and potential adjustments, keeping human oversight central to critical decisions. This approach is practical for security control applications where system safety requires careful monitoring (Zhang & Xie, 2025). Additionally, several other works, considered agentic AI strategies in power systems are presented in Table 2.

Table 2: Some of the works considered agentic AI strategies in power systems

Strategy	System	Insights	Ref.
Agentic AI-based Mathematical Framework	Electrical Distribution Systems	A dual-agent Proximal Policy Optimization (PPO) and market-based mechanisms to enhance electrical distribution system resilience against extreme weather and cyber threats. A strategic agent optimizes Distributed Energy Resources (DER)-driven configurations, while a tactical agent adjusts switch states under constraints.	(Johri et al., 2025)
Multi-Agentic AI	Built Environments	Review of agentic AI in built environments, proposing a classification framework for applications, functional roles, and learning approaches. It analyzed five key applications, categorized AI roles using the Data-Information-Knowledge-Wisdom (DIKW) hierarchy, and identified four learning approaches. Defining agentic built environments as AI-powered virtual assistants, it evaluated their development, limitations, and future directions for scalable, intelligent services across the building lifecycle.	(Lee et al., 2025)
Agentic AI (Copilot Models and Assistants)	Smart Systems	Review of agentic AI's potential in smart systems, highlighting its autonomy, reactivity, proactivity, and learning capabilities through different tools. It addresses the research gap in synthesizing agentic AI's diverse functionalities and a strategic framework for adopting generative AI, focusing on business needs, tool selection, and risk management. While Agentic AI boosts productivity, reduces costs, and drives innovation, challenges of privacy concerns persist.	(Hosseini & Seilani, 2025)
Agentic Digital Twin	Energy Sector	Review of the expanding role of AI, particularly Transformer models and LLMs, in enhancing energy management within smart grids. It reviewed the architectural foundations, domain-specific adaptations, and practical applications, highlighting generative AI's growing influence in high-level planning and daily operations of grid balancing and workforce training. It introduced the Agentic Digital Twin, a model integrating LLMs to enable autonomous, proactive, and socially interactive energy management systems.	(Antonesi et al., 2025)

The proposed advancements and recent works on agentic AI's application in power systems manifest the overall interest in it.

Challenges and future work

The integration of big data, Agentic AI, and LLMs is transforming power systems, including data centers, enabling real-time monitoring, predictive analytics, autonomous decision-making, and enhanced operator support. However, incorporating these technologies into critical infrastructure presents technical, operational, and regulatory challenges. To ensure safe, reliability, and sustainable deployment, the primary challenges (Fig. 6 (a)) should be identified and then associated with future research directions (Fig. 6 (b)) provided.

A. *Challenges*

The main challenges are presented in Fig. 6 (a).

The massive volume, high velocity, diverse formats, missing values, and limited labeled data complicate reliable analytics, while having data privacy, interoperability, and cybersecurity across complex pipelines remains a critical issue. Agentic AI, despite its potential for autonomous control, struggles with safety, explainability, and verification, especially when interacting with legacy systems and critical infrastructure, and coordinating multiple agents under partial observability, real-time constraints, and uncertain market incentives adds further complexity. LLMs face risks such as hallucinations, lack of operational grounding, limited domain knowledge, and integration challenges with real-time control, alongside high computational and energy demands that raise sustainability concerns. On the other hand, those AI technologies are heavily reliant on the data centers and their efficient performance, which increases the workload and the energy consumed. Meanwhile, data centers contend with power–thermal workload coupling, reliability–sustainability trade-offs, and unpredictable load behavior, all while needing to provide flexible demand response to support the grid.

