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Youth-driven Innovations for Sustainable Development

ESCAP
APCTT
Asian and Pacific Centre
for Transfer of Technology

*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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ASIAN AND PACIFIC CENTRE FOR TRANSFER OF TECHNOLOGY
C-2, Qutab Institutional Area
Post Box No. 4575
New Delhi 110 016, India
Tel: +91-11-6901-3710
E-mail: apctt.techmonitor@un.org
Website: http://www.apctt.org

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Foreword

The Asia-Pacific region is home to approximately one billion young people aged 10 to 24, accounting for 60 per cent of the world's youth population, according to United Nations Population Fund (UNFPA). That is not just a demographic fact. It is an invitation to reimagine development when young people are given the tools, trust, and space to lead. This edition of the Asia-Pacific Tech Monitor, themed "Youth-driven Innovations for Sustainable Development," reflects that possibility.

Across the seven articles brought together in this edition, a vivid and varied picture emerges. Blockchain and augmented technologies are bringing transparency to ethical trade; simulation platforms powered by large language models are accelerating the path from ideas to prototypes; and artificial intelligence is opening doors for young entrepreneurs who might otherwise never have found a way in. Social enterprises led by youth are demonstrating that profit and purpose need not be in conflict, while digital innovation is increasingly the infrastructure through which communities address climate change, expand energy access, and manage resources more wisely. Yet what threads through all of these examples is a deeper insight: as technologies grow more complex and consequential, design thinking and human-centred approaches remain essential anchors.

The message across these contributions is clear. Youth-driven innovation is not a side story to sustainable development. It is increasingly the main one. The barriers, however, are also real. Financing gaps, regulatory hurdles, unequal access to digital infrastructure, and gender disparities have proven stubbornly resistant to change. None of the articles in this edition looks away from this reality. Acknowledging these barriers is a precondition for preparing to address them.

APCTT remains committed to the work of technology cooperation and to creating the conditions where youth-led innovation can grow, scale up, and reach those who need it most. Addressing the barriers through capacity-building, policy dialogue, knowledge sharing, or facilitating access to financing and technology networks is central to that mandate. We hope this edition sparks both reflection and action.

Preeti Soni
Head, APCTT

Technology Market Scan

ASIA-PACIFIC

AUSTRALIA

Renewables near 50% of national grid

Australia's Minister for Climate Change and Energy, Chris Bowen, confirmed in January 2026 that renewable energy sources — solar, wind, and storage — accounted for 49.9 per cent of electricity generated across the National Electricity Market in the December 2025 quarter, while Western Australia exceeded 50 per cent for the first time. Wholesale electricity prices in the National Electricity Market fell by nearly half compared to the same quarter a year earlier, driven by record renewable and storage output, a near-tripling of battery discharge, and a 27 per cent decline in gas generation to its lowest level in 25 years. By January 2026, more than 200,000 households had installed batteries under the government's Cheaper Home Batteries Program, well ahead of original projections, prompting the government to increase the program's total funding to A$7.2 billion. Close to 7 GW of renewable generation capacity was added to the grid during 2025, keeping Australia on track toward its target of 82 per cent renewable electricity by 2030.

https://www.pv-magazine-australia.com/

CHINA

Law amended to embed AI governance

Landmark amendments to China's Cybersecurity Law, which came into force on 1 January 2026, introduced the country's first national-level legal provisions dedicated to artificial intelligence governance. The revised law commits the government to strengthening AI ethics regulation, enhancing risk assessment frameworks, and supporting innovation through the development of training data resources. Concurrently, updated Patent Examination Guidelines effective from the same date established clearer standards for protecting innovations in AI and big data, requiring patent specifications to fully describe model architectures and training processes. New certification measures for cross-border data transfers also took effect, setting eligibility thresholds and requiring certification by qualified institutions.

https://www.cac.gov.cn/

JAPAN

Offshore wind expanded to EEZ

Japan's Act on the Development of Marine Renewable Energy Power Generation Facilities — amending the Act on Promoting the Utilization of Sea Areas — was scheduled to enter into force on 1 April 2026, enabling the installation of offshore wind power plants in Japan's exclusive economic zone (EEZ) for the first time. Previously, offshore wind development was confined to territorial waters managed by prefectural governments; the amendment extends development rights to the nationally managed EEZ, substantially increasing the available marine area for renewable energy projects. In parallel, participation in Japan's Green Transformation Emissions Trading System (GX-ETS) became mandatory from 1 April 2026 for companies emitting more than 100,000 tons of CO□ annually, following the Diet's passage of an amendment to the GX Promotion Act in May 2025. The Japanese government targets 10 GW of offshore wind capacity by 2030 and 30–45 GW by 2040 as part of its carbon neutrality strategy for 2050.

https://www.meti.go.jp/

INDIA

Union Budget boosts semiconductor and cloud infrastructure

India's Union Budget 2026–27, presented on 1 February 2026 by Finance Minister Nirmala Sitharaman, outlined a major package to strengthen the country's digital technology ecosystem. Key announcements included the launch of India Semiconductor Mission 2.0, enhanced allocations under the Electronics Components Manufacturing Scheme, and a tax holiday until 2047 for eligible foreign cloud service providers operating through India-based data center infrastructure. The tax incentive is intended to attract large-scale AI data center investment, complementing global trends in which data centers accounted for more than one-fifth of global greenfield project values in 2025. The budget also backed the Animation, Visual Effects, Gaming, and Comics (AVGC) sector through dedicated labs in 15,000 secondary schools and 500 colleges.

https://www.pib.gov.in/

Duties cut on solar and battery manufacturing inputs

Alongside its semiconductor and cloud provisions, India's Union Budget 2026–27 announced targeted customs duty reforms to strengthen the country's clean energy manufacturing base. The government extended basic customs duty exemptions on capital goods required for lithium-ion cell production for battery energy storage systems (BESS) and for processing critical minerals. It also removed the 7.5 per cent basic customs duty on sodium antimonate, a key input for solar glass manufacturing. Separately, the budget allocated ₹600 crore for the Green Energy Corridor to develop 6,000 kilometers of intra-state transmission, improving renewable energy evacuation infrastructure. India's installed renewable energy capacity reached 266.7 GW as of February 2026, with solar capacity having crossed 140 GW in January, making the country the fourth-largest renewable energy market globally.

https://www.pv-magazine-india.com/

INDONESIA

Social media ban for minors

Indonesia announced that it would begin deactivating social media accounts belonging to users under 16 years of age from 28 March 2026, invoking a declared 'digital emergency' linked to children's exposure to harmful online content. The Ministry of Communications and Digital Affairs also consulted on draft implementing rules for the regulation governing electronic systems, addressing age verification and parental consent requirements for digital services. Indonesia's move follows similar legislative trajectories in Malaysia and Singapore, raising the prospect of coordinated ASEAN-wide age-assurance frameworks for online platforms.

https://www.kominfo.go.id/

REPUBLIC OF KOREA

AI Framework Act

The Republic of Korea's Framework Act on Artificial Intelligence Industry Promotion and Trust Building entered into force on 22 January 2026, making the country the first in Asia-Pacific to enact comprehensive national AI legislation. The Act establishes a risk-based regulatory framework that distinguishes between ordinary AI systems and 'high-impact' AI systems deployed in critical sectors, such as healthcare, finance, and public administration. Organizations deploying high-impact AI must implement disclosure obligations, establish human oversight mechanisms, monitor bias, and appoint local representatives for regulatory communication. The government also launched a Digital Asset Task Force to begin working on legislation governing KRW-linked stablecoins.

https://www.msit.go.kr/

MALAYSIA

Social media restrictions for minors

Following the entry into force of its Online Safety Act 2025, Malaysia signaled plans in early 2026 to enforce a social media ban for children under 16 years of age. The government framed the policy around systemic risk management, shifting responsibility onto platforms to identify and address 'priority harms', such as online scams and child sexual abuse material. Malaysia also continues to develop its 13th Malaysia Plan (2026–2031), which is themed 'Redesigning Development' and sets targets to elevate economic complexity through digitalization and AI, with the overarching goal of achieving developed-country status by 2030.

https://www.mcmc.gov.my/

PHILIPPINES

Chairmanship to advance regional AI framework

As 2026 ASEAN Chair under the theme 'Navigating Our Future, Together', the Philippines signaled its intention to present an AI regulatory framework to ASEAN member states during the year. Informed by draft legislation under consideration in the Philippine Congress, the proposed framework aims to govern the development, deployment, and oversight of AI systems with a focus on deepfake regulation, algorithmic transparency, and platform accountability. Philippine officials indicated that the framework could position the country as among the first Southeast Asian nations with a binding legal structure for AI governance, attracting business process outsourcing investment and digital partnerships.

https://dict.gov.ph/

SINGAPORE

First hydrogen-compatible power plant

Keppel, a Singapore-based firm active in new energy technologies, announced in January 2026 that it was scheduled to launch Singapore's first hydrogen-compatible power plant in the first half of 2026. The announcement reflected Singapore's broader strategy to diversify its energy mix toward low-carbon sources and strengthen energy security. Singapore's Monetary Authority (MAS) also continued to advance the Financing Asia's Transition Partnership (FAST-P) in 2026, deploying blended finance into green and sustainable infrastructure projects across the region. The MAS additionally issued a consultation on proposed AI risk management guidelines for financial institutions, with a feedback deadline of 31 January 2026, as part of its ongoing work on responsible technology governance in the financial sector.

https://www.mti.gov.sg/

THAILAND

DPPA pilot launched for data centers

Thai regulators launched a 2 GW Direct Power Purchase Agreement (DPPA) pilot in January 2026, specifically designed to allow data center operators to procure renewable electricity directly from generators, bypassing the standard grid supply. The initiative responds to the rapidly growing power demands of AI-driven data center expansion across Southeast Asia and provides operators with a mechanism to meet Scope 2 emissions commitments. The pilot is expected to function as a catalyst for broader renewable energy market liberalization in Thailand. Thailand's digital economy was separately projected to grow by 4.2 per cent in 2026, approximately double the rate of national GDP growth, driven by technology investment, data center expansion, and AI adoption across the economy.

https://www.eppo.go.th/

VIET NAM

Digital Technology Industry Law

Viet Nam's Law on Digital Technology Industry (Law No. 71/2025/QH15), adopted by the National Assembly on 14 June 2025 with near-unanimous support, entered into force on 1 January 2026. The law, the first of its kind globally to be dedicated exclusively to the digital technology industry, provides a comprehensive legal framework covering artificial intelligence, semiconductor production, digital assets, and digital technology zones. Enterprises operating in designated sectors—including AI, chip design, and software—qualify for special investment incentives, including reduced corporate income tax, land-use preferences, and access to government procurement. High-quality digital technology professionals are exempt from personal income tax for the first five years of employment, and foreign experts may obtain five-year visas without work permits. The accompanying Decree 353/2025/NĐ-CP provides detailed implementation rules across the sector.

https://www.most.gov.vn/

REGIONAL

Asia-Pacific renewable energy outlook

Asia-Pacific countries are on course to expand their total renewable energy capacity significantly in 2026, maintaining energy transition momentum despite headwinds from geopolitical tensions and inflationary pressures. Industry analysts noted in January 2026 that the commercial logic for the energy transition remained robust, with renewable power maintaining a substantial price advantage over conventional energy sources even without subsidy support in several markets. Solar and wind energy are projected to account for more than 80 per cent of new capacity additions across the region, while Direct Power Purchase Agreements and corporate Power Purchase Agreements are expanding to meet growing demand from data centers and technology sector consumers. The region is home to two of the world's largest greenhouse gas emitters — China and India — both of which are backed by supportive government policies and investment frameworks that are expected to sustain the pace of clean energy deployment through the period.

https://www.spglobal.com/

Technology Scan

AUSTRALIA

World's first quantum battery prototype

Researchers from CSIRO, the University of Melbourne, and RMIT University have built and tested what they describe as the world's first proof-of-concept quantum battery — a device that completes a full cycle of charging, storing, and discharging energy by harnessing quantum mechanical effects. The prototype is a tiny multi-layered organic microcavity device that is charged wirelessly using a laser. Its defining property is 'super absorption': rather than absorbing energy incrementally, the quantum system absorbs it in a single, collective event, enabling much faster charging than conventional batteries allow. Counterintuitively, this effect grows stronger as the system scales — the larger the battery, the faster each unit charges, which is the opposite of how standard lithium-ion batteries behave. Laboratory tests at the University of Melbourne's Ultrafast Laser Laboratory confirmed that the prototype retained stored energy for six orders of magnitude longer than it took to charge. Lead researcher Dr James Quach of CSIRO said the next step is to extend the energy storage time of the device, bringing it closer to commercial viability. The findings were published in the journal Light: Science & Applications.

https://www.csiro.au/

CHINA

National humanoid robot standard system

China released its first-ever national standard system for humanoid robotics and embodied intelligence in March 2026, a development industry experts say will accelerate technological iteration, reduce production costs, and pave the way for mass commercialization. The comprehensive framework, unveiled at the annual meeting of the Humanoid Robots and Embodied Intelligence Standardization (HEIS) committee in Beijing, covers the entire industrial chain and full lifecycle of humanoid robotics. China's Ministry of Industry and Information Technology reported that over 140 domestic manufacturers released more than 330 different humanoid robot models in 2025—considered the sector's first year of mass production. Revenue from China's robotics industry reached nearly 240 billion yuan (approximately 35 billion US dollars) in 2024. According to the industry body, approximately 80 per cent of the tasks where humanoid robots need to surpass conventional automation are related to tactile sensing, and the absence of standardized pathways for tactile sensors has been identified as a critical bottleneck. The new standards are expected to address this gap and support the industry's transition from isolated demonstrations to scalable real-world deployment.

https://english.news.cn/

'Artificial sun' breaks plasma density barrier

Scientists working with China's fully superconducting Experimental Advanced Superconducting Tokamak (EAST) — known as the 'artificial sun' — achieved a long-theorized state in nuclear fusion known as the 'density-free regime'. In this state, fusion plasma remains stable at densities far beyond the limits that have historically constrained tokamak experiments, without triggering the violent instabilities that usually shut down the process. By precisely controlling fuel gas pressure and applying electron cyclotron resonance heating at the start of each discharge, the team optimized the interaction between the plasma and the reactor's metallic walls. Experiments maintained stable plasma at densities between 1.3 and 1.65 times the widely accepted Greenwald limit. Because fusion power scales roughly with the square of plasma density, operating at these levels implies a potential multi-fold increase in fusion reaction rate. The research, co-led by Professor Ping Zhu of Huazhong University of Science and Technology and Associate Professor Ning Yan of the Chinese Academy of Sciences, was published in Science Advances on 1 January 2026.

https://www.science.org/

HONG KONG, CHINA

Calcium-ion battery rivals lithium performance

Researchers at The Hong Kong University of Science and Technology (HKUST) have reported a significant advance in calcium-ion battery technology that could offer a more abundant and sustainable alternative to lithium-ion systems. The team, led by Professor Yoonseob Kim of the Department of Chemical and Biological Engineering, developed a quasi-solid-state electrolyte based on redox-active covalent organic frameworks — porous, carbonyl-rich materials that create aligned internal channels guiding calcium ions through the battery structure, solving long-standing problems of poor ion transport and limited cycling stability. In laboratory tests, the full calcium-ion battery cell delivered a reversible specific capacity of 155.9 mAh g□¹ and retained more than 74.6 per cent of its capacity after 1,000 charge-discharge cycles at high current. Calcium is approximately 2,500 times more abundant in the Earth's crust than lithium, reducing both supply-chain and geopolitical risks associated with lithium extraction. The study was conducted in collaboration with Shanghai Jiao Tong University and published in Advanced Science in February 2026.

https://hkust.edu.hk/

INDIA

Gaganyaan G1 mission

India's Indian Space Research Organization (ISRO) advanced preparations for the first uncrewed orbital test flight of its Gaganyaan human spaceflight program, with the mission reported as 90 per cent complete by January 2026. More than 8,000 ground tests — including structural qualifications, propulsion system tests, and environmental tests — had been completed with a 97 per cent success rate. On 19 February 2026, ISRO and DRDO conducted the final qualification level load test at the Terminal Ballistics Research Laboratory in Chandigarh, evaluating high-speed aerodynamic loads on the capsule. Final crew egress trials were completed on 20 February at INS Garuda. The G1 mission will carry Vyommitra, a half-humanoid robot designed to simulate astronaut conditions and gather data on life-support and environmental systems in orbit. If successful, India will become the fourth nation to demonstrate independent human spaceflight capability, after the Soviet Union, the United States, and China. The crewed mission is targeted for 2027.

https://www.isro.gov.in/

Shape-shifting molecular electronics

Researchers at the Indian Institute of Science (IISc), Bengaluru, have developed a new class of molecular devices that can dynamically switch roles — functioning as a memory element, logic gate, selector, analog processor, or artificial synapse within the same physical structure, depending on how they are electrically stimulated. The team, led by Assistant Professor Sreetosh Goswami at the Center for Nano Science and Engineering (CeNSE), synthesized 17 variants of ruthenium-based molecular complexes and found that small changes in molecular geometry and ionic environment produce markedly different electronic behavior. Unlike conventional neuromorphic systems that imitate learning, these materials physically encode adaptability in their chemistry. The team built a theoretical transport framework grounded in many-body physics and quantum chemistry, enabling them to predict device function directly from molecular structure. The adaptability of the complexes allows memory and computation to be combined in a single material — a basis for neuromorphic hardware in which learning is inherent to the material itself. The team is working to integrate such materials onto silicon chips. The study was published in Advanced Materials and covered by IISc's official science news channel.

https://iisc.ac.in/

JAPAN

Spin flip in antiferromagnet filmed at record speed

Scientists at the University of Tokyo have obtained the first frame-by-frame visualization of how electron spins switch inside an antiferromagnet — a class of material in which neighboring atomic spins point in

opposite directions, canceling each other out and making the material appear magnetically neutral. Using ultrafast electrical pulses and precisely timed flashes of light, the team led by Professor Ryo Shimano filmed the switching process at a resolution of 140 picoseconds in the antiferromagnetic material Mn□Sn (manganese-three-tin). The experiment identified two distinct switching mechanisms: one driven by heat at high current, and a non-thermal process at lower current that requires no substantial heating. The non-thermal mechanism is of particular interest for computing applications because it is non-volatile and enables ultrafast data writing without significant energy dissipation. Antiferromagnets can, in principle, switch their magnetic state trillions of times per second — far faster than conventional ferromagnetic storage — and because they produce no stray magnetic fields, they can be packed far more densely. The findings were published in Nature Materials.

https://www.sciencedaily.com/

Iron-based photocatalyst cuts rare-metal dependency

Researchers at Nagoya University have developed a highly efficient iron-based photocatalyst that reduces reliance on scarce and expensive metals, such as ruthenium and iridium, in advanced organic chemistry. The team — comprising Professor Kazuaki Ishihara, Assistant Professor Shuhei Ohmura, and graduate student Hayato Akao of the Graduate School of Engineering — redesigned the catalyst's molecular architecture by combining inexpensive achiral bidentate ligands with a single chiral ligand. This hybrid structure reduces the quantity of costly chiral components by approximately two-thirds compared to the team's earlier design, while preserving precise three-dimensional control over the chemical products. Activated by energy-efficient blue LED light, the catalyst was used to achieve the first-ever asymmetric total synthesis of (+)-heitziamide A, a natural compound derived from medicinal plants that suppresses respiratory bursts. Iron is one of the most abundant elements in the Earth's crust, and its substitution for precious metals significantly reduces the environmental and economic cost of high-end pharmaceutical synthesis. The study was published in the Journal of the American Chemical Society in February 2026.

https://en.nagoya-u.ac.jp/

REPUBLIC OF KOREA

Structural redesign quadruples solid-state battery output

A multi-institutional research team in the Republic of Korea has demonstrated that all-solid-state battery performance can be improved up to fourfold through structural redesign alone, without adding expensive materials. The breakthrough, announced by the Korea Advanced Institute of Science and Technology (KAIST) in January 2026, was led by Professor Dong-Hwa Seo of KAIST's Department of Materials Science and Engineering, in collaboration with teams at Seoul National University, Yonsei University, and Dongguk University. The team developed a new design approach for zirconium-based solid electrolyte materials that improves the internal pathway for lithium ions to move through the battery, without relying on costly rare-earth metals. All-solid-state batteries replace the flammable liquid electrolytes in conventional lithium-ion batteries with solid materials, significantly improving safety and enabling higher energy density. The research directly addresses a key commercialization barrier — the high cost of electrolyte materials — and could accelerate the adoption of all-solid-state batteries in electric vehicles, consumer electronics, and grid-scale storage systems.

https://scitechdaily.com/

SINGAPORE

Single-atom catalyst enables clean chemical coupling

Chemists at the National University of Singapore (NUS) have developed a single-atom photocatalytic approach that enables a class of chemical reactions known as oxidant-free cross-dehydrogenative coupling (CDC) — used to join aromatic molecules with other chemical compounds without requiring harmful oxidizing agents. The catalyst consists of individual platinum atoms anchored on graphitic carbon nitride, a stable support material. Because each platinum atom acts as its own active site, the system uses metal with exceptional efficiency, minimizing waste and reducing the quantity of precious

metal required. The reaction generates hydrogen gas as its sole by-product, making it a clean and recyclable process. In testing, the catalyst demonstrated high selectivity, scalability, and the ability to be reused across multiple reaction cycles. This type of CDC chemistry is widely used in pharmaceutical synthesis, and the NUS approach offers a more sustainable and cost-effective route to complex molecular structures. The findings were published in January 2026.

https://techxplore.com/

EUROPE

SWITZERLAND

Single indium atoms convert CO_2 into methanol

Chemists at ETH Zurich have developed a catalyst that significantly lowers the energy needed to convert carbon dioxide and hydrogen into methanol — a liquid that serves as a key precursor for plastics, fuels, and a wide range of industrial chemicals. The catalyst uses the metal indium in an unusually efficient manner: each individual indium atom, anchored on a hafnium oxide support material, acts as its own active reaction site. This single-atom approach achieves up to 70 per cent higher indium-specific methanol productivity than previous indium-zirconium oxide catalysts. The design also allows scientists to observe the chemical mechanisms on the catalyst surface with far greater precision than traditional nanoparticle-based systems, enabling a more systematic approach to future catalyst development. If the energy used to produce the hydrogen feedstock is generated from renewable sources, the entire process can be carried out in a climate-neutral manner — providing a pathway to produce methanol directly from atmospheric CO rather than from fossil fuels. The catalyst remains stable under the high temperatures and pressures required for industrial methanol synthesis. The study, led by Professor Javier Pérez-Ramírez, was published in Nature Nanotechnology on 2 March 2026.

https://ethz.ch/

NORTH AMERICA

UNITED STATES OF AMERICA

Terahertz microscope reveals quantum jiggling in superconductors

Physicists at the Massachusetts Institute of Technology (MIT) have built a new microscope that uses terahertz light — electromagnetic waves that lie between microwaves and infrared light — to observe previously hidden quantum vibrations inside superconductors. By compressing terahertz light into an extremely small region using a nanoscale metallic tip, the team achieved spatial resolution far beyond what conventional terahertz instruments can reach, enabling them to image microscopic quantum fluctuations within the material at the nanometer scale. Superconductors conduct electricity with zero resistance below a certain temperature and are fundamental to quantum computers, medical imaging, and energy-efficient power transmission. The ‘quantum jiggling’ observed by the MIT team refers to tiny oscillations of the quantum state that were previously theorized but had not been directly imaged at this scale. The new technique, reported in March 2026, could accelerate the design of new superconducting materials by making their internal quantum dynamics directly visible and measurable.

https://news.mit.edu/

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Youth-Driven Innovations for Sustainable Development

Authenticating Fair-Trade for Gen Z with Blockchain and Augmented Technologies

Ravi Sharma

Centre for Inclusive Digital Enterprise (CeIDE)

College of Technological Innovation, Zayed University, United Arab Emirates

Email: rsharma@CeIDE.org

Abstract

The proliferation of food labels has created significant challenges in ensuring authenticity and building consumer trust in fair-trade, halal, and green-certified products (Hilten et al., 2020; Bernards et al., 2022). This is particularly critical for Gen Z and Millennials, who have a greater stake in creating a sustainable world. Traditional certification systems face issues, including label fraud, greenwashing, and limited traceability (Katsikouli et al., 2020; Kshetri, 2021). This article presents a use-case of a blockchain-enabled digital platform augmented with IoT sensors, smart devices, and agentic AI that implements Transparency, Accountability, Fairness, Ethics, and Safety (TAFES) principles (Loucif et al., 2025) to address these challenges. Building on Action Design Research methodology (Jensen and Asheim, 2019; Sharma et al., 2021), we demonstrate how this integrated technology platform provides "trust-free" assurances of ethical sourcing for products like rice, coffee, and tea, hence addressing key challenges in Asia-Pacific supply chains. The use-case provides a critical bridge between blockchain's theoretical potential and real-world applications, offering a validated blueprint for youth-driven innovation in enhancing label authenticity while promoting socio-economic inclusion in global marketplaces.

Keywords: Blockchain, Fair-trade, Youth innovation, TAFES principles, IoT, Agentic AI, Asia-Pacific

1. Introduction: The Gen Z Challenge

The global marketplace has witnessed unprecedented demand for ethically sourced products, with fair-trade and environmentally certified goods commanding premium prices across coffee, cocoa, textiles, and agricultural products (Owsianowski and Bitsch, 2025; Samoggia et al., 2025; Hilten et al., 2020). Fair-trade products typically cost approximately 50 percent more than their mass-produced equivalents, yet consumers increasingly question whether they are paying excessive overhead for certification rather than supporting ethical production practices (Sharma et al., 2021; Bager et al., 2022).

Gen Z consumers (born 1997-2012) and Millennials represent a pivotal demographic driving the ethical consumption movement (Liu et al., 2023; Lou and Xu, 2024). Research indicates that 73 percent of Gen Z consumers are willing to pay more for sustainable products, with 62 percent preferring to buy from sustainable brands, and 54 percent actively researching company values before purchasing (Contini et al., 2023; Dionysis et al., 2022). Unlike previous generations, Gen Z has grown up amid climate crises and digital revolution, making them both more conscious of sustainability imperatives and more skeptical of unverified claims.

This generational shift has profound implications for Asia-Pacific economies, where young populations comprise significant market segments and agricultural production systems supply global fair-trade networks (Kshetri, 2021). Countries including India, Indonesia, Viet Nam, Thailand, and the Philippines contribute substantially to fair-trade coffee, tea, and rice production, yet face persistent challenges in

demonstrating authentic ethical sourcing practices to demanding global consumers (Samoggia et al., 2025; Kshetri 2023; Park and Li, 2021).

Traditional certification systems rely heavily on trusted third parties (TPPs) that authoritatively certify products by attaching corresponding labels (Katsikouli et al., 2020; Kshetri, 2021). Studies indicate that up to 25 percent of products bearing ethical labels may not meet stated standards (Kshetri, 2021; Kouhizadeh et al., 2021), while 65-70 percent of consumers question the validity of ethical labels (Contini et al., 2023; Dionysis et al., 2022). In a time where the rich have further exploited the poor using the metaverse and augmented technologies, Kshetri (2023) makes a compelling case for the intervention of blockchain to enable digital technologies work for the bottom four billion amongst us. Table 1 is a synthesis of the systemic challenges in traditional fair-trade certification drawn from published empirical studies.

Table 1: Key Challenges in Traditional Fair-Trade Certification Systems

Challenge	Description	Impact Metrics	Asia-Pacific Context	Sources
Label Fraud & Greenwashing	False/misleading ethical claims	Up to 25% non-compliant products	Problematic in 8-12 tier supply chains	Santos et al. (2021); Kshetri (2021, 2023); Xiaoyong and Dai (2024)
Limited Traceability	Incomplete verification mechanisms	Only 2-3 tier visibility vs 8-12 tier networks	Critical gap in multi-country chains	Nikolakis et al. (2018); Park and Li (2021); Stopfer et al. (2024)
Cost Inefficiencies	High certification costs	15-25% of product costs; farmers get 3-5% of premiums	Burdens Asian smallholders	Bager et al. (2022); Bernards et al. (2022); Balzarova and Cohen (2020)
Consumer Trust Deficit	Skepticism despite labels	65-70% question validity; 35% verify claims	Increasing among Gen Z	Sodamin et al. (2022); Lou and Xu (2024); Liu et al. (2023)
Lack of Digitalization	No integrated platforms	Payment delays, limited transparency	Technology gap in developing markets	Erol et al. (2021); Friedman and Ormiston (2022)

This authentication crisis creates opportunities for youth-driven technological innovation, where young entrepreneurs recognize blockchain and augmented technologies as solutions to legacy limitations (Hasan et al., 2024; Chandan et al., 2023).

