Asia-Pacific Tech Monitor

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Technologies for Climate Resilient Infrastructure

Opportunities and challenges for Asia and the Pacific

ESCAP
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Asian and Pacific Centre for Transfer of Technology

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

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

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Foreword

Climate-induced disasters are a growing threat to the infrastructure development and resilience in the Asia-Pacific region. They significantly impact the planning, maintenance and operation of infrastructure facilities and systems. Climate change impacts such as increasing temperatures, shifting patterns of rainfall, and rising sea levels have also highlighted the vulnerability of infrastructure resulting in disruptions and substantial losses. While countries are exploring ways to scale up their efforts under the Paris Agreement, it is imperative to explore technologies that can help communities to adapt to climate change by reducing risks to lives and livelihoods.

In recent years, innovative and emerging technologies are offering many applications and solutions to enhance climate resilience and adaptability of infrastructure. Examples include early warning systems, predictive modelling, and high-performance concrete and self-healing materials. With adequate funding and investment, these technologies could help in planning, designing, building and operating resilient infrastructures. Experience shows that with increased resilience, infrastructure projects can withstand and adapt to climate-related challenges, minimizing significant disruptions and economic losses, ensuring their long-term viability. According to *Lifelines*, a report from The World Bank, investing $1 trillion in the incremental cost of making infrastructure more resilient in developing countries would generate $4.2 trillion in benefits.

This special issue of *Asia-Pacific Tech Monitor* focusses on "Technologies for climate resilient infrastructure: opportunities and challenges for Asia and the Pacific". The featured articles present insightful discussions on climate-smart technologies, adaptation and resilience plans, transport and building codes and standards, green business models, and resilience of smart cities. The articles highlight examples and case studies on climate-resilient energy infrastructure in Australia, climate-resilient cities and stormwater modelling in Japan, urban water management in China, and a Composite Adaptability Index framework for assessing urban transportation resilience to flooding in India.

We hope that this *Tech Monitor* issue will support policymakers, technical experts and practitioners in planning and designing appropriate technology interventions to strengthen climate-resilience of infrastructure facilities and systems in the Asia-Pacific region.

We also take this opportunity to wish all our readers a very Happy New Year 2025. We look forward to strengthening our association and assure you of our commitment to bring updated information and trends as well as relevant featured articles on technology cooperation and transfer in the region.

Preeti Soni
Head, APCTT

ASIA-PACIFIC

CHINA

Private firms hiking R&D spending

Government officials and industry experts say China's top private enterprises are ramping up their research and development expenditures, reflecting a shift toward innovation to become more competitive on the global stage.

As per a report released by the All-China Federation of Industry and Commerce on Monday, total 2023 R&D expenditures for the top 1,000 private firms reached 1.39 trillion yuan ($197.5 billion), up 4.78 percent year-on-year. They accounted for 41.88 percent of the nation's overall R&D spending.

The manufacturing sector emerged as a major contributor, with total R&D expenditures surpassing 1 trillion yuan last year. The highest R&D investments were observed in the computer and electronics sector, which invested 318.47 billion yuan with an impressive average R&D intensity of 8.34 percent. It was closely followed by the internet and related services sector at 245.07 billion yuan and the automotive industry at 142.56 billion yuan.

Notably, China's R&D efforts are increasingly narrowing the gap with other leading economies. Some 217 of the global top 1,000 R&D-invested firms are from China, with total R&D investments amounting to 1.27 trillion yuan. The year-on-year growth rate of R&D expenditures for these top 1,000 private enterprises last year was 12.78 percent, surpassing the growth of 6.54 percent for the global top 1,000 and 7.68 percent for the European Union. The average R&D intensity for the top 1,000 private enterprises was 3.58 percent, 0.31 percentage points higher than that of the top 1,000 firms in the EU.