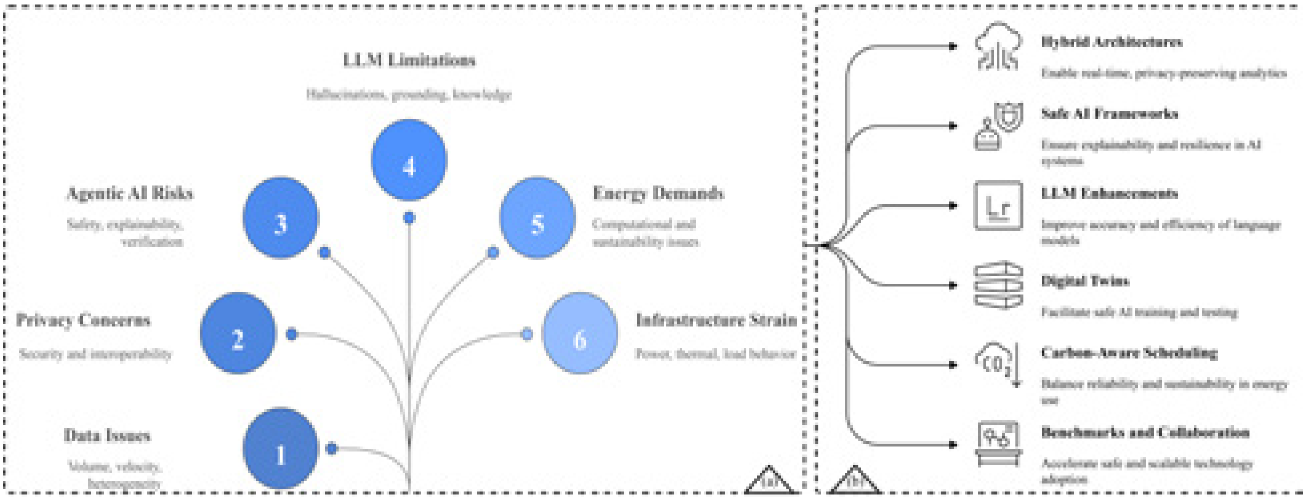

Figure 6: Big data, agentic AI, and LLMs integration in power systems: (a) Challenges, and (b) Associated future works (Source: Authors)

Figure 7: Proposed UN's SDGs related to the harnessing AI for energy transition

B. *Future works*

The future works associated with the presented challenges are shown in Fig. 6 (b). Future research should prioritize developing hybrid edge–cloud big data architectures, adaptive sampling, and more advanced self-supervised learning to enable real-time, privacy-preserving, and resource-efficient analytics. Safe and explainable agentic AI frameworks are essential, incorporating formal verification, human-in-the-loop oversight, and resilient multi-agent coordination for distributed systems, including microgrids and data centers. For LLMs, future research directions can focus on retrieval-augmented grounding, uncertainty quantification, domain-specific fine-tuning, and efficient model distillation for on-premises deployment. Cross-domain opportunities include creating digital twins of power systems and data centers for safe AI training and testing. Additionally, carbon-aware scheduling and co-optimisation of data-center workloads, facility thermal systems, and grid participation are among other strategies for balancing reliability and sustainability. Benchmarks are also helpful to further accelerate the safe, auditable, and scalable adoption of these technologies in the use of AI for energy transition.

C. *Alignment with UN-SDGs*

The UN's SDGs, adopted in 2015, are a set of seventeen interconnected global goals aimed at addressing pressing challenges, including poverty, inequality, climate change, and environmental degradation, by 2030. These goals provide a shared blueprint for governments, organizations, and individuals to promote prosperity, protect the planet, and ensure peace and justice for all (Carlsen & Bruggemann, 2022; Fernandes & Rodrigues, 2025). Among these seventeen SDGs, five of them are directly related to the use of AI in energy transition, shown in Fig. 7.

The integration of big data, agentic AI, and LLM is important in advancing SDG 7 (Pang & Chen, 2025, Zhao et al., 2025) (the most relevant SDG), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Big data and AI optimize energy systems by enhancing grid efficiency, predicting energy demand, and facilitating the integration of renewable sources. Agentic AI can autonomously manage energy storage and distribution, ensuring stability in renewable-heavy grids. Meanwhile, LLMs can process wide datasets to recommend policies, technologies, or investment strategies for clean energy adoption. By enabling smarter energy management, reducing reliance on fossil fuels, and supporting the transition to sustainable energy systems, these technologies make energy more accessible and environmentally friendly, directly supporting the goals of SDG 7.

