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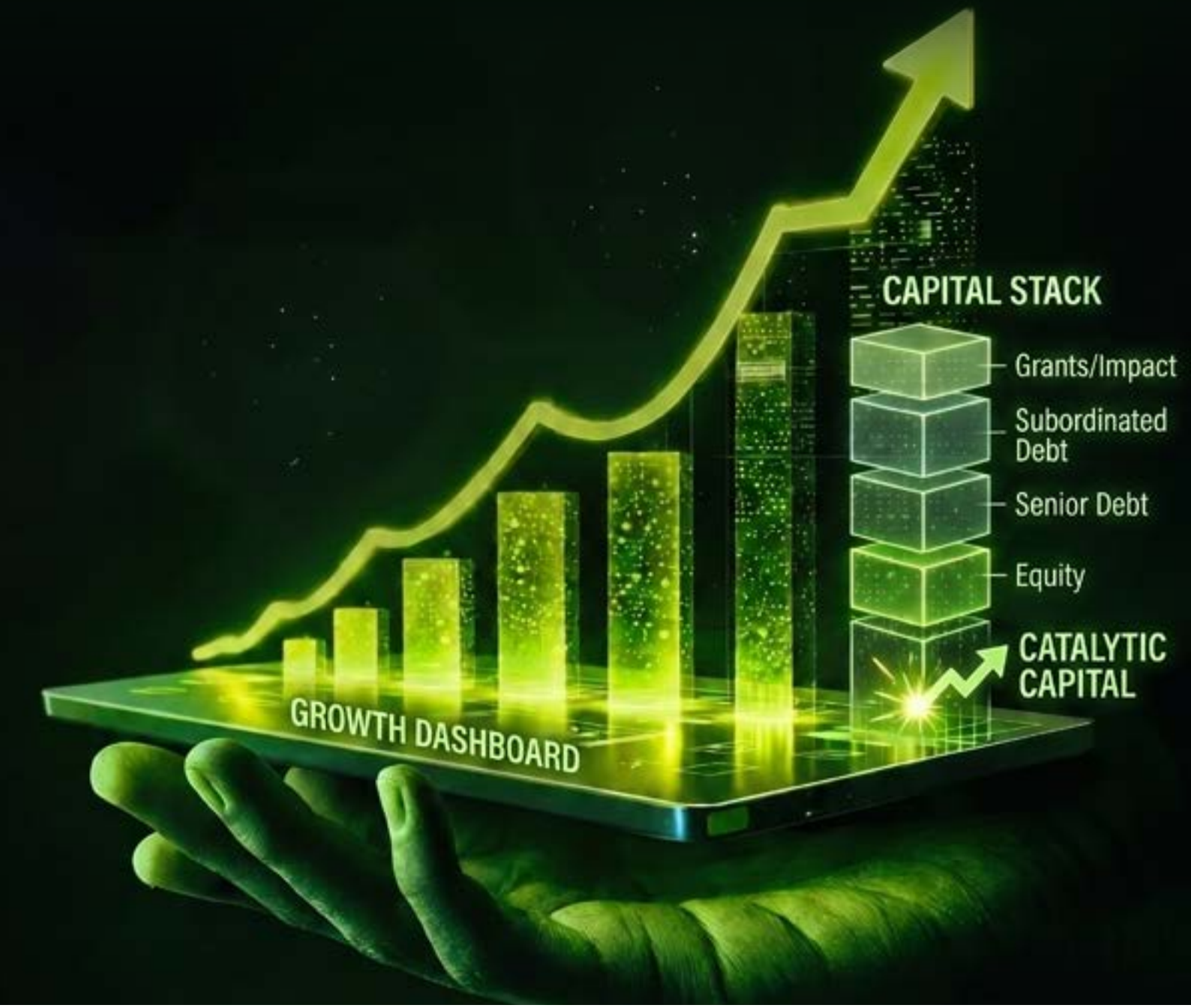
Innovative Financing Models for Emerging Technologies



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*The shaded areas of the map indicate ESCAP members and associate members.**

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

Emerging technologies are creating new opportunities to enhance productivity, strengthen resilience, and accelerate sustainable development. Their transformative potential can be realised effectively only if they are deployed at scale—and access to finance remains one of the critical enabling factors. Nowhere is the need for innovative financing more apparent than in efforts to address climate change. Developing countries require at least US$1.3 trillion annually by 2035 to meet their climate mitigation and adaptation needs, yet the international community has committed to providing and mobilising US$300 billion per year under the New Collective Quantified Goal on climate finance agreed at COP29. Bridging this gap will require not only greater volumes of finance but also innovative mechanisms capable of accelerating the deployment and diffusion of technologies that support low-carbon, climate-resilient, and sustainable development pathways.

This edition of the *Asia-Pacific Tech Monitor*, themed **"Innovative Financing Models for Emerging Technologies"**, explores how financial innovation can help unlock the potential of emerging technologies and bring transformative solutions to scale. The five articles included in this issue examine three fundamental questions: How can capital be mobilised at scale? How can risk be shared so that finance reaches ventures that markets alone would not support? How can financing mechanisms deliver measurable results? The articles explore a range of solutions, from green, social, sustainability, and sustainability-linked bonds to Islamic finance and blended finance structures capable of mobilising public and private capital at scale. They examine public-private partnerships, innovation and climate funds, venture capital, and results-based financing as mechanisms for sharing risk and unlocking investment where conventional approaches often fall short. They also highlight emerging tools such as asset tokenisation and blockchain-enabled financing, alongside a cross-country analysis of climate bonds, illustrating how financial innovation can influence technology deployment, value creation, and national development outcomes.

Taken together, these contributions underscore a simple but often overlooked truth: financing is not a technical afterthought to technology adoption. It is a critical enabler of innovation, diffusion, and impact. The availability of appropriate financing often determines whether a promising technology remains confined to pilot projects or evolves into a transformative solution that reaches communities, enterprises, and economies at scale.

APCTT remains committed to advancing policy dialogue, regional cooperation, and knowledge-sharing that help align financing solutions with technology development and diffusion priorities across Asia and the Pacific. We hope this edition offers practical insights and renewed momentum for policymakers, financial institutions, development partners, and innovators working to build more inclusive and effective financing ecosystems for emerging technologies.

Preeti Soni
Head, APCTT

Technology Market Scan

ASIA-PACIFIC

AUSTRALIA

Budget targets renewable infrastructure investment

Australia's 2026-27 Federal Budget introduced a time-limited, targeted concession under the foreign resident capital gains tax regime for investment in renewable energy infrastructure. The transitional arrangement applies to foreign investors disposing of certain renewable energy infrastructure assets from the commencement date, defined as the first day of the next quarter after Royal Assent, until 30 June 2030. The Budget frames the concession as part of the implementation of earlier reforms to strengthen the foreign resident capital gains tax regime, while maintaining support for Australia's climate transition. It is estimated to reduce receipts by A$425 million over the five years from 2025-26. The measure sits alongside wider clean energy programmes, including the Capacity Investment Scheme and household battery support, but its core purpose is to preserve foreign capital flows into utility-scale renewable infrastructure.

https://budget.gov.au

CHINA

Four ministries issue AI-energy action plan

China's National Energy Administration, together with the National Development and Reform Commission, the Ministry of Industry and Information Technology, and the National Data Administration, issued an action plan on 8 May 2026 to deepen integration between artificial intelligence and energy. The plan focuses on six policy areas: secure energy supply for computing-power infrastructure; greener and lower-carbon computing facilities; stronger coordination between electricity systems and computing demand; expanded AI applications in energy operations; better use of energy data; and innovation in energy-sector AI models. By 2030, China aims to significantly increase clean-energy supply capacity for AI computing infrastructure while improving AI deployment across the energy sector. The plan links digital industrial policy with energy-system planning, including green power procurement and wider use of AI in grid, generation and energy-management applications.

https://english.www.gov.cn

INDIA

Cabinet clears two more semiconductor projects

India's Union Cabinet approved two additional semiconductor projects under the India Semiconductor Mission on 5 May 2026, taking the total number of approved projects to 12, with a cumulative investment of around Rs 1.64 lakh crore. The new approvals cover a compound semiconductor fabrication and assembly facility in Gujarat for Mini and Micro-LED display modules and GaN foundry services, and an outsourced semiconductor assembly and test facility in Surat with a planned capacity of 1,033.20 million chips per year. The two projects involve a cumulative investment of about Rs 3,936 crore and are expected to generate 2,230 skilled jobs. Separately, the 2026-27 Union Budget provides Rs 8,000 crore for the modified semiconductor and display manufacturing programme, including a Rs 1,000 crore provision for India Semiconductor Mission 2.0 focused on equipment, materials, design IP, supply chains and R&D centres.

https://www.pib.gov.in

INDONESIA

Ministry launches digital ecosystem alignment initiative

Indonesia's Ministry of Communication and Digital Affairs launched the Digital Ecosystem Alignment initiative, known as DEAL 2026, in Jakarta on 23 June 2026. The initiative is designed as a government-led coordination platform bringing together ministries, businesses, academics, investors, startups, small and medium enterprises, communities, and regional administrations around a shared digital-transformation agenda. Eight collaboration packages were announced, covering telecommunications connectivity and industry value creation, digital consumer protection, digital innovation and technopreneurship, and the development of a healthy and secure digital ecosystem. Other packages focus on strengthening the national startup ecosystem, expanding digital inclusion and adoption of emerging technologies, and improving logistics cost efficiency. The Ministry framed DEAL 2026 around three principles – alignment of interests, shared responsibility, and national prosperity – underscoring that digital transformation requires coordinated public, private and regional participation.

https://en.antaranews.com

JAPAN

Carbon dioxide storage act enters full force

Japan's Act on Carbon Dioxide Storage Businesses reached full enforcement on 22 May 2026, following Cabinet approval of orders setting the enforcement date and related transitional measures. The law, enacted in 2024, creates the legal basis for carbon capture and storage as part of Japan's decarbonisation strategy. It establishes a licensing framework for carbon dioxide storage businesses and exploration drilling, administered by the Ministry of Economy, Trade and Industry, and provides for registered Storage Rights and exploratory drilling rights. The implementing orders also address technical conditions, including requirements for stored carbon dioxide in marine reservoirs and the registration of storage rights and mortgages. The framework is intended to support commercial CCS value-chain development, including long-term monitoring, safety obligations and regulatory certainty for storage projects that can contribute to Japan's 2050 carbon-neutrality pathway.

https://www.meti.go.jp

KAZAKHSTAN

AI and Digital Code framework advances

Kazakhstan continued building out its digital and artificial-intelligence governance framework in 2026. The Law on Artificial Intelligence, signed in November 2025 and in force from 18 January 2026, established a dedicated framework for AI development, oversight, and compliance roles. In April 2026, subordinate rules began to operationalise the law, including criteria for classifying informatisation facilities as AI systems and rules for developing, using and distributing machine-readable forms. In parallel, the Digital Code, signed by the President on 9 January 2026, is scheduled to enter into force on 11 July 2026. It consolidates digital legislation, sets ethical boundaries for neural-network use, and strengthens protections around automated decisions, data governance and digital rights. Together, these measures create a broader policy architecture for digital sovereignty, AI accountability and public-sector digital transformation.

https://primeminister.kz

MALAYSIA

Johor-Singapore SEZ framework moves ahead

Malaysia and Singapore continued operationalising the Johor-Singapore Special Economic Zone framework in 2026, following the bilateral agreement signed in January 2025. The JS-SEZ covers over

3,500 square kilometres across nine flagship areas in southern Johor and is structured to support complementary operations between Singapore and Malaysia. The zone targets priority sectors, including manufacturing, logistics, the digital economy, green economy, energy, financial services, healthcare, education, tourism, and business services. Official investment-promotion material highlights special incentives for qualifying activities, including a special corporate tax rate of five per cent for up to fifteen years for eligible companies. While the investment blueprint and master plan have been subject to timing revisions, the policy direction remains focused on attracting regional and global investment by linking Singapore's finance, R&D and connectivity strengths with Johor's land availability, labour base and manufacturing capacity.

https://www.edb.gov.sg

PHILIPPINES

DOE fast-tracks 1,471 MW of renewables to grid

The Philippines Department of Energy announced on 29 March 2026 that it was accelerating the grid entry of about 1,471 MW of committed new power capacity targeted for commercial operation by April 2026. The package covers 22 projects, led by renewable energy and storage: 12 solar projects with around 1,284 MW, six hydroelectric plants adding 48.23 MW, two biomass facilities providing 38 MW, one wind project of 13.56 MW, and a 20 MW integrated renewable energy storage system. The DOE framed the measure as a response to power-supply and fuel-price risks, and as part of the wider implementation of Executive Order No. 110 to secure stable and reliable electricity. At the time of the announcement, 24 generation plants with an aggregate capacity of 1,178.642 MW had already entered commercial operation under the broader fast-tracking programme.

https://doe.gov.ph

REPUBLIC OF KOREA

Ministry prioritises 100 GW renewables and grid

Republic of Korea's Ministry of Climate, Energy and Environment set out its 2026 energy-transition work plan with a focus on deploying 100 GW of renewable energy by 2030 and expanding grid capacity to accommodate it. The ministry reported that 3.8 GW of renewable capacity was deployed in 2025, the largest annual increase since 2022, and that the 2026 budget for renewable-energy deployment and financing had increased from KRW 1.1 trillion to KRW 1.5 trillion. The plan also points to new institutional foundations, including the Special Act on the Expansion of the National Power Grid, the launch of the National Power Grid Committee, and distributed-energy special zones. Key work areas include accelerating renewable deployment, reducing costs, expanding power-grid operations, establishing a power system suited to the energy transition, and strengthening public acceptance of nuclear-energy policy.

https://www.mcee.go.kr

SINGAPORE

National AI Strategy updated; SPEED launched

Singapore updated its National AI Strategy on 20 May 2026, when the Ministry of Digital Development and Information set out 10 refreshed priorities under the National AI Council, chaired by Prime Minister Lawrence Wong. The update focuses on sectoral AI missions in advanced manufacturing, financial services, connectivity and healthcare; wider enterprise and public-sector adoption; workforce readiness; compute access; trusted data governance; and stronger AI assurance. Separately, on 1 April 2026, Singapore launched the S$250 million Singapore Pilots for Energy and Enterprise Decarbonisation programme. SPEED, jointly issued by the Ministry of Trade and Industry, A*STAR, EDB and EMA, supports translational research and the development and demonstration of low-carbon technologies close to

market deployment. Eligible areas include solar, carbon capture and utilisation, electrification, energy efficiency, hydrogen, advanced grid technologies and energy storage.

https://www.edb.gov.sg, https://www.mddi.gov.sg/

SRI LANKA

Battery storage procurement advances

Sri Lanka advanced its largest grid-scale battery energy storage procurement in 2026 after the Cabinet approved the award of tenders for a 160 MW / 640 MWh standalone battery energy storage system programme. The Ceylon Electricity Board's international competitive bidding documents describe the programme as 16 separate 10 MW / 40 MWh projects, connected to 33 kV grid substations, to be developed on a build, own and operate basis with a 15-year operational period. The Ministry of Energy said the systems are intended to provide energy shifting capability and address one of the main challenges in integrating higher levels of daytime solar power into the national grid. Tenders were first invited on 30 July 2025, extended to 14 October 2025, and attracted 153 bids across the 16 designated substations.

https://www.ceb.lk, https://energymin.gov.lk

REGIONAL

ADB commits US$70 billion for power and digital

The Asian Development Bank announced at its 59th Annual Meeting in Samarkand that it would back US$70 billion in new energy and digital infrastructure initiatives by 2035 across Asia and the Pacific. The package combines the Pan-Asia Power Grid Initiative, expected to mobilise US$50 billion for regional power-system connectivity and cross-border renewable electricity trade, with the Asia-Pacific Digital Highway, expected to mobilise US$20 billion for digital corridors, terrestrial and subsea fibre networks, satellite links, regional data centres and cybersecurity risk management. ADB positioned the initiatives as a regional public-infrastructure push, building on existing cooperation frameworks such as the ASEAN Power Grid, the South Asia Subregional Economic Cooperation programme, and the Central Asia Regional Economic Cooperation Energy Strategy 2030. The bank expects the initiatives to expand first-time internet access and improve digital connectivity across the region.

https://www.adb.org

Technology Scan

AUSTRALIA

On-chip valleytronic nanocircuit demonstrated

Researchers at Monash University developed a nanoscale on-chip photonic circuit that can generate, route, and read light-based information within a single integrated device. The work brings together atomically thin materials with engineered metasurfaces to control the "valley" degree of freedom, a quantum property that can be used to encode and process information. Monash describes the device as the first fully integrated valleytronic system able to create special light signals, guide them in precise directions, and convert them into electrical signals on the same chip. The team also demonstrated simultaneous encoding and processing of two images, showing its potential for compact photonic information processing. The advance could support future work in quantum technologies, optical communications, advanced imaging, and energy-efficient light-based computing. The study was published in Nature Photonics and announced by Monash on 25 May 2026.

https://www.monash.edu

CHINA

JUNO reports first precision neutrino result

The Jiangmen Underground Neutrino Observatory, led by the Institute of High Energy Physics of the Chinese Academy of Sciences, published its first physics result in Nature on 10 June 2026. JUNO is a large liquid-scintillator detector located about 700 metres underground in Guangdong Province and designed to address key questions in neutrino physics, including the ordering of neutrino mass states. CAS reported that the collaboration analysed 59 days of valid data collected between 26 August and 2 November 2025 and measured two key neutrino oscillation parameters with uncertainties reduced by a factor of 1.6 compared with combined results from previous experiments. The result is significant because it confirms the detector's early performance and demonstrates that JUNO can deliver high-precision measurements soon after commissioning, strengthening its role in global neutrino research.

https://english.cas.cn

LangYa 2.0 AI model upgrades ocean forecasting

Researchers at the Institute of Oceanology under the Chinese Academy of Sciences released LangYa 2.0, an upgraded artificial intelligence model for marine forecasting, in June 2026. The model builds on LangYa 1.0, which forecasts basic ocean variables such as temperature, salinity, and currents, and extends the system toward more complex marine phenomena. CAS reported that LangYa 2.0 can support the prediction of typhoons, extreme rainfall, storm surges, internal solitary waves, and Arctic sea-ice conditions. The model was unveiled at the Fourth China Digital Earth Conference in Qingdao and is presented as a move from global ocean-state forecasting toward more decision-ready marine services. For offshore engineering, climate research, polar navigation, and coastal-risk management, the innovation is relevant because it combines multi-source observations, physical understanding, and AI reasoning to improve the usability of ocean forecasts.

https://english.cas.cn

JAPAN

Real-time X-ray data compression exceeds 8,000-fold

Researchers led by Takaki Hatsui at the RIKEN SPring-8 Center developed a real-time data-reduction method for high-throughput X-ray imaging experiments. RIKEN reported that the approach reduced X-ray imaging data files by more than 8,000 times while preserving the detailed intensity information

needed for quantitative scientific analysis. The system uses field-programmable gate array hardware to process detector data streams as they are generated, addressing a major bottleneck in synchrotron experiments where modern detectors can produce extremely large volumes of data. The related Journal of Synchrotron Radiation paper reports the use of an 840-kilopixel CITIUS detector operating at 17.4 kilohertz, with an average compression ratio over 8,000 for quasi-elastic gamma-ray scattering experiments. The advance could improve data handling for synchrotron facilities and other high-rate measurement platforms using X-rays or similar probes.

https://www.riken.jp

Theory advances one-way quantum synchronization of phonons

Three theoretical physicists at the RIKEN Center for Quantum Computing proposed a method for realizing nonreciprocal quantum synchronization of phonons, the quantum particles associated with sound and vibration. RIKEN explains that nonreciprocal behavior, where signals or synchronized motion preferentially move in one direction, is important for controlling quantum information and suppressing unwanted feedback. The team, including Franco Nori, Adam Miranowicz, and Deng-Gao Lai, showed that combining two quantum effects in a single system could produce synchronization that remains resilient against fabrication imperfections and environmental noise. The approach could inform future quantum devices that require robust one-way information flow. The findings were published in Nature Communications and announced by RIKEN on 24 April 2026.

https://www.riken.jp

REPUBLIC OF KOREA

PIBOT autonomous aircraft-piloting framework recognised

A KAIST team led by Professor David Hyunchul Shim received the IEEE Robotics and Automation Magazine Best Paper Award for work on PIBOT, a humanoid robot pilot framework. KAIST announced the award on 5 June 2026, noting that the paper was selected from publications appearing in IEEE Robotics and Automation Magazine in 2025. The work proposes an aircraft autonomous-piloting framework that allows a humanoid robot to operate existing cockpit interfaces rather than requiring aircraft to be physically modified. PIBOT is designed to interpret flight procedures, manipulate human-oriented controls, communicate with air traffic control, and respond to emergency conditions through a complete autonomous piloting architecture. This entry is framed as recognition of an advanced robotics framework, rather than as a new 2026 invention, because the underlying paper was published earlier, and the 2026 development was the award announcement.

https://news.kaist.ac.kr

SINGAPORE

Water-stable perovskite nanocrystals developed

Scientists at Nanyang Technological University Singapore developed a type of perovskite nanocrystal that remains bright and stable in water-based environments. Perovskite nanocrystals are valued for strong, tuneable fluorescence, but their sensitivity to water has limited their use in biological and aqueous settings. NTU reported on 8 June 2026 that the new nanocrystals could open pathways for sensing and photonics applications where water exposure is unavoidable. The development is relevant for quantum technologies, bioimaging, and environmental or biological sensing because it addresses a long-standing materials-stability barrier while preserving useful optical behaviour. Rather than claiming immediate commercial deployment, the entry should be read as laboratory materials advances that expand the possible operating environment for perovskite-based devices. Its importance lies in moving these bright nanomaterials closer to practical use in water-rich and biological systems.

https://www.ntu.edu.sg

Janus photocatalyst improves hydrogen production

Researchers at Nanyang Technological University Singapore designed a Janus photocatalyst that improves hydrogen generation from water under light-driven conditions. NTU reported the advance on 8 June 2026, describing a “two-faced” catalyst with a nitrogen-rich rough side and a carbon-rich smooth side made from ultrathin nanosheets. The different surfaces help move light-generated charges more effectively, which is a critical process for splitting water to produce hydrogen. NTU states that the catalyst demonstrated hydrogen generation around five to fourteen times higher than conventional photocatalysts. The finding was linked to research published in Materials Horizons and featured in NTU’s research and innovation magazine. For a technology scan, the entry is best framed as a materials-design advance for photocatalytic hydrogen production, not as a deployed green-hydrogen system. Its value is in showing how asymmetric nanoscale structures can improve solar-fuel performance.

https://www.ntu.edu.sg

EUROPE

DENMARK

Hydrogen radicals identified as key to PFAS breakdown

Researchers at Aarhus University identified hydrogen radicals as a key driver in the breakdown of per- and polyfluoroalkyl substances under intense ultraviolet light. PFAS are difficult to destroy because of their strong carbon-fluorine bonds, and many treatment methods only separate them from water rather than degrading them. Aarhus reported that hydrogen radicals, formed directly from water under high-energy UV light, play a central role in attacking PFAS molecules and driving decomposition without added chemical reagents. The study also indicates that the process is most effective at wavelengths below 300 nanometres. The finding matters because it clarifies the mechanism behind PFAS photolysis and can guide the design of more effective chemical-free treatment systems. The research was published in Environmental Science & Technology and announced by Aarhus University on 4 May 2026.

https://bce.au.dk

SWITZERLAND

Ultrafast femtosecond laser built on photonic chip

Researchers at the École Polytechnique Fédérale de Lausanne developed a chip-scale ultrafast laser that brings femtosecond-pulse performance closer to integrated photonics. EPFL announced the advance in June 2026, describing it as an important step toward shrinking lasers that have traditionally required bulky and expensive tabletop systems. The team, led by Professor Tobias J. Kippenberg, used a Mamyshev oscillator design with a nonlinear waveguide and optical filters to generate strong ultrashort pulses on a compact chip. EPFL reported pulses as short as 147 femtoseconds and energies of 1.05 nanojoules, giving the device kilowatt-level peak powers. Ultrafast lasers are used in precision micromachining, eye surgery, and optical frequency combs for advanced timing and measurement. Chip-scale integration could make such capabilities more portable and affordable for diagnostics, sensing, communications, navigation, and research instruments.

https://actu.epfl.ch

NORTH AMERICA

UNITED STATES OF AMERICA

Artemis II validates crewed deep-space systems

NASA’s Artemis II mission launched on 1 April 2026 and splashed down on 10 April 2026, marking the first crewed Artemis lunar flyby and the first human mission around the Moon in more than half

a century. For this technology scan, the entry is best framed as a systems-demonstration milestone rather than a standalone invention. NASA states that the mission tested the Orion spacecraft with crew aboard and advanced the deep-space systems needed for later lunar and Mars missions. The crew included NASA astronauts Reid Wiseman, Victor Glover, and Christina Koch, and Canadian Space Agency astronaut Jeremy Hansen. Artemis II also supported science and health investigations related to human spaceflight, including studies of radiation and microgravity effects. The mission demonstrated integrated performance across launch, spacecraft operations, crew support, lunar flyby, and Earth return.

https://www.nasa.gov

Single propellant enables dual-mode CubeSat propulsion

Engineers at the Massachusetts Institute of Technology demonstrated that one green propellant, ASCENT, can power both chemical and electrospray electric thrusters in a compact dual-mode propulsion architecture for small satellites. Chemical thrusters provide short, high-thrust maneuvers, while electrospray thrusters provide efficient low-thrust propulsion over longer periods. Small spacecraft have usually needed separate fuel systems to combine these capabilities, increasing mass and complexity. MIT reported on 1 June 2026 that ASCENT's properties allow both modes to draw from a single shared tank, which could expand the missions possible for briefcase-sized CubeSats. The team is working with NASA on the Green Propulsion Dual Mode mission, intended to test a chemical thruster and four electrospray thrusters in orbit. The advance is important because it could make small satellites more maneuverable without sacrificing fuel efficiency.

https://news.mit.edu

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Innovative Financing Models for Emerging Technologies

The Evolving Landscape of Innovative Financing Instruments for New Technologies

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Abstract

Innovative financing tools and models have proved their efficiency in supporting the adoption and scale-up of emerging technologies. They have been instrumental in different regions, including the Asia-Pacific region, which stands at the forefront of technological innovation. Studies point to several persistent emerging technological constraints that include high upfront capital costs, perceived risks, and limited access to finance, all of which disproportionately hinder small and medium-sized enterprises (SMEs), start-ups, women-led enterprises, and grassroots innovators from translating promising technologies into tangible solutions. This article examines the evolving landscape of innovative financing instruments that can mobilise both public and private capital for emerging technologies across the region to overcome these barriers.