China will scale up R&D expenditures by more than 7 percent annually during the 14th Five-Year Plan (2021-25) period. Consultancy McKinsey & Co said in a report that such a growth target will make China the world's largest R&D spender.

https://www.chinadaily.com.cn

R&D tax deductions

More than 629,000 companies across China have benefited from a total of 3.45 trillion yuan ($489 billion) in R&D expense tax deductions last year, said the country's top tax authority in a recent press conference. Huang Yun, spokesperson of the State Taxation Administration, said that last year, around 405,000 high-tech companies enjoyed R&D tax deductions totalling 2.83 trillion yuan, marking a 15.1 percent year-on-year increase. "On average, the deduction amount per high-tech enterprise was 2.5 times that of non-high-tech companies," he emphasized.

The R&D tax deduction is a preferential tax policy that allows companies to save more by way of a certain percentage of their R&D expenditure. Huang said that such a policy also effectively supported private enterprises in their innovation endeavors. Last year, private companies benefited from a total of 2.59 trillion yuan from deductions, up 12.5 percent year-on-year. It also accounted for 75 percent of all enterprise tax deductions during the period, he said.

According to Huang Yun, the spokesperson and director of the General Office of the State Taxation Administration, data from the 2023 annual corporate income tax settlement, which concluded in the first half of this year, revealed that approximately 629,000 enterprises across China benefited from R&D expense deductions totalling 3.45 trillion yuan. This policy has injected significant momentum into accelerating the development of new productivity.

On one hand, the policy strongly supported the innovation and development of high-tech enterprises. In 2023, around 405,000 high-tech companies enjoyed R&D tax deductions amounting to 2.83 trillion yuan, marking a 15.1 percent year-on-year increase. On average, the deduction amount per high-tech enterprise was 2.5 times that of non-high-tech companies. On the other hand, the policy also effectively supported private enterprises in their innovation endeavors, with private companies benefiting from deductions totalling 2.59 trillion yuan in 2023, a 12.5 percent increase year-on-year, accounting for 75 percent of all enterprise deductions.

"Moving forward, the tax authorities will fully implement the guiding principles of the 20th Central Committee's Third Plenum, further enhancing R&D expense deductions and other policies that support technological innovation, to fully support the innovative development of various enterprises and better cultivate and expand new productivity," Huang Yun emphasized.

https://www.chinadaily.com.cn

The added value of patent-intensive industries

The added value of China's patent-intensive industries in 2022 reached 15.32 trillion yuan (about 2.15 trillion U.S. dollars), contributing 12.7 percent to its GDP, according to a report released by the country's top intellectual property regulator.

The latest data shows that China's patent-intensive industries exhibit strong innovation capabilities and development potential, supporting the country's commitment to pursuing new quality productive forces and high-quality development, the China Intellectual Property Administration noted in a recent monitoring report. The report highlights that from 2018 to 2022, the added value of China's patent-intensive industries saw an average annual growth rate of 9.36 percent, surpassing the average annual GDP

growth rate by 2.37 percentage points during the same period.

The information and communications technology (ICT) service and ICT manufacturing, as representatives of emerging industries, achieved double-digit growth in added value with annual growth rates of 14.86 percent and 10.23 percent, respectively. Other patent-intensive industries include the manufacturing of new equipment and materials, medicine and the medical industry, as well as the environmental protection industry.

High investment in research and development is an important factor driving growth. According to the report, the internal R&D expenditure for patent-intensive industries in China reached 1.14 trillion yuan in 2022, marking an increase of 11.28 percent compared to the previous year and totaling 2.23 times that of non-patent-intensive industries. In 2022, more than 49 million people were employed in China's patent-intensive industries, accounting for approximately 6.7 percent of overall employment within the entire society.

However, the report noted a gap between China and Western patent-leading countries. It cited the latest report from the United States and Europe, revealing that patent-intensive industries contributed 24 percent to the U.S. GDP, with employment accounting for 13 percent. Additionally, the EU's figures that year stood at 17.4 percent and 11 percent, respectively, "significantly surpassing China's levels."

The patent-intensive industries in China still have immense growth potential, and greater efforts should be made to support the development of these industries, the report said. China has set a target for patent-intensive industries to contribute 13 percent of GDP by 2025.

http://www.china.org.cn

INDIA

Enterprise ICT market

The enterprise information and Communication Technology (ICT) market in India is set to increase at a sound compound annual growth rate (CAGR) of 17.1 percent, increasing from $161.3 billion in 2023 to $354.6 billion in 2028, a report showed. The revenue opportunity is driven by the ongoing digital transformation initiatives taken up by businesses and government, forecasts GlobalData, a leading data and analytics company. This is in line with the positive ICT investment sentiment seen among the enterprises in the country. Among the three IT infrastructure segments — hardware, software, and services — the latter will see the highest cumulative revenue increase over the forecast period.