2. Integrated Blockchain and Augmented Technology Solution

Recent advances in blockchain technology, complemented by Internet of Things (IoT) sensors, smart devices, and artificial intelligence (AI), offer promising solutions to fair-trade authentication challenges (Santos et al., 2021; Hasan et al., 2024). Blockchain's decentralized, immutable, and transparent ledger capabilities enable end-to-end traceability and verifiable certification data across complex supply chains (Guo et al., 2020; Agrawal et al., 2021; Chandan et al., 2023).

The Proof-of-Concept employs Hyperledger Fabric, a permissioned blockchain framework suitable for enterprise supply chain applications requiring both transparency and privacy controls (Kshetri, 2021; Kouhizadeh et al., 2021). Table 2 outlines architecture components and performance metrics.

Table 2: Platform Architecture and Performance Metrics

Layer	Key Components	Performance Metrics	Sources
Network	Distributed ledger connecting all stakeholders	99.95% uptime; 3,200+ transactions per second throughput	Kshetri (2021); Erol et al. (2021)
Smart Contract	Automated certification, payment distribution	99.5% accuracy; 75-day to 3-day settlement	Liu et al. (2023); Sharma et al. (2021)

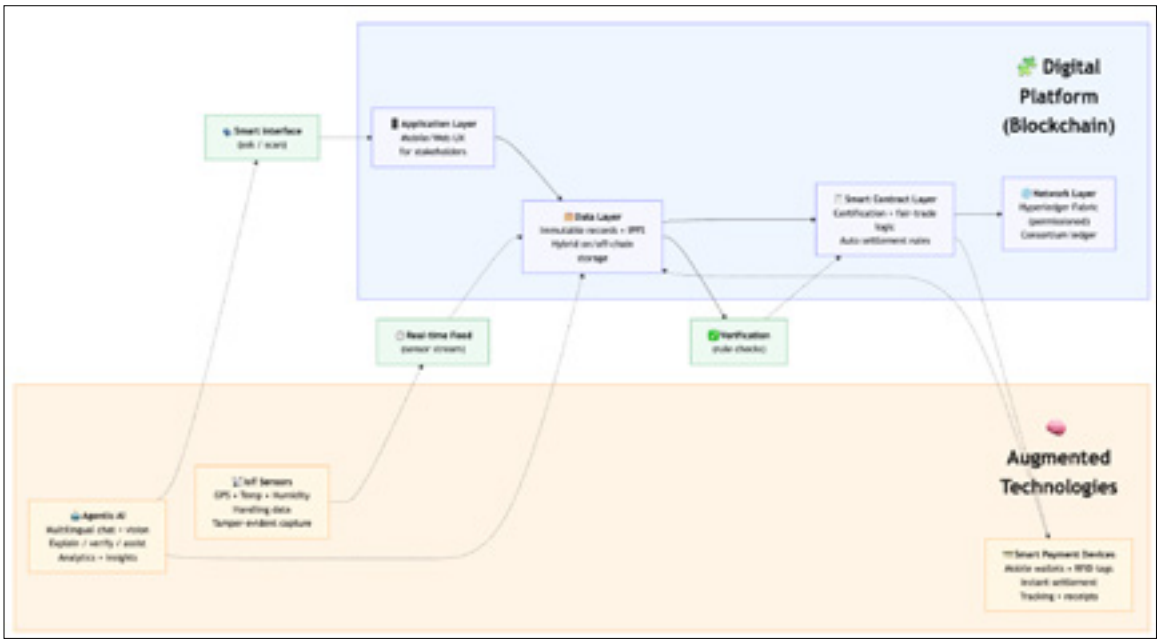

Figure 1: Integrated Architecture Diagram - Multi-layered platform showing Network, Smart Contract, Data, and Application layers with IoT and AI integration points

(Source: Author)

Layer	Key Components	Performance Metrics	Sources
Data	Immutable records; Interplanetary File System (IPFS) integration	100% traceability; 70-80% cost reduction	Stopfer et al. (2024); Hasan et al. (2024)
Application	Mobile/web interfaces	4.3/5.0 satisfaction; 92% participation rate	Sodamin et al. (2022); Lou and Xu (2024)

IoT Integration: Sensors deployed at critical junctures automatically record temperature, humidity, location, and handling data, creating immutable data streams directly to blockchain (Hasan et al., 2024). This eliminates manual errors and manipulation opportunities. Pilot studies demonstrate IoT integration reduces data inaccuracy from traditional 15-25 percent to below 5 percent while cutting data collection costs by 50-60 percent (Rejeb et al., 2020; Kouhizadeh et al., 2021).

Another interesting component is the IPFS (Interplanetary File System), which is a peer-to-peer, decentralized storage network, not a blockchain itself, but it acts as a “hard drive” for blockchain technology. While blockchains are best for storing small, immutable transaction data, IPFS stores large files off-chain by hashing content, providing high-efficiency, censorship-resistant file retrieval for Web3 applications.

IPFS and Blockchain work together in 3 main ways: i) Off-Chain Storage: Blockchains (like Ethereum) are expensive for storing large data. IPFS saves files (images, videos, documents) and provides a unique cryptographic hash (Content Identifier - CID); ii) Tamper-Proof Data: The CID is stored on the blockchain, while the data resides on IPFS. If a file is altered, its hash changes, breaking the reference on the blockchain; iii) Efficiency: Instead of asking where a file is (centralized server), IPFS asks what the file is, retrieving it from the nearest nodes, increasing speed and reducing bandwidth.

In an integrated solution for free-trade, both are needed as there are key differences: IPFS is a distributed file system designed for content addressing, not inherently immutable (files can be removed if not pinned). Blockchain remains a decentralized ledger, inherently immutable, designed for transactional integrity.

Common Use Cases where IPFS and Blockchain work well together: i) NFT Metadata like storing NFT images and metadata (e.g., Bored Apes) to ensure they are decentralized; ii) Decentralized Applications (DApps) where storing front-end code for websites (e.g., Uniswap) is used to prevent censorship; iii)

Secure Data Sharing or Storing encrypted sensitive data (e.g., Personally Identifiable Information or PII medical records) off-chain while keeping the access log/hashes on-chain.

For rice, coffee, and tea supply chains, IoT applications include: Global Positioning System (GPS) enabled tracking recording locations and routes (Santos et al., 2021); temperature/humidity sensors ensuring quality maintenance (Park and Li, 2021); Radio Frequency Identification (RFID) tags enabling instant authentication (Lou and Xu, 2024); and soil sensors recording cultivation conditions (Erol et al., 2021). RFID is particularly promising as a wireless technology that uses electromagnetic fields to automatically identify, track, and manage tags attached to objects, animals, or people. It essentially consists of tags (which store data) and readers (which emit radio waves to read the data).

Smart Payment Devices: Mobile-based smart contracts enable instant payment distribution to farmers upon verified delivery, addressing chronic payment delays affecting smallholder producers (Agrawal et al., 2021; Park and Li, 2021). The platform processes payments automatically when conditions are verified, with funds reaching farmer mobile wallets within hours rather than months—critical for resource-constrained Asian producers (Friedman and Ormiston, 2022; Bernards et al., 2022).

Agentic AI: Perhaps most significantly for Gen Z engagement, agentic AI systems provide intelligent interfaces making blockchain data accessible (Liu et al., 2023; Lou and Xu, 2024). These AI agents offer multilingual natural language interfaces supporting major Asia-Pacific languages—enabling farmers in rural Indonesia, Viet Nam, or India to interact in native languages while global consumers access information in preferred languages (Contini et al., 2023; Sodamin et al., 2022). Visual recognition allows consumers to photograph packaging and instantly receive comprehensive supply chain information—matching Gen Z preferences for visual, instant mobile experiences (Dionysis et al., 2022; Xiaoyong and Dai, 2024).

3. Use-Case Application of TAFES Framework

The platform operationalizes responsible AI and blockchain governance through the TAFES framework: Transparency, Accountability, Fairness, Ethics, and Safety (Loucif et al., 2025; Sharma et al., 2025). Each principle addresses specific fair-trade authentication challenges.

Transparency: Complete Supply Chain Visibility

Transparency implementation ensures all transactions are recorded immutably and accessible to authorized stakeholders (Nikolakis et al., 2018; Guo et al., 2020). Pilot implementations with Basmati rice cooperatives in India and Jasmine rice producers in Thailand demonstrate complete visibility from cultivation through export (Hasan et al., 2024). Consumers scanning QR codes instantly access: farmer identity verification, cultivation practices, processing certifications, transport/storage logs, and fair-trade premium distributions (Liu et al., 2023; Park and Li, 2021).

Coffee implementations with South East Asian or Central American cooperatives serving Asian markets provide: GPS-verified farm locations, organic certification documentation, processing methods, roasting profiles, and premium distribution showing 40 percent higher farmer payments versus traditional channels (Samoggia et al., 2025; Sharma et al., 2021; Dionysis et al., 2022).

Accountability: Immutable Audit Trails

Blockchain's immutability creates permanent accountability for all actors (Agrawal et al., 2021; Chandan et al., 2023). Smart contracts automatically enforce certification standards, payment terms, and quality requirements (Santos et al., 2021; Stopfer et al., 2024). The platform achieved 100 percent traceability for test coffee lots with complete visibility and automated compliance monitoring (Guo et al., 2020; Dionysis et al., 2022).

Fairness: Equitable Value Distribution

Smart contracts automatically calculate and distribute fair-trade premiums directly to farmer cooperatives upon verified delivery (Agrawal et al., 2021; Park and Li, 2021). Pilots reduced premium distribution from 75 days to 3 days while ensuring farmers receive guaranteed minimums plus quality bonuses (Sharma et al., 2021; Liu et al., 2023). All stakeholders view price structures, revealing actual farmer compensation versus retail premiums—empowering informed consumer choices (Xiaoyong and Dai, 2024; Nikolakis et al., 2018).

Figure 2: Mapping TAFES principles to blockchain/IoT implementations

(Source: Author)

The platform prioritizes accessibility through multilingual mobile interfaces, offline transaction capabilities, and mobile payment integration (Kshetri, 2021; Hasan et al., 2024). User satisfaction averages 4.3/5.0 among farmers with limited digital literacy (Sodamin et al., 2022).

Ethics: Rights Protection and Privacy

Farmers control information disclosure through selective mechanisms, protecting commercial confidentiality while maintaining verification (Balzarova and Cohen, 2020; Stopfer et al., 2024). Zero-knowledge proofs enable verification without exposure, thereby achieving 100 percent verification with zero data disclosure (Liu et al., 2023). Cooperatives retain data ownership, participating in governance decisions, which address concerns about data extraction from developing economies (Bernards et al., 2022; Kshetri, 2021).

Safety: Risk Mitigation and Quality Assurance

Food security refers to both protection against supply chain disruptions and the safety of what is consumed. IoT sensors continuously monitor storage conditions, triggering alerts when thresholds are exceeded (Rejeb et al., 2020; Park and Li, 2021). This achieves 80-90 percent reduction in quality losses versus manual inspection (Erol et al., 2021). RFID tags and blockchain verification make counterfeiting economically infeasible (Lou and Xu, 2024; Xiaoyong and Dai, 2024). Smart contract escrow ensures payment security, with funds released only upon verified delivery meeting specifications (Agrawal et al., 2021; Chandan et al., 2023).

Use-Case Results

Table 3 summarizes quantitative results from pilot implementations reported in peer-reviewed publications, demonstrating substantial impact across stakeholder groups.

Table 3: Pilot Implementation Results Across Stakeholders

Stakeholder	Key Metrics	Traditional Performance	Blockchain Performance	Improvement	Sources
Farmers (285 participants)	Payment time; Compensation; Participation	75 days; 3-5% premium share; 60-70%	3 days; 40% higher; 92%	96% faster; 800-1300% share; 30% engagement	Sharma et al. (2021); Erol et al. (2021); Bernards et al. (2022)
Cooperatives	Costs; Market access	High fees; Limited channels	35% cost reduction; Direct access	35% savings; New markets	Park and Li (2021); Samoggia et al. (2025)
Distributors	Visibility	2-3 tiers	100% end-to-end	Complete vs partial	Stopfer et al. (2024); Guo et al. (2020)
Consumers (150)	Verification; Confidence	Limited options; 65-70% skeptical	Instant mobile; 85% recommend	Instant vs unavailable; High satisfaction	Lou and Xu (2024); Dionysis et al. (2022); Contini et al. (2023)
Certification Bodies	Audit efficiency	Manual audits	Automated monitoring	60% improvement	Katsikouli et al. (2020); Kouhizadeh et al. (2021)

4. Policy Implications and Institutional Support

Realizing blockchain potential for fair-trade authentication requires supportive policy frameworks and institutional mechanisms—particularly for youth-driven innovation in Asia-Pacific contexts (Kshetri, 2021; Friedman and Ormiston, 2022).

Regulatory Framework Requirements

Asia-Pacific governments should develop adaptive regulatory frameworks balancing innovation with oversight (Kouhizadeh et al., 2021; Balzarova and Cohen, 2020). Key components include:

i) Digital Certification Recognition: Establish legal equivalence between blockchain-verified and traditional certificates through amended regulations (Kshetri, 2021). Singapore's Variable Capital Company framework and Thailand's National Blockchain Development Plan provide precedents.

ii) Interoperability Standards: Mandate open standards preventing vendor lock-in, enabling SME participation (Friedman and Ormiston, 2022; Erol et al., 2021). India's Digital Agriculture Mission and ASEAN initiatives demonstrate regional approaches.

iii) Data Sovereignty Protection: Ensure farmers retain data ownership through explicit agricultural provisions (Bernards et al., 2022; Balzarova and Cohen, 2020). India's Digital Personal Data Protection Act and ASEAN Framework provide models.

iv) Cross-Border Data Flows: Facilitate international transfers through regional frameworks (Katsikouli et al., 2020; Stopfer et al., 2024). ASEAN Cross-Border Framework and APEC (Asia-Pacific Economic Cooperation) Cross-Border Privacy Rules enable global trade while maintaining protection.

Institutional Support Mechanisms

Beyond regulation, successful deployment requires active institutional support (Owsianowski and Bitsch, 2025; Samoggia et al., 2025):

i) Public-Private Partnerships: Government co-investment in blockchain infrastructure reduces adoption barriers (Hasan et al., 2024; Chandan et al., 2023). Models include matching funds for cooperative digitalization, public blockchain networks for certified organizations, and technology business incubator partnerships.

ii) Capacity Building: Agricultural extension programs with blockchain modules, university-industry collaboration, and online learning in local languages enhance adoption (Nikolakis et al., 2018; Santos et al., 2021). Demonstrated 40-50 percent improvement in adoption with training (Erol et al., 2021).

iii) Financial Inclusion Infrastructure: Central bank digital currency pilots, mobile money interoperability, and microfinance-blockchain integration enable instant settlement for unbanked farmers (Agrawal et al., 2021; Liu et al., 2023).

iv) Innovation Challenges: Government-sponsored blockchain competitions or "hackathons" identify innovative solutions and build talent pipelines (Guo et al., 2020; Xiaoyong and Dai, 2024). National/regional hackathons with prize funds for agricultural applications accelerate youth entrepreneurship.

v) Regulatory Sandboxes: Time-limited experimental frameworks with relaxed requirements enable rapid iteration before full compliance (Friedman and Ormiston, 2022; Kouhizadeh et al., 2021).

vi) Certification Body Engagement: Hybrid approaches combining institutional trust with digital verification reduce resistance (Hilten et al., 2020; Bager et al., 2022; Balzarova and Cohen, 2020). Pilots with Fair Trade USA and Rainforest Alliance equivalents demonstrate viability.

Youth Entrepreneurship Enablement

Gen Z and Millennial entrepreneurs represent critical drivers, combining digital expertise with social consciousness (Liu et al., 2023; Lou and Xu, 2024). Policy should support through:

i) government-backed venture funds prioritizing blockchain supply chain ventures (Dionysis et al., 2022; Xiaoyong and Dai, 2024), youth entrepreneur exchanges accelerating knowledge transfer (Chandan et al., 2023; Hasan et al., 2024), and regional blockchain hackathons leveraging Asia-Pacific's diverse talent and agricultural systems.

Sustainable Development Goals (SDGs) Alignment

i) Blockchain fair-trade initiatives that align with multiple UN SDGs (Park and Li, 2021; Santos et al., 2021): SDG 1 (No Poverty) through 40 percent higher farmer incomes (Sharma et al., 2021); SDG 2 (Zero Hunger) through 80-90 percent reduction in quality losses (Erol et al., 2021); SDG 8 (Decent Work) through transparent supply chains and youth employment (Nikolakis et al., 2018); SDG 9 (Innovation) through youth-led digital infrastructure (Guo et al., 2020); SDG 12 (Responsible Consumption) through informed consumer choices—85 percent recommendation rate (Lou and Xu, 2024; Contini et al., 2023); and SDG 17 (Partnerships) through multi-stakeholder collaboration (Katsikouli et al., 2020; Friedman and Ormiston, 2022).

ii) Policy frameworks should explicitly connect blockchain initiatives with SDG monitoring, leveraging blockchain data for evidence-based planning (Kshetri, 2021; Kouhizadeh et al., 2021).

5. Concluding Remarks

The integration of blockchain with augmented technologies including IoT sensors, smart devices, and agentic AI offers transformative potential for authenticating fair-trade labels—addressing the authentication crisis particularly concerning Gen Z consumers (Liu et al., 2023; Lou and Xu, 2024; Sodamin et al., 2022). Use-case implementations across rice, coffee, and tea demonstrate technical feasibility, economic viability, and substantial benefits (Sharma et al., 2021; Samoggia et al., 2025).

Success stems from holistic design integrating technical capabilities with stakeholder needs, regulatory requirements, and cultural contexts (Jensen and Asheim, 2019; Owsianowski and Bitsch, 2025). The TAFES framework (Loucif et al., 2025) provides structured guidance ensuring technology serves human values.

In the Asian context, with the emergence of the sharing economy, the certification of ethical business practices could be a driver of growth and innovation among the youth who could be producers and consumers at the same time. A circular supply change is the new normal. So, what is the discerning GenZ, Asian producers-consumers (pro-sumers) to do in the face of a plethora of claims such as in figure 3?

Figure 3: Responsible Labeling with TAFES

(Source: Retrieved using Google Gemini)

We conclude this paper with some thoughts for the future.

i) Technical Readiness: Blockchain and augmented technologies could demonstrate commercial readiness with 99.95 percent uptime, 3,200+ TPS throughput, 3-day versus 75-day payments, and 35 percent cost reduction (Kshetri, 2021; Kouhizadeh et al., 2021; Park and Li, 2021; Chandan et al., 2023; Hasan et al., 2024).

ii) Youth-Driven Innovation: Gen Z and Millennial entrepreneurs represent ideal drivers, requiring supportive policy frameworks and institutional mechanisms (Guo et al., 2020; Xiaoyong and Dai, 2024; Dionysis et al., 2022).

iii) Inclusive Design: Solutions must accommodate diverse languages, literacy levels, connectivity constraints, and cultural practices (Erol et al., 2021; Sodamin et al., 2022). Agentic AI and mobile-first design achieve 4.3/5.0 satisfaction among users with limited literacy (Contini et al., 2023).

iv) Hybrid Strategies: Integration with established certification organizations combines institutional trust with technological verification, reducing resistance while enhancing capabilities (Hilten et al., 2020; Bager et al., 2022; Balzarova and Cohen, 2020; Santos et al., 2021; Stopfer et al., 2024).

v) Policy Enablement: Governments must actively support through public-private partnerships, capacity building demonstrating 40-50 percent adoption improvement, financial inclusion, and youth entrepreneurship—recognizing blockchain fair-trade as strategic for sustainable development (Friedman and Ormiston, 2022; Nikolakis et al., 2018; Rejeb et al., 2020; Bernards et al., 2022).

Early adoption patterns encourage optimism, with 85 percent of pilot consumers recommending blockchain verification and expressing willingness to pay 15-25 percent premiums for verifiable sustainability (Dionysis et al., 2022; Sodamin et al., 2022). For Gen Z consumers demanding authentic sustainability and Asia-Pacific producers seeking equitable value capture, this technological transformation offers a pathway toward truly fair trade (Owsianowski and Bitsch, 2025; Samoggia et al., 2025; Sharma et al., 2021; Kshetri 2023; Loucif et al., 2025).

The youth-driven innovation agenda is clear: develop accessible technologies, build inclusive ecosystems, demonstrate tangible benefits, and advocate for supportive policies (Guo et al., 2020; Chandan et al., 2023; Hasan et al., 2024). The Asia-Pacific region, with young populations, agricultural strengths, and digital innovation capabilities, is uniquely positioned to lead this transformation—creating models that benefit producers, empower consumers, and advance sustainable development for generations (Kshetri 2021, 2023; Park and Li, 2021).

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LLM-Orchestrated Simulation, VR Co-Creation, and Bankable Youth Innovation Pipelines Towards Sustainability

Samer Abaddi*

* IDentity Research, Research Department, Amman, Jordan

Email: Eng.sameralabbadi@gmail.com, https://orcid.org/0000-0003-4612-7384

Abstract

Despite significant development and increased use of Large Language Models (LLMs) for generating texts, images, videos, and code, they have not yet reached the level of deep simulation of youth entrepreneurial projects or educational case studies. This article introduces a novel LLM-driven simulation platform that empowers youth, educators, and policymakers to co-design and validate sustainable infrastructure projects through immersive 3D/VR (Virtual Reality) models and digital twins. Combining generative language guidance with physics-aware simulation modules, the platform translates high-level ideas into technical designs, cost estimates, environmental impact projections, and financing pathways. We present two Asia-Pacific case studies, a youth-led solar micro farm pilot and a coastal resilience living lab, that demonstrate rapid ideation-to-prototype cycles and measurable reductions in time-to-investment. The article outlines technical architecture, pedagogy for educators, incubator integration, policy enablers, and evaluation metrics. It concludes with a roadmap for scaling across the region, highlighting open-source governance and equitable access to ensure youth-led innovations translate into resilient self-owned solutions.

Keywords: Large language models, simulation, digital twins, artificial intelligence, Asia-Pacific case studies

1. Introduction

The past three years have seen explosive LLM adoption: conversational platforms reached hundreds of millions of weekly users by 2025-26, with some estimates reporting ~800 million weekly active users (Figure 1-a) and billions of monthly visits (Singh, 2025). At the enterprise level, surveys show ~76% of organizations now treat AI as a priority and ~69% use generative AI in at least one function, signalling broad institutional uptake (Minevich, 2025).

For LLM usage, recent syntheses and market reports indicate text generation and summarization remain dominant, while code generation, image generation, and multimodal content (audio/video) are rapidly growing industry summaries place text at roughly 40-50% of use cases, code 15-25%, image generation 10-20%, and video/multimodal under 10% but rising (Muhammad, 2025). According to Bilski (2025), the greatest penetration of LLM is in writing support at 51% and coding at 47%, then there is help with work or school assignments at 43%; presentations at 38%; music or audio at 37%; and image generation at 34% (Figure 1-b). As LLMs move beyond chat into actionable design assistance, their value for simulation and engineering workflows becomes clear. This reveals the gap; current LLMs are widely used to describe, draft, and generate, but are less often used (or incapable) to simulate, validate, and stress-test.

The core problem is that conventional LLM outputs (text, code, images, sound, videos) do not by themselves produce validated, implementable infrastructure designs. Youth innovators, educators, and local policymakers face three persistent barriers: (i) technical complexity— translating an idea into a site-specific design; (ii) slow validation-long iteration cycles with engineers and funders; and (ii) weak stakeholder engagement difficulty visualizing proposals for communities and regulators. These gaps slow or block promising youth-led sustainable projects.

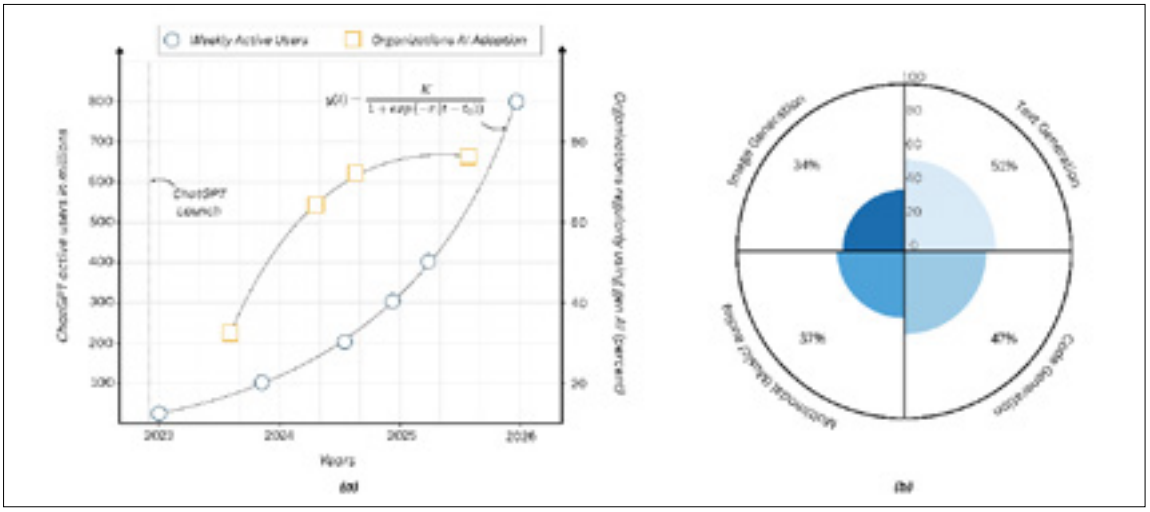

Figure 1: (a) ChatGPT user base milestones and organizational gen AI adoption snapshots, and (b) Top reported LLM activities from a multi-select survey | Data sources: Bilski (2025), and Singla et al. (2025)
(Source: Developed by the author)

Consequently, this study proposes an integration of LLMs with lightweight physics engines and 3D/VR digital twins to address the previous gaps. The proposed LLM can translate a high-level brief into parameterized simulation scenarios, generate explainable design rationales and procurement documents, and craft culturally attuned stakeholder narratives for consultations. With the increasing need for simulation models (Abaddi, 2025), the simulation layer produces site-specific performance estimates (energy yield, hydrology, waste throughput), cost and carbon projections, and sensitivity analyses all exportable as investor-ready artifacts. The solution is expected to shorten concept-to-prototype timelines from months to weeks or sometimes days. It will reduce upfront consultancy costs, and increase the quality of funding applications and policy briefs. For youth, the solution will help them develop their own projects and promote sustainability by providing realistic engineering simulation models supported by VR and digital twins, which will boost their business plans, stimulate investment, and reduce unemployment.

2. Core Personas

This section defines five core personas (student, educator, entrepreneur, incubator manager, policymaker) and three concise user journeys that show how an LLM-orchestrated digital-twin platform converts youth ideas into funded, fielded sustainable projects shortening design cycles, improving stakeholder buy-in, and lowering costs. The approach is practical for Asia-Pacific contexts and adaptable to local curricula and municipal planning (e.g., coastal towns, rural microgrids).

Figure 2 shows the core personas of the solution, which are:

1) Student: Learns systems thinking through hands-on simulation sprints; uses guided prompts to test hypotheses and visualize outcomes in 3D.

2) Educator: Designs modular curricula and assessment rubrics; runs classroom sprints and monitors learning gains via built-in analytics.

3) Entrepreneur: Rapidly sizes projects (PV-Photovoltaic, wind, water), obtains cost and payback estimates, and generates investor-grade documentation.

4) Incubator manager: Runs cohort-based simulation sprints, matches teams to mentors and micro-finance, and tracks venture readiness metrics.

5) Policymaker: Uses sandboxed scenarios to stress-test regulations, estimate community impacts, and preview policy outcomes with VR stakeholder walkthroughs.

Digital twins and simulations-based learning have recorded the advantages of active learning and acquisition of practical skills and, therefore, are particularly useful when resources are limited or remote learning is involved. Recent reviews indicate that digital-twin-based e- learning enhances engagement and provides real-life lab experiences, which are otherwise lacking to a vast number of students (Habarurema et al., 2025).