Drawing on recent developments and regional case studies, the analysis explores a diverse portfolio of financing mechanisms, like GSS+ (Green, Social, Sustainability and Sustainability-linked) bonds, Islamic finance, blended finance structures, public-private partnerships (PPPs), climate and innovation funds, venture capital, results-based financing, and carbon market instruments. By synthesising emerging best practices from across the Asia-Pacific, this article offers actionable insights for policymakers, financial institutions, development partners, and technology innovators seeking to bridge the financing gap and accelerate the region's transition toward a sustainable, technology-driven future.

Keywords: innovative financing, emerging technologies, Asia-Pacific, green bonds, blended finance, SMEs, climate finance, technology transfer

1. Introduction

The Asia-Pacific region has emerged as a global powerhouse of technological innovation. From artificial intelligence (AI) and biotechnology to renewable energy and advanced manufacturing, the region's economies are at the forefront of developing and deploying emerging technologies that promise to address pressing societal challenges, from climate change to healthcare access. Yet, despite this dynamism, there exist certain financing constraints that hinder the translation of promising innovations into tangible, scalable solutions (StemgenicGlobal, 2025).

This financing gap is not merely a matter of insufficient capital. Rather, it reflects a structural mismatch between the characteristics of emerging technologies: high upfront costs, long development timelines, uncertain returns, and perceived risks, and the risk-return profiles of traditional financing sources (International Finance Corporation, 2025). Commercial banks, conservative by nature, are often reluctant to lend to technology start-ups lacking collateral or operating histories. Venture capital, while vital for high-growth ventures, tends to concentrate in a few established innovation hubs and sectors, leaving many promising technologies and regions underserved.

The consequences of this gap are profound and unevenly distributed. Micro, small and medium-sized enterprises (MSMEs), which constitute over 90% of businesses in the region and employ nearly 68% of the workforce (ADB, 2025), are disproportionately affected. Women-led enterprises and MSMEs in rural, geographically remote and post-conflict areas face structural barriers, including limited access to collateral, networks, and financial literacy (United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), 2026). Grassroots innovators, often operating outside formal innovation systems, remain largely invisible to institutional financiers. As the Asia-Pacific region seeks to harness technology for sustainable development, closing this financing gap has become an urgent policy priority.

This article provides an overview of innovative financing models that have demonstrated efficacy in supporting emerging technologies across the Asia-Pacific region and in some countries outside the region. Previous literature on the topic has been scarce, with several studies that touch upon individual financial tools or country cases. To fill this gap, this contribution draws on recent developments, case studies, business media, and analytical reports on technology finance. The analysis covers a diverse portfolio of instruments, from green and sustainability-linked bonds to blended finance structures, results-based financing, and carbon market mechanisms. It also examines the enabling conditions, such as policy frameworks, institutional capacities, and regional cooperation mechanisms that determine the effectiveness of these instruments.

2. The Financing Landscape for Emerging Technologies in the Asia-Pacific

The financing needs for emerging technologies in the Asia-Pacific are immense and growing. The International Energy Agency (IEA) estimates that annual clean energy investment in emerging and developing economies must increase by more than seven times by 2030 to meet the climate goals (IEA, 2021). The Asian Development Bank (ADB) projects that infrastructure investment needs in the region will exceed US$1.7 trillion annually through 2030, much of it for technology-intensive projects. Yet current financing flows fall far short of these needs (ADB, 2023).

2.1 Barriers to deploying innovative financing tools

The gap is particularly acute for early-stage and growth-stage technology ventures. Geopolitical instability brings high financing costs, disrupted supply chains, and policy shifts, making large-scale, long-term projects harder to execute. However, in the Asia-Pacific region, this instability is accelerating a strategic pivot: long-term climate investment continues but is redirected toward traditional sectors and solutions that bring resilience: domestic energy security, industrial resilience, and self-sufficiency. International capital is expected to align with local policy priorities and does not enjoy the cross-border openness that was typical for international markets in the previous years. Across the Asia-Pacific region – from China's national funds to India's incentives, Indonesia's resource nationalism, and Japan's partnerships – investors align with local frameworks to access strategic sectors. This approach ensures compliance but introduces trade-offs like reduced liquidity, governance constraints, and exit limitations (Cleantech Group, 2026).

Several interconnected barriers explain this financing gap (Figure 1). First, information asymmetries are pronounced in emerging technology sectors. Investors often lack the technical expertise to evaluate the potential of novel technologies, leading to underinvestment. Second, risk perceptions are elevated; emerging technologies face technological, market, regulatory, and execution risks that are difficult to price. Third, collateral constraints are binding; technology start-ups, particularly those with intangible assets, such as intellectual property, are often unable to provide the physical collateral required by traditional lenders. Fourth, market fragmentation across the region creates additional barriers. Divergent regulatory frameworks, currency risks, and limited cross-border investment programs constrain capital flows to promising technology ventures operating in several jurisdictions. Fifth, capacity constraints at the level of MSMEs and start-ups, such as limited financial management skills, weak governance structures, and a lack of investor readiness, further impede access to finance (StemgenicGlobal, 2025).

Addressing these barriers requires not only supportive public policies but also innovation in financing. Traditional financing instruments, designed for established firms with predictable cash flows and tangible assets, are not suitable for emerging technology ventures. Innovative financing models seek to

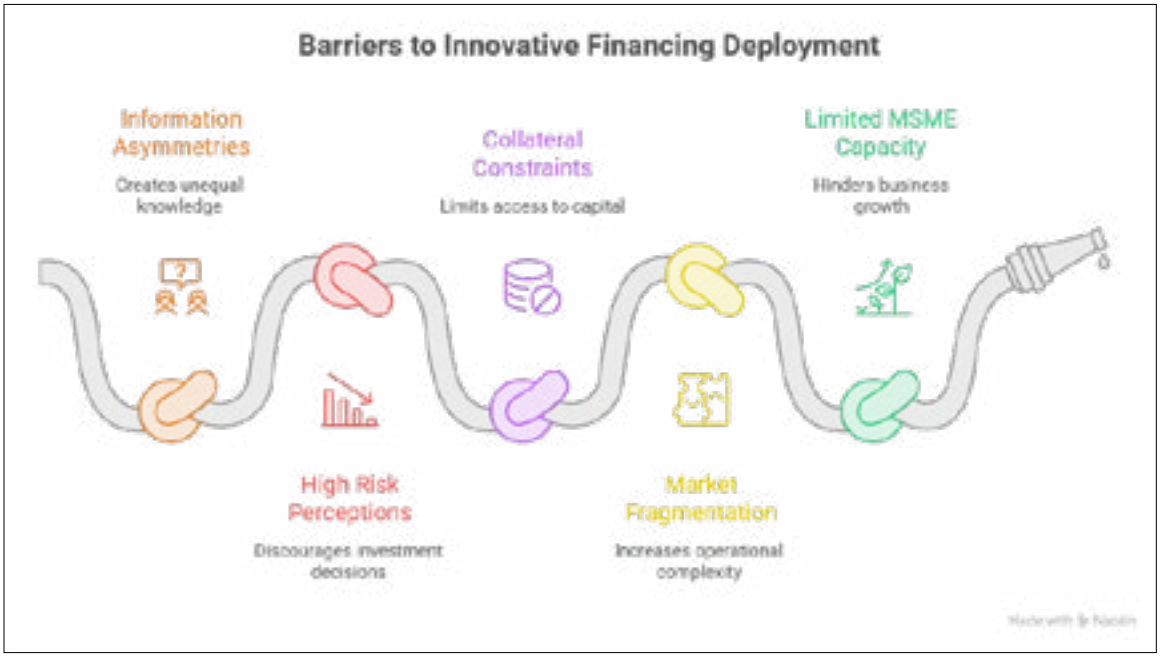

Figure 1: Barriers to emerging technologies financing in the Asia-Pacific region

(Source: Author)

address this mismatch by reallocating risks, mobilising new sources of capital, and aligning incentives among diverse stakeholders. Table 1 summarises innovative financing mechanisms applied by some of the global innovation leaders – Israel, Germany, Finland, Saudi Arabia, the United Kingdom (UK), and the United States of America (USA). Each of the countries offers its approach (model), dominated by the private sector, public-private partnerships, or national budget earmarked funds.

Israel's model is focused on using public funds to crowd in private investment. The cornerstone is the Yozma program established in 1993, where the government co-invested with private and foreign venture capital (VC) funds. The key innovation was that successful ventures could buy back the government's stake at a discount, ensuring profits flowed to private partners. This strategy, supported by R&D grants and incubators, created a self-sustaining VC ecosystem.

Germany focused on overcoming the "valley of death" where proven technologies struggle to reach industrial scale. Through its development bank, KfW, and funds like the DeepTech & Climate Fonds, the government provides long-term, low-interest loans and venture debt. This patient capital is crucial for capital-intensive sectors like advanced manufacturing and green hydrogen, forming the core of Europe's strategy for technological sovereignty.

Business Finland offers an integrated approach following the "one-stop shop" model that combines R&D funding with export credits. For a small, open economy, the program aims to establish national champions that are globally competitive from the beginning. Its approach of linking technical development with global expansion has proven highly effective in helping start-ups scale up and enter international markets.

Under Vision 2030, Saudi Arabia has become a leading VC market by leveraging its sovereign Public Investment Fund (PIF). It manages a sizeable national capital (over US$910 billion in 2025) that reassures the market and attracts international players, even during turbulence in the global markets. According to its long-term strategy, the country aims at economic diversification, and the fund primarily focuses on driving this transformation while expanding its international footprint.

The UK and the USA rely primarily on the private sector for innovation, with the government playing a catalytic role in high-risk areas. The USA has the world's deepest VC market and has established mission-oriented agencies, like ARPA-E, to fund emerging energy technologies that private investors tend to avoid. The UK combines a strong private market with government support for breakthrough research through the R&D funding agency ARIA and Catapult centres to commercialise it. The British International Investment (BII) also uses "flexible debt" in emerging markets to de-risk climate tech projects.

Table 1. Innovative models and mechanisms to support emerging technologies

Country	Primary Model	Key Mechanisms	Focus Areas
Israel	Public-Private Partnership	"Yozma" program (government matching funds with exit options), early-stage incubators, Law on Research and Development (reimbursable funds)	General Deep Tech, software, life sciences, cybersecurity
Germany	National Strategic Funds	"DeepTech & Climate Fonds" (DTCF), Kreditanstalt für Wiederaufbau (KfW) Bank (low-interest, long-term loans), "WIN Initiative"/ "Deutschlandfonds"	Deep Tech, climate tech, industrial scale-up, AI, quantum, semiconductors
Finland	Integrated Innovation & Export model	Business Finland (combines R&D funding and export promotion), global growth accelerators	Climate Tech, digitalisation (5G, IoT), industrial innovation
Saudi Arabia	Sovereign-led VC model	Public Investment Fund (PIF), Saudi Venture Capital (SVC), large-scale sovereign "backstop" funding	Fintech, E-commerce, AI infrastructure, cybersecurity
United Kingdom	Private-sector-driven model	Advanced Research + Invention Agency (ARIA) (high-risk tech research), Catapult centres (commercialisation), Living Labs, development finance (via British International Investment)	Climate Tech, advanced manufacturing, life sciences
United States	Private-sector-driven model	Advanced Research Projects Agency-Energy (ARPA-E) (high-risk energy tech), Energy Program for Innovation Clusters (EPIC), dominant private VC market	AI, biotech, semiconductors, energy, space, defense

Source: Compiled by the author based on (KfW, 2025; ARPA-E, 2026; ARIA, 2026; BusinessFinland, 2026; DTCF, 2026; EPIC, 2026; Innovate UK, 2026; PIF, 2026; SVC, 2026; Yozma, 2026).

These models continue evolving to tackle existing and new challenges. Flexible debt and venture debt go beyond standard loans. Instruments with grace periods, local currency terms, and revenue-based repayments are emerging, pioneered by development finance institutions like the UK's BII. This aligns financing with the actual cash flow of capital-intensive ventures. Securitisation of certain technology areas of critical importance is assured through direct public investment: countries are making direct, large-scale "bets" on critical sectors like AI, quantum computing, and biotech to ensure they retain sovereign control and keep pace with the global leaders. For example, the £500 million Sovereign AI Fund was launched in the UK to support homegrown AI companies with capital, compute, and government procurement, while retaining intellectual property domestically (UK Government, 2026).

There is no single best model for funding emerging technologies and no one size fits all. Each country's approach reflects its national priorities, financial capabilities, and features of its national innovation ecosystem. Israel perfected a public co-investment to launch a private VC industry. Germany provides patient, large-scale capital for deep tech to industrialise. Finland established an entire value chain, linking R&D with export support. Saudi Arabia uses sovereign wealth as a powerful catalyst. The USA and the UK rely on a dynamic private market, while the targeted public funds are only used for high-risk areas. Additionally, different types of financing mechanisms target specific types of innovations: experimental, sustaining, efficiency-improving, and market-creating technologies (Hyung, 2018).

The remainder of this article examines specific innovative financing instruments and models that have gained traction in the Asia-Pacific region, drawing on evidence of their effectiveness and identifying conditions for success.

2.2. The variety of funding tools available in the Asia-Pacific

GSS+ bonds, blended finance, venture capital, private credit, results-based financing, carbon market instruments, and Islamic finance tools are all suitable instruments for supporting emerging technologies. While these mechanisms have already been implemented individually in certain countries, it is important to examine how they can be combined within the Asia-Pacific context to achieve maximum impact.

GSS+ Bonds: Scaling Capital for Green and Social Technologies

The first green, social, sustainability and sustainability-linked bonds (collectively known as GSS+ bonds) were issued by the European Investment Bank and the World Bank in 2007–2008. However, it was not until the entry of sovereign issuers (such as Poland and France) in late 2017 that GSS+ bonds began to emerge as a major source of financing for technologies with high environmental, climate and social significance (OECD, 2023). Japan, Republic of Korea, Hong Kong, and Australia together account for more than two-thirds of GSS+ instruments in the Asia-Pacific. Global GSS+ bond issuance reached record levels in 2024-2025, with the Asia-Pacific region showing particular dynamism. The region comes second (after Europe with US$430 billion) with slightly above US$110 billion from 383 bonds. The Asia-Pacific accounts for about 60% of the total bonds and 55% of the total volume of bonds contributed by low and middle-income issuers (Cadlas, 2026). In 2022, there was a decline in bond issuances due to geopolitical turbulence, market volatility and the rising interest rate. However, the market has quickly recovered in 2023, and the increasing trend was restored (London Stock Exchange Group (LSEG), 2023).

The growth of sustainable bond markets in Asia reflects both supply-side and demand-side factors. On the supply side, governments and development finance institutions have promoted GSS+ bonds as suitable tools for financing technology-intensive infrastructure and climate projects. On the demand side, institutional investors, including pension funds and insurance companies, have increasingly integrated environmental, social, and governance (ESG) criteria into their investment decisions. Although GSS+ bonds have become a significant part of sustainable finance in the Asia-Pacific, difficulties persist regarding transparency, credibility, pricing, and sustained impact (Moeljono & Maeda, 2025).

Green bonds remain the largest (around 64% in 2025) segment of the GSS+ market (Climate Bonds Initiative, 2026), with proceeds specifically allocated to projects with positive environmental and climate impacts. In the Asia-Pacific region, green bonds have financed a wide range of climate technologies, including renewable energy installations, energy efficiency retrofits, sustainable transport, and water management systems. Studies show that investors in the region can accept lower returns when funding environmentally sustainable assets – a trend not observed in Europe. The Asia-Pacific green bonds carry lower volatility and risk compared with conventional bonds. Additionally, financing costs for these bonds decrease when issued by financial institutions with investment-grade ratings in local currencies and with external certification (Wongaree et al., 2025).

A notable development is the emergence of **transition bonds**, a hybrid instrument that finances decarbonisation efforts in hard-to-abate sectors. Transition bonds are particularly relevant for the Asia-Pacific region, where fossil fuel-dependent industries are seeking to decarbonise while maintaining economic viability. Therefore, the region has evolved to be the largest global market for transition finance, as fast-growing economies face rapid industrial growth with simultaneous demand for net-zero emission targets (The Banker, 2023).

Over the past years, there has been a remarkable growth of **social and sustainability bonds**, whose cumulative volumes grew from zero to 14% and 17%, respectively (LSEG, 2023). These bonds can, at the same time, address social challenges and aim at long-lasting effects. Social bonds, which finance projects addressing social issues, have also gained traction in the region. In Japan, expressway companies have issued social bonds to finance projects related to regional revitalisation, disaster countermeasures, and traffic safety (Nippon Expressway Company (NEXCO), 2024). Sustainability bonds, which combine green and social objectives, are increasingly used to finance technology projects that deliver both environmental and social benefits.

Sustainability-linked bonds (SLBs) differ from use-of-proceeds bonds in that the issuer commits to achieving predefined sustainability performance targets (SPTs). Failure to meet these targets results

in a penalty, typically an increase in the bond's coupon rate. SLBs have faced some investor resistance due to concerns about target rigor and the risk of greenwashing. However, they remain an important instrument for financing the transition of carbon-intensive industries. These bonds were first issued in the Asia-Pacific in late 2020 and, since then, have held around 3% of market share (LSEG, 2023).

The Association of Southeast Asian Nations (ASEAN) Capital Markets Forum (ACMF) has played a catalytic role in developing regional standards for GSS+ bonds. The ASEAN Green Bond Standards (ACMF, 2019a), Social Bond Standards (ACMF, 2019b), and Sustainability Bond Standards (ACMF, 2019c) provide a common framework for issuers across the region, reducing fragmentation and enhancing investor confidence. Brunei Darussalam, Cambodia, Lao PDR, Malaysia, Philippines, Singapore, Thailand and Viet Nam, for example, have adopted these standards, requiring that ASEAN GSS+ bonds comply with ACMF requirements (ACMF, 2018).

Blended Finance: De-risking Technology Investment

Blended finance is the strategic use of catalytic public or philanthropic capital to mobilise private investment. It has emerged as a powerful tool for financing emerging technologies in the Asia-Pacific. By absorbing early losses, providing guarantees, or offering concessional terms, blended finance structures reduce the risk-adjusted return thresholds for private investors, enabling them to invest in technologies and markets they would otherwise avoid (United Nations Educational, Scientific and Cultural Organisation (UNESCO), 2025).

The rationale for blended finance is particularly compelling in the context of emerging technologies. Many climate and social technologies are capital-intensive, have long payback periods, and face regulatory and market uncertainties. Private investors, seeking market-rate returns with acceptable risk, are often unwilling to bear these risks alone. Blended finance bridges this gap by aligning the risk-return profiles of different investor classes. For example, Asia Climate Solutions Design Grants support blended finance solutions targeting clean energy transition and the blue economy across South and Southeast Asia (Convergence, 2026).

Several blended finance structures have been deployed in the Asia-Pacific. First-loss guarantees, where a development finance institution or philanthropic organisation agrees to absorb initial losses, have been used to mobilise private capital for renewable energy and energy efficiency projects (UNESCO, 2025). Mezzanine funds, which occupy the risk-return space between senior debt and equity, have financed technology scale-ups in sectors such as agritech and cleantech (Li & Ban, 2025).

Co-investment vehicles, where public and private investors invest alongside each other, have been used to finance technology infrastructure projects. For instance, the World Bank Group and regional multilateral development banks, at the request of the G8 and G20 nations, have established the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF), which focus on low-carbon technologies and promote climate-resilient solutions in 25 Asia-Pacific developing countries since 2009. Among the CTF-supported programs are the Scaling-Up Renewable Energy in Low-Income Countries Program and Industry Decarbonisation Program, along with many others that provide ample space for emerging technologies (ADB, 2026).

Vietnam offers a compelling case study of blended finance in action. Between 2015 and 2023, 49 climate tech start-ups in Vietnam secured US$92.6 million in cumulative financing, with funding increasing 365% year-on-year from 2021 to 2023 (New Energy Nexus, 2024). This growth has been supported by a combination of venture capital, development finance, and blended structures. This funding has been instrumental in empowering climate tech founders in Vietnam to scale commercially, achieve investment readiness, and successfully secure both domestic and global venture capital funding.

In 2025, Alternō, a climate-tech start-up founded in 2023, presented its novel sustainable heat technology aimed at eliminating 100 million tonnes of CO_2 emissions annually by 2030. The start-up has closed its Series A round led by UntroD Capital Asia, with participation from ADB Ventures. The capital is accelerating manufacturing capacity and supporting R&D for advanced electricity storage solutions. Solar cleantech provider Stride secured Series A funding from United Overseas Bank (UOB) Venture Management, Clime Capital, and Touchstone Partners, enabling it to scale rooftop solar adoption through technology-driven customer experiences and innovative financing models (PR Newswire, 2025).

Venture Capital and Private Credit: Tailored Solutions for High-Growth Firms

Venture capital (VC) remains the primary source of equity financing for high-growth technology start-ups. In the Asia-Pacific, VC investment has grown substantially, with climate tech and deep tech emerging as prominent segments. However, the geography of VC investment remains uneven, concentrated in established innovation hubs, such as Beijing, Shanghai, Singapore, Bangalore, and Sydney. VC investment in climate tech has been particularly robust. The Asia-Pacific cleantech landscape is at an inflection point, with private capital increasingly asked to play a dual role: deliver near-term commercial returns and seed the structural ecosystem changes that underpin long-term value (Vandenberg et al., 2020).

While VC serves early-stage, high-growth ventures, a substantial financing gap persists for more mature MSMEs that have outgrown microfinance but remain underserved by commercial banks. This "missing middle" is particularly acute in ASEAN, where MSMEs account for the bulk of private-sector employment but often lack the collateral and formal financial records required for bank lending (GenCap, 2025).

Private credit is a bespoke form of lending outside traditional banking, as it offers a complementary solution. Unlike algorithmic lending, private credit allows for tailored structures that align with cash flows, sector dynamics, and business cycles. In ASEAN, however, private credit remains nascent. Beacon Fund, a private debt fund focused on Vietnam, illustrates the potential: a renewable energy company in its portfolio, despite stable cash flows and long-term contracts, struggled to secure bank financing due to rigid collateral requirements. A customised private credit structure bridged the gap (Beacon Fund, 2024; Vietnam Investment Review, 2024).

Digital finance has expanded access to capital for smaller technology ventures. Fintechs, digital wallets, and embedded finance platforms use real-time transaction data to assess creditworthiness, reducing friction and enabling faster loan disbursement. Initiatives such as Mastercard Strive, which supports digital and financial inclusion across ASEAN, demonstrate the potential of these tools to reach underserved SMEs, particularly women-led and informal businesses (World Economic Forum (WEF), 2025). However, digital access alone is insufficient. Many MSMEs, particularly in manufacturing, education, and healthcare, lack continuous digital records and remain invisible to algorithmic lenders. A connected financing ecosystem combining digital innovation, traditional banking, and alternative credit is needed to serve the full spectrum of SME financing needs (Chibueze, 2021).