The SDG 9 focuses on building resilient infrastructure, promoting inclusive and sustainable industrialization, and advancing innovation (Aziz et al., 2025, Pauliukevičienė et al., 2025). Following this, the proposed AI technologies are impactful in achieving these objectives within the energy sector. Big data and AI drive advancements in energy infrastructure through innovations of smart grids, which enhance energy distribution, and predictive maintenance systems that ensure the reliability of renewable energy installations. LLMs accelerate research and development by analyzing large amounts of scientific literature and proposing novel energy solutions, such as advanced battery technologies or grid optimization techniques.

In the third relevant goal, SDG 11 aims to make cities inclusive, safe, resilient, and sustainable (Bleil de Souza et al., 2025, Wang et al., 2025), and the application of big data, agentic AI, and LLMs in the energy transition significantly contributes to this goal. AI-driven smart city solutions optimize energy use in urban settings, such as in buildings, public transportation, and street lighting, reducing energy waste and emissions. Big data analytics can identify urban energy consumption patterns, enabling targeted efficiency improvements. LLMs can support urban planners by analyzing data to design sustainable energy policies or simulate the impact of renewable energy integration in cities. Additionally, SDG 12 promotes sustainable consumption and production patterns in which big data, agentic AI, and LLMs are advantageous by optimizing resource use in the energy sector (Tsai et al., 2025; Cifuentes-Faura, 2025; Oliveira & Gomes, 2025; Precious, 2025). Big data and AI enhance efficiency in energy production by minimizing waste, optimizing supply chains, and improving the lifecycle management of energy infrastructure. Agentic AI can automate processes to ensure resources are used sustainably, such as prioritizing renewable energy in production systems. LLMs are also considered important by educating stakeholders on sustainable practices, analyzing supply chains for energy-efficient improvements, or generating reports to guide policy decisions.

Climate change is another critical issue that the whole world is now facing. In sequence, SDG 13 calls for urgent action to combat climate change, its impacts (Seddik & Sovacool, 2025, Zhang et al., 2025; Ji et al., 2025). To this end, the energy transition, powered by big data, agentic AI, and LLMs, can be a main solution to this effort. Big data analytics enable real-time monitoring of emissions, optimization of energy consumption, and prediction of climate-related impacts on energy systems. Agentic AI can autonomously implement carbon-neutral strategies, such as optimizing renewable energy deployment or managing carbon capture systems. LLMs can analyze climate data or help create public awareness campaigns to promote sustainable behaviors.

Conclusion

This article presented the significance of big data in power systems, alongside advanced AI approaches such as LLMs and agentic AI. For LLMs and agentic AI alike, a dedicated case study is examined for each, drawing on multiple recent literature and emerging advancements. Finally, the discussion addresses key challenges and prospective research avenues, enriched by descriptions of the UN-SDGs (7,9,11,12,13). Massive, high-velocity data with diverse formats, missing values, and scarce labels can cause challenges in analytics, alongside privacy, interoperability, and cybersecurity issues in complex pipelines. Agentic AI's autonomy is undermined by safety, explainability, and verification challenges, especially in larger systems, alongside the coordination under partial observability, real-time constraints, and uncertain incentives. LLMs sometimes have hallucinations, poor grounding, domain gaps, integration hurdles, and energy-intensive demands threatening sustainability. These technologies strain data centers facing power-thermal coupling, reliability-sustainability trade-offs, unpredictable loads, and grid demand response needs. Future work can focus on hybrid edge-cloud architectures, adaptive sampling, and self-supervised learning for real-time, private, efficient analytics. For LLMs, focus can be on retrieval-augmented grounding, uncertainty quantification, fine-tuning, and distillation for on-premises use. Safe, explainable agentic AI needs verification, human oversight, and multi-agent coordination for power systems. Cross-domain efforts include digital twins for safe AI training, as well as the carbon-aware scheduling and co-optimization of workloads, thermals, and grids for reliability and sustainability. Combined and developed, AI can have a considerably important role in the energy transition to a net-zero system, with near-zero reliance on fossil fuels, as a critical step towards combating climate change.