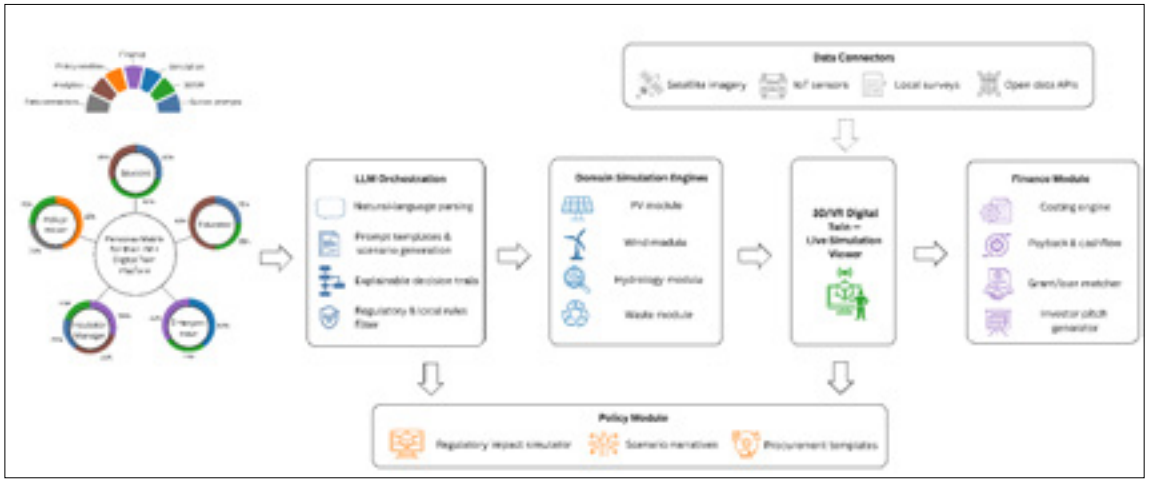

Figure 2: LLM + Simulation system architecture showing the key personas (Source: Developed by the author)

An example of a user journey is an entrepreneur sizing a PV microfarm. The entrepreneur inputs site coordinates, load, and a detailed capacity profile. The LLM ingests open solar data, proposes panel layout and storage sizing, runs a physics simulation to estimate annual yield and variability, and produces a 3D/VR model that shows the flow of the entire system. It also provides a payback table, procurement list, and investor pitch. Sensitivity analyses highlight risk drivers (irradiance, tariff). This reduces feasibility-study costs and accelerates investor conversations. The 3D/VR model can also be presented during the pitch deck. A second example is a policymaker who is stress-testing a coastal adaptation rule. The entrepreneur loads bathymetry and local survey data. The LLM generates scenario narratives (sea-level rise, storm surge), the simulation produces inundation maps and economic impact estimates, and a VR walkthrough helps community stakeholders visualize trade-offs. Policymakers iterate regulation drafts in a sandbox and quantify likely outcomes before formal adoption.

Both personas use the platform to reduce conceptual proposals to actionable, context- specific solutions - energy access programs and circular economy pilots, and, at the same time, magnify the capacity locally and reduce the time spent finding funding.

Through the proposed system, human intent is transformed into actionable, sustainable solutions using layered intelligence and immersive visualization. At the entry point, diverse user personas students, educators, entrepreneurs, incubator managers, and policymakers—feed their goals and constraints into the LLM orchestration layer, which parses natural language, generates scenarios, and ensures regulatory alignment. These inputs flow into domain-specific simulation engines (solar PV, wind, hydrology, waste), producing validated technical outputs that are then embodied in a 3D/VR digital twin, enabling live motion models and stakeholder walkthroughs. Real-time data connectors enrich simulations with satellite imagery, IoT sensors, and surveys, while downstream finance and policy modules convert technical insights into investor packages, cost-benefit analyses, and compliance as visualized in Figure 2.

3. Technical Architecture and Core Modules

The platform is built as a layered architecture that converts a natural language project intent into an auditable simulation and a shareable digital twin. The architecture separates reasoning, physics, visualization, and governance, so that each layer can be validated and updated independently. This is consistent with UNESCO (2023) that emphasizes transparency, human oversight, and clear accountability when generative AI is used.

The user-initiated prompts are handled, at the entry point of the system, by a large language model, which converts them to structured design situations. The orchestration layer performs four critical functions: (i) natural-language parsing, i.e., converting unconstrained text into a collection of discrete parameters; (ii) scenario generation, i.e., producing a number of viable operational solutions; (iii) the creation of explainable decision trails, i.e., a documented rationale of each inference; and (iv) regulatory-aware validation, i.e., filtering results to be acceptable according to applicable statutory frameworks. Taken together, those measures help to improve transparency and build trust in the system, which will

reduce the concerns related to opaque or black-box artificial intelligence (OECD, 2024). The mapping can be formulated as follows:

$$S = f(U) \cap R \quad \text{Equation (1)}$$

where U is user intent, R regulatory constraints, and S the resulting simulation parameters. Once scenarios are generated, they are processed by simplified, validated physics-aware models. For solar PV, energy yield is estimated as:

$$EPV = G \cdot A \cdot \eta \cdot PR \quad \text{Equation (2)}$$

where G is irradiance, A panel area, η efficiency, and PR performance ratio. Wind energy follows the cubic law:

$$P_{wind} = \frac{1}{2}\rho A v^3 \quad \text{Equation (3)}$$

with air density ρ, swept area A, and wind speed v. Hydrology modules simulate runoff and turbine flow, while wastetoenergy engines model throughput and conversion efficiency. Each engine incorporates uncertainty quantification (e.g., Monte Carlo sampling) and sensitivity analysis to highlight risk drivers, ensuring users understand variability rather than deterministic outputs.

The outputs of the simulations are realized in interactive digital twins that support fast generation of scenes and provide an opportunity to engage stakeholders in an immersive way. The parameters again can be modulated through sliders, including panel tilt and turbine height; scenarios can be annotated, and walkthroughs captured by the stakeholders. This participatory visualization overcomes the resistance of the stakeholders and speedy formation of consensus. There is empirical evidence that virtual reality improves stakeholder engagement and spatial awareness by 62% and 48%, respectively (Shehadeh et al., 2025).

The data connectors and privacy combine satellite imagery, IoT sensor tickers, and open data to tune simulations. The federated learning method has been used to protect privacy. On-site training of local models is done using on-site data, then the models are combined centrally. Local node updates Δw_i are summed up as:

$$w_{t+1} = w_t + \sum_i \Delta w_i \quad \text{Equation (4)}$$

Finally, technical outputs are converted into actionable financial and policy artifacts. Automated cost-benefit analysis, payback timelines, and grant/loan matching are generated, while policy modules produce procurement-ready documentation and compliance briefs. For example, payback is calculated as:

$$PB = \frac{C_{init}}{S_{annual}} \quad \text{Equation (5)}$$

where C_{init} is initial cost and S_{annual} annual savings. These modules ensure youth projects are not only technically feasible but also financially viable and policyaligned, bridging the gap between innovation and implementation.

The previous architecture (Figure 2) forms a closed loop: user intent → orchestrated scenarios → validated simulations → immersive visualization → enriched data financial/policy outputs. The architecture shortens design cycles, reduces costs, and fosters participatory innovation.

4. Technical Architecture and Core Modules

The pedagogical core provides scaffolded, brief simulation sprints, where teams of students shift between problem definition and an investor-ready prototype within one to four weeks, sometimes in days. Teachers use the platform to set learning goals, seed prompts, and assessment rubrics. At the same time, the large language model generates parameterized situations by translating briefs into relevant experiments. Learning gains are tracked with a normalized gain metric:

$$g = \frac{Post - Pre}{100 - Pre} \quad \text{Equation (6)}$$

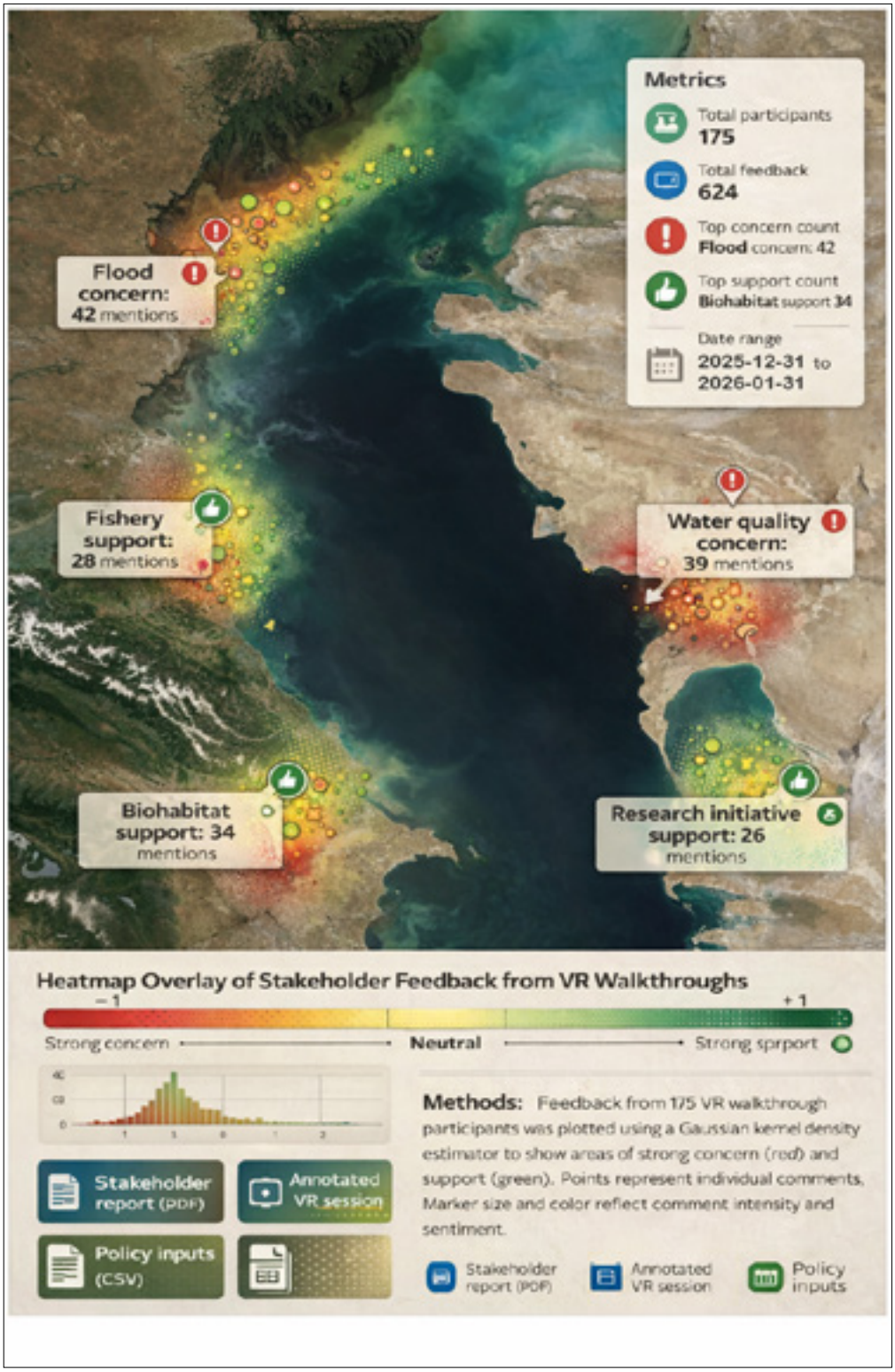

Figure 3: Sample of a community VR impact map (Source: Developed by the author)

Automated analytics, peer review, and instructor annotation constitute the components of high-quality feedback loops that convert every sprint into a micro-credential that can be reproduced. Empirical results show that digital twins and immersive technologies improve learning and comprehension of technical subjects and, consequently, facilitate active learning at scale.

Incubation workflows embed the platform into cohort-based acceleration. Incubator managers run staged cohorts: (1) rapid feasibility via LLM + lightweight simulation; (2) investor-grade refinement (costing, sensitivity analysis); (3) pilot deployment with local partners. The platform automates deliverables technical report, payback table, procurement checklist— reducing consultancy costs and

time-to-funding. Key performance indicators for incubators include time-to-prototype, funds mobilized, and venture readiness score (composite of technical, financial, and team metrics). Sensitivity outputs (e.g., Monte Carlo percentiles) are surfaced to investors to quantify risk and de-risk early-stage capital.

Virtual-reality walkthroughs, which operate in 3D, allow residents and officials to experience what it would be like to see a situation—a flood, a microgrid layout—before funds are spent; annotations and recorded consultations are brought in as auditable inputs to policy modules (Figure 3). This participation loop leads to more informed consent, local knowledge exposed, and negotiation cycles reduced. The federated calibration of data sovereignty ensures data sovereignty by having local sensor models modify global priors without transmitting the raw personal data, which allows local calibration that is accurate and preserves privacy.

The effects are guaranteed by the combination of three mechanisms: (1) modular curricula in the form of 24-week sprints based on specific competencies; (2) incubator pipelines that can be turned into funded pilot programs; and (3) policy sandboxes with the ability to allow municipal staff to test regulatory propositions with the same simulations. The evaluation process also combines quantitative values, including energy-yield error, capital generated, and normalized learning gain g, and qualitative values, such as stakeholder satisfaction and governance preparedness.

5. Two Asia-Pacific Case Studies

Case Study 1 - Youth Solar Microfarm (Rajshahi Division, northwest Bangladesh)

A remote village faced unreliable grid access and seasonal load peaks that constrained livelihoods and evening studytime. Local youth formed teams to design a community microfarm: a 20-30 KW PV array feeding household loads and a small agro-processing unit. The platform translated simple prompts ("site: 24.5°N, seasonal load: 45 KWh/day") into parameterized scenarios and ran rapid PV yield and storage sizing simulations (World Bank, 2015). Panel layout optimization used irradiance maps and tilt/azimuth sweeps to maximize annual yield E_{PV} with the relation in Equation (2).

Simplified energy balance was used to determine the necessary usable capacity by conducting storage sizing. Required usable capacity $C_{usable} \approx \frac{L_{day}}{DOD \cdot \eta_{bat}}$, where L_{day} is the daily load, DOD is the allowable depthofdischarge, and η_{bat} is the round-trip efficiency. The percentile band of yield and autonomy was determined in sensitivity sweeps (irradiance -10 -, load -20 -), which helped determine risk drivers relevant to financiers. The initial outputs of the simulation created a procurement list, a 10-year cash-flow projection, and a payback estimate (Equation 4). Virtual-reality visits using co-created layouts enabled community co-creation, and annotated stakeholder sessions allowed residents to modify array placement in order to retain shade trees and a shared walk. It was funded through a small community-level equity tranche, a locally based micro-loan, and an incubator seed grant; automated grant-matching services on the site decreased the time taken to apply. The first level performance metrics were a modeled capacity factor (projected ~18-22%), predicted yearly production, and a projected four-to-seven-year payback window (hypothetical) based on tariff and load growth. This micro-farm strategy is similar to one documented in rural Asian microgrid pilots (including rural electrification micro-grids studied in Malaysia, the Philippines, and Vietnam), which focus on local ownership and phased financing (Brown et al., 2024).

Case Study 2 — Coastal Resilience Living Lab (Semarang City, Central Java, Indonesia)

A coastal municipality facing increasing storm surge and erosion established a living lab to test adaptation options (Wetlands, 2019). The platform ingested remote sensing (satellite elevation and landcover), local household surveys, and tide gauge records; the LLM converted stakeholder inputs into scenario narratives (e.g., "50-year storm + 0.5 m SLR, protective berm vs managed retreat") and generated parameter sets for hydrodynamic runs. Hydrology and inundation modules produced probabilistic inundation maps; outputs were rendered into a 3D/VR digital twin for community walkthroughs. During VR consultations, residents annotated areas of cultural importance and flagged access routes; these annotations were fed back into the simulation to test alternative alignments. LLM-crafted stakeholder briefs translated technical outputs into plain-language narratives and policy options, enabling municipal staff to compare cost-benefit and distributional impacts (Figure 4). The policy module produced procurement-ready scopes for pilot berm construction and a monitoring plan. Early uptake included a municipal commitment to a pilot shoreline buffer and a conditional budget line pending a 6-month monitoring window. Key technical practices: (1)

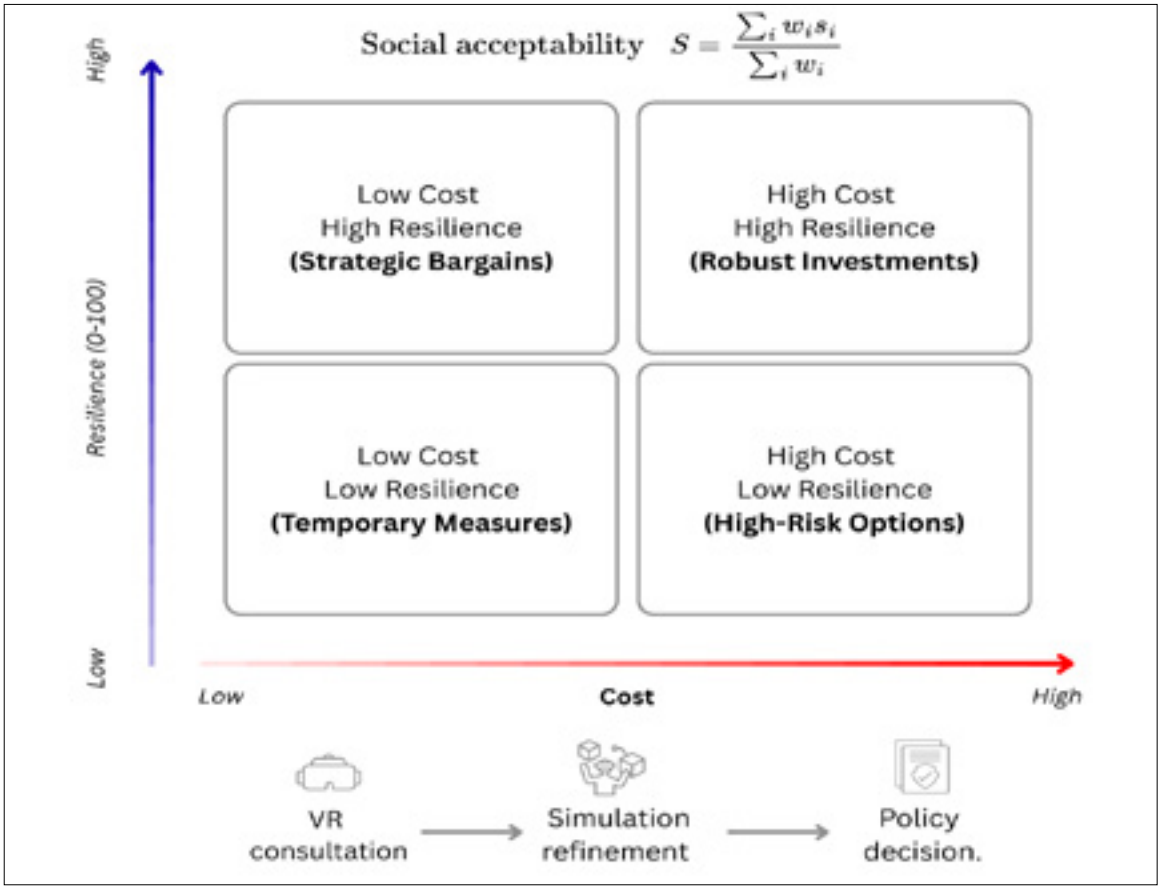

Figure 4: Living Lab decision matrix (Source: Developed by the author)

fuse remote sensing with ground surveys for local calibration; (2) use Monte Carlo ensembles to quantify uncertainty in inundation extent; (3) present results as probability of exceedance maps (e.g., 10%, 1% event) to inform risk thresholds. The living lab accelerated stakeholder consensus by making trade-offs visible and auditable, improving the likelihood of policy adoption

6. Evaluation, Validation, and Impact Metrics

The platform uses a risk informed approach that separates conceptual validity, implementation verification, and operational validity, and scales testing effort to decision consequence. This aligns with Sargent (2013) and with other credibility assessment approaches for computational models.

In the case of domain simulation engines, validation is pegged on reference tools and local measurements. The PV yield estimates are compared to the NREL PVWatts at the same location and system definition, and recalibrated where local smart meters or sensor data is available, such as National Aeronautics and Space Administration (NASA) POWER open solar and meteorological feeds. The priors of wind resources are cross-checked against the Global Wind Atlas layers, and site-specific correction is carried out. Error and bias in all PV, wind, hydrology, and waste to energy are documented using normalized measures, including:

$$NRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}}{\bar{y}} \quad \text{Equation (7)}$$

and

$$NMBE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{(n-1)\bar{y}}. \quad \text{Equation (8)}$$

Uncertainty quality is evaluated using prediction interval coverage

$$PICP = \frac{1}{n}\sum_{i=1}^{n} \mathbb{1}\{ y_i \in [\ell_i, u_i]\} \quad \text{Equation (9)}$$

Plus a sensitivity concentration score reporting how much output variance is explained by the top inputs. They support frugal data collection because they identify which parameters deserve local measurement.

In the case of the LLM orchestration layer, the focus of validation is traceability, safety, and regulatory aware validation. Every run generates a machine-readable decision trail recording prompt templates, sources retrieved, parameter defaults, rule checks, and models versions. The proportion of claims in relation to a source or a reported assumption is rated to trail completeness. Rule checking results are set to pass rate and false positive rate in comparison to a curated compliance test set. The system level assessment correlates with the features of trustworthiness, including validity, reliability, transparency, and accountability as defined in the National Institute of Standards and Technology (NIST) AI Risk Management Framework. In a federated learning approach to local calibration, privacy assessment tracks the information of whether the raw data remains local and the privacy parameters in the case of differential privacy, and convergence and drift metrics track the quality of learning (NIST, 2023).

Impact metrics connect technical quality to youth outcomes. In classrooms, learning gain is tracked using normalized gain (Equation 6) alongside rubric scores for assumption quality and scenario coverage. UNESCO reinforces the need for human agency, assessment integrity, and responsible deployment in education, which these measures operationalize (UNESCO, 2023). In incubation and policy, the headline indicators are cycle time from concept to a decision packet, cost of iteration, pilot conversion rate, and sustainability deltas such as emissions avoided and risk reduction, always reported with uncertainty bounds and equity flags.

7. Policy, Financing, and Scaling Roadmap

The primary factor as to whether a simulation LLM turns into trusted infrastructure or a pilot project is policy readiness. The roadmap is thus initiated by governance, which is readable by the regulators, educators, and communities. Specifically, the platform must conform its controls to the trustworthiness functions in the NIST AI Risk Management Framework, and the complete life cycle of models and prompts must be explicitly documented, monitored, and responded to. To become publicly adopted, the design must follow the recommended practices of traceability and explainability in the Organization for Economic Co-operation and Development (OECD) public sector advice on AI and release minimal transparency artifacts in the form of an algorithmic transparency register style pattern per deployment (OECD, 2024). The issue of interoperability is important in Asia Pacific. Its platform should be such that it aligns its governance controls with regional voluntary frameworks like the Association of Southeast Asian Nations (ASEAN) Guide on AI Governance and Ethics and its generative AI supplement, so that pilots can cross jurisdictions without having to reinvent safety and accountability anew (ASEAN, 2024). It must also reuse new assurance practices, such as the model safety evaluation approach outlined in the Infocomm Media Development Authority (IMDA) and AI Verify Foundation materials, which focus on standardized testing and documentation of risks that LLM poses (AI Verify, 2024). Government has a scaling leverage of procurement. To put it into practice, one may start by converting simulation outputs into procurement-ready packages and embrace risk controls that are in line with government directions that specifically support generative AI procurement and use in the government.

Financing must be arranged in such a way that it minimizes first-year risk, and it is used to reward proven performance. This is facilitated by the platform through the generation of standard technical, financial and governance artifacts that decrease transaction costs of funders and lowers due diligence time. Blended finance is a logical combination since it employs development finance to attract commercial capital to sustainable development, but needs transparency and local ownership to prevent low-quality deals. A leverage ratio can be reported as a mere indicator of mobilization

$$\lambda = \frac{F_{\text{commercial}}}{F_{\text{development}}}$$

and be tracked across cohorts and regions. The World Bank notes blended finance as a mechanism to improve risk adjusted returns and mobilize private capital for infrastructure and development gaps,

which is directly relevant to youth led sustainable ventures that struggle with early bankability (World Bank, 2025). On the supply side, multilateral development banks reported record climate finance volumes in 2024, alongside growth in private co finance, which signals increased appetite for pipelines that are measurable and implementation ready (Furness, 2025). The platform can connect ventures to instruments such as concessional loans, guarantees, results based grants, and insurance or resilience clauses, while generating the documentation needed for grants, green loans, and procurement.

Scaling must be done in a gradual diffusion process that will create credibility prior to breadth. Stage one entails campus and incubator pilots that ascertain acquisition of learning, model credibility, as well as compliance of governance in controlled conditions. The second stage is municipal living labs, where both the digital twin layer and the workflow of the public participation are refined using VR consultations and stress-tested rules. Stage three is a national and regional implementation using template libraries across priority areas, distributed solar, coastal resilience, and waste diversion in combination with mutual evaluation criteria and transparency reporting. Federated calibration allows local performance enhancement at every level and does not centralize sensitive data, and the assumption ledger and decision trail give the audit spine required to use the policy. The platform must use a scorecard of scale that is based on adoption and outcome, for example

$$S = w_1\Delta t + w_2\Delta C + w_3\Delta E + w_4\Delta R$$

where Δt is cycle time reduction from concept to decision packet, ΔC is avoided iteration cost, ΔE is verified emissions reduction or energy access gain, and ΔR is resilience improvement, all reported with uncertainty bounds and equity flags. This approach turns scale into an evidence-based process rather than a marketing claim.

8. Risks, Ethics, and Governance

There are four risky elements interwoven in model systems. When local conditions or social group underrepresentation occur in training data, the training data may cause a model bias, resulting in systematically biased recommendations. Excessive use of simulation also results in fragile decisions in cases of uncertainty or edge cases being brushed off. Risks of data privacy are re-identification due to high-resolution sensor or survey data. The inequity of access increases any existing inequity when the tools and funds favor actors in urban or well-connected places. All risks have both technical and social aspects and should be controlled in equal measure, as shown in Table 1.

Table 1: Risks vs Governance for the solution (Source: Developed by the author)

Risk	Governance control	Trigger / metric
Model bias	Open validation datasets; bias audits	Bias score > threshold
Overreliance	Mandatory uncertainty bands; decision gates	Exceedance probability > policy limit
Data privacy	Federated learning; DP; retention limits	Reidentification risk test fail
Unequal access	Subsidies; local capacity grants	Participation gap > 20% vs baseline

The mitigation and governance are ensured using the following:

- Transparency logs: immutable, humanreadable audit trails for prompts, model versions, parameter sets, and decision rationales.
- Community review boards (CRBs): local panels with diverse representation (youth, elders, women, technical advisors) that review model outputs, consent processes, and pilot designs before procurement. CRBs provide social validation and can veto or require redesigns.
- Open validation datasets: curated, anonymized benchmark sets for PV, hydrology, and social surveys that enable independent replication and bias testing. Public datasets reduce singlevendor lockin and enable thirdparty audits.
- Privacy-preserving pipelines: federated learning, secure aggregation, and differential privacy for local calibration; explicit data minimization and retention policies; and cryptographic provenance for sensor feeds. Federated updates Δwi should be auditable while raw data remains local.

- Equity safeguards: quotabased funding windows, subsidized access for marginalized communities, and capacitybuilding grants to ensure local teams can use and contest outputs.

The operational rules and triggers are as follows:

- Decision gates: require TEVV (testing, evaluation, verification, validation) pass and CRB sign-off before tranche release.
- Performance triggers: if observed vs modeled deltas exceed thresholds (e.g., CF error >15%), pause scaling and require recalibration and public remediation plan.
- Transparency obligations: publish model provenance, key priors, and TEVV summaries with each funding milestone.