Results-Based Financing: Focusing on Market Delivery

Results-based financing (RBF) ties disbursements to the achievement of predefined, independently verified milestones, aligning incentives and improving accountability. In the technology context, RBF has been used to finance innovation in sectors such as healthcare, education, and clean energy. This shifts performance risk to the private sector, de-risks investments, and attracts commercial capital to capital-intensive innovation. The ImpactCollab Outcomes Marketplace, launched at the Asian Venture Philanthropy Network (AVPN) Global Conference 2025 in Hong Kong, aims to shift funding in Asia from activities to verified outcomes (ImpactCollab, 2025). The platform ties its funding to impactful results in order to incentivise performance, transparency, and competition among service providers, including technology innovators (Li, 2025).

Carbon Market Instruments: Critical Supplementary Revenue for Climate Technologies

Carbon market instruments, such as carbon credits, represent a growing source of financing for climate technologies. A carbon credit represents one tonne of carbon dioxide or its equivalent that is either avoided or removed from the atmosphere. Projects that generate credits range from reforestation and renewable energy to direct air capture and can sell credits to corporates seeking to offset emissions (The World Bank, 2025). In Asia, Hong Kong Exchanges and Clearing's (HKEX) Core Climate platform, launched in 2022, provides a transparent, integrated carbon marketplace for trading and settling carbon credits. The platform reduces counterparty risk and improves transaction efficiency, supporting the development of voluntary carbon markets in the region (HKEX, 2022; Mayer Brown, 2022; Climate Finance Asia, 2025).

For technology innovators, carbon credits can provide an additional revenue stream, improve project economics, and attract investment. However, this market is becoming increasingly competitive, and integrity remains a key advantage. To address this concern, the Integrity Council for the Voluntary Carbon Market's Core Carbon Principles provides a framework for assessing credit quality, ensuring

that credits represent genuine, additional, and verifiable emission reductions (Morgan Stanley Capital International, 2023; The Integrity Council, 2026).

Islamic Finance: Shari'ah-compliant Instruments for Digital and Sustainable Technologies

Islamic finance, a rapidly growing segment of the global financial system, offers another avenue for financing emerging technologies in the Asia-Pacific. Islamic finance principles, which prohibit interest (riba), speculation (gharar), and investment in prohibited activities (haram), align closely with the values underpinning sustainable development. By 2026, Islamic finance assets have reached US$4.93 trillion, of which Islamic fintech constitutes US$179 billion. The novel digital technologies, including AI, blockchain, and big data analytics, can benefit from investments at lower cost through Shari'ah-compliant finance tools (financial products and services structured to operate according to Islamic law – Shari'ah). For example, blockchain-based smart sukuk can be provided within days, lowering costs up to 33% and increasing fund accessibility. Smart waqf models require less paperwork and provide access to charitable funding that may be used for social investment. Some countries in the Asia-Pacific, like Saudi Arabia, have already emerged as global leaders in the Islamic finance market and are driving fintech innovation (Sidra Capital, 2026).

Sukuk (Islamic bonds) have been used to finance infrastructure and technology projects across the region. Malaysia, Indonesia, and Brunei Darussalam have developed robust Islamic finance ecosystems, with regulatory frameworks that accommodate GSS+ sukuk. The Brunei Darussalam Central Bank, for example, permits the issuance of sukuk designated as ASEAN GSS+ bonds, provided they comply with ACMF standards (ACMF, 2022). Islamic finance can mobilise capital from faith-based investors who might otherwise be excluded from technology financing.

3. Enabling Regulatory Frameworks and Policy Recommendations

Government policies play a critical role in creating and enabling conditions for innovative technology finance. The main government actions include the correct identification and application of a range of policy tools:

- Tax incentives for investments in emerging technologies, such as accelerated depreciation, investment tax credits, and reduced capital gains taxes.
- Credit enhancement mechanisms, including loan guarantees, first-loss provisions, and co-investment funds, that reduce private investor risk.
- Regulatory sandboxes that allow technology innovators to test new products and business models without being subject to full regulatory requirements.
- Public procurement of innovative technologies, creating demand and reducing market uncertainty.

Based on these findings, several recommendations for policymakers may be drawn. First, it is essential to develop national technology finance strategies that map financing needs across technology lifecycles and identify specific instruments to address gaps. In addition, efforts should be made to establish or strengthen enabling frameworks for GSS+ bonds, including alignment with ASEAN and international standards. Public, philanthropic, or private funds alone cannot address all challenges: blended finance is the best approach to target priority technology sectors.

Second, unequal access to finance could exclude certain inventors and their prospective technologies from the market. The solution would be to promote digital financial inclusion to expand access to finance for smaller technology ventures, including women-led and informal enterprises. Regular information campaigns also work well to keep technology innovators in the loop on existing opportunities.

Third, some technologies are economically viable only with economies of scale. In many instances, domestic demand is not sufficient for fast-growing technology firms, while the fragmentation of financial markets across the Asia-Pacific constrains cross-border technology finance. Supporting regional cooperation to reduce market fragmentation and facilitate cross-border technology finance is a way to support gazelles and unicorn companies. The ASEAN Capital Markets Forum has developed mutual

recognition arrangements for bond offerings, including GSS+ bonds, reducing the cost and complexity of cross-border issuance. The ASEAN+3 Bond Market Forum has promoted harmonisation of bond market regulations across the region.

In addition to policy recommendations, several suggestions can be made for financial institutions and investors. For financial institutions specialists, it is necessary to build technical capacity to evaluate emerging technology investments, including developing sector-specific expertise. Further, investors seeking to support non-mainstream innovations need to develop innovative financing products tailored to technology MSMEs, including revenue-based financing, royalty financing, and intellectual property-backed lending. Additionally, financial specialists must integrate impact measurement into investment processes, using standardised frameworks and third-party verification. This will lower the investment risks and streamline the process, making it transparent for technology innovators.

Technology innovators, in turn, are advised to improve investor readiness by strengthening financial management, governance, and impact measurement capabilities. They can explore diverse financing sources, including GSS+ bonds, blended finance, and carbon markets, alongside traditional venture capital and bank lending.

4. Conclusion

This analysis has examined the landscape of innovative financing models for emerging technologies in the Asia-Pacific. Several key findings emerged. First, no single model suffices. The diversity of emerging technologies that range from AI to biotech to clean energy requires a portfolio of financing instruments tailored to different technology stages, sectors, and risk profiles. GSS+ bonds suit capital-intensive, de-risked technologies; venture capital suits high-growth start-ups; private credit suits established SMEs; and blended finance suits early-stage, high-impact innovations.

Second, context matters. The effectiveness of financing models depends on enabling conditions: robust legal and regulatory frameworks, institutional capacity, market infrastructure, and investor readiness. What works in Singapore may not work in Myanmar; what works for renewable energy may not work for biotechnology.

Third, cooperation is essential. The fragmentation of financial markets across the Asia-Pacific is a major constraint on technology finance. Regional cooperation, including harmonising standards, mutual recognition arrangements, and cross-border investment vehicles, can unlock significant capital flows.

Fourth, impact measurement matters. As sustainable finance grows, so does the risk of greenwashing. Robust, transparent, and verifiable impact measurement frameworks are essential to maintaining investor confidence and ensuring that financing achieves genuine environmental and social outcomes.

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Financing Emerging Green Technologies in Asia and the Pacific: Optimising the Use of Public Capital

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Abstract

Certain emerging technologies, particularly green technologies, can create public goods. However, the pace of green technology adoption is much slower than desired. One of the key barriers to the rapid adoption of these technologies is the limited availability and higher cost of capital, particularly in the Asia-Pacific region, where capital is scarce. The crux is to create financial models and instruments that meet the funding needs of technology adopters and the investment objectives of financiers. In economic history, financial innovations have solved this challenge, supporting not only corporations in raising capital for their business expansion but also enabling consumers to buy necessary goods and services and the government to finance public expenditure. The article offers insights into how to make public capital more catalytic in financing the adoption of emerging technologies, particularly green technologies, in the Asia-Pacific.

Introduction

It is imperative for the Asia-Pacific region to accelerate the adoption of modern and emerging technologies to enhance economic competitiveness and accelerate growth. Certain emerging technologies, particularly green technologies, not only support economic growth but also create public goods that benefit the buyers and sellers of these technologies. For example, shifting from combustion vehicles to renewable energy-powered three-wheeled EVs (Electric Vehicles) can not only offer financial benefits to the buyers and sellers, but also help reduce greenhouse gas emissions, noise and air pollution. Similarly, shifting from diesel-powered generators to hybrid renewable energy (e.g., solar plus battery) for electricity offers similar benefits. The adoption of green technologies also supports countries' climate mitigation and adaptation plans. However, the adoption of green technologies is accelerating (at a less-than-desired pace), which is absolutely necessary to mitigate and adapt to climate change. According to the International Energy Agency, global renewable energy capacity must reach 11 TW by 2030, but the agency estimates it will be 9.5 TW (IEA, 2025). Similarly, India needs to add ~45 GW of renewable energy capacity per year over FY2025 to FY2030, yet the average annual addition was between 20 GW and 30 GW in FY2025 – far lower than the requirement (IISD, 2026). Although the adoption of green technologies is slower than desired in most countries, it is even slower in many Asia-Pacific countries. The former has the structural, institutional, and financial prowess to drive green adoption when backed by political will and social acceptance, whereas the latter region lacks these capacities and finds it challenging to adopt these technologies even when there is political will. The limited availability and higher cost of capital make it challenging for most of the Asia-Pacific region, where capital is scarce. Since several green technologies are not fully commercialized or are in the early adoption stage, they need public capital support; otherwise, their adoption will not grow at the desired pace. For example, green hydrogen and long-duration battery energy storage systems are still not commercially viable (Selänniemi et al., 2025; Anisha et al., 2026), so they would need public finance support until full commercialization. However, several countries in the region lack the fiscal muscle to deploy large amounts of public capital to accelerate the adoption of green technologies.

The rapid adoption of green technologies needs both non-financial and financial policy interventions. While the former addresses challenges related to market failure, the latter concerns providing market incentives to adopt green technologies. The essence of financial policies is to design financial mechanisms and models that incentivize suppliers and users of green technologies, as well as capital providers.

Financial innovation enabled corporations to raise capital for business expansion but also allowed households and business consumers to buy technologies and services that were not previously possible (Laeven et al., 2015). A vast capital requirement to construct a massive railway network in the 19th and 20th centuries led to the development of specialized financial intermediaries and accounting systems to raise capital from investors far away from the real assets (Baskin and Miranti, 2010). Modern venture capital funds were established to screen and provide capital to early-stage information technology companies (Laeven et al., 2015). Similarly, the government also used innovative financial mechanisms to meet public expenditure. This article examines a range of innovative financial models and instruments that can be deployed in Asia-Pacific to mobilize capital for the rapid adoption of green technologies. It offers insights on how to make public capital more catalytic in financing the adoption of emerging technologies, particularly green technologies, in the Asia-Pacific.

Blended Finance

Blended financing addresses market failure by allocating public and private capital to create public goods, ensuring no consumers are left out of essential goods (International Development Club, 2019). It financially incentivizes businesses to generate positive externalities, thereby making them profitable while supporting policy objectives, such as reducing carbon emissions. Blended financing always aims to leverage public capital as much as possible to attract private capital (IFC, 2018). Mustapha et al. (2014) define blending as the complementary use of grants and non-grant financing from private and/or public sources to provide financing on terms that would make projects financially feasible and/or sustainable. The novelty of a blended finance structure lies in its flexibility, which enables differentiated financial outcomes.

Public financiers such as foundations, governments, and multilateral agencies can provide grants to corporations engaged in green technologies with no return expectation and capital with below-market returns. Global Climate Funds, such as the Green Climate Fund (GCF) and the Global Environment Facility (GEF), are established to provide concessional capital for climate projects in developing countries (Meltzer, 2018). The Rockefeller Foundation, in collaboration with other foundations, has established the Zero Gap Fund, which provides flexible, risky, and patient capital to projects that create global public goods. Access to capital at lower rates nudges corporations and manufacturers to adopt green technologies on a larger scale. Since several green projects are risky due to demand uncertainty and a lack of performance records, blended financing can provide capital to these projects and mitigate demand uncertainty and performance risk. For example, if the project incurs a loss, a blended financing mechanism can reduce project risk by taking the first loss position in the capital structure (One Planet Lab & Grantham Research Institute on Climate Change and the Environment, 2021). Besides, blended financing can be used at the early stages of projects to cover soft costs, enabling green project developers to attract private capital when the project is ready (World Economic Forum, 2015). For example, rooftop solar adoption in the Micro, Small and Medium Enterprises (MSME) segment in India is limited due to a lack of project pipelines, credit risk, and high transaction costs. The blended financing instrument can provide grants to develop bankable projects and cover transaction costs until the market finds ways to reduce them, and to reduce the cost of rooftop solar installation through production and supply chain efficiency. At the same time, a blended financing facility can also serve as a debt capital provider, enabling MSMEs to access debt at a reasonable rate to finance rooftop solar installations.

Venture Fund

Since green technologies at an early stage (e.g., battery recycling, green ammonia, sustainable aviation fuel) take a long time, likely 15 to 25 years (Rissman et al., 2020), to become commercially viable, they are often beyond the horizons of most financiers. Private equity and venture capital usually have a medium-term (5-7 years) investment horizon, so they can exit from their investment. If a subsequent round of funding is not available, technology development collapses. A public-financier-backed venture

fund would be well-suited to green technologies. Asia-Pacific countries can not only be the technology adopters but also the technology developers. Breakthrough Energy Ventures is a specialized $1 billion fund focused on bridging the valley of death in clean energy technologies, such as nuclear fission, large-capacity batteries, green hydrogen, and next-generation biofuels (Majumdar et al., 2021). ADB Ventures' Equity Fund provides equity capital to scale climate technologies. Asia-Pacific countries can set up similar funds, either jointly or alone, potentially through public-private partnerships, with governments taking an active role.

Climate Fund

An investment fund (pure debt, equity, or a combination of debt and equity) is an attractive channel for intermediating capital from capital providers to users. Many financiers do not have the willingness or capacity to invest directly in green technologies at the individual or company level due to the small size of transactions (Pailman et al., 2025); they prefer to invest through funds. For example, energy efficiency technologies in the MSME segment are small at the individual project level, but their size increases when aggregated. The investment fund can serve this segment not only by providing capital but also by improving market efficiency through the development of standardized tools (e.g., sustainable investment index and indicators, GHG calculation protocol) and a track record that will enable private investors to participate in subsequent stages. An investment fund structure can be attractive to private financiers, whereas a development finance institution can provide first-loss protection. The fund can invest in projects as an equity or debt investor, depending on the fund's mandate and the expected returns for investors. Climate Finance Lab's "Financing Low-Carbon Auto" financing instrument, in the form of a fund sourcing capital from commercial and public financiers to provide debt capital to auto-rickshaw drivers at a lower rate and without collateral, is a catalytic instrument where borrowers struggle to raise debt capital from mainstream financiers (Climate Finance Lab, 2018).

Concessional Debt, but Monetization of Green/Carbon Credit

Concessional debt capital from public financiers can support green technologies, providing necessary financing that is not accessible from mainstream financiers (e.g., commercial banks) at reasonable rates, as these technologies are highly risky. It also rewards early investors who took significant risks during the technology development stage (Beck, 2019). Kreditanstalt für Wiederaufbau (KfW) Development Bank offered concessional debt financing to local banks to lend for solar photovoltaic (PV) projects in Germany, but withdrew when private financiers were ready to finance (Geddes et al., 2018). For example, the Indian Renewable Energy Development Agency (IREDA) provided concessional debt for renewable energy projects from 2011 to 2018, resulting in accelerated deployment of RE projects in India (Sarangi, 2018). The US Department of Energy's Loan Guarantee Program for innovative clean energy technology is another example of public capital used to drive climate impact (Geddes et al., 2018). This program provides much-needed loans and loan guarantees for low-carbon technologies until these technologies can attract commercial debt financiers (Anadon et al., 2016).

The Climate Investment Fund's two funds, the Clean Technology Fund (CTF) and Strategic Climate Fund (SCF), offer a variety of financing, including debt, equity, and grants, to demonstrate and deploy climate technologies in low- and middle-income countries. The Asian Catalytic Green Finance Facility is managed by the Asian Development Bank (ADB) and funded by its development partners, including Agence Française de Développement (AFD), Asian Infrastructure Investment Bank (AIIB), and European Investment Bank (EIB). The facility has a dual approach to de-risking projects to attract private investors: originating and preparing green infrastructure projects through technical assistance and covering the project's upfront costs. Often, origination and project preparation are resource-intensive exercises that private investors avoid. The coverage of this cost can attract private investors.

Front-loaded Financing Support

Since several green technologies, some of which are mentioned earlier, are capital-intensive and not bankable (Aguila et al., 2026), users have limited or no incentives to adopt them. Even if some of these

technologies provide bankable access to capital, it is also an additional challenge for users; for example, MSMEs struggle to raise debt capital at a reasonable rate to install rooftop solar due to the lack of availability of debt financing at a reasonable rate, even though this technology is financially beneficial (Kumar et al., 2024). Hence, green technologies require capital support from public financiers until these technologies become bankable.

The feed-in tariff for solar technologies in the early 2000s, along with government-funded incentives, particularly in China and Germany, accelerated solar adoption, thereby drastically reducing the manufacturing costs of solar PV panels (Ma et al., 2021). The one-time stimulus funding expired in the first term of the Obama administration in the US. Public funding for demonstration projects fell by over 90%. The US-India Clean Energy Finance (USICEF), a grant facility funded by donors and the Governments of India and the United States, supported distributed solar projects by providing preparation support to small and medium-sized companies in India, thereby enabling them to raise large-scale debt capital (USICEF, 2022).

Result-based Financing

At several points, the success of adopting green technologies depends on recipients' willingness to utilize concessional capital and on the performance of the technologies themselves, factors that public financiers often have limited visibility into. Results-based financing also enables more effective risk-sharing between financiers and capital users. For example, the solarization of the agricultural sector depends on government policy and farmers, whereas the adoption of rooftop solar depends heavily on users and the government's electricity policy. Similarly, energy-efficiency manufacturers are best positioned to assess the performance of energy-efficiency technologies. A result-based financing mechanism funded by public financial institutions can be created to support users in adopting green technologies. For example, an energy-efficiency product manufacturer will receive a financial incentive based on the energy efficiency realized from the technology. For example, concessional capital from a Multilateral Development Bank (MDB) to governments can be linked to capacity addition in the rooftop solar sector and the solarization of agriculture. An MDB (e.g., World Bank, Asian Development Bank) or Domestic Development Bank (DDB), or a bilateral financial institution, can provide result-based financing to countries at better terms if certain results are achieved, for example, a low-cost credit line from an MDB to a government linked with 10 GW of additional rooftop solar capacity addition.

Partial Credit Guarantee to Banks

A partial credit guarantee will be immensely beneficial for the adoption of green technologies in the Micro, Small and Medium Enterprises (MSME) segment, where credit risk is high, real or perceived. A third party, a credit guarantee trust (guarantor), creates a credit guarantee scheme that provides partial risk coverage in the event of borrowers' (MSMEs) default. In return, the guarantor charges the lender a guarantee fee for providing capital to the borrower. The partial or full default risk coverage of the loan reduces the lender's credit loss exposure, even if there is no change in the amount or probability of default. Credit-loss risk coverage acts as default insurance for lenders. The decrease in expected credit losses provides lenders with greater flexibility to reduce collateral requirements. Moreover, the scheme encourages creditors to lend to companies that would not get credit without a credit guarantee. With credit risk coverage, users of green technologies can access debt capital on preferred terms, such as lower interest rates, longer maturities, and higher loan amounts.

An MDB or DDB can sponsor a loan portfolio guarantee program for local banks and financial institutions lending to rooftop solar in the MSME segment. It is important to identify institutions that have a mandate to expand green loans, maintain low levels of non-performing assets, and have a strong presence in the MSME segment. The MDB/DDB must design a mechanism to create financial additionality and encourage MSMEs to borrow at reasonable rates to adopt green technologies.

Case Study: Climate-smart Agriculture

Transitioning to climate-smart agriculture practices, including agro forestry, is essential for farmers to survive and prosper in the era of climate change, but smallholder farmers need financing to make that transition. However, commercial banks in India still consider financing for farmers to be risky. The poor creditworthiness of small farmers is further weakened by a very long payback period associated with agroforestry. Partial credit coverage can make banks more comfortable in extending credit to small farmers. The United States Agency for International Development (USAID) and Rabo Bank joined hands to create a $15 million guarantee program over 10 years with a partial coverage of ~50% of the principal outstanding in India. The first loss would be absorbed by Rabo Foundation, and the second loss by USAID. The goal of the credit enhancement program was to create a demonstration effect in the market, showing other financial institutions that the sustainable landscapes sector is financially viable. The second goal was to increase the support for projects in the sustainable landscape sector to slow, halt, and, whenever possible, reverse Greenhouse Gas (GHG) emissions from land use.

Sustainability-linked Bonds or Loans

Sustainability-linked Bonds (SLBs) and Sustainability-linked Loans (SLLs) are sustainable finance instruments in which the proceeds are general corporate financing, not earmarked for specific environmental projects, and the coupon is linked to the issuer's future sustainability performance. The instrument is often associated with a step-up in the coupon if the issuer does not achieve Sustainability Performance Targets (SPTs), such as reductions in emissions, energy efficiency gains, or ESG improvements. These instruments are immensely useful for companies where the rapid transition to renewable energy is financially and technically infeasible, but gradual carbon reduction is possible. The application of SLBs and SLLs can be similar to result-based financing, in which a coupon is linked to a performance target. For example, banks can set variable interest rates for MSMEs based on their environmental performance (e.g., carbon reduction through energy efficiency or solar). Similarly, the issuer of SLBs can reduce its interest rate by investing capital proceeds in green technologies over time. These two financial instruments can nudge companies to invest in green technologies to gain the benefits of lower interest rates and mitigate environmental performance-related reputation risk. It is important that companies availing themselves of concessional capital must have ambitious green standards, exceeding industry standards, to avoid greenwashing risk. Capital providers, particularly short-term capital providers, have limited incentives to provide capital at a lower interest rate; the government can bear the cost of interest rate benefits passed on to the user of capital, as sustainable development is a policy objective. For example, reducing Greenhouse Gas (GHG) emissions is a national policy objective of many countries.

Co-lending and Loan-syndication

MDBs can originate loans and invite other lenders to serve as co-lenders for green projects. It will reduce the transaction cost of private lenders. A mix of public and private capital can be used in this transaction. A lending portfolio program is similar to the Managed Co-lending Portfolio Program of the International Finance Corporation, where the MDBs will provide first-loss protection to private investors in the event of default. MDBs have a higher risk appetite and mandate to decarbonize the economy, so this kind of structure aligns with their investment strategy. The utility-scale green project, including solar, wind, and transmission lines, requires long-term financing; MDB participation as co-financiers can instill confidence among private financiers.

Credit Enhancements on Corporate Bonds

Green companies in several developing countries in the Asia-Pacific region rely heavily on banks for debt financing (OECD, 2025). Banks in these countries are exposed to long-term assets, which compromise their asset-liability management policies and regulations. Banks have limited operational capacity to offer long-term financing due to maturity mismatches. In this context, a bond is a better financial instrument to raise long-term debt financing. Bonds are also a preferred asset class for institutional investors such as pension funds and insurance companies, as they prefer liquid instruments. Corporations (borrowers)

can list these securities on the stock exchanges of developed markets to raise capital from international investors. Public financiers, including the government and MDBs, can offer credit enhancement to these bonds so that their rating would be good enough to raise capital from these low-risk-seeking investors. Credit enhancement, such as a first-loss guarantee or a partial credit guarantee, can improve bond ratings, thereby enhancing their credit profiles and attracting large institutional investors.

Role of Development Finance Institutions (DFIs) and MDBs

DFIs and MDBs provide critical capital, manage risks, share knowledge, and build institutional capacity and partnerships for green projects in the Asia-Pacific region. They can offer grants to green technology projects that are unable to attract commercial financing for a variety of reasons; grants can improve the risk-adjusted rate of return for private investors, thereby attracting commercial financiers. DFIs and MDBs must ensure that undue grants are not given to projects where risk is duly shared among DFIs, MDBs, and private financiers.

They can provide necessary technical assistance to countries where the adoption of green technologies is at an early stage, or to specific segments of the green sector (e.g., solar irrigation) that need support to scale up. Green project developers in several countries in the Asia-Pacific region have limited financial resources (Peimani, 2018); domestic capital is scarce in these countries, and the terms of capital are not attractive, which discourages project developers. Here, DFIs and MDBs can provide patient capital to develop project pipelines before mainstream financiers show interest.

MDBs and DFIs have a mandate to invest in riskier and more impactful sectors (e.g., health care, renewable energy) and countries, so they need to take risks and be open to investing through various financial instruments to create financial and developmental additionality. DFIs and MDBs should increase their risk-taking capacity and provide risk-mitigation support to attract private financiers, where financial additionality is highest compared to investing directly through debt or equity. In risk-mitigating instruments, DFIs and MDBs do not have to disburse capital immediately, unlike in debt or equity investments; capital is disbursed only when a risk event is triggered.