Ethical considerations

Authors' Contributions: AS– Conceptualization, Visualization, Formal Analytics, Original Writing. AR– Formal Analytics, Review/Editing.

Conflict of Interest: None

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Harnessing Artificial Intelligence for Energy Transition in the Asia-Pacific

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Note

This article was generated using Artificial Intelligence as a value-added contribution to the Asia-Pacific Tech Monitor's special issue on "Harnessing Artificial Intelligence for Energy Transition." This experiment demonstrates the potential applications of AI in knowledge synthesis and technical writing within the context of our thematic focus. The use of AI for this article is purely experimental and educational in nature. APCTT does not endorse, promote, or have any affiliation with any specific AI company, platform, or service provider.

Abstract

Artificial intelligence is reshaping how the Asia Pacific generates, manages, and uses electricity. Record renewable additions are raising the bar for short-term forecasting, grid flexibility, and asset reliability, just as AI driven data centre demand grows rapidly. Across the Asia Pacific, AI is transitioning from pilots to operations in wind and solar self-forecasting, distribution-level digital twins, and demand response. Governments are pairing these advances with major grid investments and regional power market cooperation. Realizing AI benefits at scale will require digital-ready grids, open data, model governance, and workforce capabilities to ensure AI accelerates rather than complicates the path to net zero.

Introduction

Global renewable power expanded by a record 585 GW in 2024, taking cumulative capacity to 4,448 GW; renewables accounted for over ninety percent of net additions (IRENA, 2025). Those headline numbers translate into a day-to-day operations challenge: system operators must forecast weather-driven output and balance variability across grids that were not originally designed for such dynamism. In parallel, the International Energy Agency projects global data centre electricity uses to more than double to around 945 TWh by 2030, with AI workloads the most significant driver (IEA, 2025a). Asia Pacific, already a major share of global energy demand, sits at the nexus of these trends, with implications for reliability, affordability, and decarbonization (Energy Institute, 2025).

Where AI is delivering value

Short-term forecasting for variable renewables

Australia has operationalized participant self-forecasting, allowing wind and solar farms to submit machine learning based five-minute forecasts to the market operator. Evidence from the Australian Renewable Energy Agency trial and the Australian Energy Market Operator shows self-forecasts can reduce generation forecast error and improve dispatch outcomes relative to legacy baselines (ARENA, 2021; AEMO, 2024). The mechanism matters: when forecasts are tied to incentives and integrated into operational tools, model accuracy and system value improve, especially during ramps and cloud transients that defeat simple persistence models.

Distribution level visibility and planning

Singapore Energy Market Authority and SP Group are building a nation-scale Grid Digital Twin, an integrated asset twin and network twin using real time and historical data to assess the health of grid assets and the impact of new connections (EMA, 2021; SP Group, 2023). A digital twin provides the scaffolding for AI applications: probabilistic hosting capacity for rooftop PV, dynamic thermal ratings on feeders, and predictive maintenance that prioritises field crews where risk is highest. While quantified system wide benefits will accumulate over time, the architectural shift is clear: data liquidity plus physics informed models create space for AI to assist planners and system controllers.

Demand response and resource aggregation

Japan's framework for virtual power plants and demand response, underpinned by technical and cybersecurity guidance from the Ministry of Economy, Trade and Industry (METI), enables AI driven coordination of distributed resources. As AI and data centre loads rise, flexible demand becomes a hedge against local constraints and peak pricing, complementing grid reinforcement (METI, 2023; Reuters, 2024). For Asia Pacific neighbours, Japan's approach illustrates how policy plumbing standards, telemetry, and settlement is as important as the algorithms.