9. Conclusion and Call to Action

The integrated platform—literally, consisting of the LLM coordination, proven simulation engines, simulated pilots, immersive digital twins, private data connectors, and finance/policy modules—is a feasible pathway between early concepts and pilotable, local-approved ideas. It is powerful not only because it is new, but because it connects explainable paths of decisions, outputs sensitive to uncertainty, and participatory visualizations in cutting design cycles, reducing transaction costs, and increasing social approval. To transform this potential into scale, there are three steps that are clear. First, implement 50 pilots across Asia and the Pacific in clearly defined subregions and member States—for example, energy-access microfarm pilots in rural districts of Bangladesh, Nepal and Sri Lanka (South and South-West Asia), and coastal-resilience living labs in Indonesia, the Philippines and Viet Nam (South-East Asia), with a small set of shoreline pilots in Pacific Island developing economies, such as Fiji, Samoa and Vanuatu (the Pacific). Require TEVV (testing, evaluation, verification, and validation) summaries and open data to confirm findings and publish results so stakeholders can scrutinize the evidence. Second, minimize risk and mobilize finance by establishing low-interest first-loss funds and procurement templates that accept digital-twin outputs, targeting private-capital leverage of three or greater. Third, enforce operational rules by requiring transparency logs, local community review boards, and shared calibration of any funded pilot to prevent privacy harms and unfairness.

Stakeholders should act in various ways: funders to underwrite standardized TEVV and blended instruments; municipalities to open regulatory sandboxes and adopt procurement templates; and incubators to scale youth cohorts and convert top teams into blended-finance pipelines. The immediate objective is pragmatic: prove replicable models meet technical, financial, and social thresholds within 24 months, so municipalities can mainstream proven pilots into budgets and policy.

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Youth-Driven Digital Innovation as Infrastructure for Sustainable Development

Goksu Aslan[1] and Marco Gallieri[2]

[1]Yildiz Technical University, Istanbul & Zayed University, Abu Dhabi.

Emails: goksu.aslan@yildiz.edu.tr, goksu.aslan@zu.ac.ae

[2]Independent Researcher, Lugano, Switzerland.

Email: mgallieri.ac@gmail.com

Abstract

Youth-led digital innovation is emerging as an important enabler of sustainable development in the Asia-Pacific region, which is home to a significant share of the world's youth population. As young people increasingly harness digital technologies, such as artificial intelligence, data platforms, and other advanced digital tools, their innovations are being recognized as a form of development infrastructure. This article examines how youth-driven digital solutions are contributing to climate action, clean energy access, and resource efficiency across diverse sectoral contexts. It analyzes the policy, institutional, and technology transfer mechanisms that shape the ability of these innovations to scale and presents selected case studies demonstrating tangible outcomes in areas such as climate resilience, environmental governance, and service delivery. The article identifies key barriers, including regulatory complexity, financing gaps, infrastructure disparities, and gender divides, and highlights policy-relevant insights to strengthen youth innovation ecosystems and support inclusive and sustainable digital transformation.

Keywords: youth innovation; sustainable development; digital public infrastructure; artificial intelligence; digital twins; climate action; energy transition; Asia-Pacific.

1. Introduction

Sustainable development in the 21st century increasingly depends on digital infrastructure and innovation. Beyond traditional physical infrastructure, digital technologies, from AI and big data platforms to Internet of Things (IoT) networks and digital twin simulations, now provide critical building blocks for progress on the Sustainable Development Goals (SDGs) (World Bank, 2025; United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2024). In the Asia-Pacific region, youth are at the forefront of this digital transformation. The region's youthful demographic (with approximately 60% of the world's young people) represents a vast reservoir of tech talent and innovative potential (United Nations Population Fund (UNFPA), 2024). Young innovators are not merely passive beneficiaries of new technology; they are active leaders developing and deploying digital solutions to strengthen climate resilience, energy access, and resource efficiency (ESCAP, 2024; United Nations Development Programme (UNDP), 2024).

Crucially, these youth-driven digital innovations can serve as enabling infrastructure for sustainable development, analogous to how roads or power grids enable economic activity. They provide platforms and tools that improve the delivery of services, optimize resource use, and connect communities in new ways. Examples across the region include AI-driven tools for climate-smart agriculture and disaster response, as well as digital twin models for optimizing grid reliability and renewable integration (International Energy Agency (IEA), 2017; United Nations Conference on Trade and Development (UNCTAD), 2025). Youth-led firms are pioneering decentralized climate analytics, hyper-local risk platforms, and open-source tools to bridge service delivery gaps (ESCAP, 2024). These efforts illustrate how the creativity and digital acumen of young people are being channeled into a new layer of development infrastructure: open, adaptive, and driven by innovation.

Realizing the full potential of youth-driven digital innovation requires supportive ecosystems. Policy frameworks, institutional capacities, and technology transfer mechanisms must evolve to include and

empower young innovators (United Nations Department of Economic and Social Affairs (UN DESA), 2025; United Nations Educational, Scientific and Cultural Organization (UNESCO), 2024). This article examines the enabling conditions that allow youth-led innovation to evolve into infrastructure. Section 2 outlines a conceptual framework; Section 3 discusses institutional and policy mechanisms; Section 4 presents three case studies; Section 5 identifies barriers to scale; and Section 6 offers actionable policy recommendations.

To synthesize the core argument of this article, Figure 1 presents a conceptual framework that positions youth-driven digital innovation as a layered form of sustainability infrastructure. The framework organizes the discussion across foundational enablers, core digital building blocks, youth-led solution layers, institutional embedding mechanisms, and sustainable development outcomes. Each layer corresponds to specific analytical sections of this paper, creating a structural map that links conceptual framing to empirical examples, policy analysis, and recommendations.

2. Youth-Led Digital Innovation as Enabling Infrastructure

Youth-led digital innovations are increasingly understood not as isolated tools, but as enabling infrastructure and interoperable systems that deliver essential services for sustainable development. This perspective stems from the role such innovations play in areas ranging from climate data and energy management to healthcare and education. In many Asia-Pacific contexts, young people have helped fill gaps left by inadequate traditional infrastructure by building platforms that bridge service gaps in energy, health, agriculture, and climate adaptation; connecting citizens to actionable data and support networks. For instance, youth innovators have developed mobile applications for real-time alerts, open data tools for hazard mapping, and coordination platforms for relief logistics, forming digital lifelines in regions underserved by physical infrastructure (UN DESA, 2025; ESCAP, 2024). By rapidly adopting new technologies, Asia-Pacific youth bring fresh perspectives to persistent development challenges, often devising solutions that are more agile, affordable, and user-centric (ESCAP, 2024).

One salient example is the use of digital twin technology in energy and urban systems. Digital twins, dynamic, data-driven replicas of physical systems, enable predictive simulation, optimization, and real-time decision support. In the hands of young tech entrepreneurs and researchers, digital twins are being

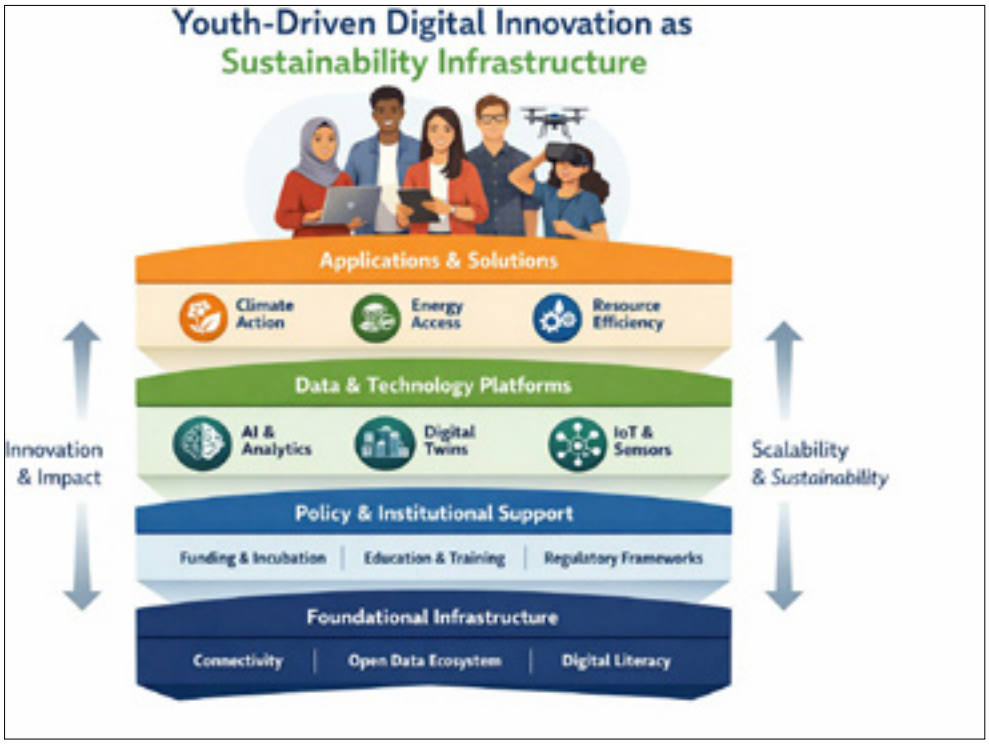

Figure 1: Conceptual layers of youth-driven digital innovation as sustainability infrastructure.

Notes: The framework also implies feedback loops, whereby demonstrated development impact strengthens institutional support and further investment in foundational enablers.
(Source: Authors' elaboration)

applied to model renewable energy grids, water networks, and even cities for sustainability planning. The broader trend of digitalization in the energy sector (encompassing sensors, connectivity, data platforms, and analytics) has been identified as a pathway to improved system efficiency and flexibility (IEA, 2017). These developments underscore that youth-driven digital innovation, whether an AI algorithm for energy optimization or a data platform for climate resilience, often functions as critical infrastructure by improving decision-making, efficiency, and reach of development interventions.

To clarify how youth-driven digital innovation is structurally enabled, Figure 2 presents a conceptual representation of a youth innovation ecosystem built upon core components of digital public infrastructure (DPI). The figure illustrates how foundational DPI layers, such as digital identity, payment systems, government service portals, and shared data protocols, interact to create an enabling environment within which young innovators can design, test, and scale digital solutions. These layers collectively lower transaction costs, improve access to services and data, and facilitate collaboration between youth, public institutions, and markets. The framework operationalizes the notion of youth-led digital innovation as infrastructure by showing how technological building blocks support sustained innovation capacity rather than isolated applications.

Youth-led innovations in AI and data analytics are also contributing to infrastructure-like services. AI chatbots and mobile platforms created by young developers are enhancing public service delivery at scale. In South and Southeast Asia, youth innovators have developed systems using machine learning to support flood forecasting, agricultural advisories, and community-level climate risk information (UNDP Viet Nam, 2025; ESCAP, 2024). These AI-driven services operate as digital infrastructure by providing timely information and analysis that communities rely upon for livelihoods and safety. Importantly, many solutions use open-source data and emphasize interoperability, enabling transfer across regions, a hallmark of effective infrastructure. For example, youth-led climate-smart agriculture platforms increasingly combine low-cost sensing and AI analytics to generate actionable recommendations for smallholders, functioning as a digital extension layer for rural services (ESCAP, 2024; UNDP, 2024).

This framing also implies durability and scalability. Encouragingly, youth-led initiatives in Asia-Pacific show potential for both. Many began as pilot projects or hackathon prototypes and have grown into sustained operations or social enterprises. Their scalability is often supported by the low marginal cost of digital services, especially when delivered via mobile platforms and cloud infrastructure. However, scale

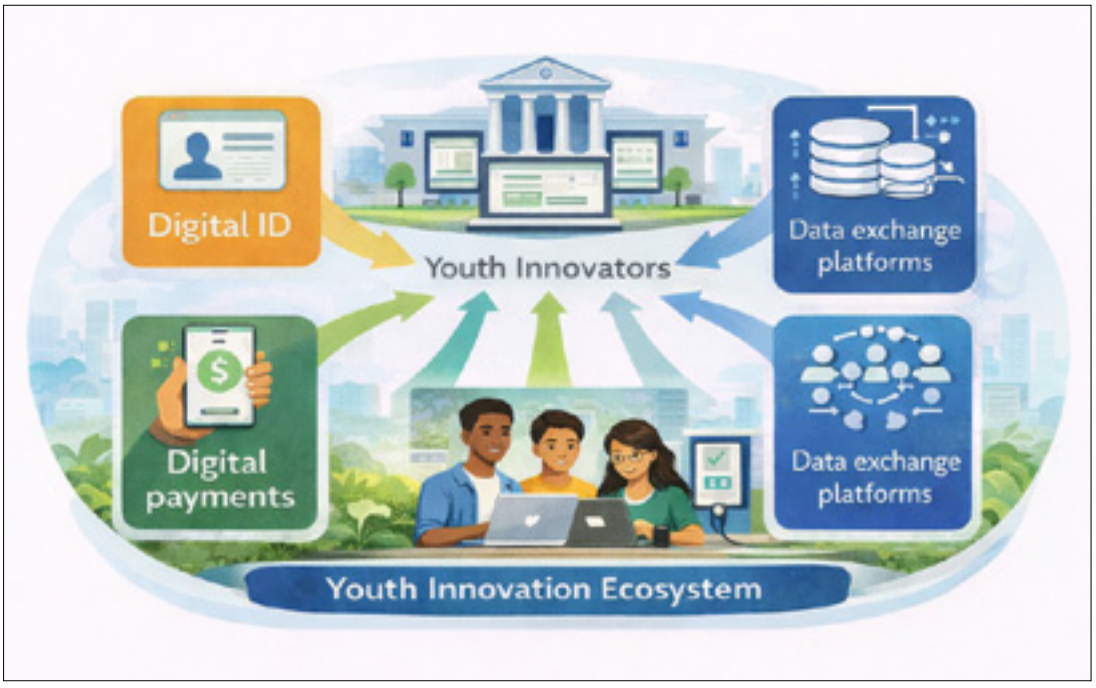

Figure 2: Building blocks of digital public infrastructure supporting youth innovation ecosystems.

Notes: Core DPI layers include digital identity, digital payments, public service portals, and data interoperability standards, which together enable youth innovators to develop, deploy, and scale digital solutions for sustainable development. (Source: Authors' elaboration, informed by World Bank (2025) on digital public infrastructure)

alone is insufficient. Lasting impact depends on institutional embedding, where public agencies adopt youth-built systems, integrate them into service delivery, and align with national digital strategies such as DPI. DPI is increasingly recognized as a foundational approach to building interoperable, reusable digital systems that governments and societies can build upon (World Bank, 2025). Recognizing youth-led innovation as infrastructure aligns with global efforts to build inclusive digital public goods and achieve SDG 9 (industry, innovation, and infrastructure) and SDG 17 (partnerships for the goals).

In summary, youth-driven digital innovations in AI, data platforms, and digital twins are increasingly fundamental to sustainable development. They act as infrastructure enablers by providing new channels for service delivery, optimizing resource management, and connecting stakeholders into functional networks. Recognizing them as infrastructure urges policymakers and institutions to invest in their interoperability, governance, and long-term sustainability, as well as to nurture the talent behind them. The following sections examine enabling policy and institutional mechanisms—and where gaps remain.

3. Policy, Institutional and Technology Transfer

Transforming youth-led innovations into durable infrastructure demands a supportive ecosystem, in particular, one that spans ideation, piloting, institutional embedding, and transnational scaling. In the Asia-Pacific, several policies and institutional mechanisms have begun to facilitate this process, though persistent shortcomings remain.

3.1 Policy frameworks and regulatory environment

An inclusive and flexible policy environment is paramount. Governments in the region increasingly acknowledge youth as key stakeholders in innovation policy. Including young people in digital strategy and policy-making can result in more youth-sensitive, responsive policies (ESCAP, 2024). Some initiatives explicitly aim to amplify youth participation and build digital capacity for climate action, including efforts targeted at digitally empowering girls and young women in remote regions. Such approaches integrate innovation policy with equity objectives, ensuring that digital strategies prioritize gender, geography, and access.

On the regulatory front, many young entrepreneurs struggle with complex rules not designed for digital startups. Flexible mechanisms such as regulatory sandboxes can help. Sandboxes allow innovators to pilot new technologies under supervised conditions, enabling iteration while regulators learn and adapt rules for emerging technologies. Guidance on sandbox design emphasizes the need for clear scope, safeguards, evaluation criteria, and pathways for successful pilots to transition into mainstream compliance frameworks (CGAP, 2020,). While sandboxes are often associated with fintech, their logic can be extended to climate-tech, energy-tech, and public-interest AI.

3.2 Institutions: education, incubation, and collaboration

Educational institutions play a dual role as skill builders and innovation hubs. Interdisciplinary innovation labs and challenge-based learning help students develop practical solutions for real-world sustainability problems. Across the region, universities are establishing accelerators and technopreneurship programs focused on sustainable development. Incubation support can include mentorship networks, prototyping facilities, legal guidance, and connections to investors, elements that youth innovators often lack (World Bank, 2020; UNESCO, 2024).

Beyond universities, dedicated youth incubators and hubs have proliferated across Asia-Pacific, ranging from government-funded centers to non-governmental organizations (NGOs) or private-sector labs. These institutions help reduce the networking and information barriers youth face, providing pathways to partnerships, customers, and capital (UNDP, 2024, 2019). They also enable peer learning across cohorts and geographies, accelerating diffusion of workable models. Where youth-led solutions align with digital public infrastructure (DPI) components, for instance, open data protocols or shared digital ID, are more likely to scale sustainably.

3.3 Technology transfer and collaboration mechanisms

Technology transfer for youth innovation occurs through knowledge exchange, open-source platforms, partnerships, and institutional adoption. Cross-border innovation challenges and youth forums are

venues where young innovators showcase solutions to peers and potential adopters from other countries. International organizations contribute by documenting cases and disseminating good practices (ESCAP, 2024; UNDP, 2024). Corporate partnerships can scale youth innovations via technology licensing, integration into supply chains, or collaboration with utilities and public agencies.

However, gaps remain in institutional silos, weak public procurement channels, data access constraints, and limited support for intellectual property and standards adoption. Addressing these gaps requires institutional coordination, strengthening procurement for innovation, interoperability standards, and cross-border alignment with DPI frameworks.

4. Case Studies: Youth-Driven Digital Solutions

To ground the discussion in real-world outcomes, this section presents three in-depth case studies of youth-led digital innovation advancing sustainable development. Figure 3 visually summarizes these examples, which span climate-smart agriculture, community-based water governance, and AI-enabled emergency response. Together, they illustrate how youth-led platforms operationalize core digital technologies, such as mobile applications, AI, and open data systems, into practical services that deliver sustainability outcomes across agri-food systems, energy access, disaster risk management, and water governance.

Table 1: Policy and institutional tools to scale youth-driven digital innovation.

Policy Institutional Tool	What it does	Barrier addressed	Key reference(s)
Regulatory sandboxes	Enables controlled experimentation with emerging digital models under supervisory over sight	Regulatory uncertainty; compliance burden for early-stage teams	(World Bank and CGAP, 2020; United Nations Department of Economic and Social Affairs (UNDESA), 2025)
Innovation-oriented public procurement	Creates demand for solutions aligned to public objectives; pilots and scales innovations through public adoption	Market access; “pilot trap”; lack of anchor customers	(Organisation for Economic Co-operation and Development (OECD), 2017, 2023)
Digital public infrastructure (DPI)	Provides interoperable, reusable platforms (data exchange, standards, shared services) for scaling digital services	Fragmented systems; interoperability; duplication; inequitable access	(World Bank, 2023)
Incubators/accelerators with SDG focus	Provides mentorship, facilities, legal support, investor access, partnerships; improves investment readiness	Networking deficits; capability gaps; financing barriers	(World Bank, 2018; United Nations Development Programme (UNDP), 2024)
STI policy instruments for SDGs	Aligns R&D, incentives, and institutional programs with SDG outcomes and inclusion	Weak policy coordination; limited translation from R&D to deployment	(United Nations Educational, Scientific and Cultural Organization (UNESCO), 2024)
Indusive Al governance frameworks	Supports responsible, indusive Al deployment; addresses bias, access, and capacity constraints	Exclusion; trust deficits; uneven distribution of benefits	(United Nations Conference on Trade and Development (UNCTAD), 2025)

Notes: Authors’ elaboration, based on WB and CGAP, 2020; UN DESA, 2025; OECD, 2017, 2023; WB, 2023; WB, 2023; UNDP, 2024; UNESCO, 2024; UNCTAD, 2025.

The first case study highlights how digital platforms can address productivity, finance, and market access gaps for small-scale farmers. The second examines citizen-science and mobile technologies that improve transparency in rural water governance. The third explores sensor-integrated AI systems for disaster preparedness and response in urban environments. Collectively, these initiatives exemplify how youth-led innovation ecosystems convert digital infrastructure into scalable, mission-driven services that align with the Sustainable Development Goals.

Figure 3: Selected case studies of youth-driven digital innovation for sustainable development: (i) iFarmer; (ii) MyH2O; and (iii) Alerto PH.

(Source: Compiled by the authors from Future Startup (2020), iFarmer (2024), Wang (2021), Chen (2019), Mondares (2025), and DOST (2025))

4.1 Case Study 1

iFarmer: A Technology Platform Enabling Profit Maximization for Small-Scale Farmers (Bangladesh)

iFarmer is a youth-led digital agri-fintech platform launched in Bangladesh in 2019. It connects smallholder farmers to finance, inputs, advisory services, and structured markets through mobile and web-based systems (Future Startup, 2020; iFarmer, 2024). By addressing constraints such as limited access to finance, information asymmetries, and inefficient market structures, digital platforms contribute to higher productivity and income generation in rural areas. Through improved connectivity, access to services, and market integration, they also support more inclusive and resilient economic outcomes (World Bank, 2022). As a platform delivering public-interest outcomes, iFarmer demonstrates how youth-built platforms can function as enabling infrastructure for development and support policy discussions on strengthening youth innovation ecosystems and digital inclusion aligned with SDGs 2, 8, 9, and 13 (UNCDF, 2023).

4.2 Case Study 2

MyH2O: A Digital Innovation Supporting Rural Water Governance (China)

MyH2O is a youth-driven citizen-science initiative in China launched in 2015. It mobilizes students and volunteers to collect water quality data in rural areas, uploading results to an open-access platform that addresses persistent data gaps in water governance (United Nations Environment Programme (UNEP), 2020). Local governments and NGOs use the data for planning and monitoring, while the platform also connects underserved communities with potential service providers (Wang, 2021; Chen, 2019). MyH2O exemplifies how youth engagement and open digital systems can complement public infrastructure in environmental monitoring, contributing to SDG 6 and SDG 17.

4.3 Case Study 3

Alerto PH: AI-Enabled Emergency Alerting and Response for Local Government Units (Philippines)

Alerto PH is a woman-led Filipino startup that provides an AI-powered emergency alert system for disaster-prone communities. First operational in 2025, the platform integrates mobile apps, sensors (e.g., flood,

smoke, gas), and automated alerting into a decentralized emergency response network (Mondares, 2025). Its back-end command system uses AI for real-time data processing and coordination with local government units (LGUs), enhancing situational awareness and response speed (Apple App Store, 2025; Department of Science and Technology (DOST), 2025). The platform is available publicly via app stores and is being deployed in collaboration with national agencies (Alerto PH, 2025; Google Play, 2026).

Alerto PH operates as civic digital infrastructure: (i) integration infrastructure linking heterogeneous IoT devices; (ii) information infrastructure enabling real-time awareness; and (iii) coordination infrastructure connecting responders to incidents. Its scaling is enabled by device interoperability and public agency adoption, but challenged by procurement fragmentation, connectivity gaps, and data governance risks. It advances SDGs 9, 11, and 13 by strengthening digital resilience to disasters and climate shocks.

Table 2: Summary of illustrative youth-driven digital innovation case studies

Case & Domain & Location	Core Digital Components	Development Challenges Addressed	Key Stakeholders	Main Scaling Constraints	SDG Alignment.
iFarmer: A Technology Platform Enabling Profit Maximization for Small Scale Farmers (Bangladesh)	Mobile and web-based agri-fintech platform linking farmers to finance, inputs, advisory services, and markets.	Credit access gaps, market inefficiencies, climate risk in smallholder farming.	Smallholder farmers; agripreneurs; financial institutions; agribusinesses; development partners.	Access to affordable finance; regulatory barriers; farmer digital literacy; climate and market shocks.	SDG 2 (Zero Hunger); SDG 8 (Decent Work and Economic Growth); SDG 9 (Industry, Innovation and Infrastructure); SDG 13 (Climate Action).
My H2O: A Digital Innovation Supporing Rural Water Governance (China)	Citizen-science platform for mobile-based water quality testing and open data sharing	Rural water quality data gaps and weak local monitoring capacity.	Rural communities; youth volunteers; universities; local governments; NGOs	Sustaining volunteer engagement; data quality assurance; policy uptake of citizen data.	SDG 6 (Clean Water and Sanitation); SDG 17 (Partnerships for the Goals).
Al-Enabled Emergency Alerting and Response for Local Government Units - Alerto PH (Philippines)	AI-enabled, sensor integrated emergency alert platform for LGUs.	Fragmented early warning systems and delayed local emergency response.	LGUs; emergency responders; technology providers; national agencies; communities.	Procurement complexity; device interoperability and maintenance; data privacy and cybersecurity.	SDG 11 (Sustainable Cities and Communities); SDG 9 (Industry, Innovation and Infrastructure); SDG 13 (Climate Action).

Notes: Synthesized from (Future Startup, 2020; iFarmer, 2024; World Bank, 2022; United Nations Development Programme, 2023; United Nations Environment Programme, 2020; Chen, 2019; Wang, 2021; Mondares, 2025; Apple App Store, 2025; Department of Science and Technology (DOST), 2025; Google Play, 2026). SDG alignments reflect the primary development objectives addressed by each innovation.

5. Barriers to Scaling Youth Innovation

Despite compelling examples, youth-led digital innovations face structural constraints that prevent them from scaling into durable and inclusive infrastructure. These barriers are multi-dimensional and span regulation, finance, access, and inclusion, often mutually reinforcing each other and disproportionately affect early-stage innovators.

5.1 Regulatory and bureaucratic complexity

Many regulatory environments in the Asia-Pacific region remain designed for established firms and legacy technologies. Young innovators must often navigate unclear rules on data governance, AI accountability, or sector-specific compliance (e.g., energy, health, agriculture). These burdens can delay or derail early-stage deployment. In the absence of adaptive mechanisms like regulatory sandboxes, youth-led teams are frequently expected to meet full compliance requirements prematurely, thus undermining their capacity to iterate and scale (CGAP, 2020; UN DESA, 2025).

5.2 Funding gaps and financial barriers

Access to finance is a persistent obstacle. Youth-led ventures commonly lack credit histories, formal registration, or investor networks. This limits their eligibility for public funding and deters private investment, especially for solutions with public good characteristics. As a result, many innovations remain trapped in the pilot stage, without resources to scale infrastructure, strengthen governance, or sustain operations (UNDP, 2024; World Bank, 2020).

5.3 Infrastructure disparities and the digital divide

Scaling digital solutions requires foundational enablers such as reliable internet, stable electricity, and access to devices. In rural and underserved areas, these enablers are often absent or unevenly distributed. Digital literacy gaps further constrain adoption. Without these basic infrastructure layers, identified in Figure 1, higher-order innovations cannot scale equitably. These divides are often exacerbated by broader patterns of socioeconomic inequality and geographic isolation.

5.4 Networking, mentorship, and market access

Youth-led teams frequently lack access to mentorship, institutional partners, and procurement pathways. Weak connections to anchor customers, such as local governments, utilities, or development agencies, limit the embedding of youth innovations into public systems. Difficulty navigating procurement processes and enterprise channels also hinders scaling and sustainability (UNDP, 2024). Strengthening ecosystem linkages is thus critical for overcoming fragmentation.

5.5 Gender and social inclusion barriers

Systemic inclusion barriers persist across the innovation lifecycle. Young women and marginalized groups often face obstacles in education, entrepreneurial support, and investment access. Without deliberate interventions, such as gender-sensitive procurement, targeted digital skills programs, and safe innovation spaces, youth-led innovation ecosystems risk reinforcing exclusion. Inclusive AI and equitable governance frameworks are essential for broadening participation and ensuring benefits are fairly distributed (UNCTAD, 2025; ESCAP, 2024).

6. Recommendations: Strengthening Youth Innovation Ecosystems

Overcoming the barriers outlined above and amplifying the systemic impact of youth innovation requires coordinated action across institutions. The following recommendations are designed to transition youth-led solutions from isolated pilots to scalable, transferable, and embedded infrastructure for sustainable development.