MDBs and DFIs can take government risk guarantees (such as political risk) on financing for green projects; they have some leverage to influence governments (Koh, 2018) to mitigate contractual and regulatory risks.

MDBs can also play an important role in partnership mobilization. They can set up a financial intermediary that connects financiers and projects. Since MDBs have extensive experience in Asia-Pacific countries, they can originate and conduct the necessary due diligence on behalf of private investors, particularly those with no or limited experience investing directly in these countries. Besides, the financial intermediary can design a financial structure tailored to the needs of projects and investors. Green finance performance is poorly tracked from both private and public financiers' perspectives (Ahmad et al., 2025). MDBs, as public institutions, can track their green financing record. An MDB-led tracking of green finance will bring transparency and confidence among stakeholders regarding its effectiveness and efficiency.

Donor and Philanthropist Investors

Donors and philanthropic investors can play a similar role to DFIs or MDBs, but their scale of support is comparatively small. Small-scale green projects or certain segments of the green sector at a very early stage do not attract DFIs and MDBs. Here, donors/philanthropic investors can play a catalytic role in taking the project to the stage where DFIs and MDBs can support it.

Given the high risk of failure at an early stage, grants can serve as an incentive to attract private financiers. Grants can be used in combination with private capital (corporate or venture capital) to support early-stage innovations and proof-of-concept for green projects in the Asia-Pacific region. For example, distributed solar, solar water pumps, and battery storage are at a very early stage in most Asia-Pacific countries. Donors' grant funding and philanthropic investors' concessional capital can be blended with DFIs' capital to increase the risk capital size for green projects. In addition, donors can review non-bankable green projects and finance them through grants to make them attractive to both DFIs and private financiers.

Assessing the Effectiveness and Efficiency of Innovative Financing Instruments

These financial instruments can improve the risk-reward ratio for the private sector in several ways. High perceived and actual risk in green projects makes them commercially unviable. On the one hand, these innovative financial instruments can reduce the cost of capital, thereby generating higher returns for private investors in green projects; on the other hand, they can take on risks, thereby reducing the riskiness of these projects. Through these financial models/instruments, public capital can be applied smartly to mobilize additional private capital to achieve certain policy objectives.

Leverage is one of the key metrics for assessing the effectiveness of these instruments, as it indicates additional private capital mobilized by public capital intervention. For example, if the size of public capital was $1, which enabled attracting $5 in funding through the instrument, then the leverage would be 5X. The higher the leverage, the greater the effectiveness and efficiency of these instruments. Besides, these instruments must also be assessed from a public policy objectives lens. For example, if the policy objective of the instrument is to support achieving 500 GW of solar in the next 5 years, the instrument can be assessed for its contribution to that objective.

Conclusion

The Asia-Pacific region stands at a pivotal point in the green transition – on one side, it needs to invest in green technologies to meet its climate ambitions, and on the other, green technologies must support its growth and development ambitions. However, financing green technologies remains a key challenge for countries in the region seeking to adopt these technologies. Innovative financing technologies – such as blended finance, government-sponsored venture capital fund and facility, and result-based financing, SLLs/SLBs and PCGs – can be deployed effectively by both the government and the private sector to attract large-scale capital for green technologies. The key enablers for deploying these financing instruments at scale hinge on the appetite of MDBs, Domestic Development Banks, and financial institutions; cooperation between different institutions in countries and regions; and policy and regulatory reforms. All ecosystem players in the Asia-Pacific region must break their respective institutional shackles and introduce innovations in their practices to attract large-scale capital to the green sector, which is crucial for their rapid economic growth, competitiveness, and sustainable development.

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Advancing Sustainable Innovation, Small and Medium-Sized Enterprise Resilience and Green Transition in the Asia-Pacific Region

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Abstract

Emerging technologies such as artificial intelligence (AI), climate technologies, clean energy systems, digital platforms and green innovation are increasingly central to sustainable development in the Asia-Pacific region. Yet adoption remains constrained by high upfront costs, uncertain returns, perceived investment risks and uneven access to finance, particularly among small and medium-sized enterprises (SMEs), start-ups, women-led enterprises and grassroots innovators. This article examines how innovative financing models can help close this gap by mobilising public and private capital for technology adoption, transfer and commercialisation. It discusses green finance, sustainability-linked finance, blended finance, public-private partnerships, venture capital, carbon market instruments, impact investment and de-risking mechanisms. The article argues that innovative finance should not be treated merely as a funding mechanism, but as a strategic enabler of inclusive technology diffusion, cleaner production, SME resilience and green transition across the Asia-Pacific region.

Keywords: innovative finance; emerging technologies; small and medium-sized enterprise resilience; green transition; blended finance; technology transfer; Asia-Pacific

1. Introduction

The Asia-Pacific region is entering a critical phase in which technological transformation, sustainability transition and inclusive economic development must be advanced simultaneously. The region contains dynamic manufacturing systems, rapidly expanding digital markets, major innovation hubs and extensive SME sectors. At the same time, it faces development pressures that include climate vulnerability, environmental degradation, widening digital divides, infrastructure gaps, financing constraints and uneven technological capabilities.

Emerging technologies offer an important pathway to address these pressures. Artificial intelligence, clean energy systems, climate technologies, digital platforms, circular economy solutions, electric mobility, smart logistics, green manufacturing systems and carbon monitoring tools can improve productivity, reduce environmental impacts, strengthen supply chain resilience and support new forms of sustainable enterprise development. However, technological potential does not automatically translate into broad-based development impact. Diffusion depends not only on scientific discovery or technological availability, but also on whether enterprises and public institutions can access suitable, affordable and risk-sensitive finance.

This financing challenge is especially acute for SMEs, start-ups, women-led enterprises and grassroots innovators. Although these actors are central to employment creation, local innovation and technology diffusion, they frequently lack collateral, long credit histories, audited sustainability data, investment-ready business plans or access to formal investor networks. The International Finance Corporation (IFC) estimates that the micro, small and medium-sized enterprise finance gap now stands at USD 5.7 trillion, rising to USD 8 trillion when informal enterprises are included (IFC, 2025). Firms that recognise the

need to digitalise, decarbonise and improve resource efficiency may, therefore, be unable to absorb the upfront costs or implementation risks associated with new technologies.

The global financing environment further reinforces the urgency of this issue. The United Nations (2024) estimates that developing countries require about USD 4 trillion in additional annual investment to meet sustainable development needs. United Nations Conference on Trade and Development (UNCTAD) in 2025 further reports that global foreign direct investment fell for a second consecutive year in 2024, illustrating a weaker external investment environment for development-oriented sectors. These trends demonstrate why innovative finance is not only a financial issue, but also a development, technology-transfer and sustainability-transition issue.

For the Asia-Pacific region, the implication is clear: traditional financing models are not sufficient to support the scale, speed and inclusiveness required for emerging technology adoption. Conventional bank lending tends to favour firms with predictable cash flows and collateral, while emerging technology projects frequently involve uncertain returns, longer payback periods and higher perceived risks. Public grants and technical assistance remain important. For example, the Asian Development Bank (ADB) committed USD 24.3 billion from its own resources in 2024 and mobilised USD 14.9 billion in co-financing (Asian Development Bank, 2025a). Nevertheless, public finance cannot meet the full financing requirement alone, which makes a diversified financing architecture necessary.

This article examines innovative financing models that can support emerging technologies in the Asia-Pacific region. It focuses on green finance, sustainability-linked finance, blended finance, public-private partnerships, venture capital, impact investment, carbon market instruments and results-based finance. It further argues that innovative finance should be understood as part of a broader technology-transfer ecosystem, involving policy certainty, institutional coordination, risk-sharing, gender inclusion, environmental accountability and regional cooperation.

2. Why Do Emerging Technologies Require Innovative Finance?

Emerging technologies often encounter a financing gap between technical feasibility and commercial adoption. At the early stage, a technology may show strong potential but remain commercially unproven. At the adoption stage, enterprises may understand its benefits but hesitate because of high upfront costs, uncertain returns or organisational readiness challenges. At the scaling stage, larger volumes of capital are required, yet investors may remain cautious due to market, regulatory or technological uncertainty. This stage-specific gap explains why grants, concessional loans, guarantees, venture capital and results-based instruments must be sequenced rather than treated as interchangeable tools.

This problem is often described as the ‘valley of death’ in innovation financing. Technologies can fail to diffuse not because they lack social, environmental or productivity value, but because they cannot secure appropriate financing at the right stage of development. The problem is visible in clean energy, climate technology, circular economy innovation, AI applications, digitalisation and advanced manufacturing.

The International Energy Agency (IEA) (2025) estimates that global energy investment will reach USD 3.3 trillion in 2025, with about USD 2.2 trillion directed to clean energy technologies and infrastructure. However, clean energy investment remains unevenly distributed, and emerging and developing economies outside China continue to face higher capital costs and weaker investment pipelines. This imbalance is highly relevant to the Asia-Pacific region, where several economies need to scale clean energy and industrial transition while maintaining affordability, competitiveness and resilience.

The same logic applies to AI-enabled and digital technologies. Digital platforms, automation, data analytics and AI can significantly improve firm competitiveness, but SMEs may lack digital readiness, internal expertise, cybersecurity systems and financing capacity. The Organisation for Economic Co-operation and Development (OECD) notes that limited access to reliable digital infrastructure and digital skills continues to constrain SME digital transformation (OECD, 2025). In some cases, the technology is available, but the enterprise is not investment-ready. In other cases, financing exists, but the project is not sufficiently structured to attract lenders or investors.

Innovative finance must, therefore, address three interrelated challenges. First, it must improve affordability by reducing the cost of capital. Second, it must reduce perceived and actual risks through guarantees, blended finance, concessional capital, technical assistance and clearer policy frameworks. Third, it must promote inclusion by ensuring that smaller firms, women-led businesses, rural innovators and community-based enterprises are not excluded from technological upgrading.

3. Green Finance for Cleaner Production and Environmental Management

Green finance refers to financial flows that support environmentally beneficial activities, including renewable energy, energy efficiency, pollution control, sustainable transport, water management, green buildings and cleaner production. It is directly relevant to emerging technologies because priority technologies for the Asia-Pacific region include solar photovoltaic systems, grid modernisation, electric mobility, waste-to-resource systems, water treatment technologies and low-carbon industrial equipment.

Green bonds are a widely used green finance instrument. They enable governments, development banks, financial institutions and corporations to raise capital for projects with clear environmental benefits. These projects may include solar energy, wind power, electric mobility, smart grids, waste management systems, water treatment technologies and low-carbon industrial processes. The value of green bonds lies not only in raising capital; it also requires issuers to specify eligible uses of proceeds, management of proceeds, reporting and external review.

In the Association of Southeast Asian Nations (ASEAN), the ASEAN Green Bond Standards were launched in November 2017 to facilitate green finance and support sustainable regional growth. The ASEAN Capital Markets Forum (ACMF) developed the standards in alignment with the International Capital Market Association's Green Bond Principles to improve transparency and investor confidence (ASEAN Capital Markets Forum, 2019). This responds directly to investors' need for assurance that green claims are credible and that proceeds are directed toward genuine environmental outcomes.

For emerging technologies, green finance can support large-scale infrastructure and cleaner production systems. However, labelled bond markets are generally more accessible to large corporations, public institutions and established financial issuers than to SMEs because issuance requires minimum scale, credit standing, external review, use-of-proceeds management and continuing disclosure capacity. To address this limitation, financial institutions and development agencies can develop aggregation models, where multiple small green technology projects are bundled into larger portfolios suitable for institutional investors.

The ASEAN Catalytic Green Finance Facility (ACGF) illustrates this aggregation and de-risking logic. Launched under the ASEAN Infrastructure Fund and administered by ADB, the ACGF provides technical assistance and access to more than USD 1 billion in loans from co-financing partners to support green infrastructure preparation and financing (Asian Development Bank, n.d.-a). For stakeholders, the practical lesson is that green finance becomes more accessible when project preparation, technical assistance and concessional resources are packaged with investment capital.

Green finance should also be linked to environmental management practices. Financing a cleaner technology is insufficient if firms do not have systems to monitor energy use, waste reduction, emissions, water consumption and resource efficiency. Green finance programmes should, therefore, be complemented by environmental audits, technology advisory services, measurement tools and capacity-building support, especially for SMEs.

4. Sustainability-Linked Finance for Transition-Oriented Enterprises

Sustainability-linked finance differs from project-based green finance because the use of proceeds is not necessarily restricted to a specific green project. Instead, the financial terms are linked to whether the borrower achieves predefined sustainability performance targets. These targets may relate to emissions reduction, renewable energy adoption, energy efficiency, waste reduction, water efficiency, circular economy practices or social inclusion.

This model is particularly useful for transition-oriented enterprises. These are firms that operate in carbon-intensive or resource-intensive sectors but have credible plans to improve environmental performance over time rather than immediately meeting a strict green classification. Transition-oriented enterprises need finance that rewards measurable progress, not only finance that labels a single project as already green.

For example, a manufacturing SME may receive financing to install energy-efficient machinery, with loan terms linked to electricity savings. A logistics company may link financing conditions to fuel efficiency, route optimisation or electric vehicle adoption. A hospitality enterprise may receive financing tied to measurable improvements in water efficiency, renewable energy use or waste reduction. In each case, the instrument rewards progress rather than symbolic green labelling.

The ASEAN Sustainability-Linked Bond Standards provide a useful regional reference for performance-based sustainable finance instruments. Issued in 2022, the standards define sustainability-linked bonds as forward-looking instruments whose financial or structural characteristics may vary depending on whether predefined sustainability objectives are achieved (ASEAN Capital Markets Forum, 2022). This approach is relevant for firms that require transition finance rather than project-based green finance alone.

The advantage of sustainability-linked finance is flexibility. It can support firms that need to transform their overall business model rather than finance only one discrete project. However, this flexibility also creates risks. If targets are weak, vague or easily achieved, sustainability-linked finance may become symbolic rather than transformative. Strong governance is, therefore, essential.

For SMEs, the design of sustainability-linked finance must remain practical. Reporting requirements should be proportionate to firm size and capacity. Simple, measurable and verifiable indicators may be more effective than complex environmental, social and governance (ESG) metrics. Examples include energy saved, waste reduced, water conserved, digital systems adopted, emissions intensity lowered or women's participation improved.

5. Blended Finance and De-Risking Mechanisms

Blended finance combines public, concessional or development finance with private capital. Its purpose is to improve the risk-return profile of projects that generate social, environmental or developmental benefits but may not attract sufficient private investment on purely commercial terms. Blended finance may include guarantees, concessional loans, first-loss capital, co-investment, credit enhancement and technical assistance.

This model is highly relevant for emerging technologies because several technology projects generate public benefits that are not fully captured by private investors. Renewable energy, climate adaptation, pollution control, clean transport, circular economy systems and digital inclusion projects may produce long-term social and environmental value, but investors may still perceive them as risky. Public or development finance can help reduce these risks and attract private participation.

Malaysia's National Energy Transition Facility (NETF) provides a useful example. Established under the National Energy Transition Roadmap (NETR), the facility was announced in 2023 with RM2 billion in seed funding to enable catalytic blended finance for energy transition projects that are marginally bankable or yield below-market returns (Prime Minister's Office Malaysia, 2023). Its eligible areas include energy efficiency, renewable energy, hydrogen, bioenergy, green mobility and carbon capture, utilisation, and storage (Bank Pembangunan Malaysia Berhad, n.d.).

The facility has also moved beyond policy announcement. Malaysia Debt Ventures reported in August 2025 that it had approved RM122.65 million in financing for six technology-based companies undertaking energy transition projects under the NETF, including RM40.09 million in targeted incentives to reduce financing costs and improve bankability (Malaysia Debt Ventures Berhad, 2025). This provides a concrete case for stakeholders: blended finance can work through rebates, credit enhancement and project-specific incentives rather than through grants alone.

The importance of blended finance lies in its ability to move projects from policy aspiration to investment readiness. However, blended finance should be used carefully. Public funds should not simply subsidise

projects that private investors would have financed anyway. Concessional resources should be targeted at identifiable barriers such as early-stage risk, weak collateral, high transaction costs or technology uncertainty.

De-risking is not only financial. It may also be regulatory, technical and informational. Regulatory de-risking requires stable policies, clear incentives and predictable standards. Technical de-risking requires feasibility studies, demonstration projects and technology validation. Informational de-risking requires reliable data, transparent reporting and credible impact measurement. These elements are essential to transform emerging technologies into bankable investments.

6. Public-Private Partnerships for Technology Transfer

Public-private partnerships can support emerging technologies when projects require infrastructure, policy coordination and long-term implementation capacity. Examples include smart grids, electric vehicle charging networks, green ports, digital public infrastructure, waste-to-energy systems, water treatment plants, climate-resilient infrastructure and cross-border digital trade platforms.

The value of public-private partnerships lies in their ability to combine the strengths of different actors. Governments can provide policy direction, regulatory support, public procurement, land access and risk-sharing mechanisms. Private firms can contribute technology, capital, managerial capability and operational expertise. Development agencies can provide technical assistance, concessional finance and regional knowledge-sharing.

For technology transfer, public-private partnerships are especially important because technology adoption is rarely an isolated firm-level decision. Electric mobility, for instance, requires charging infrastructure, grid capacity, battery standards, maintenance skills and consumer incentives. Digital trade platforms require interoperability, cybersecurity, logistics integration and cross-border regulatory cooperation. The NETR's proposal for an energy service company platform to pool government building retrofit projects illustrates how public-private coordination can create a market for SME service providers while supporting energy efficiency (Prime Minister's Office Malaysia, 2023).

However, public-private partnerships must be governed carefully. Poorly designed arrangements may create fiscal risks, weak accountability or unequal benefit distribution. Transparent procurement, clear performance indicators, balanced risk allocation and public-interest safeguards are essential. Technology projects should also include knowledge-transfer provisions so that local firms, workers and institutions develop long-term capability.

Public-private partnerships can also be used to establish demonstration projects, regulatory sandboxes, pilot facilities and innovation hubs. These mechanisms reduce uncertainty by allowing technologies to be tested before large-scale deployment. They are particularly useful for SMEs, which may be unwilling or unable to absorb the full risk of experimentation alone.

7. Venture Capital, Impact Investment and Start-Up Financing

Venture capital is a critical source of finance for start-ups and high-growth firms developing emerging technologies. Unlike traditional banks, venture capital investors are more willing to accept uncertainty in exchange for future growth potential. This makes venture capital relevant for AI, financial technology, health technology, education technology, climate technology, digital platforms and smart logistics.

However, venture capital does not automatically support all socially valuable technologies. It tends to favour digitally scalable business models, urban innovation ecosystems and firms with rapid growth potential. Technologies with longer development cycles, hardware requirements, infrastructure dependence or stronger public-good characteristics may struggle to attract conventional venture capital. Examples include grid storage, industrial decarbonisation equipment, water treatment systems and climate adaptation technologies that require demonstration sites or public procurement before commercial scale-up.

ADB Ventures offers a regional example of a more development-oriented venture model. Established by ADB in 2020, it provides patient venture capital and seed capital to early-stage technology companies with climate and impact-focused solutions in emerging Asia (ADB Ventures, n.d.; Nordic Development Fund, 2020). This type of platform is relevant because it combines capital with networks, market-entry support and impact screening, helping start-ups address both commercial and development barriers.

Impact investment can help address the limitations of conventional venture capital. Impact investors seek both financial return and measurable social or environmental impact. The Global Impact Investing Network defines impact investments as investments made with the intention to generate positive, measurable social or environmental impact alongside a financial return (Global Impact Investing Network, 2025). In the Asia-Pacific context, impact investors can support clean energy access, climate adaptation, inclusive digital finance, sustainable agriculture, circular economy platforms, women-led innovation and community-based technology solutions.

Gender inclusion is an important dimension of innovative finance. Women-led enterprises may face structural barriers, such as limited collateral ownership, weaker investor networks, lower visibility and unconscious bias in financing decisions. Evidence from Indonesia, for example, shows that lack of collateral is a key financing challenge for women entrepreneurs, partly because asset ownership and registration are often not in women's names (World Bank, 2016). Gender-responsive finance should, therefore, be treated as part of the innovation-financing agenda rather than as a separate social add-on.

Start-up financing should also be connected to universities, research institutions and technology promotion agencies. Useful technologies remain under-commercialised when research outputs are not translated into market-ready solutions. Proof-of-concept grants, seed funding, intellectual property advisory services, incubators and university-industry financing platforms can help bridge this gap.

8. Carbon Markets and Results-Based Finance

Carbon market instruments can provide additional revenue streams for projects that reduce or remove greenhouse gas emissions. Relevant projects may include renewable energy, methane reduction, energy efficiency, clean cooking, forest conservation, blue carbon, waste management and industrial decarbonisation. When properly governed, carbon finance can improve the commercial viability of emerging technology projects.

For example, a renewable energy project may generate revenue from electricity sales and carbon credits. A waste-to-energy project may combine waste management fees, energy revenue and emissions reduction benefits. A blue carbon project may combine ecosystem restoration, community livelihoods and carbon revenue, particularly in coastal and mangrove ecosystems. These examples show how carbon markets can support both environmental and economic objectives when benefits are measured credibly and shared fairly.

Results-based finance is closely related. Under this model, payments are made only after verified outcomes are achieved. These outcomes may include emissions reduced, households connected to clean energy, water saved, waste diverted, jobs created or adaptation benefits delivered. This creates stronger accountability because financing is linked to results rather than intentions.

However, carbon markets and results-based finance require credible measurement, reporting and verification. Weak verification, double counting and low-quality credits can undermine investor confidence and public trust. The World Bank's State and Trends of Carbon Pricing 2026 reports that carbon pricing covers nearly 30% of global greenhouse gas emissions and mobilised more than USD 107 billion for public budgets in 2025, while also noting the need for quality and integrity in crediting markets (World Bank, 2026). Strong standards, transparent registries, third-party verification and community safeguards are, therefore, necessary.

For SMEs, direct participation in carbon markets may be difficult because of technical complexity and high transaction costs. Aggregation platforms and digital monitoring, reporting and verification systems can reduce these barriers by grouping smaller projects, standardising data and improving transparency. The World Bank has noted that digital monitoring, reporting and verification can reduce the cost of generating carbon assets and increase transparency and security in carbon market transactions

(World Bank, 2022). Similarly, the Climate Action Data Trust provides an open-data metadata platform intended to link and harmonise carbon credit registry data, helping to reduce double-counting risk (Climate Action Data Trust, n.d.).

9. Technology Management and Investment Readiness

Innovative finance will not be effective if enterprises lack technology management capability. Technology projects can fail not because the technology is weak, but because firms are not ready to implement, operate or maintain it. Financing must, therefore, be accompanied by technology assessment, managerial capability, technical support and organisational learning.

Enterprises should begin with a clear technology-needs assessment. This involves identifying operational problems, evaluating available technologies, estimating costs and benefits, assessing implementation risks and determining whether internal skills are sufficient. Technology adoption should be problem-driven rather than trend-driven.

Technology promotion agencies and financial institutions can support this process by offering diagnostic tools. These tools may assess digital maturity, energy efficiency potential, environmental management readiness, cybersecurity preparedness and financing needs. In Malaysia, SME Corp's Business Accelerator Programme 2.0 uses integrated assistance to support SME capability development, while the SME Competitiveness Rating for Enhancement provides a diagnostic tool for assessing enterprise competitiveness (SME Corp. Malaysia, n.d.). In the wider region, ADB has also developed digital maturity assessment tools to identify gaps and guide technology roadmaps in specific value chains (Asian Development Bank, 2025b).

Technology forecasting is also important. Governments and investors should identify which technologies are likely to generate high development impact and commercial potential. Priority areas for the Asia-Pacific region include renewable energy, energy storage, circular economy systems, water technologies, AI for productivity, climate adaptation technologies, smart agriculture and digital public infrastructure.

Intellectual property rights must also be considered. Technology transfer requires clarity on ownership, licensing, royalties and commercialisation rights. For universities and research institutions, weak intellectual property management can prevent promising technologies from reaching the market. For SMEs, unclear intellectual property protection may reduce investor confidence. Financing models for emerging technologies should, therefore, include support for intellectual property advisory services and commercialisation agreements.

10. Case Example 1: Malaysia's Energy Transition Financing Approach

Malaysia's NETF illustrates how national policy can relate to innovative finance. The facility is designed to support Malaysia's energy transition priorities by enabling catalytic blended finance for projects that may otherwise face bankability constraints. The NETR identifies six energy transition levers — energy efficiency, renewable energy, hydrogen, bioenergy, green mobility and carbon capture, utilisation and storage — and positions finance as a cross-cutting enabler for implementation (Ministry of Economy Malaysia, 2023).