Aligning new digital loads with clean power

Malaysia has committed RM 43 billion, approximately 10.1 billion US dollars, to upgrade its national grid, with leaders explicitly citing the role of AI and battery storage in improving flexibility for growing demand, including data centre clusters. The investment aims to speed renewable integration while meeting the reliability expectations of digital industries (Reuters, 2025; The Edge Malaysia, 2025). Experience from mature data centre markets suggests siting clusters near clean supply and storage, procuring twenty-four by seven carbon-free electricity, and minimising power usage effectiveness with AI optimised cooling are emerging good practices (IEA, 2025a).

Country snapshots

Australia: Australian Energy Market Operator (AEMO) has formalized participant self-forecasting pathways and continues to publish forecasting accuracy and improvement roadmaps, reflecting how machine learning is moving from trials to day-to-day system operations. The lesson for the region is to build the market interface for AI, including data specifications, submission windows, and validation alongside the models (AEMO, 2024).

Singapore: The Grid Digital Twin supports faster and safer interconnections and better asset management, creating a platform for AI to scale responsibly from predicting asset failures to evaluating scenarios for electric vehicle charging and distributed storage (EMA, 2021; Channel NewsAsia, 2021).

Japan: Facing surging data centre loads, Tokyo Electric Power Company (TEPCO) plans to invest 470 billion yen, approximately 3.25 billion US dollars, by fiscal year 2027 to expand its power grid. In parallel, virtual power plant and demand response guidelines enable aggregated flexibility to complement physical upgrades, an approach that spreads risk between infrastructure and software (Reuters, 2024).

Malaysia: The government's 43-billion-ringgit grid modernization program aims to add capacity for renewable integration and anticipated AI driven demand, with public statements pointing to AI and storage as enabling technologies (The Edge Malaysia, 2025; Reuters, 2025).

Regional cooperation and technology transfer

Interconnection and market integration can spread variability, lower balancing costs, and amplify AI value by enlarging balancing areas and data pools. The ASEAN Power Grid initiative envisions integrated operation and cross-border power trade by 2045, supported by multilateral partners such as the Asian Development Bank (ADB, 2025). Recent analyses argue that modern grids, including new transmission corridors and digital backbones, are the unlock for clean energy investment in Southeast Asia. One estimate peg the regional transmission need at around 100 billion US dollars by 2045 (Ember, 2025; Eco Business, 2025). For AI practitioners, this implies prioritising tools that support regional scheduling, congestion forecasting, and probabilistic reserve sharing as interties expand.

Policy and market priorities

Invest in digital-ready grids. AI value is limited by the availability, latency, and quality of telemetry. Advanced metering infrastructure, phasor measurement units, distributed energy resource telemetry, and cyber-secure data exchanges are prerequisites (IEA, 2025b). Regulators can unlock innovation by standardising data formats and enabling third-party access where appropriate, like open data models that catalysed forecasting advances in Australia.

Model assurance and open data. Because AI can inform dispatch, interconnection, and protection settings, operators should require documentation, continuous monitoring, fallback modes, and robustness testing. Japan resource aggregator guidance and Australia knowledge sharing from the short-term forecasting trial offer practical starting points (METI, 2023; ARENA, 2021).

Align digital growth with clean power. Data centre clusters should be co-sited with renewables and storage, pursue round the clock carbon free electricity procurement, and drive power usage effectiveness toward best-in-class levels via AI optimised thermal controls. The IEA outlook highlights why AI related processing is a major contributor to rising electricity use this decade (IEA, 2025a).

Finance and skills. Regional energy reviews point to capacity gaps in data engineering, power systems analytics, and cybersecurity within utilities and regulators' skills that determine whether AI pilots scale into operational practice (Energy Institute, 2025). Multilateral programmes linked to the ASEAN Power Grid and national grid upgrades can embed training and knowledge transfer into capital projects.