Revenue growth in the IT services segment will primarily come from the high enterprise adoption of cloud computing services, which is set to see its revenue grow at a CAGR of 25.3 cent percent over the forecast period, the report noted.

The BFSI sector to be the largest end-use vertical segment for the ICT market in India, in terms of revenue contribution, and will remain so over the forecast period. The segment is set to account for an 11.3 percent share of the total cumulative revenue forecasted for 2023-2028.

A recent GlobalData survey revealed that a majority 87.9 percent of respondents, who are key ICT decision makers in their respective enterprises, have confirmed that there has been an increase in their enterprise ICT budgets in 2024 as compared to the previous year. India's ICT market is expected to grow steadily in the coming years, supported by government policies like tax incentives and digital infrastructure improvements, which aim to enhance SME competitiveness, the report noted.

https://www.smetimes.in

INDONESIA

Solar outlook for 2025

The Indonesia Institute for Essential Services Reform (IESR) recently released its "*2025 Indonesia Solar Outlook*" report, revealing that as of August, the country's installed photovoltaic capacity reached 717.71 MW. IESR Executive Director Fabby Tumiwa emphasized that following a downturn in the solar industry over the past two years, Indonesia needs to "catch up" with global solar trends. He further stated that this trend is reversing, and the future of Indonesia's photovoltaic industry looks promising. According to IESR, Indonesia's state electricity company, PLN, plans to increase renewable energy generation by adding 7.9 GW of solar capacity by 2033. Additionally, policy changes from the Ministry of Energy and Mineral Resources are expected to add over 5 GW of rooftop solar capacity within five years.

The report indicates that as of August 2024, there are 16.92 GW of announced solar projects in preparation nationwide, with an anticipated addition of 350 GW to 550 GW of solar capacity by 2050. It also noted that Indonesia's solar-related investments nearly doubled, increasing from $68 million in 2021 to approximately $135 million in 2023. By August 2024, announced solar investments reached around $112 million.

Tumiwa urged the Indonesian government to set more ambitious solar deployment targets, explaining that the current plans' capacity is insufficient to meet the goals of the Paris Agreement. IESR asserts that to achieve these goals, Indonesia needs to add 77 GW of solar generation before 2030, equivalent to an annual increase of 9 GW to 15 GW in photovoltaic capacity.

Tumiwa stated, "The photovoltaic industry indeed faces several intermittent challenges, but limiting development because of these issues is unreasonable. Many countries have solar penetration rates exceeding 10% of total generation capacity without facing power supply issues or blackouts. Intermittency can be addressed by integrating energy storage systems into the grid."

https://www.solarbeglobal.com

MALAYSIA

National cloud policy, AI regulations planned

Malaysia plans to create a national cloud policy and introduce regulations to encourage the ethical use of artificial intelligence (AI), Prime Minister Anwar Ibrahim said. The announcement

comes amid a wave of investments by global tech firms in Malaysia over the past year, as they seek to build critical infrastructure to cater to growing demand for their cloud and AI services.

Anwar said Malaysia's national cloud policy will focus on four core areas, namely public service innovation and efficiency, economic competitiveness, and growth, strengthening user trust and data security, and empowering citizens through digital inclusivity. The government would also set up a national AI office to coordinate initiatives, including completing a five-year technology action plan as well as a regulatory framework to increase the adoption of ethical and sustainable AI within the next 12 months, he said.

"We aim to position Malaysia as a hub for generative artificial intelligence and investments from tech partners will be critical in building a robust and secure digital infrastructure," Anwar said at a ground-breaking ceremony for Google's (GOOGL.O), opens new tab new $2 billion data centre and cloud region in the country.

Google, which announced a multi-year partnership with a local tech firm to provide sovereign cloud services, said its investments in Malaysia would create 26,500 jobs and contribute more than $3 billion to its economy by 2030.