The case is relevant because Malaysia's energy transition requires investment beyond ordinary public expenditure. The Prime Minister's Office reported in 2023 that at least RM1.2 trillion would be needed between 2023 and 2050 for a responsible energy transition, while RM60 billion to RM90 billion would be required in the current decade for crucial projects such as public transport expansion, grid strengthening and human-capital reskilling (Prime Minister's Office Malaysia, 2023). The RM2 billion NETF seed fund should, therefore, be interpreted as catalytic capital intended to mobilise and structure further finance rather than as the full financing solution.

The 2025 MDV implementation update strengthens the case example. The approval of RM122.65 million in financing for six technology-based companies under the NETF, together with RM40.09 million in targeted incentives, shows how blended finance can be operationalised through lower financing costs,

rebates and credit enhancement (Malaysia Debt Ventures Berhad, 2025). This directly addresses the stakeholder question of whether the facility has moved from design to actual financing.

For SMEs, the key lesson is that financing must be accompanied by technical guidance. Smaller firms may be willing to adopt solar energy, energy-efficient machinery or green mobility solutions, but may lack the capacity to prepare financing proposals. Advisory support, standardised project templates, energy audits and simplified application processes can help SMEs become investment-ready.

Malaysia's case also highlights the importance of transition finance. Firms in manufacturing, logistics, construction, hospitality and agriculture cannot become low-carbon immediately. They require staged financing to move from existing systems toward cleaner technologies. Such transition finance should be linked to measurable progress, credible targets and transparent reporting.

11. Case Example 2: ASEAN Sustainable Finance Standards

ASEAN sustainable finance standards provide an important regional example of market-building. The ASEAN Green Bond Standards were launched in November 2017, followed by the ASEAN Social Bond Standards and ASEAN Sustainability Bond Standards in October 2018 (ASEAN Capital Markets Forum, 2019). The ASEAN Sustainability-Linked Bond Standards were then issued in 2022 to support performance-based transition finance (ASEAN Capital Markets Forum, 2022). Together, these standards support labelled sustainable finance instruments in regional capital markets by improving consistency, transparency and investor confidence.

This regional approach is valuable because emerging technology solutions often require cross-border cooperation. Clean energy supply chains, electric mobility, green logistics, digital platforms, circular economy systems and climate technologies operate across national boundaries. Common standards can help investors compare projects, reduce due diligence costs and support regional capital flows. For stakeholders, the relevance is that standards reduce uncertainty for issuers, investors, regulators and technology providers.

The standards also create a foundation for technology finance because they define what qualifies as green, social, sustainability-linked or transition-oriented financing. This is important for emerging technologies whose benefits may otherwise be difficult to evaluate. For example, an electric mobility project, renewable energy project or circular economy platform can be assessed not only by its commercial return, but also by whether its environmental objectives, performance indicators and reporting practices meet recognised standards.

However, standards alone are insufficient. SMEs remain far from capital-market readiness when they lack sustainability data, disclosure systems, project documentation, technical capacity and external-review budgets. Therefore, regional standards should be complemented by SME-friendly disclosure tools, credit guarantees, blended finance platforms, project aggregation mechanisms and technical assistance. Without these complementary measures, sustainable finance standards may primarily benefit larger issuers and leave smaller technology adopters outside the market.

The ASEAN case shows that innovative finance must combine credibility with accessibility. Strong standards are necessary to prevent greenwashing, but practical support is needed to ensure smaller enterprises can participate in sustainable finance markets. In this sense, ASEAN's standards are best understood as market infrastructure: they improve trust, but their development impact depends on whether governments, development banks and financial institutions translate the standards into investable SME and technology-transfer pipelines.

12. Policy Recommendations

Several policy actions can strengthen innovative financing for emerging technologies in the Asia-Pacific region:

1) Establish national technology-finance platforms that connect ministries, development banks, private financial institutions, investors, technology providers, universities and enterprises. These platforms can identify priority technologies, develop project pipelines and match projects with appropriate financing instruments.

2) Expand blended finance and guarantee schemes for SMEs. Public and development finance should be used strategically to reduce risk, crowd in private capital and support firms adopting clean technologies, digital systems and circular economy solutions.

3) Encourage project aggregation. Individual SME technology projects are often too small for institutional investors; aggregating projects by sector, location or technology type can reduce transaction costs and create investable portfolios.

4) Keep sustainable finance standards credible but proportionate. Standards are essential to prevent greenwashing, but overly complex reporting requirements may exclude SMEs. Simplified disclosure frameworks and practical indicators can improve participation.

5) Mainstream gender-responsive finance. Women-led enterprises should have access to dedicated financing windows, mentorship, investor-readiness support and gender-sensitive performance indicators.

6) Link finance to capability-building. Technology adoption requires managerial skills, technical support, digital readiness and environmental measurement capacity. Finance without capability may lead to weak implementation.

7) Strengthen regional cooperation. Asia-Pacific economies can share technology information, financing models, standards, case studies and investment platforms. Regional cooperation can also support cross-border technology transfer and climate finance.

8) Use simple, credible and outcome-oriented impact measurement. Indicators may include emissions reduced, energy saved, waste diverted, jobs created, women entrepreneurs supported, productivity improved and technologies commercialised.

13. Conclusion

Emerging technologies can support sustainable innovation, SME resilience and green transition in the Asia-Pacific region. However, technological promise will not automatically become development impact. The missing link is often finance. Promising technologies remain under-adopted when firms lack affordable capital, investors perceive high risk, and public support is not sufficiently connected to market-based financing mechanisms.

Innovative financing models can help bridge this gap. Green finance, sustainability-linked finance, blended finance, public-private partnerships, venture capital, impact investment, carbon markets and results-based finance each play different but complementary roles. A stronger approach is to build a financing ecosystem that supports technologies from early-stage innovation to commercial scale rather than relying on a single instrument.

For the Asia-Pacific region, innovative finance should be understood as a strategic capability for technology transfer and sustainable development. It can help governments move from policy ambition to implementation, SMEs move from intention to adoption, and investors move from risk avoidance to impact-oriented participation. The future of emerging technology finance will, therefore, depend not only on mobilising more capital, but also on the right kind of capital: inclusive, patient, accountable and aligned with long-term sustainable development.

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GreenTech Transition and Financial Innovation: Emerging Mechanisms for Sustainable Development

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ABSTRACT

The transition to low-carbon and climate-resilient technologies requires innovative financing solutions to address challenges such as high upfront and operational costs, limited access to funding, technological and investment risks, and concerns about impact assessment and verifiability. We explore how emerging financing instruments, including sustainability-linked loans and bonds, blended finance, asset tokenisation, and blockchain-enabled financing, are driving the adoption of green technologies in the Asia-Pacific region. Drawing on case studies from energy-efficient data centres, renewable energy infrastructure, energy efficiency solutions for Small and Medium Enterprises (SMEs), and digital green bond issuances, the article highlights how performance-based financing, public-private risk-sharing, and IoT-enabled verification can reduce financing barriers and mobilise capital. The findings suggest that innovative financing frameworks can accelerate adoption of sustainable technology, while supporting industrial competitiveness under evolving regulations such as the European Union's Carbon Border Adjustment Mechanism (CBAM). In conclusion, we highlight the need for harmonised taxonomies and supportive policies to scale sustainable finance across Asia-Pacific economies.

Keywords: climate change, sustainable development, green technology, sustainability-linked loans, blended finance, performance-based financing, asset tokenisation

1. Introduction

Growing climate risks and extreme weather events pose significant challenges to sustainable development. The Asia-Pacific region, accounting for more than half of global greenhouse gas emissions, includes some of the world's most climate-vulnerable economies, with projected temperature increases and sea-level rise expected to exceed global averages under a high-emissions scenario (Asian Development Bank, 2024). Limiting global warming to 1.5°C requires greenhouse gas emissions to be reduced to nearly half by 2030, with the largest emitting countries expected to make the most substantial reductions (United Nations Environment Programme, 2024). Achieving this transition will require widespread adoption of low-carbon and climate-resilient technologies. It is projected that around USD 9-10 trillion is required annually to finance this transition. However, the economic costs of delayed action are likely to be far greater, including losses from stranded assets, climate-induced migration, and rising adaptation and mitigation expenditures (Buchner et al., 2023). Yet, mobilising finance remains a primary bottleneck for scaling up climate-resilient technologies.

Historically, climate finance has been largely driven by public sources such as supranational organisations, national governments, and development banks. Nationally Determined Contributions (NDCs), pledged under the Paris Climate Agreement, have further strengthened the resolve to finance the transition, yet an estimated USD 6 trillion is required by 2030 to meet these targets (United Nations Development Programme, 2025). Bridging this gap will require the effective mobilisation of private capital alongside public finance. While climate policy uncertainty and investment risks remain challenges in attracting private capital, financing this transition is also increasingly seen as an important investment

opportunity. Effective policies can play a key role in making investments in low-carbon technologies commercially viable through subsidies and tax incentives. Given the long gestation periods of these projects, mechanisms such as feed-in tariffs and guaranteed prices can provide revenue certainty, while de-risking instruments, such as first-loss guarantees, can protect investors against potential losses, thereby making GreenTech investments more attractive to private capital (Koerner et al., 2022; McKinsey, 2023). Further, sustainability outcomes need to be tied to actual investments to enhance credibility and attract greater investor participation (Asian Development Bank, 2024).

Innovative financing instruments, such as sustainability-linked bonds and loans, blended financing, performance-based financing, and tokenised bonds, have emerged as important mechanisms for addressing these challenges and mobilising capital towards green technology investments. This article examines financial instruments through four case studies that demonstrate their role in mobilising capital for green technologies. The following sections provide an overview of emerging innovative financial instruments, followed by four case studies from the Asia-Pacific region. The article then discusses key challenges and opportunities, presents policy recommendations and a conceptual framework, and concludes with final remarks.

2. Innovative Financial Instruments

2.1. Sustainability-linked Bonds (SLBs)

Sustainability-linked bonds (SLBs) are an innovative sustainable finance instrument where the financing costs of the bond or other financial characteristics are linked to specific sustainability performance targets. Unlike traditional green bonds, which include use-of-proceeds clauses that restrict funds to eligible green projects, SLBs do not impose such restrictions. Instead, the bond's financial terms are linked to the achievement of predetermined key performance indicators (KPIs) within a specified timeframe (Organisation for Economic Co-operation and Development, 2025). If the issuer fails to meet these targets, the coupon rate generally increases, whereas meeting the targets may result in more favourable financing terms. This structure directly links financing incentives to sustainability outcomes while providing greater flexibility in capital use. This makes SLBs particularly useful for firms in transition-intensive sectors where sustainability improvements require broader operational changes rather than investment in a specific green project.

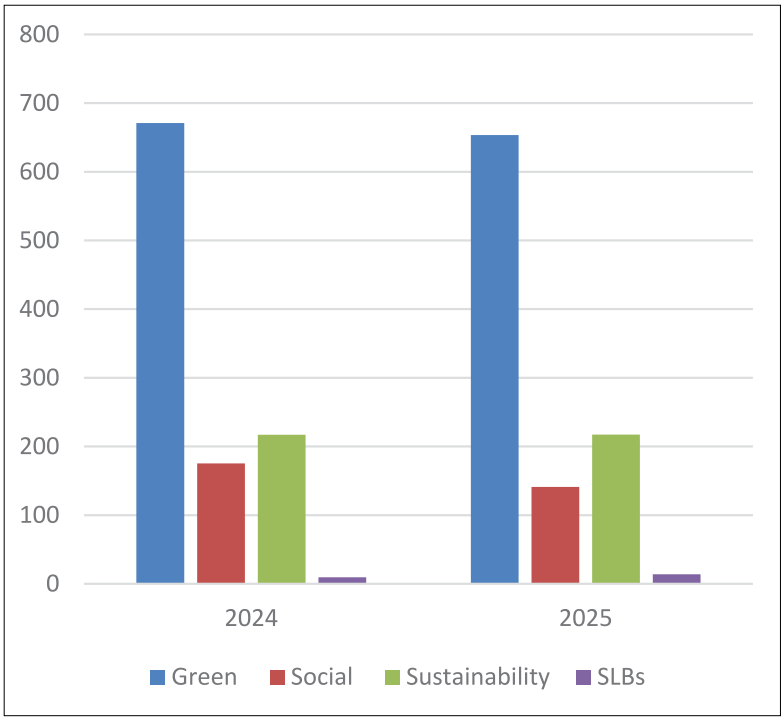

Figure 1: Green, Social, Sustainability and Sustainability-linked Bond Issuances in USD Billions

Source: Climate Bonds Initiative

Sustainability-linked bonds are still at a relatively early stage of development, with the first SLB issued by the utility company, Enel, in 2019 (Vulturius et al., 2024). Figure 1 illustrates the global issuance of green, social, sustainability, and sustainability-linked bonds over the last two years. Green bonds continue to dominate the sustainable bond market, accounting for approximately 64% of total issuance in 2025. Sustainability-linked bonds have also witnessed steady growth, with annual issuance increasing from around USD 9.6 billion in 2024 to USD 14 billion in 2025, representing a 46% YoY increase (Climate Bonds Initiative, 2026).

2.2. Blended Finance

Blended finance refers to the strategic use of public and philanthropic capital to mobilise private capital towards projects that deliver sustainable development outcomes. Traditionally, sustainability projects have mostly depended on public concessional funds and grants, as private capital considers them too risky or unprofitable due to their high costs and investment risks. Blended finance enables private investors to participate by using concessional capital to improve the risk-return profile of projects (Flammer et al., 2026). A common mechanism is the first-loss tranche, in which public or philanthropic funds are placed at the bottom of the capital stack to absorb initial losses if a project fails. Private investors only start losing money after this cushion is exhausted. This protects private capital and makes otherwise risky projects commercially viable (Organisation for Economic Co-operation and Development, 2026).

Other de-risking mechanisms commonly used in blended finance include first-loss guarantees (in which a guarantor covers a specified percentage of losses) and cross-currency swaps (which hedge against currency fluctuations). Blended finance is particularly important for sustainability projects with high impact in countries where political and investment risks discourage private investors. In such cases, concessional capital is used to help attract private investment rather than to substitute for it (Flammer et al., 2026). Figure 2 presents the distribution of blended finance deals by sub-sector from 2022 to 2024 (Convergence Blended Finance, 2025). The data reveals that renewable energy accounted for the largest share at 47%, followed by transportation infrastructure (21%) and water/sanitation infrastructure (16%).

2.3. Performance-based Financing

Performance-based financing is a financing mechanism where funds or payments to service providers are linked to performance or results achieved. Unlike traditional financing, which provides funds upfront, performance-based financing links payments to actual results (World Bank, 2022). For example,

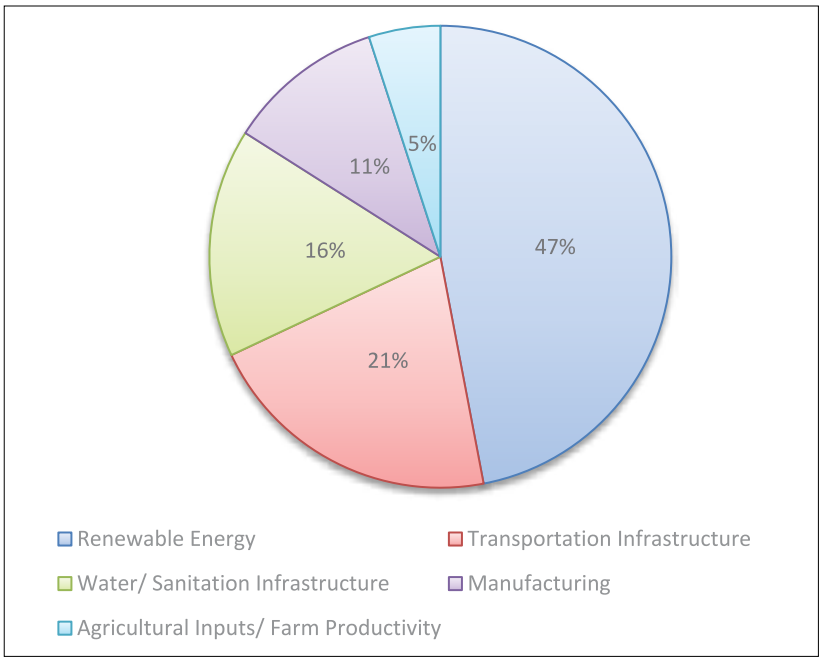

Figure 2: Distribution of Blended Finance Deals by Sub-Sector, 2022–2024

Source: Convergence State of Blended Finance 2025

payments may depend on the amount of energy saved or emissions reduced. This ensures that funding is tied to measurable outcomes rather than planned activities, serving as an important enabler for small and medium enterprises and allowing them to adopt capital-intensive technologies that were previously inaccessible.

A key feature of performance-based financing is the verification of results. IoT sensors, smart meters, and digital monitoring systems are often used to track energy savings and other outcomes in real time, ensuring that payments are linked to actual performance rather than estimates. By reducing upfront costs and linking payments to actual performance, this approach can help businesses adopt sustainable technologies while lowering financial and operational risks. For instance, in a Kenyan initiative using solar-powered cold storage hubs, farmers using a performance-based payments service increased their incomes by 20–40% while cutting food waste to as low as 2% (Refindustry, 2025). At the same time, verifying measurable outcomes improves transparency and accountability while reducing the risk of greenwashing.

2.4. Asset Tokenisation

Asset tokenisation is the process of converting ownership rights in a financial asset into digital tokens that can be recorded, traded, and tracked using distributed ledger technology (DLT) or blockchain-based platforms. Tokenisation of financial instruments, such as green and sustainability bonds, offers several advantages over traditional mechanisms.

Tokenisation enables fractional ownership, lowering entry barriers and broadening access to investment opportunities by widening the pool of investors. A wider, more diverse investor base can improve market liquidity by enabling more participants to buy and sell tokens, reducing the risk of illiquidity that often affects traditional bond markets (Hong Kong Monetary Authority, 2023). Further, blockchain-based technology can also improve transparency and verification while enabling other stakeholders to track and verify transactions and sustainability outcomes and helping to reduce concerns about greenwashing. For instance, in a study of 15 European green enterprises, blockchain-enabled systems improved carbon reporting accuracy by 25%, delivered 18% savings in wasted energy and showed a 15% reduction in operational costs (Zhang, 2025). To understand how these instruments function, the following section examines four real-world case studies from the Asia-Pacific region, each illustrating how innovative financing mechanisms reduce traditional investment barriers and support capital flows into green technology.

3. Case Studies

3.1. AirTrunk, Asia-Pacific and Japan

The growing demand for artificial intelligence and cloud computing has accelerated the need for data centres (Cruzes, 2026). Data centres are highly resource-intensive, with their share of global electricity demand projected to increase from around 2% currently to 4% by 2030 (Deloitte, 2024). Cooling systems alone can account for up to 40% of a data centre's energy consumption and may require 3-5 million gallons of water per day in large facilities (Johnson, 2025). Amid these growing environmental concerns, AirTrunk, a leading hyperscale data centre operator in the Asia-Pacific and Japan region, provides a notable example of how innovative financial instruments can mobilise finance for sustainable infrastructure.

AirTrunk utilises sustainability-linked loans and bonds to raise capital for its regional expansion. In 2025, it closed an A$16 billion (Australian dollar) sustainability-linked financing deal, becoming one of the largest sustainable finance issuers in the data centre industry. Through these instruments, the company links borrowing costs to key performance indicators focused on energy efficiency, renewable energy adoption, water efficiency, and social impact, embedding sustainability considerations across its digital infrastructure footprint. The company targets industry-leading levels of operational efficiency through metrics such as Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE), while increasing the share of renewable energy used to meet its electricity requirements, aligning its commitment with the UN's Sustainable Development Goals (AirTrunk, 2025).

Unlike traditional debt financing, sustainability-linked instruments can create direct financial incentives for organisations to achieve measurable environmental impact. The case demonstrates how performance-based financing can reduce funding constraints for resource-intensive industries, such as data centres, while encouraging greater accountability for environmental performance.

3.2. Just Energy Transition Partnership (JETP), Indonesia

With electricity generation remaining heavily dependent on coal and energy demand continuing to rise, Indonesia faced the urgent challenge of transitioning to clean energy while ensuring a just transition for workers and communities dependent on the coal industry (Resosudarmo et al., 2023). The early retirement of coal power plants and the scaling of renewable energy infrastructure required massive investments. In 2022, the Indonesian Government entered into a partnership with the International Partners Group (which includes the governments of Canada, the United Kingdom, the United States, Denmark, France, Germany, Italy, Japan, and Norway) and the Asian Development Bank, acting as the lead development partner, to mobilise more than USD 20 billion over the next 3–5 years to support Indonesia's clean energy transition (Jazuli et al., 2024).

The JETP uses a blended finance model funded jointly by public and private investments. Around USD 10 billion is provided by the International Partners Group, while the remainder is expected to be raised through private investment (PricewaterhouseCoopers, 2024). The blended finance structure helps reduce investment risks and makes clean energy projects more commercially viable. The project also enables the partners to contribute their technical expertise and know-how to support the development of innovative technologies. A key part of the JETP is its blended finance approach, which uses concessional loans, commercial debt, guarantees, and carbon credit revenues to make renewable energy projects more viable. By combining concessional funding with commercial finance, the partnership aims to lower borrowing costs, increase project profitability, and attract additional private investment (Asian Development Bank, 2024). The initiative also includes a just transition framework to support workers and communities affected by the move away from coal. This case study demonstrates how a combination of public and private funding, technical expertise, and institutional coordination can reduce investment risks and mobilise capital for new green technologies.

3.3. Smart Joules, India

As global warming intensifies, demand for cooling energy continues to rise across India, while many businesses face difficulties in investing in energy-efficient technologies due to the significant upfront capital required (Gupta, 2025). Smart Joules provides an interesting solution to this problem through its innovative models. While the company is headquartered in Delhi, it has expanded pan-India, serving prominent hospital chains such as Apollo, Fortis, and Aster, among others (Smart Joules, 2019). The company offers "Cooling as a Service (CaaS)", in which it owns, operates, and maintains cooling infrastructure for large and MSMEs (Micro, Small and Medium Enterprises) businesses, while the client only pays for the cooling service they consume. This enables client businesses to reduce the upfront costs and transfer the operating risks to the service provider, thereby transforming a large capital expenditure into a manageable operating expense.

The company also provides a "Pay as you Save" service for implementing energy conservation measures and energy-efficiency technology upgrades in existing buildings. The client does not pay the cost of the upgrades; instead, they pay from the energy savings. IoT and AI-enabled tracking of energy savings ensures payments are linked to actual performance.

Smart Joules is using these innovative performance-based models to enable companies to adopt energy-efficient technologies and make a significant impact, particularly in the hospital and healthcare sectors in India (ADB Ventures, 2023). The case highlights how removing the need for large upfront investments and linking payments to actual savings can reduce barriers to the adoption of green technologies while encouraging more efficient energy use.

3.4. Digital Green Bonds, Hong Kong Special Administrative Region (HKSAR) Government

The HKSAR Government in Hong Kong issues digital green bonds, which combine sustainable finance with digital technologies to improve the efficiency, transparency, and accessibility of green bond markets.

Unlike conventional bonds, digital green bonds utilise asset tokenisation, whereby bond ownership and transactions are recorded on a digital ledger (Hong Kong Monetary Authority, 2023). Blockchain technology streamlines issuance and settlement processes, reducing administrative costs. The platform also integrates green disclosures with the digital asset, improving transparency in the management and reporting of funds raised for environmental projects.

A key feature of tokenised bonds is fractional ownership. Traditional green bonds often have high minimum investment amounts, making them out of reach for smaller investors. Tokenisation divides a single bond into many smaller digital tokens, each representing a fraction of the underlying asset. This significantly lowers the entry barrier, allowing participation from a wider pool of investors and potentially improving market liquidity for these bonds. The third issuance of these bonds in November 2025 also integrated e-CNY (electronic Chinese Yuan) and e-HKD (electronic Hong Kong Dollar), enabling shorter T+1 settlement cycles and reducing costs and counterparty credit risk (Hong Kong Monetary Authority, 2025).

The case demonstrates how HKSAR's tokenised green bonds combine blockchain with green finance to address persistent barriers in sustainable debt markets by improving access and liquidity, reducing costs and settlement cycles, and enhancing transparency and accountability in the use of proceeds.

4. Challenges, Opportunities and Policy Recommendations

Despite the growing adoption of innovative financing mechanisms, economies face several challenges that continue to limit their ability to mobilise capital at the scale required for the transition to green technology. A major constraint is the shortage of commercially viable green technology projects. Even when capital is available, projects with clear financial returns and measurable environmental impact remain limited, discouraging private capital. This challenge is particularly pronounced in emerging economies, where policy uncertainty, inconsistent regulatory frameworks, and the lack of standardised sustainability taxonomies increase investment risk. Without harmonised taxonomies aligned with global standards, mobilising cross-country private capital remains challenging.