6.1 Governments and policymakers

Governments should: (i) invest in foundational digital enablers, such as connectivity, digital literacy, and open data access—to reduce structural inequities; (ii) expand adaptive regulatory mechanisms, including sandboxes for climate-tech, energy-tech, and public-interest AI; (iii) institutionalize innovation-oriented public procurement to stimulate demand for youth-driven solutions; and (iv) align national digital and sustainability strategies with principles of digital public infrastructure (DPI) (World Bank, 2025; Organisation for Economic Co-operation and Development (OECD), 2017, 2023).

6.2 Universities and educational institutions

Universities should embed challenge-based learning, interdisciplinary labs, and translational research pathways that connect students to real-world problem solving. Institutions should foster inclusive STEM and digital skills pipelines for women and marginalized youth, linking education with incubation, partnerships, and deployment opportunities (UNESCO, 2024; World Bank, 2020).

6.3 Incubators, accelerators, and innovation hubs

Innovation hubs should provide comprehensive support in the form of mentorship, prototyping facilities, investor access, and regulatory navigation. Programs must intentionally broaden inclusion

through scholarships, dedicated cohorts, and gender-responsive mentorship. They should also promote interoperability and standards adoption, enabling youth-built solutions to integrate with government and enterprise systems.

6.4 Private sector and industry

Private companies can strengthen youth innovation ecosystems by engaging in open innovation partnerships, adopting youth-developed solutions, offering mentorship, and providing catalytic venture funding. Embedding these solutions into supply chains and service models accelerates scaling and commercial viability, especially when aligned with corporate sustainability goals.

6.5 International organizations and development partners

Development actors should (i) facilitate cross-border knowledge exchange and peer learning; (ii) document replicable good practices and support regional technology transfer; (iii) invest in pilot-to-scale mechanisms and innovation infrastructure; and (iv) strengthen governance capacity for inclusive, responsible AI and digital transformation in development contexts (UNCTAD, 2025; UNDP, 2024; ESCAP, 2024).

7. Conclusion

Youth-led digital innovation is emerging as a critical driver of sustainable development, functioning not merely as a collection of individual applications but as an evolving layer of enabling infrastructure. In the Asia-Pacific region, where youth comprise a majority demographic and digital adoption is accelerating, these innovations offer tangible solutions to long-standing challenges in climate resilience, agriculture, public service delivery, and disaster preparedness.

This paper has conceptualized youth-driven digital innovation as a layered infrastructure system: built upon foundational enablers such as connectivity and skills; structured through core digital components including AI, data platforms, and digital twins; applied via youth-led solutions; and institutionalized through policy and procurement mechanisms. Through illustrative case studies, from agri-fintech in Bangladesh to citizen science in China and AI-enabled emergency systems in the Philippines, we have demonstrated how youth are transforming abstract technologies into practical services that advance multiple SDGs.

However, realizing the full potential of this transformation depends on overcoming systemic barriers. Regulatory rigidity, financial exclusion, infrastructure disparities, and inclusion gaps all constrain the scalability and durability of youth-led initiatives. These barriers are not incidental as they reflect deeper asymmetries in how innovation ecosystems are structured and resourced. Without intervention, even the most promising pilots risk stagnation or fragmentation.

The policy recommendations offered in this paper emphasize the need for ecosystemic approaches. Governments must institutionalize innovation-oriented procurement and adaptive regulation. Universities should integrate inclusive digital skills training with challenge-based, interdisciplinary innovation models. Incubators and hubs must go beyond access to facilities by supporting interoperability, investment readiness, and equity. Private firms and development partners have essential roles in embedding and scaling youth-built solutions, especially those delivering public goods.

Looking ahead, three key priorities stand out. First, youth-led digital innovation must be anchored in robust digital public infrastructure: open, reusable systems that lower the entry cost for new innovators and ensure continuity. Second, inclusion must move from rhetoric to design principle, shaping funding models, capacity-building, and governance. Third, research and evidence gaps persist. In particular, we need better metrics to assess the long-term impact of youth-led digital solutions, as well as comparative studies on ecosystem models that enable successful scaling.

If supported with the right policies, institutions, and infrastructure, youth innovators can become central architects of a more resilient, equitable, and sustainable future. Investing in youth-led digital ecosystems is a strategic route to better public services—provided governments institutionalize adoption pathways, safeguards, and inclusion from the outset. In doing so, countries can accelerate progress toward achieving the SDGs, particularly those related to inclusive growth, resilient infrastructure, climate action, and strengthened partnerships.

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Youth-Driven Social Enterprises and Sustainable Development in the Asia–Pacific Region: Strategy, Evidence, and Policy Implications

Lukman RAIMI[1], Morufu Oladimeji SHOKUNBI[2], Quazi Mohammed Habibus SAKALAYEN[3] and Iznan TARIP[4]

Affiliations 1 – 4: School of Business and Economics

Universiti Brunei Darussalam, Brunei Darussalam

Corresponding author's Email: luq_man2001@yahoo.com

Abstract

Across the Asia–Pacific region, youth-driven social enterprises, such as Hapinoy (Philippines), Green Monday (Hong Kong), Siam Organic (Thailand), ECO Bali Recycling (Indonesia), and Koto (Viet Nam), are addressing development challenges by combining entrepreneurial approaches with social and environmental objectives. This paper examines how these social enterprises contribute to the Sustainable Development Goals (SDGs) by embedding sustainability within their business models. Using an integrative literature review, the study synthesizes peer-reviewed research, authoritative policy documents, and case-based reports relevant to the Asia–Pacific context. The analysis is guided by the Business Model Canvas and Theory of Change frameworks to explain how value is created, delivered, and sustained. Findings show that the enterprises function mainly as problem solvers, inclusive employers, and sustainable operators, generating impacts across People, Planet, Prosperity, Peace, and Partnerships (5Ps). Despite demonstrable contributions to poverty reduction, sustainable consumption, environmental protection, skills development, and community resilience, scaling impact remains constrained by financing gaps.

Keywords: Youth entrepreneurship; social enterprise; Sustainable Development Goals; Asia–Pacific; sustainable business models; Theory of Change

1. Introduction

Youth-driven social enterprises are emerging as transformative actors in sustainable development, uniquely positioned to address pressing global challenges, such as climate change, inequality, and youth unemployment. Blending innovation with social purpose, these ventures empower young people to co-create community-rooted solutions through mission-driven, hybrid business models. Research affirms that such enterprises strengthen local economic resilience, promote inclusive growth, and meaningfully advance the United Nations Sustainable Development Goals (SDGs) (Czyżewska et al., 2025; de Villiers Scheepers et al., 2021). Their success is often linked to enabling ecosystems that include financial access, mentorship, and entrepreneurial education (Ramasamy et al., 2024; Gali et al., 2020). Moreover, youth-led social innovation has been found to outperform traditional institutions in responsiveness and adaptability, often catalyzing grassroots empowerment and systems change (Littlewood & Holt, 2018). These ventures are increasingly recognized as embedded within broader social innovation ecosystems, where youth entrepreneurship drives inclusive, sustainable development (Sampaio & Dias, 2024; Enaifoghe et al., 2024; OECD, 2022).

Nowhere is this potential more urgent and promising than in the Asia–Pacific region. As home to the world's largest youth population, the region carries a powerful demographic dividend. Yet, high rates of youth unemployment, informality, and socioeconomic inequality persist, constraining the full realization of this potential (Halid et al., 2023; Zahid et al., 2025). These challenges are exacerbated by environmental degradation and macroeconomic volatility, while traditional economic models, centered on wage-based employment or public sector expansion, have struggled to accommodate the creativity and aspirations of young people. In response, youth entrepreneurship and social innovation have gained momentum

as a strategic pathway toward inclusive, sustainable development. Studies from emerging economies show that when financial viability, environmental awareness, and innovation are integrated, youth-led enterprises can become key drivers of sustainable growth (Aguirre et al., 2025).

Youth-led social enterprises typically adopt hybrid business models that merge commercial viability with social and environmental objectives (Martin & Osberg, 2007; Raimi & Khudoykulov, 2025). In this context, hybrid refers to business models that combine revenue-generating commercial activities while simultaneously advancing social and environmental objectives, enabling enterprises to pursue financial sustainability while delivering societal impact. In settings where public service delivery is weak or markets fail to meet essential needs, such hybridity becomes critical (London & Hart, 2004). The global SDG framework introduced in 2015 further validated this model, aligning the goals of social enterprises with five interlinked pillars – People, Planet, Prosperity, Peace, and Partnerships (United Nations, 2015; Sachs, 2015). These enterprises seek to create multidimensional value and systemic change, rather than simply maximizing profits.

Although the literature recognizes the contribution of social entrepreneurship to sustainable development, it provides limited insight into the specific business model mechanisms through which youth-led enterprises generate measurable SDG outcomes (Roundy et al., 2018; Díaz-Sarachaga & Ariza-Montes, 2022). Our own current study addresses the knowledge gap mentioned above by examining how youth-led social enterprises in the Asia–Pacific region operationalize sustainable development in practice, through business model design, strategic partnerships, and context-specific impact pathways.

The inquiry is structured around four guiding research questions: (i) How do youth-led social enterprises integrate SDG objectives into their business models? (ii) What strategic patterns emerge in how these enterprises balance mission and market? (iii) What are the contributions across the 5Ps among these social enterprises? and (iv) What are the constraints and practical limitations of these social enterprises?

This research contributes to the literature in three ways. First, it shows how youth-led enterprises act as problem-solvers, inclusive employers, and sustainable innovators, delivering impact across the 5Ps. Second, through case-based analysis, it demonstrates how innovative business models translate into tangible outcomes, including poverty reduction, environmental protection, and skills development. Third, it identifies the structural barriers, such as financing gaps, fragmented regulation, and weak support ecosystems, that must be addressed to scale these initiatives effectively. By doing so, the paper enhances both theoretical and practical understanding of youth-led entrepreneurship as a lever for sustainable development in the Asia–Pacific.

2. Methodology

This study adopts an integrative literature review methodology, enabling the structured synthesis of theoretical, empirical, and policy-oriented insights within a single analytical framework (Adams et al., 2017; Raimi & Khudoykulov, 2025). This approach is well-suited to interdisciplinary research on social entrepreneurship and sustainable development, where evidence spans fields such as management, development studies, and public policy. Alongside the literature synthesis, the study incorporates case-based analysis of five youth-led social enterprises in the Asia–Pacific region – Hapinoy (Philippines), Green Monday (Hong Kong), Siam Organic (Thailand), ECO Bali Recycling (Indonesia), and Know One, Teach One (KOTO) (Vietnam) – to ground conceptual insights in practice. The selection of five cases reflects a purposive, theory-building design rather than statistical generalization. In multiple-case research, analytical sufficiency is achieved through theoretical replication and variation across cases rather than sample size. Each enterprise represents a distinct sustainable business model and institutional context, providing a diverse yet comparable set of examples. This allows for cross-case comparison and analytical generalization, consistent with established case study methodology (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2018).

2.1 Data Sources

The study draws on peer-reviewed journal articles indexed in Scopus and Web of Science, complemented by authoritative policy and institutional reports from organizations such as the United Nations Development Programme (UNDP), the International Labour Organization (ILO), the Asian Development Bank (ADB), and UN ESCAP. In line with the case-oriented focus, additional data were obtained from

credible case documentation, including enterprise reports, development bank case notes, and reputable practitioner-oriented publications. Sources were selected based on their relevance to social enterprise business models, SDG implementation, and 5Ps (People, Planet, Prosperity, Peace, Partnerships) impacts within the Asia–Pacific region.

2.2 Case Selection and Analytical Framework

The five cases were selected using purposive sampling, based on three criteria: (i) clear identification as social enterprises operating in the Asia–Pacific region, (ii) documented contributions to one or more SDGs, and (iii) demonstrable business model innovation addressing social or environmental challenges. Two complementary frameworks guide the analysis. The Business Model Canvas (BMC) is used to examine how each enterprise structures its value proposition, key activities, resources, partnerships, and revenue mechanisms (Osterwalder & Pigneur, 2010). The Theory of Change (ToC) framework is then applied to trace causal pathways linking enterprise activities to outputs, outcomes, and longer-term development impacts across the 5Ps (Mayne, 2017; 2023). Together, these frameworks clarify how Asia–Pacific social enterprises operationalize sustainability within their business models and translate entrepreneurial action into measurable SDG-related outcomes.

3. Conceptual and Theoretical Foundations

Social enterprises operate as hybrid organizations that combine commercial strategies with explicit social objectives (Defourny & Nyssens, 2010; Battilana & Lee, 2014). This hybridity allows them to scale innovative solutions while remaining mission-driven, but it also brings governance and legitimacy challenges (Ebrahim et al., 2014). From the perspective of institutional theory, social enterprises adapt to their environments by responding to normative, regulatory, and cultural pressures (DiMaggio & Powell, 1983). In many Asia–Pacific contexts, where institutions are often fragmented or underdeveloped, youth-led social enterprises rely on informal norms, community trust, and partnerships to sustain operations (Desa, 2012; Raimi & Khudoykulov, 2025).

Sustainable business models (SBMs) further develop this logic by embedding social and environmental goals into value-creation, delivery, and capture processes (Bocken et al., 2014; Schaltegger et al., 2016). Tools such as the triple-layered business model canvas highlight how economic, social, and ecological value can reinforce one another, reducing trade-offs (Joyce & Paquin, 2016). The Cases chosen from the Asia–Pacific region evidently demonstrate this integration through inclusive employment, ethical supply chains, circular systems, and skill-building.

The SDGs offer a complementary policy framework that aligns well with these models. By emphasizing interconnected development outcomes, the SDGs promote integrated and systemic solutions (Le Blanc, 2015; Sachs et al., 2019). Youth-led social enterprises embody this logic, addressing unemployment, inequality, and environmental degradation simultaneously. Their capacity to produce cross-cutting impacts affirms the relevance of sustainable business models as mechanisms for translating global development goals into actionable, context-sensitive outcomes. Their capacity to generate impact across multiple SDG targets underscores the role of sustainable business models as practical vehicles for translating global goals into actionable, context-sensitive outcomes on the ground.

3.1 Youth-Led Asia–Pacific Social Enterprise Cases

Across the Asia–Pacific, youth-led social enterprises exemplify how innovative models align with the Sustainable Development Goals (SDGs) and the 5Ps framework. Emerging as responses to local socio-economic and environmental pressures, these ventures often adopt hybrid or *"serve-and-survive"* structures to balance financial viability with mission-driven impact (Littlewood & Holt, 2018). Informed by social entrepreneurship theory, these enterprises leverage innovation and community engagement to deliver context-specific, scalable solutions (Dees, 1998; Zahra et al., 2009). Regional evidence indicates that youth-led experimentation in inclusive employment, circular models, and skills development transforms social entrepreneurship from a mere development tool into a dynamic, locally grounded strategy for long-term sustainability (Díaz-Sarachaga & Ariza-Montes, 2022). By integrating economic and social objectives, these young entrepreneurs prove that profitability and purpose can be mutually reinforcing rather than contradictory.

Hapinoy (Philippines) empowers women micro-retailers by enhancing the traditional *sari-sari* store model with microfinance, digital tools, and business training. Rather than displacing informal systems, it integrates social impact into its revenue model through multi-sector partnerships (ADB, 2016; London & Hart, 2004). This approach advances SDGs 1, 5, and 8 by bolstering income stability and gender empowerment (Dacanay, 2019). Guided by ToC, its inputs, retail aggregation, and collaboration foster resilient livelihoods, as evidenced by case studies. Hapinoy exemplifies how inclusive, youth-driven enterprises leverage local networks to align "People, Prosperity, and Partnerships" within the 5Ps framework, demonstrating that grassroots economic empowerment is a sophisticated, locally grounded strategy for achieving long-term sustainable development.

Green Monday (Hong Kong) illustrates how social enterprises influence environmental outcomes by shifting consumption habits. By integrating plant-based innovation, retail, and advocacy, it renders sustainable diets accessible and socially acceptable (Poore & Nemecek, 2018; Willett et al., 2019). The model advances SDGs 12, 13, and 3 by prioritizing behavioral change over production reform (Green Monday, 2021). Through institutional partnerships and consumer engagement, the enterprise reduces ecological footprints, though specific emissions data lacks independent verification. Within the 5Ps framework, Green Monday's impact is most pronounced across Planet and People, driven by strategic Partnerships with schools and businesses. This demonstrates that multi-sector collaboration can operationalize climate action by embedding sustainability into everyday choices.

Siam Organic (Thailand) demonstrates how sustainable agriculture drives poverty alleviation and environmental progress. Equipping smallholders with organic skills and exporting premium "*Jasberry*" rice raises incomes while reducing chemical dependency (ADB, 2017). This model advances SDGs 1, 2, and 12 by integrating livelihood security with responsible production (Schaltegger et al., 2016). Its innovation stems from reorganizing traditional value chains through ethical sourcing and market coordination. Guided by ToC, Siam Organic leverages knowledge-sharing and partnerships to foster resilient farming systems, though formal impact assessments remain limited. Within the 5Ps framework, the enterprise bridges Planet and Prosperity via robust Partnerships, proving that reconfiguring market access can operationalize sustainability for marginalized producers.

ECO Bali (Indonesia) demonstrates how community-rooted circular models address environmental degradation and unemployment. By integrating waste collection, recycling, and education, it reduces reliance on landfills while generating local jobs (Geissdoerfer et al., 2018; OECD, 2022). The enterprise advances SDGs 11, 12, and 13, with secondary benefits for SDGs 8 and 14 through marine waste reduction (Eco Bali, 2023). ECO Bali's innovation lies in adapting service delivery to regions with weak municipal infrastructure, linking grassroots participation to sustainable livelihoods. While its environmental logic is robust, the absence of third-party verification for waste outcomes limits measurable impact claims. Within the 5Ps framework, the model effectively integrates Planet and People, underpinned by active Partnerships that bridge the gap between waste management and social inclusion.

KOTO – *"Know One, Teach One"* (Viet nam) exemplifies how vocational training creates pathways out of poverty for marginalized youth. Integrating hospitality training with income-generating operations provides practical skills, mentorship, and job placements to foster social inclusion (OECD, 2022; Sen, 1999). The model advances SDGs 4, 8, and 10, while promoting Peace through social cohesion (Dredge, 2017). Guided by ToC, KOTO links structured training and employer networks to job readiness and societal integration. While program outcomes are well-documented, long-term data on generational income mobility remains limited. Within the 5Ps framework, KOTO's impact is most pronounced across People and Peace, underpinned by sustained Partnerships with the hospitality industry, demonstrating that inclusive education can operationalize long-term economic and social stability.

Table 1: Cross-Case Synthesis of Asia–Pacific Youth-Led Social Enterprises

Dimension	Hapinoy	Green Monday	Siam Organic	ECO Bali Recycling	KOTO
5Ps	People, Prosperity, Partnerships	Planet, Partnerships	People, Planet, Prosperity	Planet, People, Partnerships	People, Peace, Partnerships

Core Challenge Addressed	Poverty, gendered exclusion, and informal retail inefficiency	Unsustainable food systems, climate impact of diets	Smallholder poverty, chemical-intensive farming	Waste mismanagement, pollution, and local unemployment	Youth poverty, unemployment, and social exclusion
Primary SBM Logic	Inclusive market upgrading	Demand-side consumption shaping	Inclusive agri-value-chain upgrading	Community-embedded circular services	Training-based hybrid enterprise
Business Model Innovation	Institutional innovation (formalizing informal markets)	Behavioral and norm-shaping innovation	Certification + branding value-chain innovation	Service-delivery and institutional innovation	Human-capital and work-integrated learning
SDGs	SDGs 1, 5, 8	SDGs 12, 13, 3	SDGs 1, 2, 12	SDGs 11, 12, 13	SDGs 4, 8, 10
Environmental Focus	Minimal / incidental	Core	Strong	Core	Minimal
Social Inclusion Focus	High (women micro-entrepreneurs)	Moderate	High (smallholder farmers)	Moderate	Very high (marginalized youth)
Theory of Change	Partnerships → retail aggregation → income stability	Advocacy + retail → behavior change → lower food footprint	Training + market access → income & sustainable farming	Community participation → waste diversion → cleaner environment	Training + placement → employability → social cohesion
Evidence Strength	Strong case evidence; no counterfactuals	Strong scientific rationale; limited firm-level audits	Strong case evidence; limited LCAs	Strong case evidence; limited audited metrics	Strong program evidence; limited longitudinal audits
Key Constraints	Thin margins, partner dependence	Price sensitivity, cultural diets	Certification costs, market volatility	Market prices, scalability	Donor reliance, sector shocks
References	ADB (2016); London & Hart (2004)	Poore & Nemecek (2018); Willett et al. (2019)	ADB (2017); Schaltegger et al. (2016)	OECD (2022); Geissdoerfer et al. (2018)	OECD (2022); Sen (1999)

4. Findings and Discussion

4.1 RQ1. How do youth-led social enterprises integrate SDGs objectives into their business models?

Youth-led social enterprises in the Asia–Pacific embed SDG objectives directly into their core business models, ensuring social and environmental goals shape operations rather than superficial commitments. Across cases, impact is integrated into how value is created and captured. For instance, Green Monday promotes plant-based consumption to address climate and health challenges (SDGs 3, 12, 13), while Hapinoy bolsters micro-retailers via financial services and training (SDGs 1, 5, 8). By utilizing revenue-generating models instead of donor reliance, these ventures pursue poverty reduction and climate action through sustainable business frameworks and Theory of Change analysis. This alignment of mission and market logic enables the integration of SDG objectives across all operational facets, from partnerships to customer engagement, demonstrating that sustainability is commercially viable when grounded in purposeful, inclusive enterprise strategies.

4.2 RQ2. What strategic patterns emerge in how these enterprises balance mission and market?

Five strategic patterns emerge from these cases, illustrating diverse methods for balancing mission and market. First, inclusive market enablers (Hapinoy) strengthen local economies by upgrading informal retail systems. Second, system builders (Siam Organic and ECO Bali) restructure agricultural and waste

value chains to embed social and environmental outcomes into commercial activity. Third, behavior shapers (Green Monday) utilize retail innovation and education to shift consumer norms towards sustainability. Finally, human capital models (KOTO) link vocational training directly to employment pathways for marginalized youth. In each instance, commercial strategies reinforce rather than dilute social missions. These enterprises achieve sustainability not through compromise, but through strategic coherence, where the business model itself serves as the primary mechanism for delivering impact at scale. This alignment ensures that profitability and purpose remain mutually reinforcing.

4.3 RQ3. What are the Contributions Across the 5Ps Among These Enterprises?

The five enterprises provide varied, interconnected contributions across the 5Ps. People outcomes are central to KOTO and Hapinoy through training and livelihood support that enhance social mobility. Planet contributions are driven by Green Monday, ECO Bali, and Siam Organic via plant-based innovation, circular waste management, and organic agriculture. Regarding Prosperity, Hapinoy, Siam Organic, and ECO Bali foster income generation for micro-retailers and farmers. Peace is supported indirectly through youth employment and reduced social exclusion in marginalized contexts. Finally, Partnerships are foundational; each venture relies on cross-sector collaboration to scale impact and ensure operational effectiveness. Together, these models demonstrate a multidimensional impact: progress in one domain, such as income, reinforces outcomes in others, including health, education, and regional stability.

4.4 RQ4. What are the Constraints and Practical Limitations of These Social Enterprises?

Despite their innovations, youth-led social enterprises in the Asia–Pacific region continue to face persistent structural constraints. One of the most significant challenges is limited access to patient and blended finance, which is essential for hybrid organizations that generate both financial and social returns but often operate with longer impact horizons than conventional firms. Traditional financial markets frequently undervalue social and environmental outcomes, leaving many social enterprises undercapitalized (Nicholls & Pharoah, 2008; OECD, 2022). Regulatory fragmentation also complicates operations. Because social enterprises typically operate across multiple policy domains, including labor, environmental management, and trade, they often face complex compliance requirements and administrative burdens that hinder growth (Battilana & Lee, 2014; Doherty et al., 2014). Furthermore, many youth-led ventures operate with limited institutional capacity, which constrains their ability to scale operations or navigate regulatory environments effectively. As these organizations expand, they may also encounter tensions between growth and mission fidelity, particularly when maintaining inclusivity, community engagement, and environmental standards becomes operationally demanding (Ebrahim et al., 2014). These constraints highlight the importance of enabling regulatory frameworks, supportive entrepreneurial ecosystems, and impact-aligned financing mechanisms. Strengthening these structural supports is crucial to enabling youth-led social enterprises to move beyond successful pilot initiatives toward scalable, resilient solutions that deliver sustained progress toward the SDGs across the Asia–Pacific region.

5. Conclusion and Policy Implications

This study highlights how Asia–Pacific youth-led social enterprises operationalize the SDGs through business models that integrate social and environmental objectives. Across five cases, impact stems from context-specific value creation and revenue generation rather than symbolic alignment. These ventures adopt strategic approaches across the 5Ps, tailored to their specific problem domains. Evidence suggests that mission-market integration is a structural feature of effective design rather than a trade-off. Cross-sector partnerships emerge as essential enablers, bridging institutional gaps and enhancing legitimacy. Conversely, persistent barriers, such as regulatory fragmentation and limited patient finance, shape how these enterprises adapt. Ultimately, the study affirms a context-sensitive, practice-based model of youth-driven sustainable development that translates global goals into tangible, scalable regional impact.

This study suggests several critical implications for Asia–Pacific policymakers and practitioners. First, regulatory frameworks must recognize the hybrid nature of social enterprises, thereby reducing sectoral fragmentation and lowering entry barriers. Second, the scarcity of suitable capital necessitates a shift

towards patient and blended finance; development banks should prioritize risk-tolerant, SDG-aligned funding over short-term returns. Third, governments should act as ecosystem conveners, facilitating multi-sector collaboration rather than relying on subsidies. Tailored support, such as market access for agri-value chains or awareness campaigns for consumption-based models, is vital. Finally, impact assessments must move beyond rigid metrics to evaluate contextual relevance across the 5Ps. For practitioners, integrating mission and revenue logic from the outset enhances credibility and scalability. Ultimately, aligning policy instruments with these operational realities will unlock the transformative potential of youth-led enterprises as drivers of regional sustainable development.

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Artificial Intelligence as an Enabler of Youth Entrepreneurship: Strategy and Practical Insights from Singapore

Huong Ha

School of Business

Singapore University of Social Sciences

Email: huongha@suss.edu.sg

Abstract

Artificial intelligence (AI) is increasingly shaping youth entrepreneurship by lowering entry barriers, enhancing data-driven decision-making, and accelerating innovation. For young founders, AI tools support key stages of the design-thinking process, ideation, market analysis, and business model development. This paper examines how AI adoption can support youth entrepreneurship in Singapore in diverse startup contexts. Adopting a practice-oriented lens, the study illustrates how AI, data analytics, and intelligent automation enable young entrepreneurs to develop viable business models and sustainability-oriented solutions. Singapore provides a compelling context due to its advanced digital infrastructure and strong institutional support. The findings highlight how its ecosystem, including strategic direction, digital infrastructure, capability development, financial and resource, and responsible AI governance, shapes entrepreneurial capabilities and outcomes. The article concludes with policy implications for technology agencies, enterprises, entrepreneurship educators, and policymakers in ASEAN economies, emphasizing inclusive AI capability-building, ecosystem coordination, and responsible innovation to strengthen youth entrepreneurship development.

1. Introduction

Artificial intelligence (AI) is considered a transformative technology changing entrepreneurial processes (Organisation for Economic Co-operation and Development (OECD, 2025). According to Mayer et al. (2025), “92 percent of companies plan to increase their AI investment” in the next three years, and 92 percent of businesses in Singapore adopted AI (PR Newswire, 2025). AI is increasingly deployed to shape the entrepreneurship landscape, especially for young founders, by reducing entry barriers, improving data-driven decision-making, facilitating networking, and accelerating innovation. AI tools support the key stages of the design-thinking process, including identifying problems, generating ideas, scanning and analyzing the market, and selecting suitable business models.

This paper examines how AI enables youth-led enterprises in Singapore and how ecosystem conditions shape their success. It also outlines key policy implications for policymakers, technology agencies, and relevant stakeholders. The paper concludes with recommendations to strengthen inclusive AI capability-building, enhance ecosystem coordination, and promote responsible use of AI and responsible innovation frameworks. Such measures are essential to ensure that AI-driven youth entrepreneurship contributes meaningfully to sustainable development.