Outlook

Over the next five years, three trends will define AI's contribution to the Asia Pacific transition. First operationalisation: more markets will emulate Australia's self-forecasting model, allowing AI to participate in dispatch relevant processes. Second granularity: distribution level visibility via digital twins will bring AI closer to grid edge assets, including behind-the-meter solar, electric vehicle charging, and heat pumps. Third integration: regional interconnectors and cross border trade under the ASEAN Power Grid will expand the canvas on which AI can optimise flows. Each step requires governance covering data rights, security, model auditability, and equitable access so smaller utilities and emerging markets benefit alongside digital hubs. Done well, AI will help the region integrate more renewables faster and more reliably, turning software intelligence into real world system flexibility.

Conclusion

AI is not a silver bullet, but it has become a system enabler where infrastructure and institutions are ready. In the Asia Pacific, where renewable additions are breaking records and AI era loads are rising, the practical path is clear. Invest in digital ready grids, publish data and require model assurance, align data centre growth with clean power, and expand regional cooperation so software driven efficiencies compound hardware investments. The result can be a cleaner, more reliable, and more competitive power system for a digitally powered economy (IRENA, 2025; IEA, 2025a).

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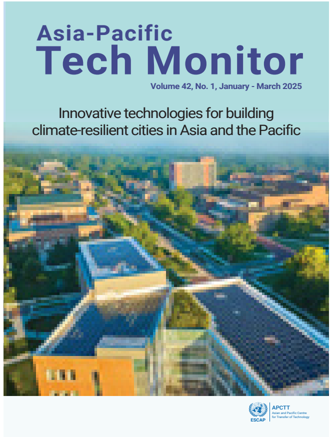
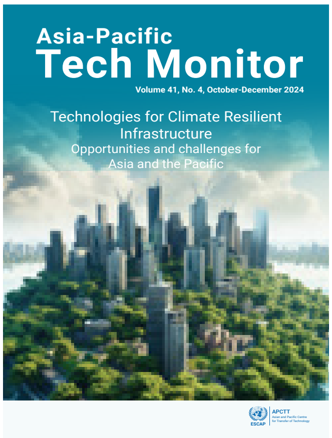


Jan-Mar 2025

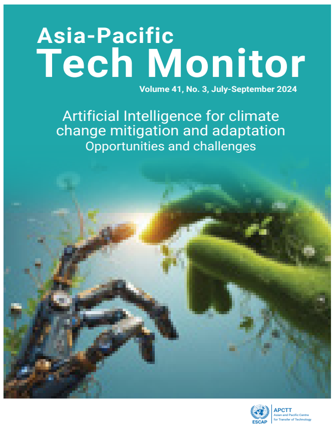
Innovative technologies for building climate-resilient cities in Asia and the Pacific



Oct-Dec 2024

Technologies for Climate-Resilient Infrastructure

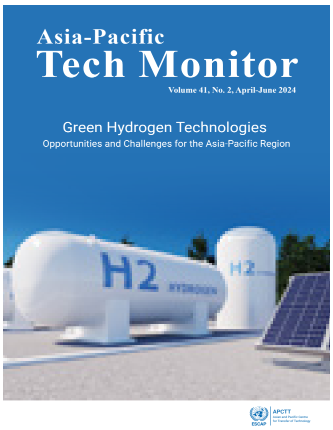
Opportunities and challenges for Asia and the Pacific



July-September 2024

Artificial Intelligence for climate change mitigation and adaptation

Opportunities and challenges



April-June 2024

Green Hydrogen Technologies

Opportunities and Challenges for the Asia-Pacific Region

Jan-Mar 2024

Digital Innovations for Sustainable Development in Asia and the Pacific

The **Asia-Pacific Tech Monitor** has been the flagship periodical of APCTT since 1993. It is an online quarterly periodical featuring theme-based articles that provide trends in technology transfer and development, innovation and technology policies, market, data and analysis with respect to relevant issues, case studies, good practices and innovative technologies. Each issue of Tech Monitor focuses on a special theme and the articles are written by authors/experts of national and international repute. The periodical aims to enhance the technology intelligence of relevant stakeholders from member States of ESCAP to meet the challenges of today's dynamic business and technological setting.

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