Further, many innovative financing instruments rely on the measurement and verification of sustainability outcomes. However, the digital infrastructure required to support these processes, including IoT and AI-based monitoring systems and blockchain platforms, remains underdeveloped in several developing economies (Ahmad et al., 2025). Regulatory uncertainty and limited institutional capacity may further slow the adoption of these technologies. Addressing these challenges is crucial in improving accountability, reducing greenwashing concerns, and building investor confidence in sustainable finance markets.

Significant opportunities exist, despite these challenges. Advances in digital verification technologies and blockchain platforms are making it easier and more cost-effective to monitor and verify sustainability outcomes. At the same time, efforts to align sustainability taxonomies, such as the European Union Taxonomy and the Association of Southeast Asian Nations (ASEAN) Taxonomy for Sustainable Finance, are helping to reduce fragmentation across jurisdictions. As common standards emerge, cross-border investments are likely to become more efficient and accessible. Multilateral development banks and development finance institutions are also expanding the use of blended finance and risk-sharing mechanisms to attract private capital into green projects, particularly in emerging economies (International Monetary Fund, 2024). In addition, rising carbon prices in both voluntary and compliance markets are creating new revenue opportunities for low-carbon investments.

A particularly significant opportunity stems from the European Union's Carbon Border Adjustment Mechanism (CBAM). CBAM imposes carbon tariffs on imports of high-emission goods, such as steel, aluminium, and fertilisers. For Asia-Pacific economies that rely heavily on exports to European markets, this creates a strong economic case for adopting green technologies. Industries that invest early in low-carbon production will gain a competitive advantage, helping them maintain market access and reduce future costs. This creates a strong incentive for governments and businesses in the region to prioritise green technology financing and accelerate the transition towards more sustainable production systems.

To address these challenges and capitalise on emerging opportunities, policymakers should focus on strengthening digital verification infrastructure, including IoT and AI-based monitoring systems, while creating regulatory frameworks that enable the safe adoption of blockchain-based financing instruments. Further, policymakers should work towards harmonising sustainability taxonomies at the regional and international levels to facilitate cross-border investments. Targeted tax incentives and subsidies can lower upfront costs and improve project viability, particularly for SMEs. In addition, development banks, public finance institutions, and governments should expand blended finance and risk-sharing mechanisms to attract private capital and support the adoption of low-carbon technologies. Together, these measures can improve access to finance, reduce investment risks, and accelerate the green transition across the Asia-Pacific region.

5. Framework for Innovative Financing Mechanisms for Green Technology Adoption

Based on our study, we present a conceptual framework (Figure 3) to understand the key enablers of innovative financing for green technologies. The framework is built around three interconnected pillars: technological, financial, and regulatory. The technological pillar focuses on digital tools such as IoT-enabled monitoring systems, AI-based verification, and blockchain platforms that improve transparency, verification, and accountability of sustainability outcomes. The financial pillar comprises mechanisms such as blended finance, concessional capital, first-loss guarantees, and performance-based financing that help reduce investment risks and improve access to capital. The regulatory pillar includes supportive policies, sustainability taxonomies, disclosure standards, subsidies, and public-private partnerships that create an enabling environment for sustainable investment. Together, these pillars help address key

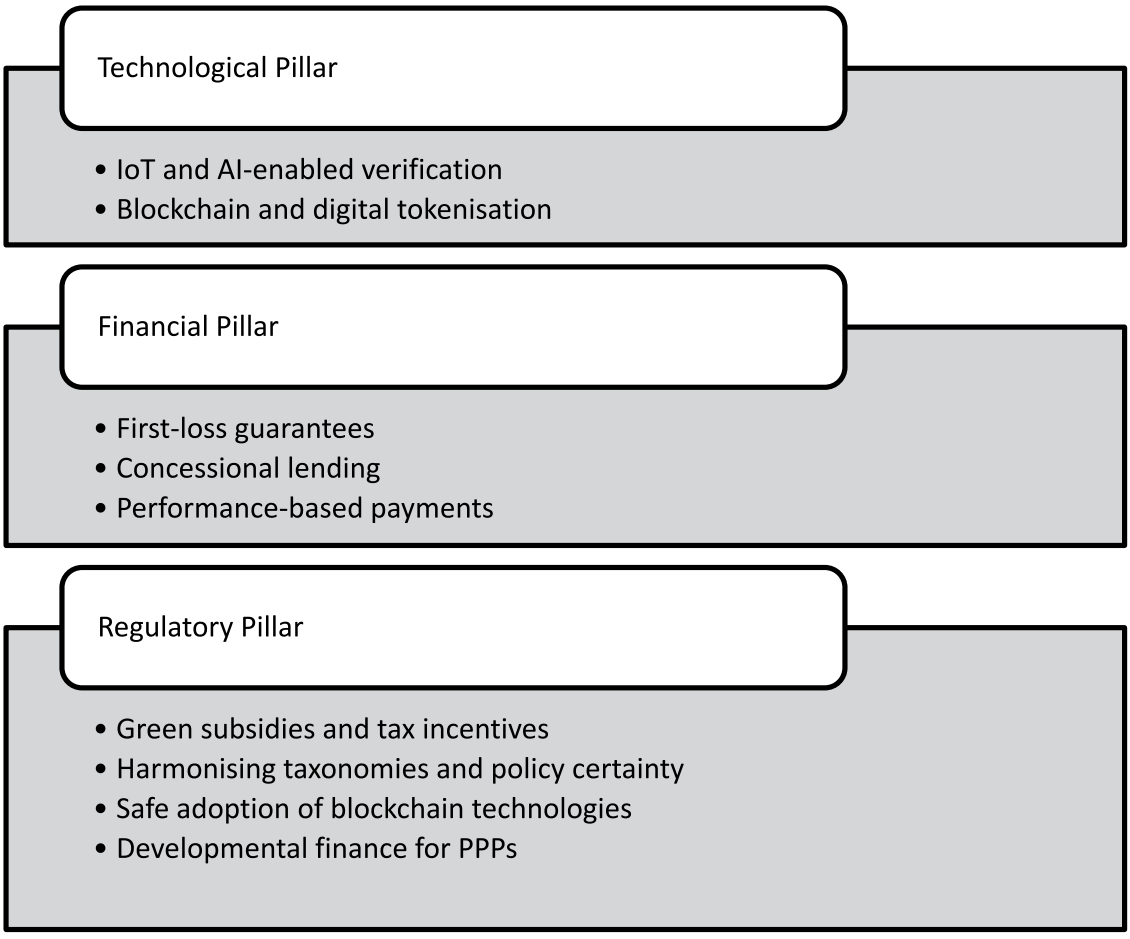

Figure 3: Framework for Innovative Financing Mechanisms for the Adoption of Green Technologies

Source: Author

barriers relating to financing, risk, transparency, and verification, thereby supporting the mobilisation of private capital and the adoption of green technologies.

6. Conclusion

Financing remains one of the most significant barriers to the large-scale adoption of green technologies. This article examined how innovative financing mechanisms, such as sustainability-linked instruments, blended finance, performance-based financing, and asset tokenisation, can help overcome these constraints by reducing investment risks, improving access to capital, enhancing transparency, and linking financing to measurable sustainability outcomes. The article draws upon four contemporary case studies from the Asia-Pacific region to demonstrate how innovative financing removes investment barriers and democratises access to green technology investments. The article also provides policy recommendations and presents a conceptual framework, highlighting the key enablers of innovative financing mechanisms for green technology adoption. With appropriate policy support and enabling frameworks, these innovative financing mechanisms can play an important role in mobilising private capital and accelerating the adoption of green technologies across the Asia-Pacific region.

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Financing Asia's Energy Transition: Role of Climate Bonds in Scaling Emerging Technologies in China, India, and the Republic of Korea

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Abstract

Asia's energy transition requires long-term capital at a scale public finance alone cannot supply, and climate bonds have emerged as a principal instrument for mobilising it. This article examines how corporate green and sustainability bond finance is allocated within the energy and utilities (E&U) sectors of China, India, and the Republic of Korea (ROK), and traces the economy-wide consequences of those allocations. Firm-level E&U bond issuances are mapped through creating detailed use-of-proceeds (UoPs) profiles, integrated by sector and region into the EXIOBASE 3, an environmentally extended multi-regional input-output (EE-MRIO) framework. This enabled estimation of direct and indirect domestic and cross-border value added, embedded greenhouse gas (GHG) emissions, and employment effects generated by bond-financed investments across global supply chains. Through comparative case studies of China, India, and ROK, the analysis identifies three distinct economy-wide signatures: China, anchored in a domestic manufacturing base, retains roughly 89 per cent of value added at home and carries the lowest GHG intensity, at 928 tonnes CO_2e per million dollars of issuance; ROK, whose taxonomy admits gas-fired generation as a transitional activity, registers the highest GHG intensity, at 2,005 tonnes; and India, dependent on imported components for panel modules and inverters, retains 73 per cent of value added domestically, with 27 per cent externalised across its trading partners, with associated GHG intensity of 1,257 tonnes CO_2e per million dollars of issuance. The results show that taxonomy design, industrial structure, and trade orientation jointly determine whether a climate bond's developmental promise is realised within the issuing economy or distributed across the supply chains that serve it, with direct implications for how alignment with Nationally Determined Contributions (NDCs) should be assessed across the Asia-Pacific.

Introduction

Asia's energy transition is advancing rapidly; however, despite falling renewable energy costs and accelerating technological progress, investment flows remain insufficient. The International Energy Agency (IEA) estimates that annual clean energy investment in emerging and developing economies, excluding China, must increase from the existing approximately USD 260 billion to nearly USD 1.4–1.9 trillion by the early 2030s to remain aligned with global climate goals (IEA, 2023). Southeast Asia alone will require nearly USD 190 billion annually to support long-term decarbonisation pathways and energy system transformation (IEA, 2022). These financing requirements substantially exceed the capacity of public finance alone. Simultaneously, Asia's increasing exposure to heat stress, floods, sea-level rise, water scarcity, and extreme weather events has made adaptation finance equally critical alongside mitigation investments (United Nations Environment Programme (UNEP), 2024; Asian Development Bank (ADB), 2024).

Despite the rapid expansion of climate finance markets, several structural characteristics continue to constrain sustainable finance mobilisation across emerging economies of Asia. High capital costs, elevated sovereign risk, and currency volatility significantly increase financing costs for renewable

energy and low-carbon infrastructure projects in emerging markets (International Renewable Energy Agency (IRENA), 2023; International Monetary Fund (IMF), 2023). Financial systems across many Asian economies remain institutionally bank-dominated, with relatively shallow corporate bond markets and limited institutional investor participation, restricting the availability of long-term transition finance (ADB, 2024). In addition, fragmented sustainable finance taxonomies, inconsistent Environmental, Social, and Governance (ESG) disclosure standards, and weak climate-risk reporting frameworks continue to generate regulatory uncertainty and concerns regarding greenwashing (Organisation for Economic Co-operation and Development (OECD), 2023). These economies also exhibit strong fossil-fuel dependence and carbon lock-in through coal-intensive industrial structures and energy systems, which increase transition risks and complicate capital reallocation toward cleaner technologies (IEA, 2024). Further, although Asia remains among the world's most climate-vulnerable regions, adaptation finance flows remain substantially below estimated requirements, particularly for resilient infrastructure, water systems, agriculture, and coastal protection (UNEP, 2024; ADB, 2024).

Within this context, green bonds have emerged as one of the most important innovative instruments for mobilising long-term climate finance. Green bonds are debt instruments whose proceeds are earmarked specifically for green transition and environmentally beneficial projects, including renewable energy systems, clean transportation, energy efficiency upgrades, resilient infrastructure, and climate adaptation initiatives (International Capital Market Association (ICMA), 2021). By linking debt issuance with climate-oriented investment, green bonds expand access to long-term capital while attracting environmentally conscious institutional investors and ESG-oriented portfolios (Flammer, 2021). Importantly, green bonds also improve transparency and accountability through disclosure requirements, certification standards, and use-of-proceeds reporting frameworks, thereby strengthening investor confidence in climate-related investments (OECD, 2020). Studies suggest that green bonds generally perform comparably to conventional bonds in financial markets and may occasionally benefit from a "greenium", where investors accept slightly lower yields in exchange for environmental credibility and reduced transition risk exposure (Zerbib, 2019; Tang & Zhang, 2020). Beyond financial performance, empirical studies increasingly associate green bond issuance with measurable environmental improvements. Firm-level evidence indicates that green bond financing contributes to reductions in carbon emissions, improvements in environmental governance, and increased investment in clean technologies (Flammer, 2021; Tolliver et al., 2020).

However, the literature also highlights significant heterogeneity in the effectiveness and distribution of green finance across countries and sectors. Environmental outcomes depend heavily on institutional setup, depth and structure of financial markets, policy coherence, and industrial structure (Taghizadeh-Hesary & Yoshino, 2020). Studies emphasise that green bonds are most effective when embedded within broader climate policy frameworks supported by clear taxonomies, disclosure standards, transition strategies, and climate-aligned financial regulation (OECD, 2020; IMF, 2023). Governance mechanisms such as third-party verification, environmental reporting obligations, investor monitoring, and ESG-linked disclosure requirements play a critical role in determining whether green finance translates into measurable sustainability outcomes (ICMA, 2021). Moreover, green bond issuance increasingly serves as a signalling mechanism through which firms communicate commitment to low-carbon transition pathways and cleaner technologies under conditions of market uncertainty (Tang & Zhang, 2020; Flammer, 2021).

Since the launch of the first green bond by the World Bank (WB) in 2008, green bonds have evolved into a major component of global sustainable finance markets by linking debt issuance directly to environmentally beneficial investments (World Bank, 2008). The global green and sustainable debt markets have expanded rapidly, with cumulative climate-aligned sustainable debt surpassing USD 6 trillion by 2025, according to the Climate Bonds Initiative (Climate Bonds Initiative, 2025d). Green bonds alone continue to dominate sustainable debt issuance, accounting for over 60% of aligned sustainable finance markets in 2024 (Climate Bonds Initiative, 2025c). Asia's green and sustainability bond market has emerged as one of the fastest-growing segments of global sustainable finance, driven by rising climate commitments, renewable energy deployment, and industrial decarbonisation needs. By the end of 2024, Asia accounted for nearly 24% of the global sustainable bond market, with outstanding sustainable bonds issued by Asian companies reaching approximately USD 572 billion (OECD, 2025). China remains the dominant regional issuer, accounting for nearly 43% of Asia-Pacific green funding, followed by Japan, the Republic of Korea, Singapore, and India (Climate Bonds Initiative, 2025c). Hong Kong alone arranged over USD 43 billion in Green, Social, Sustainability, and Sustainability-linked (GSS+) bonds in

2024, representing nearly 45% of Asia's international sustainable debt market (Climate Bonds Initiative, 2025a). India's sustainable debt market has also expanded rapidly, with cumulative GSS+ issuance reaching nearly USD 56 billion by the end of 2024, largely concentrated in clean energy, transport, and infrastructure sectors (Climate Bonds Initiative, 2025b). Despite this rapid expansion, Asia's green bond market continues to face several structural constraints, including fragmented taxonomies, inconsistent disclosure standards, currency risks, limited secondary market liquidity, and concerns regarding greenwashing (OECD, 2025).

The energy sector's role in the low-carbon transition is pivotal, with the sector's investment generating disproportionately large economy-wide and environmental spill-overs. Further, globally, this sector also emerges as one of the key sectors driving green and sustainability bonds linked to climate finance. A key component of green bond evaluation is **use-of-proceeds (UoP) analysis**, which assesses whether funds are allocated to eligible environmental projects. UoP disclosure enhances transparency and investor confidence and supports post-issuance monitoring (Labatt & White, 2002; ICMA, 2023). Yet, it does not ensure environmental additionality, as it may not reflect changes in issuers' overall emissions or investment behaviour (OECD, 2020; Network for Greening the Financial System (NGFS), 2024). Consequently, third-party reviews, such as second-party opinions, verification, and certification, serve as governance mechanisms that reduce information asymmetry and limit greenwashing (Zerbib, 2019; Flammer, 2021); though differences in review rigour still raise comparability and harmonisation concerns (OECD, 2020).

This article examines the role of green bonds in supporting Asia's energy transition through a comparative analysis of corporate utility and energy-sector bond investments in China, India, and the Republic of Korea. The three economies represent distinct transition pathways shaped by differing levels of industrial development, financial-market maturity, technological capability, and climate-policy ambition. China leads in renewable-energy manufacturing and green bond issuance, India represents a rapidly expanding renewable-energy market facing developmental and financing challenges, while Republic of Korea pursues technology-intensive transition strategies centred on industrial modernisation and advanced energy systems. Together, these economies provide important insights into how green finance is shaping Asia's low-carbon transition pathways.

Methodology and Analytical Framework

This study employs a multi-regional input-output economy-wide assessment with a comparative analytical approach to examine the allocation of green and sustainability bond finance by corporate entities in the energy and utility sectors across major Asian economies. The analysis provides a cross-sectional overview of how corporate energy & utilities (E&U) bond investment is being distributed across transition-relevant sectors and technologies, while also identifying the distinct strategic priorities, industrial structures, and transition pathways emerging across different geographic contexts. The study focuses on understanding the composition, direction, and strategic orientation of green finance flows, along with direct and indirect economic and emission impacts that further their prospective implications for Asia's energy transition.

We construct a firm-level, sector-mapped database of green and sustainability bond investments for corporate utilities and energy-sector firms across three major Asian economies. Comprehensive bond-level UoP data are sourced from the International Capital Market Association (ICMA) sustainable bond database hosted on the Luxembourg Green Exchange (LGX) data hub (Luxembourg Stock Exchange, n.d.), which compiles issuer-level information, including issuer name, issuer location, issuer sector, bond type, number of bonds issued, issuance value (USD billion), and the latest external review form. In addition, a detailed use-of-proceeds profile is developed for each bond issuance, using firm-level bond disclosure reports, allocation statements, sustainability reports, annual reports, and ESG disclosures. Bond proceeds are systematically mapped into transition-relevant sectors, such as renewable energy, grid modernisation, energy efficiency, electric mobility, hydrogen systems, climate adaptation infrastructure, and low-carbon industrial technologies. Each observation in the dataset thus represents a unique issuer–bond type combination, enabling cross-country and sector-level comparison of sustainable finance allocation patterns and issuance strategies. The database thus provides a comparative empirical foundation for evaluating how corporate green and sustainability bond markets are shaping technology-specific investment flows and low-carbon transition pathways across Asia's utility and energy sectors.

The sectoral investment allocations are further integrated within an environmentally extended multi-regional input–output (EE-MRIO) framework based on EXIOBASE 3[1] to estimate associated domestic and international value-added generation, employment effects, and direct and indirect greenhouse gas emissions embedded across global supply chains (Stadler et al., 2026). In this study, we specifically examine allocation patterns across corporate utility and energy-sector green and sustainability bonds in these three economies to compare how differing institutional structures, financial systems, regulatory frameworks, and corporate governance models shape corporate climate-finance decisions and investment priorities. By focusing on firm-level corporate action and the direct allocation of bond proceeds, we analyse how green finance is being operationalised toward renewable energy, grid modernisation, clean transport, hydrogen systems, and other emerging transition technologies. We further assess the extent to which corporate green bond investments are contributing to structural transformation away from fossil-fuel-intensive energy systems and aligning with broader national decarbonisation pathways. The following section presents the case study findings and key comparative insights emerging from our analysis.

Case Studies

China, the Republic of Korea, and India are among Asia's more substantial issuers in the Energy & Utilities (E&U) segment, and their contrasting industrial structures, ownership models, and trade positions make them an instructive comparative frame for tracing how each of the economies' climate bond market has varied economy-wide effects in terms of value addition, embedded GHG footprint, and employment.

Figure 1: Cumulative sustainable-bond issuance in China, the Republic of Korea and India, by issuer sector and by bond type within the corporate energy and utilities segment

Source: Authors' illustration based on the ICMA database

[1] **EXIOBASE** is a global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT). It was developed by harmonising and detailing supply-use tables for a large number of countries, estimating emissions and resource extractions by industry. Subsequently, the country supply-use tables were linked via trade, creating an MR-SUT and producing MR-IOTs from this. The MR-IOT can be used for the analysis of the environmental impacts associated with the final consumption of product groups. EXIOBASE 3 is one of the most extensive EE-MRIO systems available worldwide. EXIOBASE 3 builds upon the previous versions of EXIOBASE by using rectangular supply-use tables (SUT) in a 163 industry by 200 products classification as the main building blocks.

Green bonds dominate across all three economies, particularly in India, where issuance is almost entirely renewable-focused.

ROK exhibits a more diversified structure with a relatively larger share of sustainability and social bonds, reflecting broader transition financing priorities under the Korean taxonomy framework (Figure 1). China shows a relatively diversified market structure, while the ROK's issuance is dominated by sovereign-linked and financial institutions. India displays a comparatively larger share of corporate utility issuers, reflecting the important role of private renewable-energy developers in financing the country's energy transition. Each of the three markets emerged through a distinct route.

1. China

China's market was catalysed by the People's Bank of China's green bond guidelines of December 2015, one of the first operational regulatory frameworks for bank and corporate issuance. It triggered a rapid expansion that made China one of Asia's two largest issuers of labelled debt (Escalante et al., 2020). China moved early and on its own terms; its green bonds were, for much of this period, governed in ways that diverged from the international standards, which were taking shape in parallel. Oversight was fragmented across four authorities, each with its own definitions: the People's Bank of China (PBoC) for green financial bonds, the National Development and Reform Commission (NDRC) for green enterprise bonds, the China Securities Regulatory Commission for green corporate bonds, and the National Association of Financial Market Institutional Investors for debt-financing instruments. The treatment of proceeds was comparatively lenient: where the Climate Bonds Standard requires at least 95 per cent of funds to flow to eligible green assets, Chinese rules permitted issuers to channel up to half of their proceeds into repaying bank loans or general working capital (J.-D. Lin, 2023). Furthermore, the taxonomy defined "green" more broadly than the international standards taking shape alongside it, admitting coal washing and higher-efficiency supercritical and ultra-supercritical plants under 'clean utilisation of coal', a category the Climate Bonds Taxonomy explicitly excludes (Liu, 2020). Compounding these gaps, third-party verification remained voluntary and followed no unified certification process, while sustainability disclosure was required only to a limited degree, given that the informational quality of the market was uneven and certain concerns of greenwashing have been in critique (J.-D. Lin, 2023; L. Lin & Hong, 2022). Over the years though, there has been a story of gradual, state-directed convergence and stringency in these norms, propelled by China's 2030/2060 carbon-peaking and neutrality goals; the 2021 Green Bond Endorsed Projects Catalogue unified the fragmented domestic standards and removed fossil-fuel categories from the list of eligible activities. Convergence on the use-of-proceeds followed with the 2022 China Green Bond Principles, which aligned domestic practice with the ICMA framework by requiring that the full proceeds of a green bond be allocated to eligible projects.

The Chinese E&U total sectoral allocation comes to about USD 9.3 billion, in which a major allocation has been towards renewable generation. Wind alone absorbs 40 per cent of proceeds (USD 3.75 billion) and solar photovoltaics a further 22 per cent (USD 2.0 billion); with hydro (7 per cent) and biomass (10 per cent), the four renewable categories together take close to four-fifths. The largest non-generation

Table 1: China's cumulative energy & utilities bond allocation disaggregated sector-wise

China

9 sectors · $9.38 total

Sector	M USD	%
Elec. wind	3,749.2	40.3
Elec. solar PV	2,001.6	21.5
Water collect. & distrib.	1,124.0	12.1
Elec. biomass	961.6	10.3
Elec. hydro	630.3	6.8
Gas distrib.	408.9	4.4
Elec. nuclear	268.8	2.9
Waste water treat.	83.4	0.9
Motor vehicles	69.6	0.7

Source: Authors' compilation from firm-level use-of-proceeds database using bond disclosure documents.