Singapore is selected for its advanced digital infrastructure, pro-innovation policies, and strong AI regulatory frameworks. Institutionally, Singapore has well-established institutions that govern AI development and facilitate its adoption by business and startups. Key institutions, such as the Infocomm Media Development Authority and AI Singapore, have positioned the country as a regional AI hub. Enterprise Singapore provides targeted support for startups, while higher education institutes have launched initiatives to nurture future entrepreneurs. Research coordination through the National Research Foundation (NRF) further strengthens the innovation ecosystem. In the 2026 budget, the Singapore government announced a $154.7 billion investment in AI and expanded national support to

help enterprises and individuals adopt AI technologies (Chelvan and Teo, 2026; Tham, 2026). A National AI Council, announced during Singapore Budget 2026 on 12 Feb 2026, will also be established to advance the country's AI agenda (Chelvan and Teo, 2026). Overall, the Singapore case offers a valuable case for digital adoption that underpins AI-driven and youth-led entrepreneurship.

2. Artificial Intelligence and Youth Entrepreneurship

2.1 Functional Capabilities of AI in Entrepreneurship

AI has been recognized for its foundational enabling technology that can improve entrepreneurial capability across various stages of the business venture lifecycle. For young founders, AI adoption reduces entry barriers, enhances data collection and analytical capacity, and facilitates sustainability-oriented innovative product/service and process development. AI can serve as a capability amplifier, supporting problem identification, idea generation, experimentation, and impact monitoring and measurement (Organisation for Economic Co-operation and Development (OECD), 2023a; United Nations Conference on Trade and Development (UNCTAD), 2021a).

2.1.1 AI for Ideation, Opportunity Recognition, and Market Validation

Entrepreneurship often starts with opportunity recognition. Traditionally, this process requires industry experience, professional networks, resource availability, and market intelligence. However, resources and networks are often limited for young founders. In the digital era nowadays, AI-enabled tools help address these constraints by rapidly collecting business intelligence, analyzing market size and trends, processing large datasets, and producing business concepts, etc. Speed is important as business opportunities are often time-sensitive.

Large language models and AI applications enable young entrepreneurs to identify customer pain points and needs, and underserved customer segments or markets, analyze competitor landscapes, create many business model alternatives, prepare a business plan, including financial projects and pitch materials, validate their proposed business models and/or prototypes, and find funding opportunities (Tian et al., 2026).

AI adoption also reduces the costs of testing, monitoring, and commercializing new products/services, which can accelerate early-stage iteration. OECD (2025) explains that AI enhances innovation cycles, productivity, and decision-making capabilities. UNCTAD (2021b) further highlights that AI-driven analytics enables firms to decode market signals and respond quickly to consumer demands. Advanced analytics and predictive modeling also assist startups in conducting sentiment and market analysis, forecasting demand patterns, and anticipating market volatility more accurately. This strengthens evidence-based and data-driven entrepreneurship, which is valuable for newcomers regarding reducing uncertainty.

2.1.2 AI-Enabled Automation and Productivity

AI-enabled tools can also improve enterprises' operational efficiency and scalability. Automation systems can simplify administrative and operational processes, engage customers, and support logistics management. Traditionally, labor and overhead costs spent on these functions are substantial; besides, there are lengthy periods of time to complete the tasks.

Young entrepreneurs and startup founders can leverage AI-enabled applications to improve productivity and streamline business processes, which can lead to lower prices. These include AI-powered chatbots for pre- and post-sales customer service, AI-driven accounting and financial tracking systems that can also help to early detect frauds, AI-based marketing automation tools that can personalize marketing messages to customers, and AI solutions for supply chain optimization (McKinsey & Company, 2025).

Empirical evidence shows that firms implementing AI technologies have experienced improved productivity and operational efficiency. By automating routine and time-consuming tasks, AI enables entrepreneurs to focus on strategic activities, conceptual thinking, product and service innovation, and partnership development (OECD, 2023a). Young founders usually operate with limited manpower and resources; these productivity gains are particularly important to their business sustainability in the long term. AI makes it possible for small startups to compete in digitally intensive markets, reducing structural disadvantages relative to established firms. This aligns with the observation by Miah et al. (2025) that

digital entrepreneurship ecosystems flourish when small enterprises can have access to scalable digital infrastructure.

2.1.3 AI for Social and Sustainability-Oriented Entrepreneurship

AI should not only be considered a commercial enabler as it also facilitates purpose-driven social entrepreneurship. Youth-led ventures can integrate sustainability (social, economic, and environmental) and social impact value propositions in their business models. In Singapore, about 40 percent of social enterprises are led by young people (35 years and below) (Soristic, n.d.). For example, *Seastainable*, a social enterprise in Singapore providing environmental consultancy started by a young entrepreneur, redirects 50% of its profits to support marine conservation in the Southeast Asian region, and *Commenhers*, "a youth-run clothing brand that upcycles denim to create re-fashioned denim clothes and accessories" (Dharshini, 2023, para. 7).

AI systems support social impact initiatives by enabling data-driven sustainability measurement and optimization. Applications consist of tools to optimize energy and water consumption, carbon footprint estimation systems, analytics platforms to monitor waste generation and recycling performance, and AI-enabled solutions that improve vulnerable populations' access to essential services. AI also enhances transparency and accountability in social enterprises by improving impact tracking, data reporting, and performance monitoring.

Such innovations align with the Sustainable Development Goals (SDGs), which are prioritized across Association of Southeast Asian Nations (ASEAN) member states. UNCTAD (2021a) notes that advanced technologies, including AI, have accelerated progress toward the SDGs when adoption is inclusive and supported by responsible governance.

However, challenges of AI adoption remain. For instance, unequal access to AI infrastructure, unaffordable AI tools and systems, and persistent digital literacy gaps may widen inequalities among entrepreneurs. Thus, responsible governance frameworks, focusing on algorithm-agnostic, technology-agnostic, sector-agnostic, and scale- and business-model-agnostic elements, are essential to ensure fairness, transparency, and trust in AI-enabled ventures (Infocomm Media Development Authority, 2026).

2.2 Structural Conditions for AI-Enabled Entrepreneurship

Practically, structural conditions also influence the impact of AI on youth entrepreneurship. These conditions may include digital infrastructure availability, affordable and easy access to the internet and cloud computing, financial systems, and education systems that jointly reduce entry barriers and enhance scalability (OECD, 2023a; World Bank, 2022). Entrepreneurial innovative ecosystems, involving many stakeholders, shape the landscape within which youth-led ventures emerge. The concentration and coordination of these actors affect opportunity identification and capture, resource mobilization and allocation, and market access for young entrepreneurs.

2.3 Normative Foundations of Responsible AI Adoption

Besides functional capabilities and structural conditions, youth-led entrepreneurship also requires normative foundations that can ensure legality and build trust. Ethical AI principles, data protection standards and guidelines, cybersecurity principles, and regulatory approaches help address concerns related to privacy, security, transparency, and data bias (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2021; OECD, 2019). Such AI-related governance mechanisms would contribute to mitigating reputational uncertainty and regulatory costs while reinforcing stakeholder confidence. Therefore, responsible adoption of AI strengthens legitimacy and supports sustainable and socially responsible entrepreneurial growth.

3. Singapore's AI-enabled Youth Entrepreneurship Ecosystem

Building on the conceptual framework discussed in the previous section, the Singapore case illustrates how institutional, infrastructural, and governance operationalize AI-led youth entrepreneurship in practice. Singapore's experience illustrates that access to technology, and a coordinated national ecosystem together with digital readiness, strong institutional support, skills development, infrastructure,

finance, and responsible governance influence AI adoption among young entrepreneurs (Cockburn et al., 2018; Nambisan et al., 2019; Obschonka and Audretsch, 2020). Instead of operating in silos, these factors reinforce and supplement one another, creating a conducive environment for AI-enabled entrepreneurship. Recent studies show that AI-driven entrepreneurship can develop when it is embedded within an ecosystem that aligns policies, strategies, skill development, leadership, and governance (Khanal et al., 2024; Kim and Jin, 2024).

3.1 AI Strategic Direction and Institutional Support

AI adoption can reduce experimentation costs and enlarge the range of viable venture possibilities for entrepreneurs. However, institutional coordination affects its transformative potential. Lee et al. (2024), Nzembayie and Urbano (2025), Stefan et al. (2025) further argue that new ventures can grow more rapidly, and technologies are diffused faster when AI strategy is well connected to startup support systems.

Singapore has established a national AI agenda supported by the NRF and implemented through AI Singapore. AI Singapore is tasked to bring "*together all Singapore-based research institutions and the vibrant ecosystem of AI start-ups and companies developing AI products to perform use-inspired research, grow knowledge, create tools, and develop the talent to power Singapore's AI efforts*" (AI Singapore, n.d.).

This strategy has been further strengthened by the government's long-term commitment to invest more in AI. Thus, Singapore illustrates a coordinated approach that integrates AI policy and research, entrepreneurial incentives, startup support, and digital governance.

3.2 Digital Infrastructure for AI Deployment

Digital infrastructure plays a key role in entrepreneurial activities because AI tools require reliable high-speed internet connectivity and well-developed digital systems. Countries and locations with good broadband connections and digital interoperability witness a higher rate of startup formation and innovation outputs (World Bank, 2021).

Singapore's Smart Nation initiative, a national strategy launched in 2014, leverages digital technologies and data to enhance governance, economic growth, and citizen's quality of life, with a strong emphasis on digital inclusion and innovation (Smart Nation Singapore, 2025). This initiative exemplifies transformation by enabling robust high-speed broadband connectivity, interoperable digital systems, and secure data governance frameworks. Such reliable infrastructure reduces operational and transaction costs and expedites AI deployment across sectors. This also enables youth-led startups to adopt AI systems without heavy upfront capital investment. Access to reliable and scalable digital infrastructure allows young founders to focus on opportunity exploration and business development instead of technical constraints. In this sense, infrastructure not only supports entrepreneurship but also makes innovation more achievable (Goldfarb and Tucker, 2017).

3.3 AI Capability Development

Human capital is also a predictor of AI-enabled entrepreneurship. Young founders with AI literacy and digital capabilities are likely to achieve stronger performance and survival outcomes (Bharadwaj et al., 2013; Colombo and Grilli, 2005). A key differentiated factor of knowledge-intensive ventures is their ability to strategically apply AI-generated insights, instead of mere access to AI tools (Obschonka and Audretsch, 2020).

In this context, higher education institutes in Singapore play a critical role in developing such competencies for young entrepreneurs. They have promoted AI responsible use in entrepreneurship education, which allows learners to apply AI in opportunity identification, market validation, and business model development (Dwivedi et al., 2023; Nabi et al., 2017; Ng et al., 2021). For instance, through the geron-preneurship course at the Singapore University of Social Sciences (SUSS), AI topics are incorporated to prepare learners to design technology-enabled solutions for seniors with both technical skills and ethical awareness.

Academic training at higher education institutes is complemented by incubators, mentorship, industry linkages, and opportunities for learners to test their ideas in the market. Strong networks and ecosystem support assist young founders of startups and improve their chances of success (Stam and van de Ven,

2021). A good example is the Agri-preneur Incubation Program offered by SUSS, where students can gain hands-on urban farming experience and develop sustainable agritech ventures through practical training and pitching opportunities (Begum, 2024). Bharadwaj et al., (2013) and Tambe (2014) also explain that enterprises possessing internal AI capabilities tend to achieve higher productivity than those relying only on outsourced expertise. Higher education institutes and incubators can jointly transform AI from a basic tool into a strategic entrepreneurial capability, enhancing youth venture resilience.

3.4 Resources and Financial Support

Access to finance and other resources play a significant role in an enterprise survival and growth, and startup viability. AI adoption increases firms' productivity, but sustained growth depends much on financial resources and ecosystems (Chen et al., 2025). Apparently, productivity gains do not automatically translate into long-term growth without any complementary funding mechanisms.

Singapore addresses this through several financial mechanisms, such as grants, co-investment schemes, and mentorship-linked funding (Ministry of Digital Development and Information, 2026). The alignment of funding, skill development, and market access reduces fragmentation and access inequalities and enhances ecosystem efficiency. Public-private collaboration further accelerates experimentation and commercialization. For example, the AI Trailblazers initiative, a collaboration between Singapore's Ministry of Communications and Information, Digital Industry Singapore, Smart Nation and Digital Government Office, and Google Cloud, enables firms and government agencies to adopt AI to address real-world challenges. This initiative has enabled about 100 organizations in Singapore to access Google Cloud's high-performance graphical processing units in a streamlined and efficient manner (Economic Development Board, 2023). Another initiative is the Digital Enterprise Blueprint, which brings together government, industry, and educational institutions to support SMEs and workers with expertise, resources, and digital technologies. Initially, eleven partners, including Amazon Web Services (AWS), Google, Microsoft, Alibaba Cloud, DBS Bank Ltd, Prudential, Salesforce, ST Engineering, Singapore Business Federation (SBF), Singapore Computer Society (SCS), and SGTech, committed to support SMEs through initiatives promoting AI adoption, cloud solutions, cybersecurity, and workforce upskilling, thereby enabling firms to enhance productivity, scale operations, and strengthen digital resilience (Ministry of Digital Development and Information, 2025). Close coordination among government agencies, universities, and enterprises strengthens the financial and institutional support structure for startups.

This integrated approach reflects entrepreneurial ecosystem theory, which emphasizes the importance of multi-sector coordination among government, higher education institutions, industry, and other stakeholders to support long-term venture success (Stam and van de Ven, 2021). For young entrepreneurs adopting AI, a well-connected ecosystem reduces avoidable risks and improves their adaptability for growth.

3.5 Responsible AI Governance

In the digital era, AI-driven enterprises and startups operate in data-intensive and ethically sensitive conditions. Thus, trust, transparency, and accountability would greatly influence stakeholders' acceptance and investors' decisions. Firms with transparent AI governance easily attract more external financing and gain stakeholders' trust (Dwivedi et al., 2023; OECD, 2019; World Economic Forum, 2022).

The Infocomm Media Development Authority introduced Singapore's Model AI Governance Framework (MGF) in 2020 and launched a new Model AI Governance Framework for Agentic AI in January 2026. It is "first-of-its-kind framework", which aims to help organizations deploy AI systems responsibly by clearly depicting risk management practices, technical and non-technical control mechanisms, and focusing on meaningful human accountability and oversight when using AI systems (Infocomm Media Development Authority, 2026).

These AI governance frameworks are reinforced by the *Personal Data Protection Act 2012* and grounded in principles of fairness, explainability, and accountability. By setting clear standards for responsible AI deployment, they enable young entrepreneurs to build trust with stakeholders, proactively mitigate risks, and strengthen their legitimacy through recognized ethical governance practices. Therefore, responsible governance acts as a strategic asset, instead of a constraint (Papagiannidis et al., 2025). It differentiates AI ecosystems based on reliability, credibility, and legitimacy that are valued by stakeholders in the entrepreneurial journey.

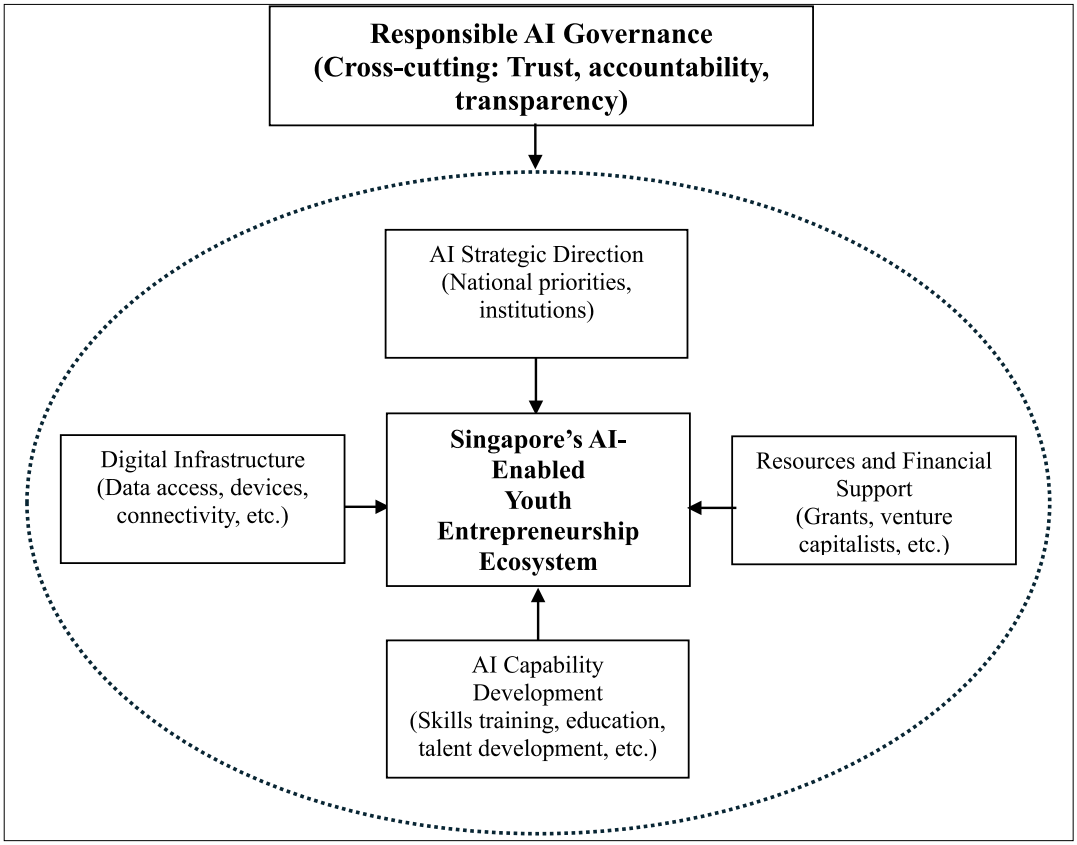

Figure 1: Singapore's AI-Enabled Youth Entrepreneurship Ecosystem

(Source: Created by the author)

Overall, responsible AI governance operates as a cross-cutting foundation shaping strategic direction, infrastructure deployment, capability development, and financial support mechanisms as depicted in Figure 1.

3.6 Case study: Alibaba Cloud–SUSS Entrepreneurship Program

A good example of higher education-industry collaboration in advancing AI-enabled youth entrepreneurship is the Alibaba Cloud–SUSS Entrepreneurship Program, jointly launched by SUSS and Alibaba Cloud (Alibaba Cloud, 2017). Participants in this program receive structured entrepreneurship training supported by industry-grade AI tools provided by Alibaba Cloud. The curriculum integrates technology and business innovation, including the development of AI-driven solutions, and they are granted complimentary access to Alibaba Cloud services. Beyond infrastructure, the program strengthens participant's AI literacy and entrepreneurial competence through experiential learning, mentorship, and pitching opportunities. Participants are trained not only to use AI tools but to apply them strategically to identify business opportunities and design business solutions as well as solutions that can create social impact (SUSS 2021).

One participant developed *Cloud Intern*, a startup that designs AI-powered chatbots to automate customer communication and response management for small businesses (SUSS, 2021). Using AI tools and predictive automation, the chatbots can handle customer enquiries, forecast demand, and schedule services with clients. This demonstrates how participants in the program have leveraged AI to create practical business solutions.

This case illustrates how structured support from universities and industry, blending entrepreneurship education, access to AI technologies, financial resources, and real-world business exposure, can enable participants to go beyond theoretical learning and develop AI-enabled startup ventures (SUSS, 2021). Access to cloud infrastructure and enterprise-level AI tools significantly reduces technical and financial barriers during the prototyping stage, allowing participants to focus on refining business models and market validation.

The program reflects a strategic direction of linking higher education, industry partnerships, and digital innovation to accelerate AI capability development. It also illustrates how AI-enabled youth entrepreneurship emerges from coordinated ecosystem support rather than isolated training. This capability-building function is critical, as sustainable AI entrepreneurship depends on informed and responsible use rather than passive technological adoption (Alshibani et al., 2025). Resource availability, financial support, and industry exposure further reduce early-stage vulnerability. At the same time, operating within Singapore's responsible AI and data governance framework ensures that AI-driven ventures remain transparent, secure, and compliant.

Overall, these interconnected elements, strategic partnership, digital infrastructure, capability development, resource access, and governance, exhibit how higher education institutions can serve as catalysts for scalable innovation and responsible AI-enabled youth entrepreneurship (UNESCO, 2025; Vecchiarini and Somia, 2023).

4. Key Enablers and Challenges

AI-enabled youth entrepreneurship can only thrive if foundational enablers are robust, as AI strengthens individual capabilities through interconnected mechanisms, including skill enhancement, improved access to capital, and reduced risk exposure (Ganuthula, 2025). The key enablers of AI-enabled youth entrepreneurship are discussed below:

- Affordable and accessible AI tools and analytics platforms reduce digital divides, lower entry barriers, improve operational efficiency, and advance digital inclusion for emerging ventures (OECD, 2023b; United Nations Conference on Trade and Development (UNCTAD), 2021a).
- Capability and capacity building regarding AI literacy and digital skills would improve venture performance (Ng et al., 2021; Obschonka and Audretsch, 2020). Thus, sustained capability development through education, mentorship, internship, etc. are important (OECD, 2024; World Economic Forum, 2023).
- Strategic public policies, startup financing mechanisms, and collaborative partnerships among education providers, industry, and government further enhance ecosystem cohesion and effectiveness, and foster knowledge transfer, strengthen resource mobilization, which may lead to better venture outcomes (World Economic Forum, 2024).
- Clear AI guidelines and strong data protection frameworks can build trust, reduce regulatory uncertainty, and support responsible innovation. When aligned, these enablers position young entrepreneurs not simply as technology adopters, but as competent and sustainable drivers of AI-driven growth.

Although AI-enabled youth entrepreneurship can benefit from robust digital infrastructure, policy support, and clear AI guidelines, key challenges remain.

- Young entrepreneurs and founders often encounter gaps between using basic AI tools and in-depth technical and strategic competencies required to develop competitive ventures. They also have limited access to high quality data, which can affect scalability beyond pilot projects (OECD, 2023a, b; World Bank, 2021).
- Compliance with data protection and AI governance requirements, which are necessary for building trust, may complicate operations and increase operational and regulatory costs for early-stage ventures. Ethical concerns, such as data bias and data privacy risks, may affect stakeholder trust if they are not well managed (Dwivedi et al., 2023; Stefan et al., 2025).
- Rapid technological advancement and global competition require continuous learning, skill upgrading, and adaptation to on-going changes in the external environment to sustain and grow the business.

Overall, AI adoption can improve entrepreneurial productivity but also entails many challenges (Brynjolfsson et al., 2024; Raisch & Krakowski, 2021). Hence, responsible ecosystem design is critical to ensure inclusive and sustainable AI-driven entrepreneurship (Stam, 2015; Autio et al., 2018).

5. Policy Implications for ASEAN Economies

From the analysis of emerging opportunities, key enablers, and challenges, the following are recommended:

- ***Integrated digital infrastructure development***

The public and the private sectors, including technology providers and research centers, should invest more in AI-ready digital infrastructure and provide equitable access to AI tools, platforms, high-quality datasets, and integrated digital platforms to minimize structural entry constraints and address operational bottlenecks and growth limitations (OECD, 2023a, b; Stefan et al., 2025).

- ***Advanced AI capability and entrepreneurial skills development***

Education providers, industry partners, and public agencies should expand advanced AI skills development, beyond basic tool usage or AI literacy awareness, by incorporating machine learning engineering, data governance, and responsible AI topics in entrepreneurship curriculum to narrow capability gaps and improve venture scalability (OECD, 2023; Wordl Economic Forum, 2023).

- ***Enhancing ecosystem cohesion through strategic partnerships***

Multi-sector stakeholders (e.g., public authorities, education providers, venture capitalists, industry, technology providers, etc.) should formalize educator–industry–investor collaboration platforms to enhance ecosystem cohesion, efficient allocation of resources, and strengthen technology transfer pathways and enhance startup survival (Stam and van de Ven, 2021).

- ***Inclusive resource and market access***

Key players in relevant sectors should provide financial support, expand targeted financing schemes, cloud credits, mentorship networks, and access to national and regional markets. This aims to ensure that young entrepreneurs, especially those without sufficient capital or strong networks, can participate effectively in the digital economy (OECD, 2023b; UNCTAD, 2021a, b).

- ***Operational and trustworthy AI governance***

Players in the entrepreneurial ecosystem should develop and implement clear and innovation-friendly AI governance and data protection frameworks to manage risks, reduce regulatory ambiguity, and facilitate responsible scaling of your-led ventures (OECD, 2019). These are essential to enhance credibility and promote responsible entrepreneurship.

Overall, a multi-dimensional approach with a well-developed and coordinated ecosystem, integrating skills, infrastructure, and governance, is fundamental to harnessing AI for inclusive youth entrepreneurship.

6. Conclusion

AI has emerged as a structural enabler of youth entrepreneurship. AI enables young entrepreneurs to compete in rapidly digitalizing markets by lowering entry barriers, reducing data and testing costs, expanding access to analytics, and accelerating product development and market entry. However, only relying on technology does not guarantee sustainable outcomes. The Singapore experience demonstrates that responsible AI capability-building and collaboration among sectors are equally important. Stakeholders should work closely with one another to ensure that AI adoption fosters entrepreneurial resilience instead of deepening inequality and intensifying risk exposure.

For the region, the key lesson is clear. AI-driven youth entrepreneurship depends not only on AI tools but also on inclusive digital skills, entrepreneurship education, strong partnerships, and sound governance. AI can become a catalyst for innovative and sustainable youth-led entrepreneurship only if technological capability development is supported by a coherent and responsible ecosystem.

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Youth-Led Digital Innovation for Sustainable Development: Transforming Indonesia's Economic and Educational Ecosystems

Muryanto Amin[1], Alwi Dahlan Ritonga[2], Agus Marwan[3]

[1] Department of Political Science, Faculty of Social and Political Sciences, Universitas Sumatera Utara, Medan, Indonesia. *Rector of the Universitas Sumatera Utara (2026-2031) (muryantoamin@usu.ac.id)

[2] Department of Political Science, Faculty of Social and Political Sciences, Universitas Sumatera Utara, Medan, Indonesia (alwidah-lanritonga@usu.ac.id)

[3] Department of Political Science, Faculty of Social and Political Sciences, Universitas Sumatera Utara, Medan, Indonesia (agusmarwan@usu.ac.id)

Abstract

Indonesia is currently at a crucial point in utilizing its demographic dividend to drive sustainable development through digital innovation led by young people. This article analyzes the role of frugal innovation in transforming Indonesia's economic and educational ecosystems, with a primary focus on the case studies of Gojek and Ruangguru. Gojek, through its "Three Zeros" commitment (Zero Emissions, Zero Waste, Zero Barriers), demonstrates the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies to create an inclusive economy and support the green energy transition. In the education sector, Ruangguru uses adaptive AI to democratize access to high-quality content and enhance educators' capacity across the region. The success of these innovations is driven by strategic public-private partnerships (PPPs), such as the Pre-Employment Card Program, as well as progressive regulatory support. Despite facing structural challenges in the form of a digital divide, Indonesia's innovation model provides valuable lessons for the Asia-Pacific region in aligning technological progress with the principles of inclusivity and long-term sustainability.

1. Introduction

The Asia-Pacific region is currently at a crucial point in its development history, where the convergence of rapid digital technological advances and demographic shifts is creating unprecedented opportunities and challenges. At the heart of this transformation, Indonesia has emerged as a dynamic laboratory of innovation, driven by a young population that acts not only as consumers of technology but also as architects of the future digital landscape (IDN Research Institute, 2025). As the fourth most populous country in the world, Indonesia has a strategic advantage in the form of a demographic bonus, with more than 69% of its population being of productive age and a median age of around 30 years (Indonesian Central Statistics Agency, 2025). These demographic characteristics create a foundation for rapid technology adoption, from artificial intelligence (AI) to blockchain, all of which are geared towards achieving the Sustainable Development Goals (SDGs) by 2030 (Acosta, 2025; Medium, 2025).

Youth-led innovation in Indonesia resonates strongly with the vision of "Digital Indonesia 2045" — a national masterplan issued by the Government of Indonesia — that positions digital technology as the main driver of national sovereignty, prosperity, and sustainability (Acosta, 2025; Medium, 2025). Indonesia's digital economy is projected to exceed US$ 146 billion by 2025, a growth driven by smartphone penetration exceeding 75% and an internet user base reaching more than 200 million people (Medium, 2025; Primantoro, 2025). However, the essence of this innovation is not merely in the economic growth figures, but in how it addresses systemic challenges, such as the education access gap, transportation inefficiencies, and environmental degradation.