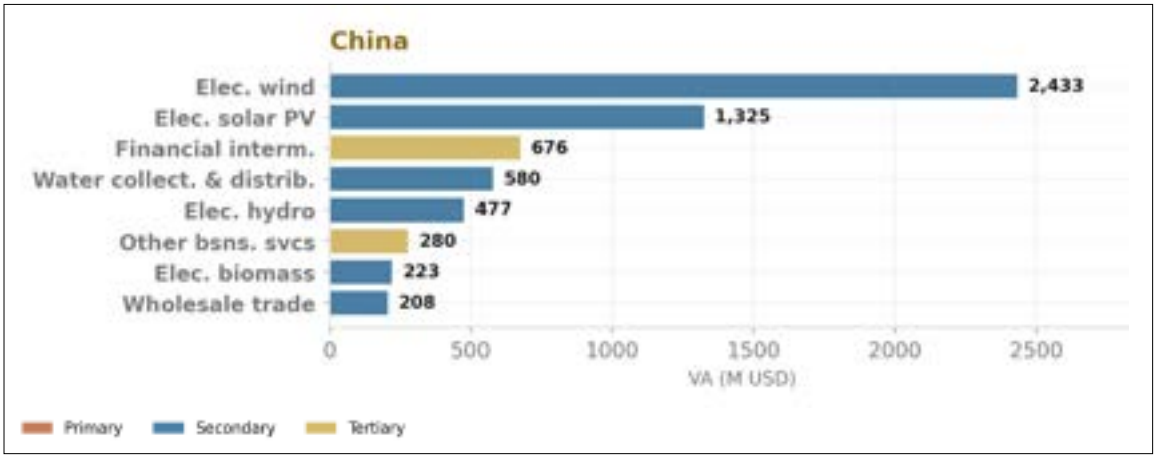

Figure 2: China's top domestic sectors by bond-induced value added (in millions USD)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

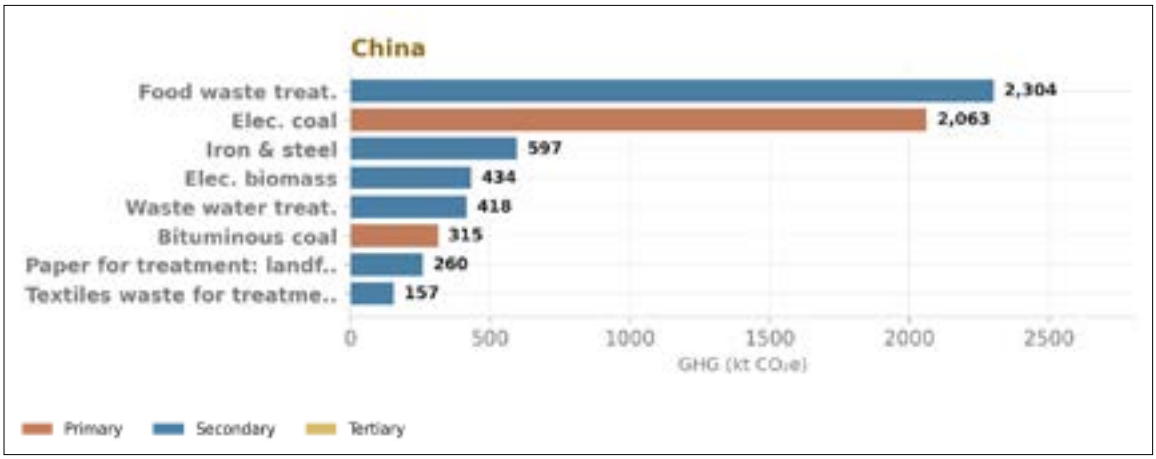

Figure 3: China's top domestic sectors by bond-induced GHG footprint (in $ktCO_2e$)

Source: Authors' illustration for EE-MRIO analysis using EXIOBASE 3

allocation is to water collection and distribution (12 per cent, USD 1.12 billion), with smaller amounts to gas distribution and nuclear (Table 1).

China retains about 89 per cent of the associated value added domestically, the highest share of the three economies in our study. As it's the manufacturing base for many of the renewable sector required components and materials, it retains that value largely in the funded sectors themselves: electricity by wind contributes the single largest block of domestic value added (USD 2,433 million), followed by solar (USD 1,325 million), water collection and distribution (USD 580 million) and hydro (USD 477 million), while financial intermediation is notable among the top five value-added sectors indirectly (Figure 2).

China manufactures the turbines, modules, and structural inputs a renewable build-out consumes; the demand the bond creates is met within its own borders, and the value it generates accrues to the generation assets it finances rather than leaking into an import dependency. The emissions panel tells a different and more revealing story, as the GHG footprint does not arise from the wind and solar activity that the bond funds directly. Rather, the largest domestic emission sources are from food-waste treatment (around 2,304 $ktCO_2e$), followed closely by coal-fired electricity (2,063 $ktCO_2e$), and iron and steel (597 $ktCO_2e$) (Figure 3).

The renewable-electricity sectors are not themselves demanding of the upstream economy, wind's backward linkage being 0.81 and solar's 0.95, both at or below the economy-wide average, but their effects are seen through the forward linkages, electricity being a near-universal input. Building and connecting new capacity in the renewables, instead, draws on construction, electrical machinery, and basic steel, and decisively on coal-fired power, which combines a high backward linkage (1.37) with the

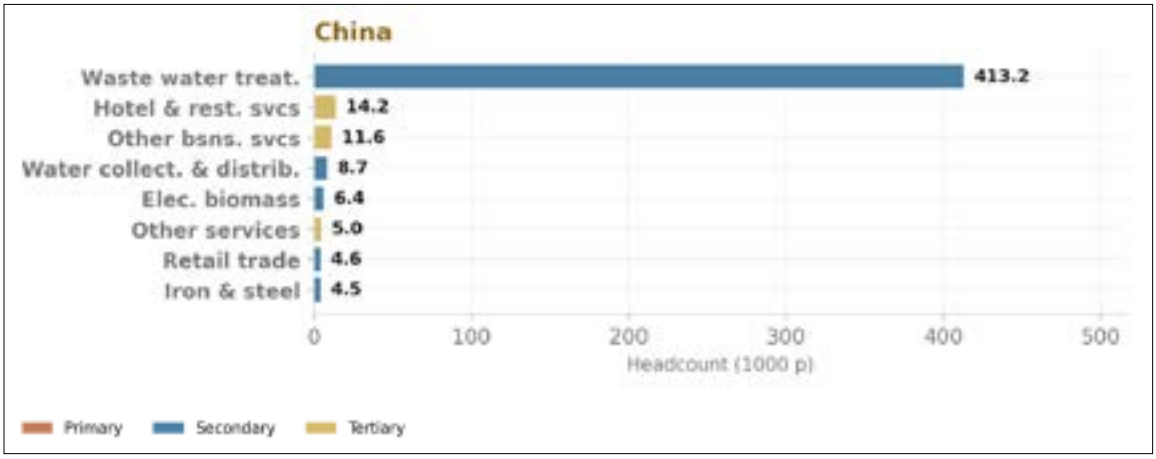

Figure 4: China's top domestic sectors by bond-induced Employment (in 1000p)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

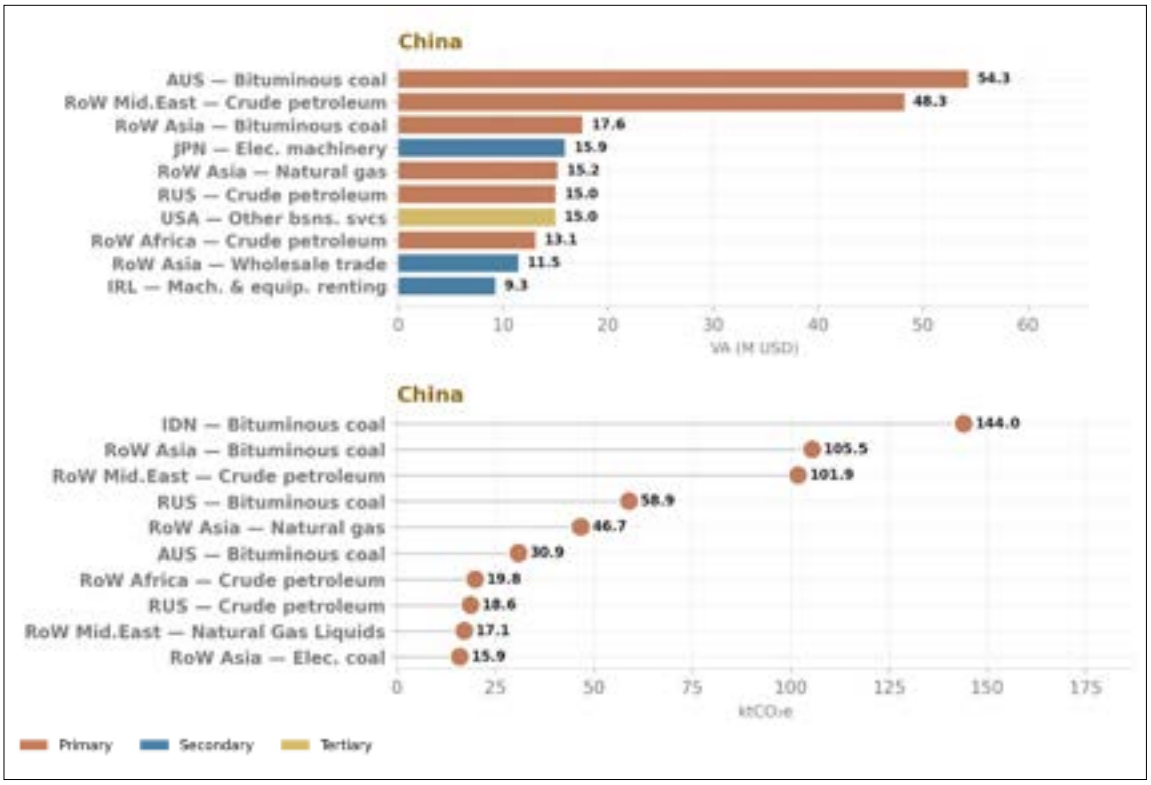

Figure 5: Cross-border value-added (in million USD) and embodied greenhouse gas emissions (in ktCO2e) induced abroad

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

broadest forward reach in the system (1.45) and so transmits its emissions across the entire production network. These are markers of the transitioning economy that's aggressively building clean capacity inside a supply chain still anchored in coal, heavy industry, and methane-intensive waste services. Around 85 per cent of the emissions arise domestically, the overwhelming majority of them through the indirect sectoral demands.

The employment results reflect wastewater treatment as the dominant labour-absorbing sector, with hospitality, business, and water-collection services as resultant indirect effects. Trailing far behind are the renewables themselves, employing comparatively few directly. Thus, 12 per cent of proceeds directed to water and waste, in other words, account for the bulk of both the bond's domestic emissions and its domestic employment. Hence, the renewables as such are not among the top employing sectors directly.

China's external footprint is correspondingly contained and diffuse. Only about a seventh of the embodied emissions surface abroad, and it is spread thinly across fuel suppliers rather than concentrated on any single partner: the largest cross-border emission flows are Indonesian and other Asian bituminous coal (144 and 106 $ktCO_2e$), Middle Eastern crude petroleum (102 $ktCO_2e$) and Russian coal, with the corresponding value-added leakage flowing to Australian and Asian coal and to Middle Eastern crude (Figure 5).

The domestic renewable projects are reliant on the region's coal and oil-linked primary sectors, but, as such, China has internalised the value addition as well as its GHG footprint within the domestic economy, compared to Korea and India. This is the dividend of an industrial base complete enough to supply most of its own transition; thus, the bonds are effectively addressing both climate finance and industrial policy.

2. India

India issued its first green bond in February 2015, when Yes Bank raised INR 10 billion through a green infrastructure bond to finance renewable energy projects (Darby, 2015); later that year, in a first of its kind, the International Finance Corporation (IFC) issued an offshore rupee-denominated 'green masala' bond, opening a parallel channel for mobilising international capital toward domestic climate goals (IFC, 2016). The market deepened over the following decade through issuance by privately held renewable developers and by public-sector banks and state financing agencies, such as REC Limited, the Power Finance Corporation and the Indian Renewable Energy Development Agency, with further support through the Reserve Bank of India's inclusion of renewable energy within priority-sector lending.
The regulatory architecture tightened in step: the Securities and Exchange Board of India first issued disclosure norms for green debt securities in 2017, mandating minimum use-of-proceeds and reporting standards, and revised them in 2023 to require independent third-party review at both the pre- and post-issuance stages (Damodaran & van den Heuvel, 2023). India's E&U segment is all concentrated in renewables, primarily in solar (47.4%) and wind (34.3%) projects, followed notably by hydro (17.9%), mostly all under a build-own-operate model backed by both foreign (ReNew, Continuum) and domestic capital (JSW, Adani, SAEL); the average bond size is among the lowest reflecting a still nascently emerging segment.

The Indian E&U total sectoral allocation comes to about USD 3.9 billion, the smallest of the three cases and is directed almost entirely to renewables; solar photovoltaics absorb 47 per cent of proceeds (USD 1.85 billion) and wind a further 34 per cent (USD 1.34 billion), with hydro (18 per cent, USD 0.70 billion) and a minor but notable allocation into electricity through biomass.

The issuance is almost entirely green-labelled, and the issuer base is privately held, with the developers building, owning, and operating the assets under a Build-Own-Operate (BOO) basis. The project aims toward long-term offtake to the state distribution utilities, with foreign (ReNew, Continuum, Greenko) and domestic (JSW, Adani, SAEL) capital alongside the public Indian Renewable Energy Development Agency.

India retains about 73 per cent of the associated value addition domestically, the lowest share of the three economies in our study. The value it does retain lands first in the directly allocated renewables sectors themselves, solar photovoltaics contributing the largest block (USD 965 million), followed by wind (USD 689 million) and hydro (USD 373 million), and then by wholesale trade, transport, and financial services through indirect associated sectors. The comparatively lower domestic retention reflects the import dependency of the renewables sector in India. Thus, although the funded sectors carry above-average

Table 2: India's cumulative energy & utilities bond allocation disaggregated sector-wise

India
4 sectors · $3.9B total

Sector	M USD	%
Elec. solar PV	1,853.8	47.4
Elec. wind	1,339.9	34.3
Elec. hydro	698.2	17.9
Elec. biomass	16.8	0.4

Source: Authors' compilation from firm-level use-of-proceeds database using bond disclosure documents.

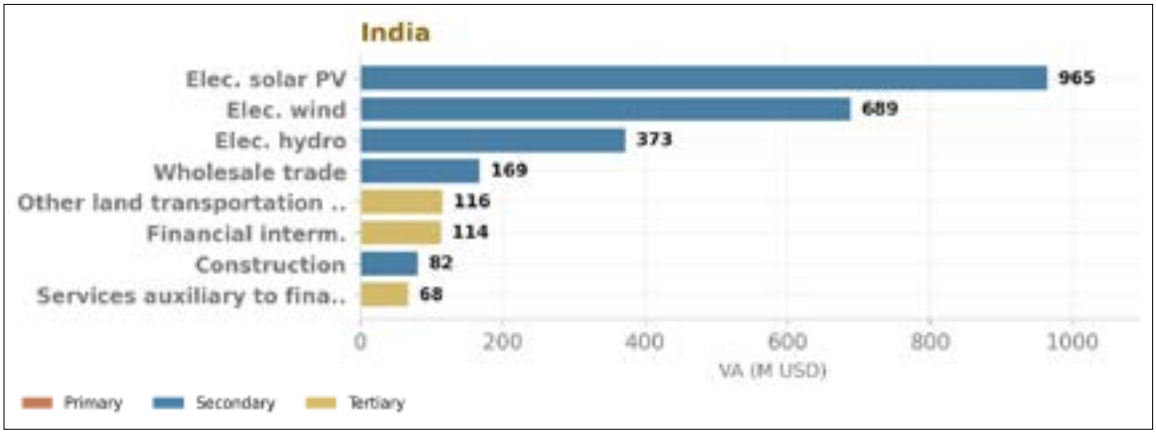

Figure 6: India's top domestic sectors by bond-induced value added (in millions USD)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

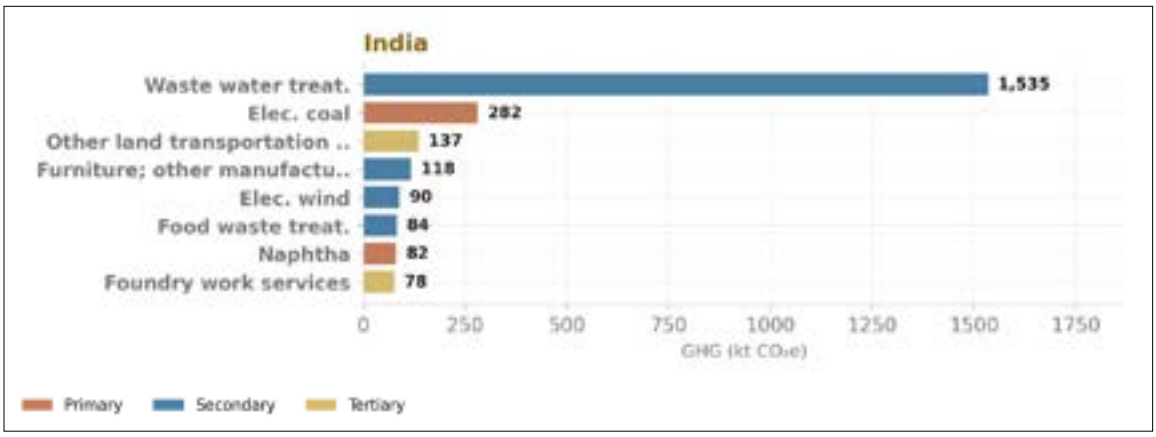

Figure 7: India's top domestic sectors by bond-induced GHG footprint (in $ktCO_2e$)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

backward linkages with the domestic economy (solar 1.24, wind 1.15), the upstream sectoral demand they generate is largely met through foreign supply chains rather than domestic supplies.

The GHG footprint does not arise from the allocated renewables but rather, akin to the case of China, it's from wastewater treatment, accounting for the largest domestic emission source (around 1,535 $ktCO_2e$), a methane-intensive service. This is followed by coal-fired electricity that still energises the grid and the supply chain for the ancillary supporting service sector (282 $ktCO_2e$). The remainder of emissions is through road transport (137 $ktCO_2e$), miscellaneous manufacturing and furniture (118 $ktCO_2e$), the wind generation itself (90 $ktCO_2e$) and food-waste treatment (84 $ktCO_2e$). Naphtha appears among the emission sources (around 82 $ktCO_2e$) for a less obvious reason worth tracing. As a refinery product, it enters the renewable supply chain on two paths: as a petrochemical feedstock for the plastics, resins, and insulation embodied in cabling, mounting structures, and balance-of-system components; and as part of the refined-petroleum stream that fuels the transport. Refined-petroleum products occupy a high-forward-linkage position in the Indian economy, feeding transport and petrochemicals across nearly every sector, so even the modest material and fuel demand a solar and wind programme places on them pulls measurable naphtha refining into activity, carrying its process and combustion emissions with it. Indian electricity through coal, as such, carries a below-average backward linkage (0.85), so its emissions propagate less widely through the production network than China's coal power does.

The employment results are the most pronounced of the three cases, with the bond's labour absorption per unit of finance being the highest, distributed across labour-intensive sectors. Wholesale and retail trade, road transport and construction, together with the water and waste services, dominate, while the renewables again employ comparatively few directly.

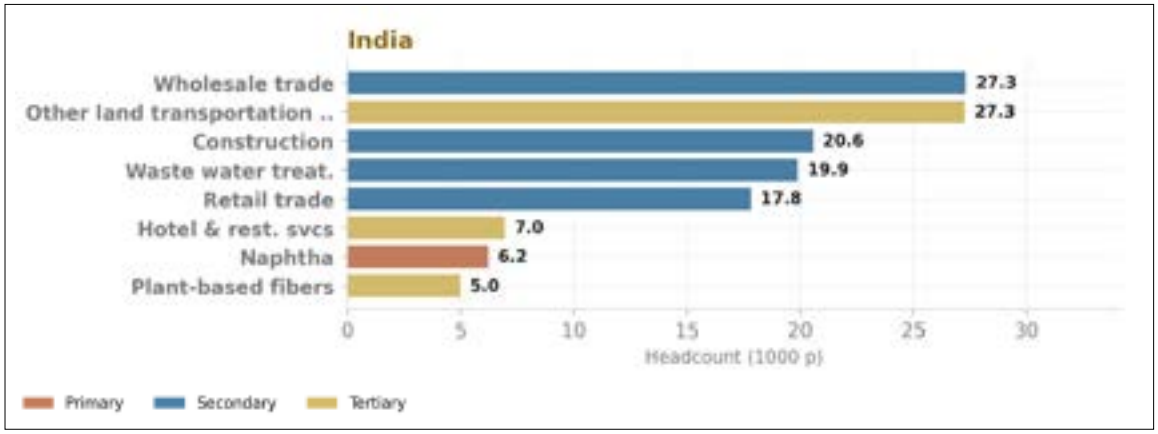

Figure 8: India's top domestic sectors by bond-induced employment (in 1000p)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

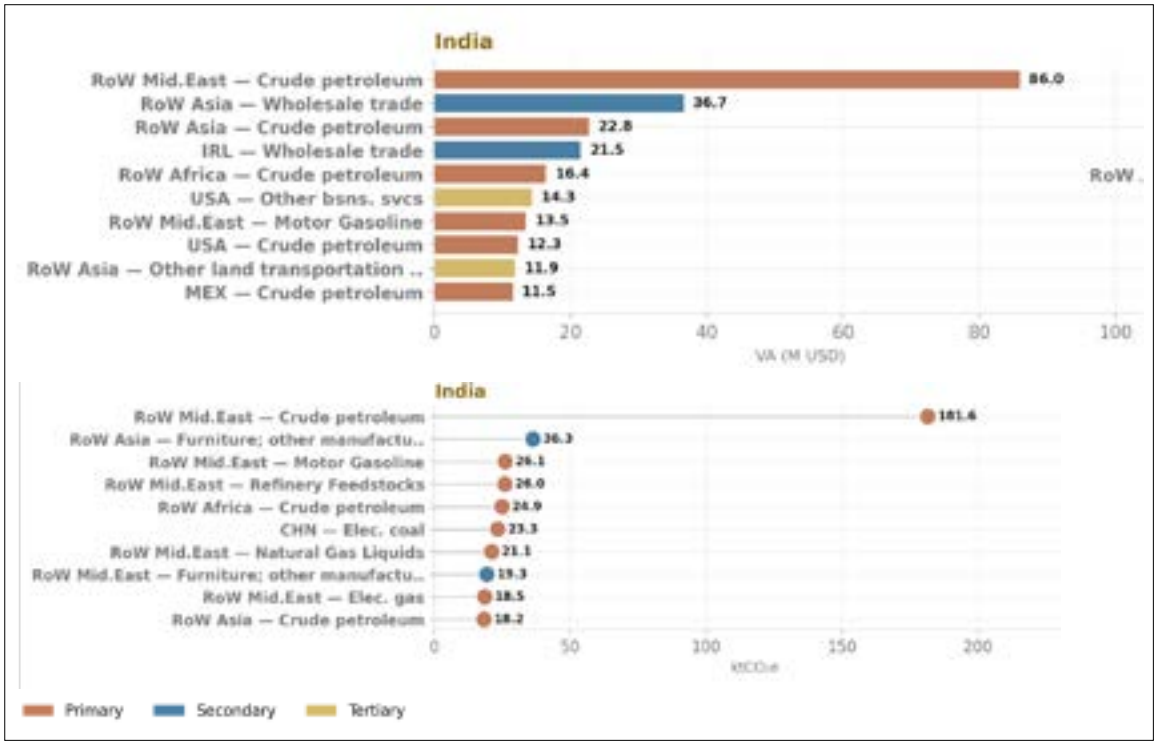

Figure 9: Cross-border value added (in million USD) and embodied greenhouse gas emissions (in $ktCO_2e$) induced abroad

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

The pattern is structurally reflective of low labour productivity as it is clustered around mostly sectors with higher occupational informality. The same thinner value retention that limits India's domestic capture turns each unit of green finance into a disproportionately large, if informal, employment effect, absorbed through trade, transport, and construction services through the build-out. Naphtha reappears here too, absorbing around 6,200 jobs, the labour counterpart of the refining and petrochemical activity traced above.

India's external footprint is the largest of the three, with about 27 per cent of the associated value addition surfacing abroad. The leakage is concentrated in the imported petroleum supply chain: Middle Eastern crude petroleum is the single largest cross-border flow in both value addition and embedded GHG footprint, followed by crude from the rest of Asia and Africa and by refined products such as motor gasoline and refinery feedstocks, reflecting the imported oil that fuels the transport, handling, and petrochemical inputs the construction draws upon. A further share accrues to wholesale trade and

business services in the rest of Asia, Ireland, and the United States, representing the intermediation and financing margins on imported goods.

A smaller but distinct flow originates in the imported hardware itself: the embodied emissions of Chinese coal-fired electricity (around 23 $ktCO_2e$), together with component manufacturing elsewhere in Asia, are carried into India through the solar modules on which the programme depends. Because India manufactures little of its own photovoltaic hardware, the emissions of producing that hardware are incurred abroad. A measurable part of the GHG footprint of India's domestic renewable transition is thus discharged in the manufacturing economies from which it imports. India is, in this sense, a genuinely green and developer-led bond market, whose value addition and a significant share of GHG footprint are externalised through an import-dependent supply chain.