In this context, the crucial role of young innovators in integrating new technologies, such as the Internet of Things (IoT), AI, and open-source technology, into low-cost and frugal innovation solutions is very important to discuss (Aquilani et al., 2020; Qin, 2024). Indonesia presents a rich case study through start-ups such as Gojek and Ruangguru, which have successfully transformed the informal sector and traditional education systems into inclusive digital ecosystems (Ayundasari et al., 2025; Cho, 2025; Gojek, n.d.; Ruangguru, 2021; Suhag, 2022; Usman, 2020). This report will analyze how these companies, supported by strong public-private partnerships and progressive policy frameworks, are able to create tangible social and environmental impacts while maintaining sustainable business growth.

2. Frugal Innovation as a Development Strategy in Emerging Markets

The concept of frugal innovation has been central to the success of many start-ups in Indonesia (Cadeddu et al., 2019). Unlike innovation approaches in developed markets, which often focus on premium products with high development costs, frugal innovation in Indonesia prioritizes creating maximum value with minimal resources (Cadeddu et al., 2019). This strategy involves reorganizing existing systems—such as traditional motorcycle taxis or conventional tutoring services—and empowering them through digital platforms to improve efficiency and reach (Cho, 2025).

PricewaterhouseCoopers (PwC) suggests that companies in the Association of Southeast Asian Nations (ASEAN) market need to encourage cost-effective innovation to create devices and services that are suited to local economic, infrastructure, and environmental conditions (ASEAN Secretariat, 2021). In Indonesia, this is reflected in the ability of young innovators to utilize existing infrastructure, such as mobile connectivity and private vehicle fleets, to provide services that are ten times cheaper than traditional business models (Cho, 2025). This approach is not only democratic because it reaches low-income communities, but also sustainable because it reduces the need for massive, carbon-intensive physical infrastructure investments (Makarim, 2018).

Table 1. Frugal Innovation Strategies in Indonesia's Startup Ecosystem and Their Impact on Sustainability

Characteristics of Cost-Effective Innovation	Implementation in the Indonesian Startup Ecosystem	Impact on Sustainability
Asset Optimization	Utilization of motorcycles already owned by the community for logistics and transportation (Gojek).	Reducing the need for costly new infrastructure development.
Digital Scalability	Use of application-based video learning modules for millions of students (Ruangguru, an Indonesian AI-powered online learning platform founded in 2014).	Expanding access to quality education without geographical barriers.
Cost Inclusivity	Micro payment and affordable subscription models (GoPay, Ruangguru).	Promoting financial inclusion and education for the lower pyramid community.
Local Adaptation	Integration with cash transaction habits through the driver top-up feature.	Accelerating the gradual transition of society towards a digital economy.

(Source: Composed by the authors based on Ayundasari et al., 2025; Cho, 2025; Nadiem Makarim, 2019; Usman, 2020)

The success of cost-effective innovation in Indonesia is also driven by its founders' deep understanding of the "fiction" or obstacles in everyday life. As stated by Nadiem Makarim, technology is capable of leapfrogging developing countries by opening up new economies, new jobs, and new access to information that was previously limited to only a handful of people (Makarim, 2018). This shows that youth-led innovation is not just about technical discoveries, but about organizing existing realities in a smarter and more efficient way (Cho, 2025).

3. Case Study I: Gojek and Inclusive Economic Transformation through the "Three Zeros" Strategy

Gojek — Indonesia's pioneering on-demand multi-service platform and digital payments group, originally launched in 2010 as a motorcycle taxi (ojek) ride-hailing service by Nadiem Makarim, now part of the

PT GoTo Gojek Tokopedia Tbk (GoTo) group, has transformed from a simple call center in 2010 into the largest digital ecosystem in Indonesia (Babu, 2019). As a startup led by a social vision, Gojek has proven that technology can be a driving force for economic inclusion. In 2024, the Gojek ecosystem reportedly supported more than 3 million driver partners and 2.2 million Micro, Small, and Medium Enterprise (MSME) partners (GoFood), which significantly contributed to the national gross domestic product (GDP) (The Jakarta Post, 2025).

The core of Gojek's sustainability strategy is its "Three Zeros" commitment, which it aims to achieve by 2030: Zero Emissions, Zero Waste, and Zero Barriers (The Jakarta Post, 2025). This commitment is not just marketing jargon, but has been integrated into the company's operations through the use of AI, IoT, and strategic partnerships. For example, through the Zero Emissions pillar, Gojek is accelerating the transition to 100% electric vehicles (EVs) across its entire ecosystem, a crucial step considering that the transportation sector is one of the largest contributors to carbon emissions in Indonesian cities (Sani, 2021).

4. The Electric Vehicle Revolution and Battery Swapping Infrastructure: The Role of Electrum

To overcome the high cost barrier to EV adoption, Gojek, through its joint venture Electrum (with PT TBS Energi Utama Tbk, an Indonesian publicly listed energy and mining company pivoting towards clean energy transition), has developed an innovative battery exchange system (ASEAN Secretariat, 2024). This system is designed to accommodate the limited household electricity supply in Indonesia and the intensive usage patterns of driver-partners who require high mobility without lengthy charging times (ASEAN Secretariat, 2024). By the end of 2023, Electrum had installed 25 battery exchange stations and aimed to expand the network through partnerships with minimarkets, public fuel filling stations (SPBU), and automotive workshops (ASEAN Secretariat, 2024).

The integration of AI in EV fleet management is key to operational efficiency. Machine learning algorithms process telemetry data from vehicles to monitor battery health in real time, optimize routes based on the location of the nearest exchange station, and provide predictive maintenance recommendations to extend asset life cycles (Roy & Capgemini, 2025). Data from pilot projects shows that the use of AI can reduce fleet operating costs by up to 25% and increase service reliability by 28% (Roy & Capgemini, 2025).

Table 2. Gojek's 'Three Zeros' Commitment Targets (2030) and Strategic Sustainability Achievements for 2024/2025

2030 Sustainability Goals	Key Initiatives	Realistic Achievements (2024/2025)
Zero Emissions	Transition to 100% Electric Vehicles (EV) and Carbon Offsets.	Reduction of 12,847 tons of CO2e; EV fleet growth >3 times.
Zero Waste	Reduction of single-use plastics and food waste management.	Reduction of 2,004 tons of single-use plastic; >95% of consumers choose to go without cutlery.
Zero Barriers	Economic empowerment of partners and financial inclusion (GoPay).	90% of MSME merchants are using cashless payments for the first time.

(Source: Composed by the authors based on Sani, 2021; Sullivan, 2024; The Jakarta Post, 2025)

5. Waste Management and Circular Economy in Food Delivery Services

In addition to carbon emissions, plastic waste is a major environmental challenge for food delivery platforms. Gojek, through its #GoGreener initiative, has implemented a "nudging" strategy to encourage consumers by making the "no plastic cutlery" option the default setting on the GoFood app (The Jakarta Post, 2020). This simple yet impactful step has successfully saved more than 6.2 tons of plastic cutlery in its first year of implementation (The Jakarta Post, 2020).

In addition, Gojek is collaborating with partners such as Waste4Change to facilitate recycling and responsible waste management for MSME partners (The Jakarta Post, 2025). The Catalyst Changemakers

Figure 1. The Circular Economy Model Catalyst Changemakers Ecosystem (CCE) implemented by Gojek (Source: GoTo Impact Foundation, 2025)

Ecosystem (CCE) program managed by the GoTo Impact Foundation also demonstrates how technology and local wisdom can be combined to manage waste in priority tourist destinations such as Bali and Lake Toba, where 91% of the waste managed is successfully converted into products of economic value or alternative fuels (Sullivan, 2024). This initiative creates "green jobs" or environmentally friendly jobs at the village level, while strengthening community resilience to the threat of climate crisis (GoTo Impact Foundation, 2025).

6. Case Study II: Ruangguru and the Democratization of Quality Education

Education is the root of all opportunities and challenges in Indonesia. With the fourth-largest education system in the world, Indonesia faces major challenges in terms of equalizing quality between urban areas and remote areas or 3T (frontier, outermost, and disadvantaged) areas (Usman, 2020). Ruangguru, founded by Belva Devara and Iman Usman, has emerged as an innovative solution that utilizes technology to bridge this gap through an AI-based adaptive learning platform (Usman, 2020).

Ruangguru's vision centers on three main pillars: Accessibility, Quality Content, and Employability (Ruangguru, 2021). Through an affordable subscription model—even ten times cheaper than conventional tutoring centers—Ruangguru has provided access to millions of students to obtain learning materials from the best teachers in the country (Usman, 2020). In 2021, Ruangguru reported that it had provided affirmative scholarships to more than 25,000 students and conducted capacity building for more than 150,000 teachers throughout Indonesia (Ruangguru, 2021).

7. Implementation of Adaptive AI for Personalized Learning

One of Ruangguru's breakthroughs is the integration of artificial intelligence into their learning system. This technology enables the platform to analyze student performance data, learning preferences, and cognitive abilities in real-time to provide personalized learning pathways (adaptive learning pathways) (Bhakti et al., 2019; Manurung, 2025; Munawwir & Nerizka, 2021). This is particularly crucial in Indonesia, where an unfavorable teacher-to-student ratio — reported at approximately 1:28 at the

primary level and even higher in remote 3T regions (Manurung, 2025) — often makes differentiated instruction difficult in conventional classrooms (Manurung, 2025).

Analysis of public sentiment shows that 90% of Ruangguru users feel helped by features such as animated videos that explain difficult concepts (e.g., mathematical formulas or biological concepts) in a simpler and more enjoyable way (Munawwir & Nerizka, 2021). In addition, AI is also used to provide instant feedback to students as they work on practice questions, allowing for immediate improvement in understanding without having to wait for the next class session (Agustina et al., 2025). This innovation is in line with the Indonesian government's "Merdeka Belajar" (Freedom to Learn) policy, which emphasizes curriculum flexibility and student-centered learning (Agustina et al., 2025).

Table 3. Ruangguru Strategic Impact Indicators and the Role of Technology in Educational Transformation (Through 2024/2025)

Ruangguru Impact Indicators	Achievement Description (Until 2024/2025)	The Role of Technology
User Reach	>20 million students in Indonesia and expansion into Vietnam (Kienguru).	Cloud infrastructure and mobile-first apps.
Teacher Development	>150,000 teachers received digital pedagogy training.	*Learning Management System* (LMS).
Material Quality	>250 teaching modules are used by educators nationwide.	Data Analytics and Creative Content Production.
Regional Inclusion	The program is available in 34 provinces, including 3T areas.	Low bandwidth optimization technology.

(Source: Composed by the authors based on Orissa International, 2025; Ruangguru, 2021; Ruangpeduli, n.d.; Usman, 2020)

8. Improving Educator Capacity and Education Resilience in Times of Crisis

The COVID-19 pandemic has been a real test of the resilience of the global education system. Ruangguru responded to this crisis by launching various free initiatives to support distance learning, including the Online School platform and classroom management features for teachers (Ruangguru, 2021). Ruangguru's success in maintaining the continuity of education during the pandemic shows that digital platforms are not only supporting tools, but also a vital infrastructure for national social resilience (Ruangguru, 2021).

Furthermore, Ruangguru focuses on the pillar of Employability by providing soft skills training and career preparation for new graduates and young professionals. Through the Ruangpeduli program (Ruangpeduli, n.d.), more than 50,000 adult learners have participated in entrepreneurship and job preparation programs, which are highly relevant to addressing the issues of unemployment and underemployment among young people. This proves that youth-led educational innovation has a broad ripple effect on overall economic productivity.

9. New Technologies as Enablers: Blockchain, IoT, and Open Source Technology

The success of startups such as Gojek and Ruangguru cannot be separated from their courage in adopting and contributing to the development of new technologies. The use of open source technology has become standard in their product development, which not only accelerates internal innovation but also strengthens the global technology ecosystem. Gojek, for example, has released several of its data infrastructure tools to the open source community, such as Firehose for data injection and Optimus for data workflow management (Suhag, 2022). This step reflects the spirit of collaboration that characterizes innovation among young people in the digital age.

On the other hand, the potential of Blockchain technology is beginning to be explored as the foundation for "Digital Identity" and transaction transparency in Indonesia. With more than 14 million crypto investors by mid-2025, Indonesia ranks third globally in terms of digital asset adoption (Medium, 2025).

Projects such as Mandala Chain are developing sovereign blockchain infrastructure that is aligned with W3C standards for citizen services, educational credentials, and digital medical records (Medium, 2025). The implementation of blockchain is expected to eliminate inefficient intermediaries, reduce the risk of fraud, and strengthen national data sovereignty.

10. Utilizing IoT for Climate Resilience and Smart Agriculture

The integration of the Internet of Things (IoT) has also begun to penetrate crucial sectors such as agriculture and energy efficiency. In the energy sector, IoT is used in electrical load management systems for EV charging, which enables automatic charging during off-peak hours to reduce pressure on the national power grid (blinkcharging.com, 2025). In the context of climate resilience, IoT sensors connected to AI algorithms can provide early warnings of natural disaster risks, an application particularly relevant for the Asia-Pacific region, which is vulnerable to the impacts of climate change (UN ESCAP, 2020).

In the climate-smart agriculture sector, young Indonesian agri-tech startups — such as TaniHub (an agricultural marketplace connecting farmers to buyers; TaniHub, n.d.), iGrow (a crowdfunding platform for agricultural investment; iGrow, n.d.), and Habibi Garden (an IoT-based crop monitoring system; Habibi Garden, n.d.) — are beginning to utilize IoT to monitor soil moisture, temperature, and plant health with precision. Although specific data on the integration of Ruangguru or Gojek in this sector is still limited, Gojek's logistics ecosystem provides valuable infrastructure for the distribution of agricultural products directly from farmers to consumers, reducing food loss along the supply chain (Sullivan, 2024). The reorientation of the food system supported by digital technology is key to Indonesia's future food security.

11. Public-Private Partnerships (PPPs) and Institutional Support for Young Innovators

One of the main enablers of youth-led innovation in Indonesia is close collaboration between the public and private sectors. The Indonesian government has realized that to achieve inclusive digital transformation, it cannot work alone. This strategic partnership is reflected in various national programs that involve startups as key implementing partners.

The most prominent example of this partnership model is the Pre-Employment Card Program. Launched in 2020, Pre-Employment is a large-scale competency development initiative that uses the G2P 3.0 (Government-to-Person) scheme (Purbasari et al., 2025). This program integrates an ecosystem comprising six digital platforms (including Ruangguru as a training partner), 188 training institutions, and six payment partners (such as GoPay) (Purbasari et al., 2023; United Nations, n.d.). Through advanced Application Programming Interface (API) integration, the government can distribute aid directly, transparently, and accurately to more than 16.4 million beneficiaries (Purbasari et al., 2023; United Nations, n.d.).

12. Policy Instruments and the Role of Technology Business Incubators

In addition to direct partnerships, the government also provides a policy framework and institutional support through various ministries. The Ministry of Communication and Digital Affairs (Komdigi) runs the National Movement for 1,000 Digital Startups, which aims to assist young entrepreneurs from the ideation stage to market validation (ANTARA News, 2025). Meanwhile, the Ministry of Tourism and Creative Economy (Kemenparekraf) supports the acceleration of digital startups in the creative economy sector through the BEKUP (Bekraf for Startup, or the Creative Economy Agency Startup Acceleration Program) program (Pradolo, 2025).

The Financial Services Authority (OJK) is also strengthening the ecosystem through the 2024-2028 Roadmap for the Development and Strengthening of Venture Capital Companies. This roadmap aims to create a healthy and ethical venture capital industry that is oriented towards funding startups and

developing MSMEs (Financial Services Authority, 2024). Regulatory certainty and funding support are crucial to ensure that young people's innovations do not stop at the prototype stage, but can grow into national and regional businesses.

Table 4. Policy Instruments and Institutional Support Programs for the Young Innovator Ecosystem in Indonesia

Policy Programs/Instruments	Implementing Agency	Key Focus for Young Innovators
Together Prakerja (PPP Model)	Coordinating Ministry for Economic Affairs	Skilling, Reskilling, and Upskilling through EdTech platforms.
1.000 Startup Digital	Ministry of Communication and Digital Affairs (Komdigi)	Mentoring, networking, and building an early-stage startup ecosystem.
BEKUP & BSC	Ministry of Tourism and Creative Economy (Kemenparekraf)	Accelerating creative economy startups towards pre-series A funding.
Venture Capital Roadmap	Financial Services Authority (Otoritas Jasa Keuangan / OJK)	Strengthening funding governance and consumer protection.
Digital Talent Scholarship	Ministry of Communication and Digital Affairs (Komdigi)	Technical training (AI, Cybersecurity, Cloud) for the younger generation.

(Source: Composed by the authors based on ANTARA News, 2025; Otoritas Jasa Keuangan, 2024; Pradolo, 2025)

13. Structural Challenges and the Path to a Sustainable Future

Despite significant progress, Indonesia's digital innovation journey still faces serious structural challenges. The digital divide remains an acute issue, especially in remote areas where internet infrastructure is still inadequate (Helsa & Yulianti, 2024). Although the SATRIA-1 satellite has been launched to connect 30,000 public service points, there are still around 3,000 villages that do not have stable communication signals (ANTARA News, 2025). This gap has created what is known as the "Digital Divide 2.0", in which marginalized groups such as rural communities, women, and people with disabilities are at risk of being left behind in the digital transformation (Helsa & Yulianti, 2024).

In addition to infrastructure issues, digital literacy and educator readiness are also major challenges. In the education sector, 75% of teachers stated that the lack of technology-based resources was the main obstacle to integrating digital tools into the learning process (Pratiwi et al., 2025; Wijaya et al., 2024). Therefore, investment in human capital through continuous training for teachers and workers is urgently needed (Makarim, 2019).

On the environmental side, the transition to a low-carbon economy requires significant upfront investment and fundamental behavioral changes from all stakeholders. The adoption of EVs, for example, still heavily depends on the availability of charging infrastructure and consistent government incentive policies (ASEAN Secretariat, 2024). The challenges of plastic waste and urban waste management also require stricter law enforcement and broader cross-sectoral collaboration rather than merely independent corporate initiatives (Dahman-Leloup et al., 2024).

14. Conclusions and Recommendations for the Asia-Pacific Region

The case studies of Gojek and Ruangguru in Indonesia provide valuable lessons for the Asia-Pacific region on how youth-led innovation can be a driving force for sustainable development. The key to their success lies in their ability to combine cost-effective innovations rooted in local problems with the intelligent use of advanced emerging technologies. The existence of a supportive ecosystem, ranging from innovative public-private partnerships to progressive policy instruments, has proven capable of accelerating the social and environmental impact of digital technology.

As a recommendation for the future, digital innovation must continue to be guided by the principles of inclusivity and long-term sustainability. This includes:

Accelerating Infrastructure Equity: Ensuring digital connectivity reaches the most remote areas to prevent social exclusion.

Strengthening Human Capital Capacity: Making massive investments in digital literacy and future skills (AI, IoT, Blockchain) for young people and educators.

Deeper Environmental, Social, and Governance (ESG) Integration: Encouraging technology companies to make environmental and social targets an integral part of their business models, rather than just corporate social responsibility (CSR) programs.

Asia-Pacific Regional Collaboration: Strengthening technology transfer and exchange of best practices among member countries through platforms, such as Asian and Pacific Centre for Transfer of Technology (APCTT)-ESCAP, to accelerate the collective achievement of the 2030 SDGs.

With optimism and a willingness to experiment, Indonesia's young innovators have written a blueprint for how technology can serve humanity on a large scale. Their journey reminds us that the most transformative innovations are often the most practical ones—those that bridge the gap between traditional systems and a greener, fairer, and more prosperous future for all.

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APCTT
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Transfer of technology to the metaverse: Human factors and analogical thinking

Chien-Sing Lee

Georgia Tech (Fulbright Visiting Scholar, 2009), IEEE

Faculty of Engineering and Technology, Sunway University, Malaysia

Email: csleester@gmail.com

Abstract

Asia is one of the most vibrant socio-economic regions in the world. As we venture into possible open innovations for socio-economic-technological development, drivers and challenges may be similar, though of different scales and orientations. This paper reviews design thinking, creativity-analogical thinking, and some case studies led by youths, guided by prior literature, towards the United Nations Economic and Social Commission for Asia and the Pacific's (UNESCAP) demographic dividend and the metaverse. Findings indicate that first, despite variations in centralities in design, abstracted key engagement design factors concur with Venkatesh, Speier-Pero, and Schuetz's (2022) online shopping factors, especially on congruence, perceived value and enjoyment; second, design thinking via Maslow's hierarchy of needs when balancing/ reviewing SDGs, metrics and Innovation Helixes sustains; third, capacity building should work towards integrated loosely-coupled systems, to allow country/region-specific benchmarks and choice, to simplify design and balance across country/ region-specific goals to meet and sustain country/region, community and individual needs, while instantiating from global frameworks, best practices, benchmarks and diverse collective-cross-disciplinary metrics.

1. Introduction

The Brundtland Report (1987) has provided the bases for 3 pillars of sustainability, i.e., environment, social, and economic sustainability, assisted and integrated by governance via systems and policies (ESG). Moreover, the United Nations Economic and Social Commission for Asia and the Pacific's (UNESCAP) demographic dividend (DD) (Figure 1) promotes economic structures, social (environment, education, health), and good governance (Figure 2) to facilitate demographic growth. Some exemplary sub-DD (economic-education-governance) integrated systems in the Asia Pacific are Lazada/Taobao/Shopee.

Furthermore, Venkatesh, Speier-Pero, and Schuetz (2022) note that amidst intense competition, consumer adoption of technology for online shopping is not a given. Findings from their longitudinal study into how much culture, demographics, economics, technology, and personal psychology influence online shopping reveal congruence, impulse buying behavior, risk, local shopping, browsing enjoyment, and shopping enjoyment as key drivers (Figure 3). Among these, they find congruence to be the key factor influencing value consciousness, mediated by enjoyment (browsing and shopping), moderated by risk tendencies, e.g., impulse buying behavior.

1.1 Problem statement

Gartner's elements of the metaverse (Figure 4) focus on Augmented Reality, Virtual Reality, and Mixed Reality. It is, however, not clear whether integrated eco (systems) without these elements can be considered a form of the metaverse and/or a type of DD subsystem. This study hypothesizes that to be sustainable (especially for developing countries), the metaverse needs to include drivers for DD and good governance, and drivers for online shopping, parallel to each other, similar to intertwining chromosomes. This can lead to Medkova and Fifield's (2016) redesign and cross-disciplinary intelligence for the circular economy (Figure 5) and "genetic" crossovers. Such transformation can open channels of possibilities and better fit/sustainable partnerships/supply chains/ ecosystems development and transfer of technology (*Carayannis, & Campbell, 2009)*.

1.2 Research questions

The research questions in this review/opinion paper are:

RQ1: Can design thinking via Maslowian themes map to the UNESCAP's demographic dividends (DD) and good governance?

RQ2: Can modular integrated systems learn from analogical model-based thinking towards cross-disciplinary intelligence?

RQ3: Can design thinking via Venkatesh, Speier-Pero, and Schuetz's (2022) online shopping factors, especially on congruence, perceived value and enjoyment map to the UNESCAP's demographic dividend and good governance?

1.3 Objectives

Emulating the United Nations, Malaysia, as the Chair of Association of Southeast Asian Nations (ASEAN), with the theme "Our People, Our Community, Our Vision", introduced knowledge transfers via the

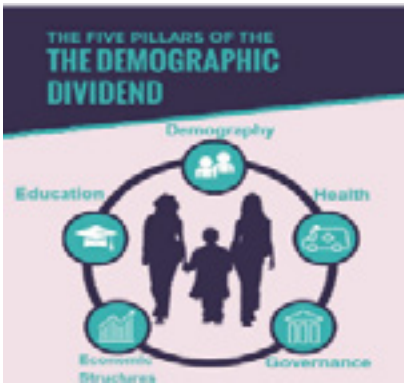

Figure 1. UNESCAP's (2022) Demographic Dividend

Figure 2. UNESCAP's (2009) good governance traits

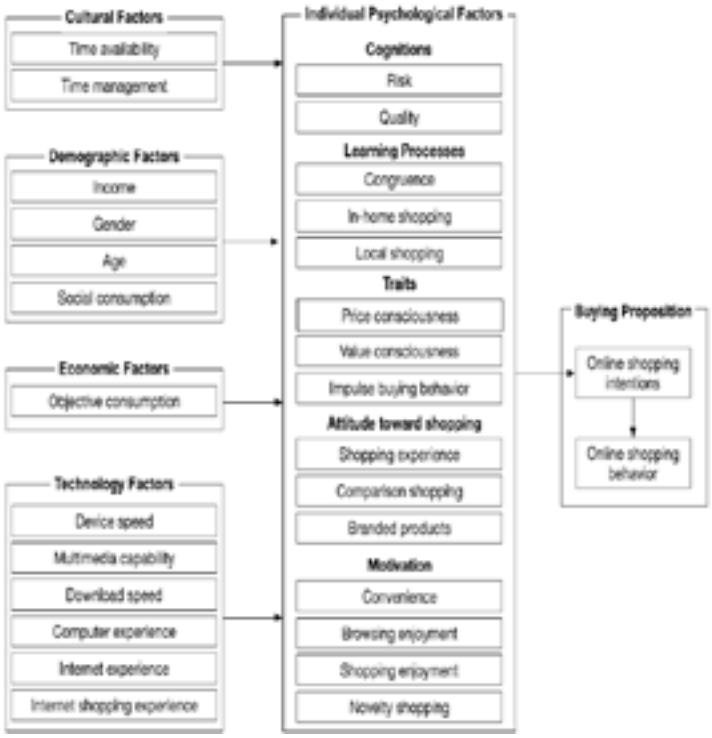

Figure 3. Venkatesh, Speier-Pero & Schuetz's (2022) online shopping factors

Figure 4. Gartner's metaverse

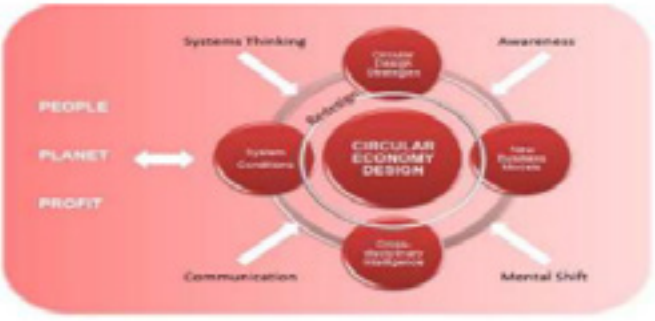

Figure 5. Medkova & Fifield's (2016) circular economy components

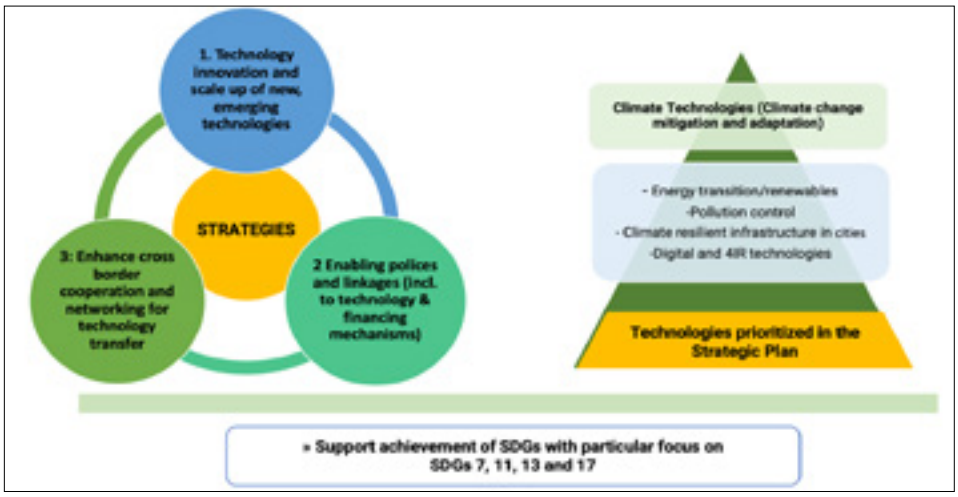

Figure 6. **APCTT's 2023-27 Strategic Plan framework: Strategies (up), priorities (down)**

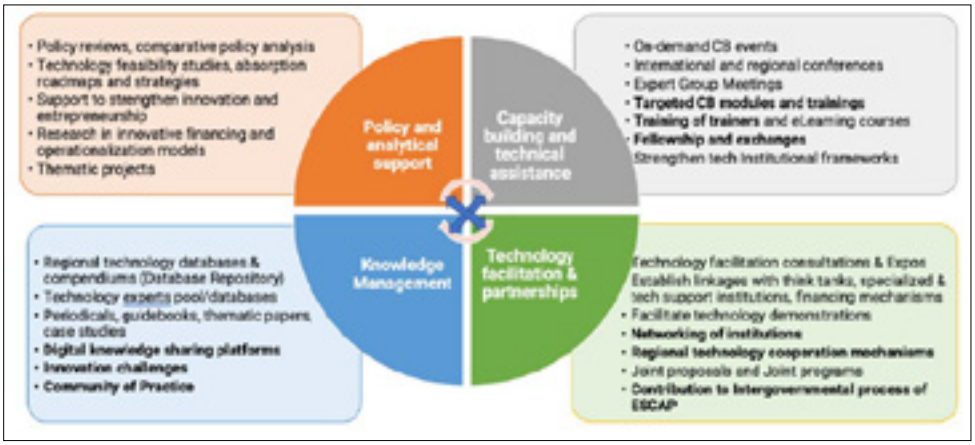

Figure 7. **APCTT's 2023-27 implementation modalities**

Multimedia Super Corridor in 1997, and sustainability policies, to identify, and promote best practices and capacity building/transfer in 2009 with the Ministry of Energy, Green Technology and Water (APCTT, 2015). Continuing from prior studies on reference modeling best practices (Lee, Koper, Kommers & Hedberg, 2008), Lee and Kolodner (2009) have proposed object-oriented strategies and tactics to enable reference modeling of sustainable development between/ among countries.

These concur with the APCTT's 2023-27 Strategic Plan framework (Figure 6). Change management strategies, e.g., promoting cross-border cooperation, networking, innovation, technology transfer, and scaling up of emerging technologies through policies and financial institutions (Figure 6 left) and implementation modalities (Figure 7), have aided the APCTT's development of priority technologies (Figure 6 right). Digital and the fourth industrial revolution technologies enable climate-resilient infrastructure. Infrastructure enables control and transformation/ renewal. Over time, mitigation and adaptation strategies mature.

For the emerging and/or developing countries, perhaps, the pyramid should be a matrix as resources are not always available or adequate, and development is often across SDGs (Lee, 2025). Hence, focusing on the environment, social, and governance (ESG) metrics may be better. But if the metrics are too complex, strategies may be difficult to adopt, achieve, or evaluate. In line with Ryan and Deci's (2000) self-determination theory's constructs of autonomy, competency and relatedness and the Institute of Electrical and Electronics Engineering's (IEEE) tenets of lifelong learning, Lee (2025) has, thus, proposed simplification, loosely coupled partnerships based on the well-known Capability Maturity Model, and freedom to choose, as capabilities/capacities via talent, infrastructures and supply chains grow and as standards/best practices are regionally and nationally localized.

Subsequently, this paper discusses some youth-led innovations guided by prior literature and adaptations, with interconnected (eco)systems as the primary technology design factor as we venture into the metaverse. These innovations map to a very humble extent to the UNESCAP's demographic dividend (DD), where economic structures, social (environment, education, health), and governance (ESG) facilitate demographic growth.

2. Methodology

This study reviews five undergraduate student researches into interlinked/integrated systems in two universities in Malaysia. Foundational to these studies are:

design challenges where student-designers hypothesize and validate what and how they want their future to be like, in line with Ryan and Deci's (2000) self-determination theory's constructs of autonomy, competency, and relatedness, Dym, Agonino, Eris, Frey and Leifer's (2005) design thinking (needs-based) computational thinking (examples of such needs are Maslow's (1943) hierarchy of needs), analogical thinking (Goel, 1997) and the Learning Sciences' problem-based learning-case-based reasoning (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar & Ryan, 2003), where problem-solutions are retrieved, reused, revised and retained based on multiple facets/criteria/attributes (the simplest and most common is the table of comparison, as a summary of reviewed literature), other disciplines to enrich design possibilities via crossovers and mutations based on criteria/attribute-based/driven pivot points, modularity and loosely coupled to enable efficient/effective management/refinements.

3. Findings and discussion

3.1 RQ1: Can design thinking via Maslowian themes map to the UNESCAP's demographic dividends (DD) and good governance?

Maslow's hierarchy of needs maps well to UNESCAP's demographic dividends (Table 1).

Table 1. Environmental, Social and Economic (ESE) sustainability via ESG mapped to Maslow's hierarchy of needs ()

Environmental sustainability (physiological needs)	climate-changing emissions, expand the use of renewable energy, protect biodiversity, ecosystems, and living species, circular economy and waste reduction, agriculture and food supply chains more sustainable	SDG 6 clean water and sanitation, SDG 7 affordable and clean energy, SDG 13 climate action, SDG 14 life below water, SDG 15 life on land	SDG 17 Partnership for the goals [individual, social, economic, political, environmental]
Social sustainability (physiological, safety and security, love & belonging, self-esteem, self-actualization)	equity and human rights	SDG 1 no poverty, SDG 2 zero hunger, SDG 5 gender equality, SDG 10 reduced inequalities, SDG 16 peace, justice and strong institutions	
	access to healthcare, quality education	SDG 3 good health and well-being, SDG 4 quality education	
	decent employment	SDG 8 decent work, economic growth	
Economic sustainability (safety and security, love & belonging, self-esteem, self-actualization)	Responsible resource management	SDG 9 industry, innovation and infrastructure, SDG 11 sustainable cities and communities, SDG 12 responsible consumption and production	
	The efficiency and innovation capacity of economic systems and businesses		
	Financial stability at the macroeconomic level		

3.2 Case studies

3.2.1

RQ2: Can modular integrated systems learn from analogical model-based thinking towards cross-disciplinary intelligence?
Problem-solving through case-based reasoning (Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, and Ryan, 2003) and Goel's (1997) computational analogical creativity recommends substitution and refactoring. Analogical cross-disciplinary intelligence based on metadata/meta models is likewise feasible, given desired frameworks/goals/criteria/trade-offs. For example, the same strategic workflow to recommend items in e-learning (Lee, 2008) and e-commerce (Lim & Lee, 2008) depends on the user's preferences, past browsing history, and past purchases metadata, and best/top *n* matches with the database's resource/product metadata. Pivots or crossmatches are also based on matching metadata.

3.2.2

RQ2: Can modular integrated systems learn from analogical model-based thinking towards cross-disciplinary intelligence?

RQ3: Can design thinking via Venkatesh, et. al.'s (2022) map online shopping factors, especially on congruence, perceived value, and enjoyment, to the UNESCAP's DD and good governance?

For the metaverse, the sustainability of/for socio-economic-technological development among interconnected systems is a multi-faceted, criteria-based experimental playground. With diverse selection of within and cross-disciplinary framework and metrics, richer and more meaningful outcomes may result. An example is Becker, *Betz, Chitchyan, Duboc, Easterbrook, Penzenstadler, Seyff, and Venters*' (2023) Sustainability Awareness Framework. It covers five dimensions, i.e., individual, social, economic, technical, and environmental.

There is a need to simplify/integrate, as we are often overwhelmed with too many apps. As exemplified in Lee (2025), Asian countries, which focus on the people, i.e., wellness or education, develop faster while developed countries focus on energy, as they are more advanced, stable, and established. Hence, some humble beginnings with slightly different centrality in designs are Lee and Wong's (2018; 2021) QR-linked systems focusing on reusable material-craft (Figure 8) for pre-school and music for mental health (Patatap). Continuing with Lee and Wong's (2018) gamified learning for Smart Cities, Phang and Lee (2025) have integrated system focusing on climate change (Figure 9a), Chong and Lee (2026) have integrated system focusing on circular economy (Figure 8), Lee and Ding (2025) have integrated system focusing on mental-health (Figure 9b) and Look and Lee's (2026) integrated wellness with positive psychology chatbot (Figure 9c).

Integrating mini-games and gamification into e-commerce climate change (Phang & Lee, 2025), the mobile application aims to (in)directly persuade the individual to reduce his/her carbon footprint by transforming a simple calculator into a visualized carbon footprint report. Alpha-beta user testing based on Technology Acceptance Models 1-3 confirms that the personal carbon footprint report has the greatest impact, followed by the individual's willingness to act on climate change, alternatives for mitigating climate change, and cause-and-effect purchase decisions in the 'Shop' feature.

Figure 8. Lee and Wong's (2021) material-QR-linked craft for pre-school (left), graphic design (Patatap and its sources of inspiration, i.e., the incredibox and musical assistive lights) (Universiti Tunku Abdul Rahman, based on Stanford's design thinking, completed April 2015)

Figure 9a. **Phang and Lee's (2025) DD focusing on climate change (Sunway University/SU)**

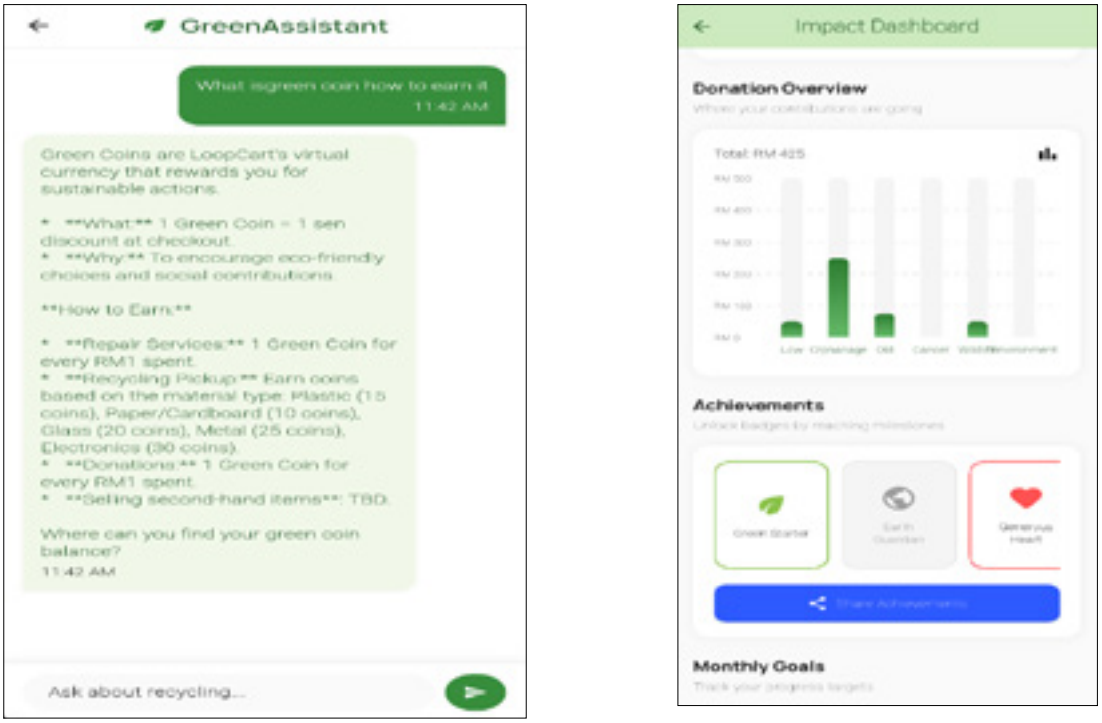

Figure 9b. **Chong and Lee's (2025) DD focusing on circular economy (SU)**

Chong and Lee's (2026) *LoopCart* integrates circular economy (CE) principles to promote sustainable consumption. Key features aligned with the 6R framework are best value comparison, personalized product filtering, repair services, daily quiz, Green Coin reward system, chatbot, and reflective sustainability analytics/ report. Alpha-beta findings via the User Experience Questionnaire (UEQ) and the Technology Acceptance Models (TAM) 1-3, confirm that value via personalization, and feature-based learning from multiple channels can lead to more meaningful, responsible consumption.

Lee and Ding's (2025) *Mindful Quest* incorporates reflective self-care activities and adventure/time management, outward/societal activities, and an enrichment self-paced educational library. Alpha-beta user testing findings reveal that congruence is reflected in value (and price) consciousness, technological factors, and browsing enjoyment. In terms of user acceptance, clarity and ease of use average is 89%, usefulness of mental health/well-being activities 88%, and productivity 91%. The most important strengths are gamification (47%) and enjoyment from mixed content (e.g., education/personal growth and entertainment; work and self-care; productivity and mental health/ wellbeing goals; self-care and rewards) 17%.

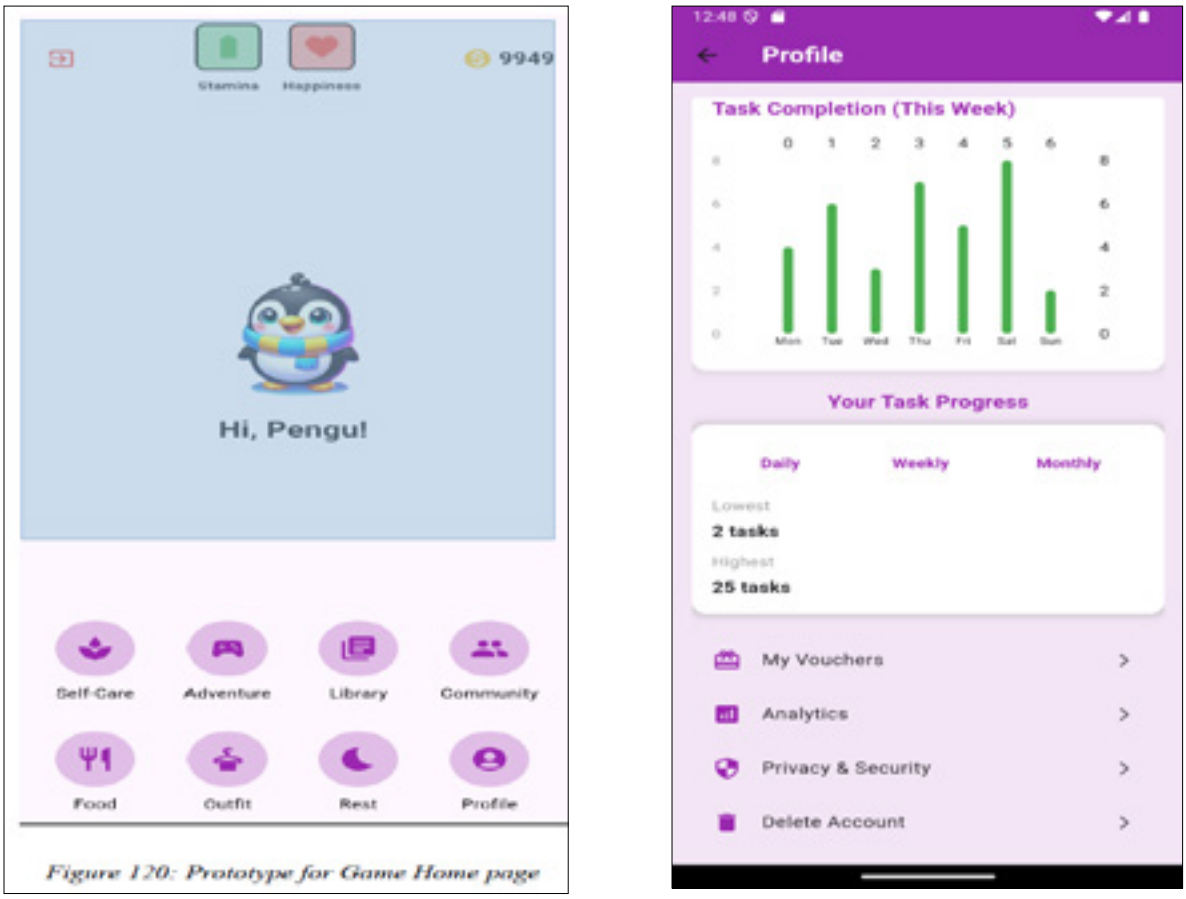

Figure 9c. Lee and Ding's (2025) DD focusing on mental health (SU): Game Home Page and Profile page

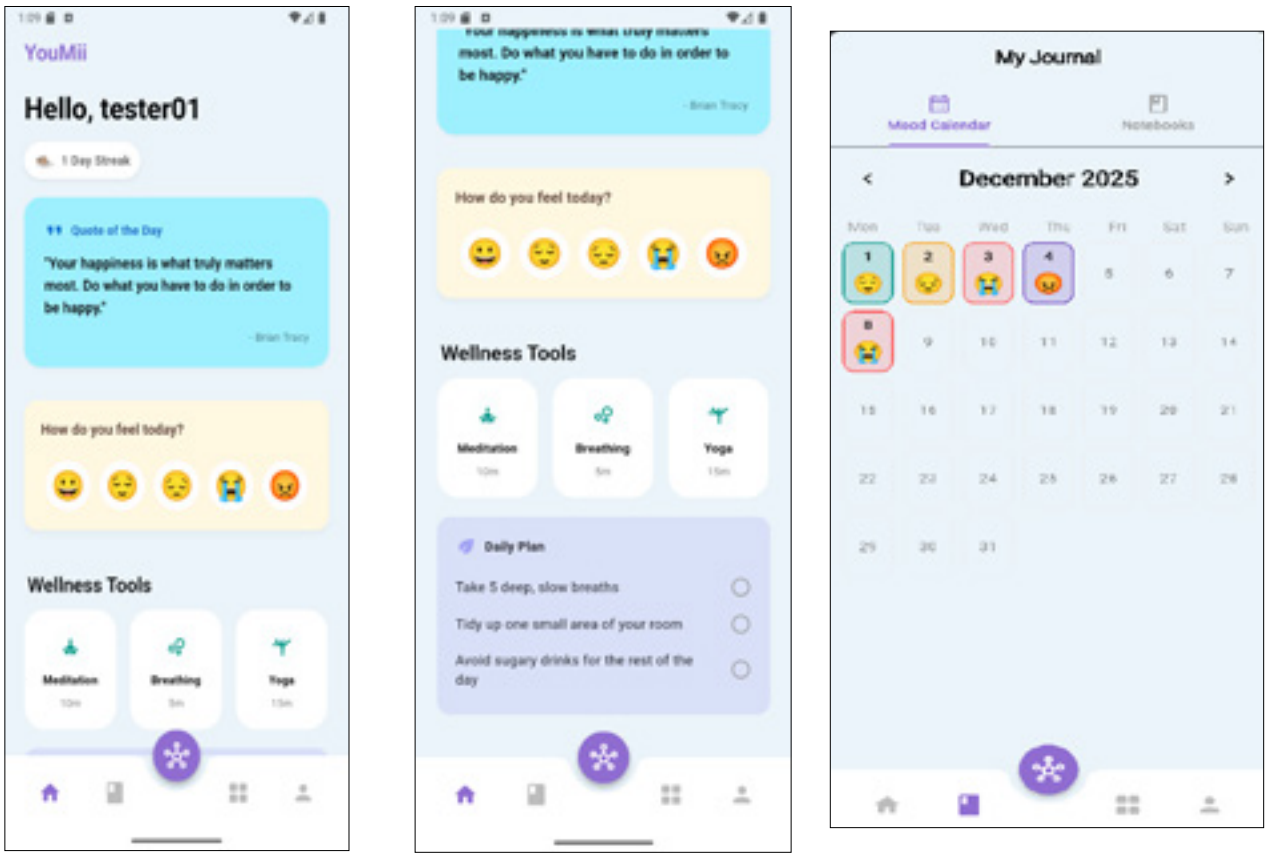

Figure 9d. Look and Lee's (2025) DD on mental health with chatbot (SU): daily wellness, mood calendar and notebook

Aimed at offering personalized mental health support, Look and Lee's (2026) *YouMii*, a positive-psychology-Gemini-based mobile app AI companion, integrates mood-based and behavioral tracking, and recommends proactive self-care activities and context-aware conversational interactions/intervention via contextual reasoning.

Abstracted findings from these studies confirm that design thinking maps well with Venkatesh, et. al.'s (2022) online shopping factors, especially on congruence, perceived value, and enjoyment map, as well as with UNESCAP's DD and good governance.

RQ3: Can modular integrated systems learn from analogical model-based thinking towards cross-disciplinary intelligence?
Gentner and Forbus' (2025) review of four decades of symbiotic interactions between psychology and artificial intelligence, structure-mapping engine (SME) simulations, e.g., via *CogSketch* and *Companion* indicate that analogical SMEs can be operationalized across disciplines. As such, case-based reasoning and analogical reasoning complement matching objectives with metadata and identifying the fit based on the degree of similarity.

Furthermore, with ontology, if the problem in one discipline is similar to that of another discipline, e.g., encouraging more active participation in e-learning and e-commerce, then similar but tweaked/extended variables can be included in the if-then rules/business logic when applying rewards, e.g., gamification. In past and current research, there is no penalty, only rewards. Hence, it is not reinforcement learning, but refinement and sustaining motivation/interest (Lee & Wong, 2015; 2018).

At a higher level of the Semantic Web, ontology reduces the cold start problem. Sasenaa, M. J., Papalambrosa, P. and Goovaerts, P. (2002). Exploration of metamodeling sampling criteria for constrained global optimization". Sigurdarson, N. S., Papalambros, P. Y., Eifler, T. (2023) "Managing Functional Trade-Offs In The Mechanical Design of integrated products using multi-objective monotonicity analysis", User-item collaborating filtering subsequently depends on semantic relationships. To enhance learning of non-linear relationships during user-item collaborating filtering and further reduce the cold start/data scarcity problem in new contexts, Ong, Ng and Haw (2021) have incorporated deep neural networks to complement matrix factorization. In initial tests, the consequent neural matrix factorization (NeuMF++) or neural collaborative filtering (NCF) improves identification of matching latent matrices. Intelligent knowledge-project-management optimization approaches, such as Li, Wang, Qi, Liu, Wu & Jia's (2020), can help to reduce global-local regret and optimize user satisfaction. Rewriting the ontology, e.g., by Heru, Haw and Lee (Xu and Ye (2020)), can also build on.

4. Implications

Complementing the above Web Engineering technological solution is simplification via data-driven choice and simplification. In Lee's (2025) review and analysis of UN SDG country performances across regions, it is found that there are differences in strengths across regions. The more advanced countries focus more on energy, while, understandably, the less developed or developing countries focus on basic and progressive needs. Furthermore, countries that frame policy design based on Maslow's hierarchy of needs (the originator of design thinking) exhibit commendable progress. With improvements in SDG4 Quality Education, SDGs 1 (no poverty), 2 (no hunger), and 3 (good health and well-being) improve, though at different rates. Subsequently, SDG11 sustainable cities and communities improve.

Hence, the goal is not merely about meeting metrics, but about improving quality of life/Maslow's hierarchy of needs. More importantly, the focus of discussion should recognize differences in regions and moderate and/or allow contextual choices while benchmarked to cross-regional goals, characteristics, and impacts. Moreover, capacity building should work towards integrated loosely coupled systems, in order to simplify design and balancing/tradeoffs across the chosen country-specific goals and their importance to country, community, and individual needs. Else, countries and individuals may be overwhelmed.
Can there be an integrated collective metrics and aggregation for the Asia Pacific towards win-win collaborative cross-selling (Rudas, et. al., 2013)?

5. Conclusion

Ultimately, the quality of outcomes depends on how well the problem is modeled in terms of real-world individual-socio-technical-political-technological dimensions. Sometimes, the weightage of importance amongst these dimensions differs. Thus, outcomes are different. As such, the value of developing DD-oriented systems thinking is critical. Aggregation and meta modeling, e.g., by the UN and the UNESCAP, do help to develop better transfers of knowledge and best practices in technology. As with model-driven architectures, organizations/countries can select which components/technology from the global or Asia Pacific knowledge repository better suits them, for further localization and refinement.

Freedom to develop different centralities of design, of relevance to the designers (youths) of diverse backgrounds, influences the quality/type of design outcomes. Nevertheless, relevance is primary. To refine, will require some fractal learning, as there must be a degree of monotonicity (Sigurdarson, Papalambros & Eiffler, 2023) to keep the design's fundamentals stable/consistent over time. Computationally, this implies identifying significant features/aspects and representing these via matrix factorization, towards systemic dynamic micro-macro analogies/adaptivity/balances and redesign in the future. Most importantly, systemic sustainable design for augmented/lean systems should consider the UNESCAP's DD and good governance.

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2026 SuperAI
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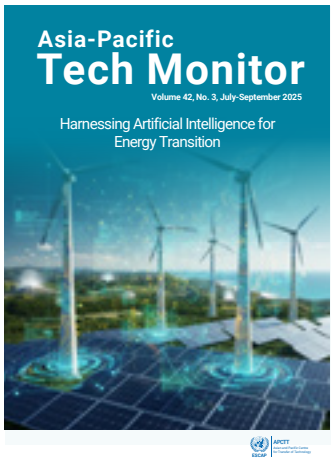

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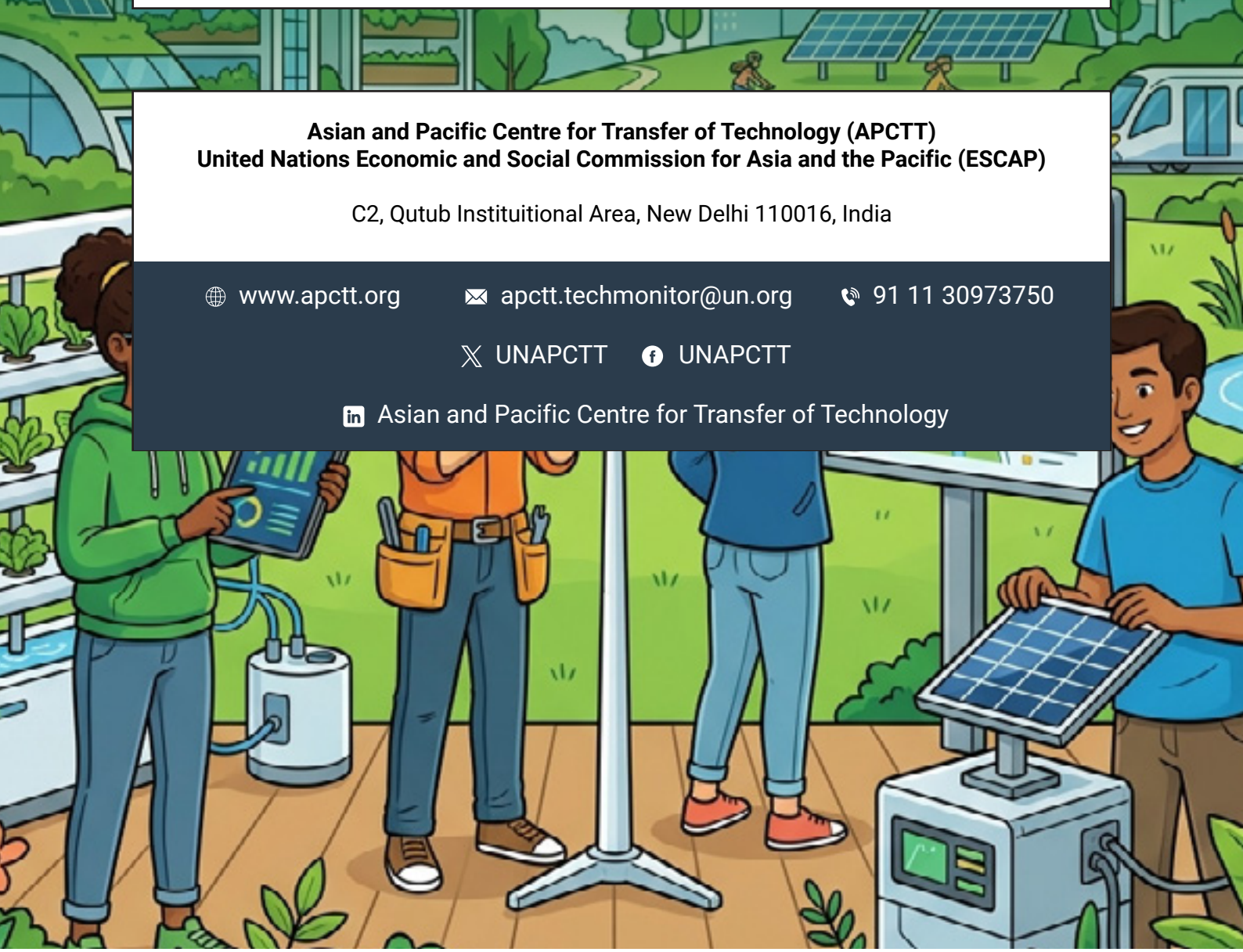

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