3. Republic of Korea

The Republic of Korea (ROK) reached a labelled-bond market by a third route, neither regulator-catalysed like China's nor developer-led like India's, but driven by the state-owned power complex itself. Korean issuers first tapped international ESG demand in foreign currency in the 2010s, and subsequently, the Export-Import Bank of Korea issued an overseas green bond in 2013, among the first in Asia (Oh & Kim, 2018). A won-denominated green, social, and sustainability-bond market grew rapidly, intermediated through the Korea Exchange's dedicated socially-responsible-investment bond segment. The classificatory architecture that followed is comparatively permissive: the Korean Green Taxonomy (K-Taxonomy), finalised in late 2021 and amended through 2022, admits liquefied natural gas as a transitional activity and, contentiously, new and conventional nuclear generation as eligible, and still remains voluntary for issuers (Tachev, 2022). In the E&U segment, the issuer base is mostly dominated by state-owned enterprises: Korea Electric Power Corporation (KEPCO) and its five generation subsidiaries, Korea Hydro & Nuclear Power, the Korea Gas Corporation and the Korea District Heating Corporation, together accounting for the bulk of the segment with private refiners and independent power producers (the GS, SK and Hanwha group entities) forming a smaller group. In contrast to China and India, wherein the top priority sectors are in renewables, a majority of the Korean green bond proceeds are allocated to financing for liquefied natural gas (LNG) projects and the construction and completion of nuclear power plants.

The Korean E&U total sectoral allocation comes to about USD 10.8 billion, the largest of the three, but unlike China and India, only a small fraction has been allocated towards renewables. Wind and solar together account for under four per cent of proceeds; the bulk is directed instead to construction (23 per cent), gas-fired generation (19 per cent), nuclear capacity (15 per cent), electrical machinery (15 per cent), and the transmission-and-distribution grid (around 15 per cent combined). The allocation reflects the breadth that the K-Taxonomy permits. As such, in the case of ROK, the bond portfolio is dominated by a single state utility family financing the modernisation of an entire power system, generation, network, and the capital goods that build them, rather than new renewable capacity.

Table 3: Republic of Korea's cumulative energy & utilities bond allocation disaggregated sector-wise

Korea

17 sectors · $10.8B total

Sector	M USD	%
Construction	2,450.2	22.7
Elec. gas	2,002.9	18.6
Elec. nuclear	1,628.0	15.1
Elec. machinery	1,627.0	15.1
Elec. distrib.	1,267.3	11.7
Elec. transmission	363.1	3.4
Sea transport	276.7	2.6
Elec. wind	267.2	2.5
Chemicals	232.0	2.1
Heavy Fuel Oil	207.7	1.9
Elec. solar PV	120.2	1.1
Computer svcs	94.3	0.9
Elec. biomass	67.7	0.6
Secondary raw mats	63.4	0.6
R&D svcs	60.9	0.6
Health & social	43.9	0.4
Elec. hydro	19.9	0.2

Source: Authors' compilation from firm-level use-of-proceeds database using bond disclosure documents.

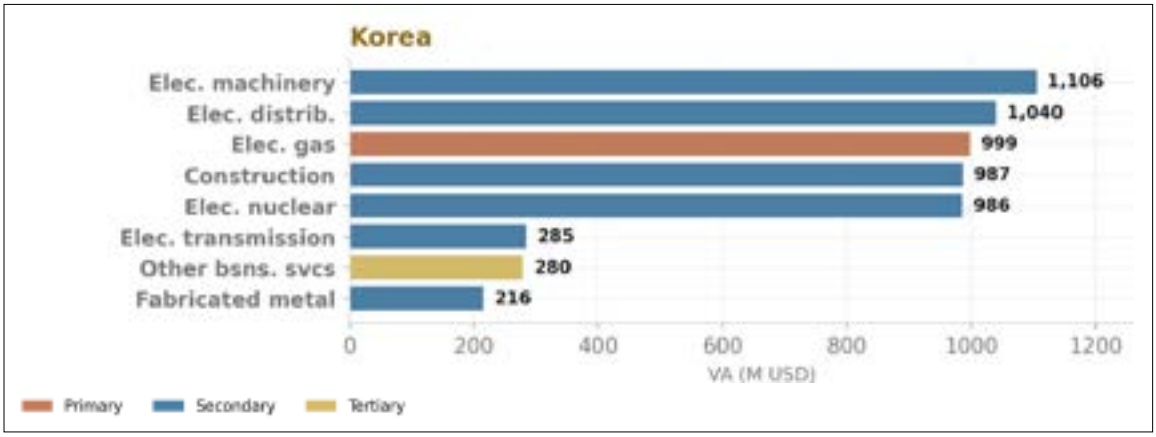

Figure 10: Republic of Korea's top domestic sectors by bond-induced value added (in millions USD)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

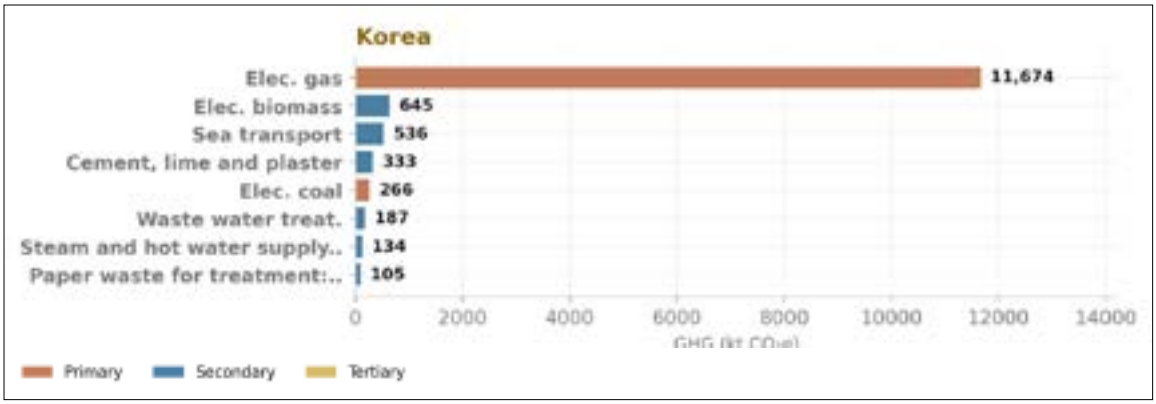

Figure 11: Republic of Korea's top domestic sectors by bond-induced GHG footprint (in $ktCO_2e$)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

ROK retains about 77 per cent of the associated value addition domestically, below China's 89 per cent. The lower retention reflects an advanced economy that nonetheless imports much of its primary energy, along with certain major heavy inputs.

The value it retains is not through power generation directly but through supporting capital-goods and infrastructure sectors that build and connect it; electrical machinery contributes the largest block of domestic value addition (around USD 1.1 billion), followed by electricity distribution, gas, construction, and nuclear, each near USD 1.0 billion. The domestic benefit is captured in the ROK's equipment and engineering base.

The GHG footprint is where ROK departs most sharply from the other two, and where the permissive or broad considerations under the K-Taxonomy are reflected through the embedded emissions. The most GHG-intensive of the three by a wide margin is ROK, and the reason is structural rather than incidental, as close to a fifth of bond proceeds finance gas-fired power generation. The bonds fund a combustion asset directly, so that the emissions arise not in the upstream supply chain but at the point of use. Domestic emissions are overwhelmingly concentrated in gas-fired electricity (around 11,700 $ktCO_2e$), an order of magnitude above any other domestic source. The gaseous-fuel distribution sector, carrying a high forward linkage (1.65), transmits the GHG footprint further across the production network. Where China's GHG footprint is the indirect marker of building or expanding the renewables sector within a coal-anchored supply chain, the ROK's is the direct combustion emission of the gas plants, as its taxonomy permits it as a transitional "green" activity.

The employment results are the weakest of the three. The bond's labour absorption per unit of finance is the lowest, concentrated in construction and electrical machinery, with a modest services sector impact.

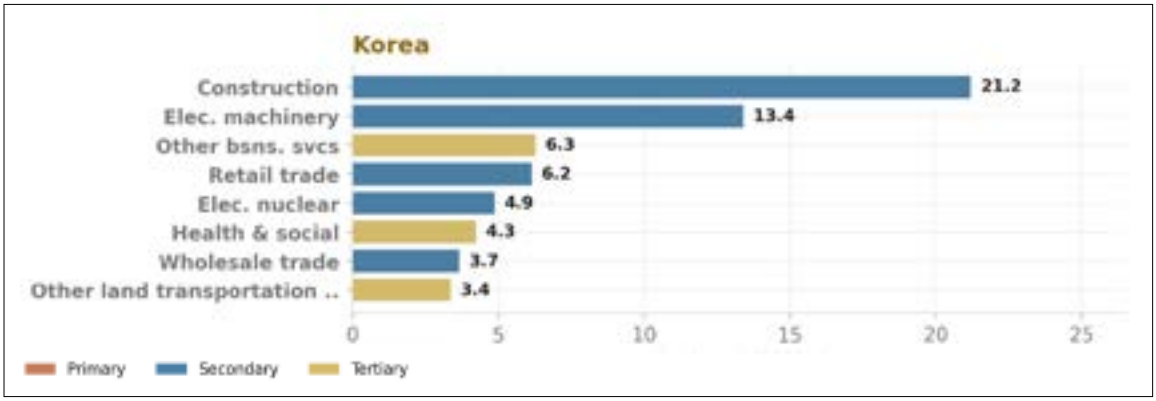

Figure 12: Republic of Korea's top domestic sectors by bond-induced Employment (in 1000p)

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

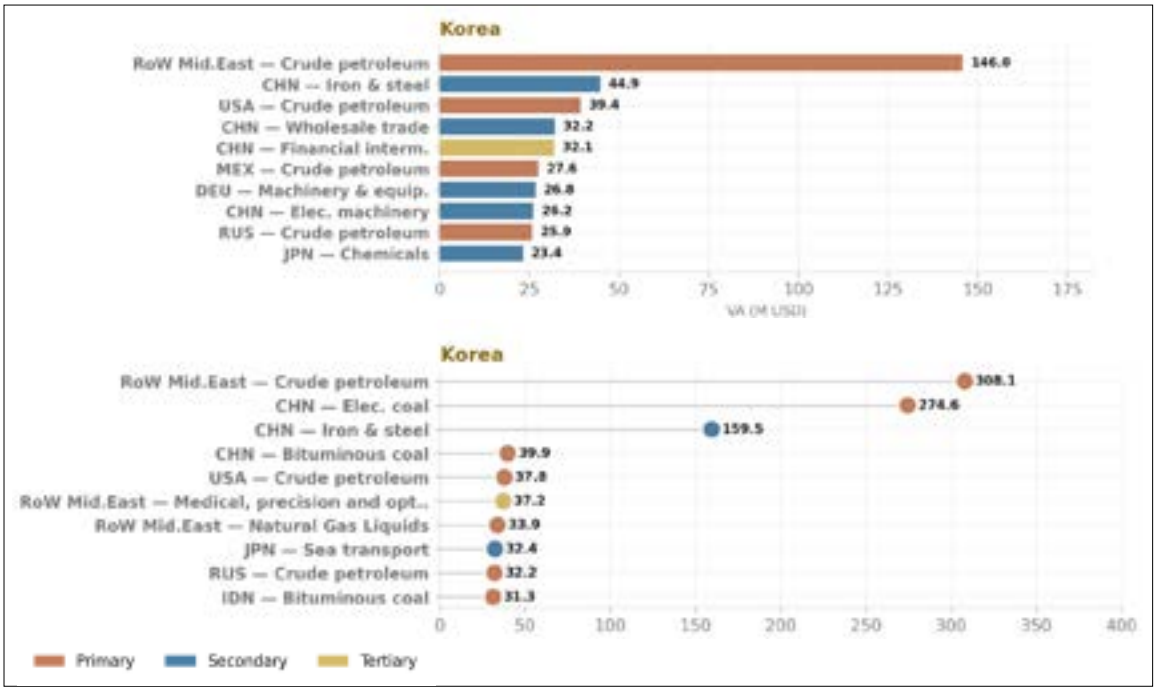

Figure 13: Republic of Korea's cross-border value added (in million USD) and embodied greenhouse gas emissions (in $ktCO_2e$) induced abroad

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

In a high-income economy with high labour productivity, a unit of green finance supports proportionally fewer jobs, and the developmental dividend ROK draws from the instrument is technological and infrastructural rather than employment-generating.

ROK's external footprint is larger and more concentrated than China's: close to a quarter of the associated value addition and a substantial share of the embodied GHG footprint surface abroad, both tracking ROK's import dependence. The largest cross-border value-addition flow is to Middle Eastern crude petroleum (around USD 146 million), followed by Chinese iron and steel, wholesale trade, and electrical machinery. The largest cross-border emissions are likewise Middle Eastern crude (around 308 $ktCO_2e$), Chinese coal-fired electricity (275 $ktCO_2e$), and Chinese iron and steel (160 $ktCO_2e$), the GHG footprint embodied in the fuel ROK burns and the steel and equipment it imports to build with. A significant part of the GHG footprint of ROK's energy transition is thus discharged in China's coal-fired power stations and the Gulf's oilfields.

Comparative Discussion

The three case studies return three distinct economy-wide signatures with varying implications for the respective economies. Although a unifying theme emerges from consideration of an economy-wide assessment or the varying types and nature of climate bonds, the developmental and environmental footprint of a green bond is neither legible from the label, nor even from the allocation alone. Rather, it follows from the interaction between what the governing taxonomy permits the proceeds to finance and the structure of the economy through which that finance propagates.

China captures the largest share, at about 89 per cent, India the smallest, at about 73 per cent, and the ROK sits between them at about 77 per cent. China retains the most because its manufacturing complex supplies most of what a renewable build-out consumes, so that the bond's demand for turbines, modules, and structural inputs is met within its own borders and the value lands in the same renewable-generation sectors it nominally finances. India retains the least because its solar programme is dependent on imported modules and balance-of-system equipment, so that even though the funded sectors carry above-average backward linkages with the rest of the economy, the upstream demand they generate is satisfied through foreign supply chains rather than at home. ROK, despite its high-income status, retains comparatively less than China because it imports almost all of its primary energy and several heavy material inputs, so that its retention takes the form of capital goods, engineering, and construction services rather than generation.

ROK registers the highest GHG intensity at about 2,005 tCO_2e per million dollars of issuance, followed by India, 1,257 tCO_2e, and China, 928 tCO_2e. ROK's emissions arise at the point of use, in the gas-fired generation its taxonomy permits; China's are indirect, transmitted through the coal-fired power, iron and steel, and methane-intensive waste services its renewable build-out draws upon; India's are likewise indirect but propagate less widely through a thinner production network, with a measurable share of its hardware emissions discharged in the manufacturing economies from which it imports.

The geography of the value addition and embodied emissions that surface abroad sharpens the varying implications for the three, 11% for China, 23% for ROK, and 27% for India. China has the least and across the widest set of Asian and Asia-Pacific trading partners; leading cross-border flows accrue to Indonesian, other Asian, and Russian bituminous coal, followed by West Asian crude petroleum, to Australian coal and Japanese electrical machinery, distributed across the Asia-Pacific. ROK's externalisation is intra-Asian but markedly more concentrated, organised along two corridors: West Asian crude petroleum on the energy side, and Chinese iron and steel, coal-fired electricity, and electrical machinery on the materials and capital-goods side. India similarly imports West Asian and African crude on the energy side and Chinese hardware on the materials side, but with a structural addition; the imported solar module components on which the renewable programme depends carry the embodied emissions of Chinese coal-fired electricity into India's own transition. The comparative externalised value addition and embodied carbon of all three economies induced through E&U bonds are retained mostly within Asia and its near energy-supplying partners; what varies between them is the breadth and the structure of intra-Asian supply-chain sectoral dependence.

Figure 14: Economy-wide footprint of corporate energy and utilities green bond issuance, compared across China, India and the Republic of Korea

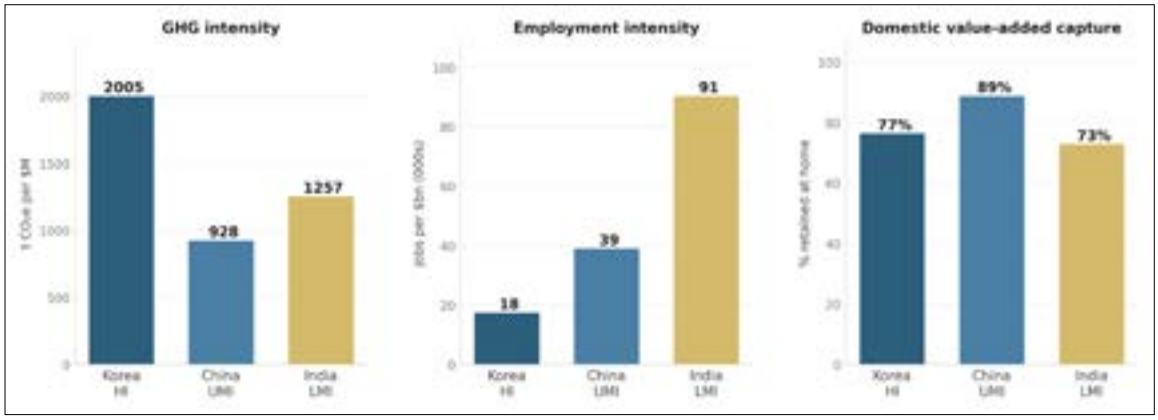

Table 4: Summary of economy-wide results of energy and utilities green bond issuance, China, India, and Republic of Korea.

Indicator	Republic of Korea	China	India
Total allocation modelled (USD billion)	10.8	9.3	3.9
Dominant allocation (share of proceeds)	Construction 23%, Gas 19%, Nuclear 15%, Electrical machinery 15%, Grid ~15%	Wind 40%, Solar 22%, Biomass 10%, Water 12%	Solar 47%, Wind 34%, Hydro 18%
Domestic value-added capture (%)	77	89	73
GHG intensity (tCO_2e per USD million)	2,005	928	1,257
Employment intensity (thousand job-years per USD billion)	18	39	91
Foreign value added (%)	23	11	27
Principal Destinations/ Sectors	Middle Eastern crude, Chinese iron and steel, Chinese coal-fired electricity, Chinese electrical machinery and wholesale trade	Indonesian and other Asian bituminous coal, Russian coal, Middle Eastern crude, Australian coal	Middle Eastern crude, refined petroleum from the rest of Asia and Africa, Chinese coal-power and module manufacturing with a smaller financial-intermediation to wholesale-trade and business services in the rest of Asia, Ireland and the United States

Source: Authors' illustration of EE-MRIO analysis using EXIOBASE 3

Conclusion

The three economies considered in this study are by United Nations Framework Convention on Climate Change (UNFCCC) convention non-Annex parties, expected under the principle of common but differentiated responsibilities to peak their emissions before declining, thereafter, rather than to cut from a historical base. The pertinent test is, therefore, the credibility of the post-peak trajectory, and towards which the role of climate financing is going to be instrumental in governing the country's Nationally Determined Contribution (NDC). At present, the NDCs are rated "Insufficient" or worse and all three net-zero strategies "Poor" by the Climate Action Tracker (2025); the sharper distinction lies between near-term (2035) trajectories that appear broadly on course (China, already, aggressively on course) and the longer net-zero pathways that are not. Our economy-wide results supply a third lens that neither the use-of-proceeds label nor the territorial NDC inventory provides.

China's updated 2035 NDC retains a commitment to peak CO_2 emissions before 2030 and reach carbon neutrality before 2060, and sets a seven-to-ten per cent reduction in economy-wide net greenhouse gas emissions from peak levels by 2035, alongside a thirty per cent non-fossil share in total energy consumption and 3,600 gigawatts of installed wind and solar by 2035, building on the 1,200-gigawatt 2030 capacity goal already met in 2024 (Climate Action Tracker, 2025); the renewable-concentrated bond allocation observed in our sample lands directly within these targets and is, in that sense, the cleanest alignment of the three, although the ambition itself is judged conservative against the roughly thirty per cent reduction analysts associate with neutrality before 2060. India has not committed to a peak at all, and its 2031-2035 NDC, submitted in April 2026, expresses targets instead in terms of a forty-seven per cent cut in the emissions intensity of GDP and about sixty per cent non-fossil installed capacity by 2035, the latter expressly conditional on transfer of technology and low-cost international finance (Government of India, 2026). The solar-and-wind-dominated bond allocation aligns with the capacity target, yet capacity is not generation, and with electricity demand rising and coal output expanding, the non-fossil share of generation remains low: the bond finances clean capacity while the grid it feeds

remains the second-largest domestic emission source. ROK is the only one of the three formally past peak, having reached its emissions peak in 2018, and its 2035 NDC, submitted in December 2025, commits to a fifty-three to sixty-one per cent reduction below those 2018 levels by 2035 and to an indicative 2040 coal phase-out announced at COP30 (Climate Action Tracker, 2025); yet against that target, the K-Taxonomy permits an E&U bond programme weighted toward gas-fired generation, nuclear capacity and grid build-out, with renewables a minor share.

The role of the climate finance taxonomy in mediating and aligning respective NDCs is not only understood as a checklist of permissible activities but also as a strategic tool for both economic restructuring and climate policy. Green finance taxonomies have, since China's first catalogue in 2015, been adopted in most jurisdictions as instruments for building local financial-market transparency and attracting international investors, rather than as domestic policy tools capable of restructuring the economy, the European Union (EU) and China being the principal exceptions where the taxonomy has been threaded through disclosure rules, bond standards and, in China's case, mandatory guidelines for banks and insurers and pilot zones tied to taxonomy-aligned investment.

The three economies considered here sit at three different phases along this spectrum. China sits closest to the industrial-policy end, with a perimeter cinched around sectors its own manufacturing base can supply, and a 2025 cohort of issuances aligned with the EU-China Common Ground Taxonomy (S&P Global, 2025). India sits at the transparency end, with a green label conceived under SEBI's disclosure norms (yet to be implemented); the Climate Finance Taxonomy Framework was released in draft for review in 2025 (Department of Economic Affairs, 2025). The proposed taxonomy reserves a continuing role for coal-based thermal power to meet base-load demand, in the intermittency of renewable build-out. The adoption of cleaner coal-generation technologies has been described as a "pragmatic" lower-emission baseload strategy, though no coal-based projects have, so far, been conceived under India's climate bonds issuance. The additionality risks posed by the lack of a well-defined taxonomy and stricter governance of bond UoPs are already visible at the issuer level; a few of the large issuers in our Indian E&U sample faced sustained greenwashing and governance concerns: investigations found value flowing from green subsidiary to coal-linked sister companies within the group, through related-party transactions and the pledging of corporate Green shares as collateral for coal-project financing, alongside a withdrawn dollar bond (U.S. Securities and Exchange Commission, 2026).

India's climate-bond market is still in an emerging phase, but is expected to pick up pace soon, and its developmental momentum will depend upon alignment between the climate finance taxonomy regime and its orientation towards the varied policy dimensions of just transition. The draft Framework describes itself as *"a living document"* to be reviewed periodically to keep pace with the dynamic landscape, a useful framing in principle, but one that raises concerns of the same shape as the K-Taxonomy's admission of Liquefied Natural Gas (LNG) without any planned phase-out at conception. The integrity of such dynamic framing will depend on whether periodic review moves the taxonomy beyond a transparency device toward a policy instrument for just transition, bolstering domestic manufacturing, grid and storage investment, and the workforce transition the renewable build-out presumes, rather than accommodating the incumbent thermal capacity it is meant to displace.

The Korean Green Taxonomy admits gas-fired generation as a transitional "green" activity through the 2030 to 2035 window, conditional on facility emissions remaining below 340 grams of CO_2e per kilowatt-hour, a threshold materially more permissive than the 270 grams of the European Union's complementary act and one set without the latter's safeguards against carbon lock-in (Tachev, 2022; Ng, 2021). The permissiveness is consequential, as a combustion-based threshold understates the very footprint it is meant to bound, for in lifecycle terms the end-use CO_2 of liquefied natural gas accounts for only about a third of its greenhouse gas footprint, the larger share arising from upstream methane, liquefaction and tanker transport (Howarth, 2024), all of which fall on an economy that imports almost the entirety of its gas.

The economy-wide results we present here show each country's transition reaching into the other's; the modules that carry India's solar capacity are manufactured on China's coal-fed grid, the steel and the power embedded in Korea's build-out are likewise drawn from its neighbours, and the value and the carbon a green bond sets in motion settle, in good part, across frontiers that neither the use-of-proceeds label nor the territorial inventory is constructed to follow. Alignment, on this reading, is not simply a matter of each country meeting its own target, but of the mutual configuration of the supply chains

through which each is bound together. It is here that economy-wide and consumption-based assessment holds its principal promise: by making these interdependencies legible, that is, by tracing where the value lands and where the emissions arise, it offers a more cooperative basis for gauging NDC progress, one in which the manufacturing scale, technology transfer, and regional supply-chain decarbonisation that let these economies support one another become levers of collective alignment.

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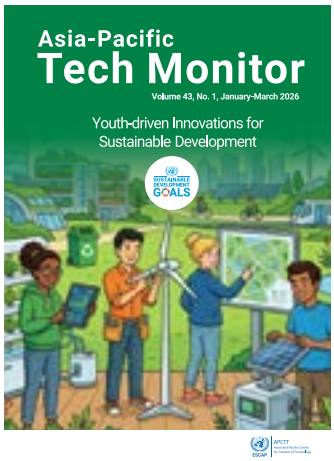

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