Digital investments have helped propel Malaysia's economy this year, with growth beating market expectations in the last two quarters and the ringgit currency becoming one of Asia's top performers. Google's moves are a part of a wider expansion by global tech companies into Southeast Asia, as they vie for a greater presence in a region with a young tech-savvy population of 670 million.

https://www.reuters.com

PHILIPPINES

Strategic IP development initiative

The Intellectual Property Office of the Philippines (IPOPHL) has launched its Intellectual Property Regional Development Plan (IPRDP) for the Cagayan Valley, a strategic initiative aimed at positioning the region as a pivotal East Asian gateway for investment. This ambitious plan has garnered support from stakeholders, including various regional government agencies, the private sector, and educational institutions.

From the regional government, the new partners to the IPRDP include the Commission of Higher Education (CHED), Department of Agriculture (DA), Department of Education (DepEd), Department of the Interior and Local Government (DILG), Department of Science and Technology (DOST), Department of Trade and Industry (DTI) and the National Economic and Development Authority (Neda).

From the private sector, the Philippine Chamber of Commerce and Industry (PCCI) from the region joined hands to support the IPRDP. From academe, the Batanes State College (BSC), Cagayan State University (CSU), Isabela State University (ISU), Nueva Vizcaya State University (NVSU) and Quirino State University (QSU) joined.

On October 9, these partners formalized their commitment by signing a memorandum of understanding (MOU), which outlines their shared vision to create and implement a cohesive framework to safeguard and commercialize intellectual property in the region. Located in the northeastern part of mainland Luzon, Cagayan Valley stands as the second-largest region in the country. In 2023, the Cagayan Valley's economy grew by 6.2 percent to P447.07 billion, making it the seventh fastest-growing economy out of 17 regions in the country.

https://businessmirror.com.ph

Digital payments headway

The Philippines is making significant strides in the digital payment landscape across Southeast Asia as the use of buy now pay later (BNPL) and point-of-sale (POS) among Filipinos showed significant growth, as of July this year, according to financial technology firm UnaCash. Based on the latest report from UnaCash, BNPL adoption in the Philippines has grown over the past few years as the share of users rose to 24.7 percent as of July, expanding by 9.6 times since 2018. This placed the Philippines among the top three countries in Southeast Asia in terms of BNPL adoption. The stable share of users also reflected a strong consumer shift toward flexible payment solutions. UnaCash also recorded a monthly increase of 3.3 percent for BNPL users aged fifteen and above, from September 2018 until July 2024. Erwin Ocampo, head of product for UnaCash, said there is a growing appetite for BNPL services in the Philippines, driven by increased e-commerce and a rising preference for convenient financial options.

Singapore led the region with BNPL users at 75.4 percent as its user base rose by 7.1 times as of July, with a modest average monthly growth rate of 2.8 percent since 2018. Vietnam also saw a penetration rate of 24.9 percent, with a 2.8 percent monthly increase. Other Southeast Asian markets such as Malaysia (10.2 percent), Thailand (six percent), Brunei (4.2 percent), and Cambodia (3.6 percent) had a lower share of BNPL users.

Meanwhile, the Philippines recorded a 33.1 percent share of POS users among adults aged 15 and older as of July. This marks a significant increase from just 3.2 percent in September 2018.

"POS adoption reflects the country's increasing digitalization and the widespread use of mobile payment solutions. The development of self-service kiosks and enhanced e-commerce platforms have further contributed to this significant rise," Ocampo said. A POS is a location or system where a retail transaction occurs. It typically involves the place where a customer makes a payment for goods or services, such as a cash register or a digital system that processes card and mobile payments.

While the Philippines has made impressive gains, Indonesia continues to lead the region with a 67.5 percent share of POS users, driven by the widespread adoption of cloud technologies, thriving e-commerce, and successful integration of digital payments. In contrast, neighboring Southeast Asian countries are still in the earlier stages of POS market development. Vietnam reports a modest 4.5 percent share of POS users, while Malaysia and Singapore lag

further behind with 2.8 percent and 1.6 percent, respectively

https://www.philstar.com

Guidelines to accelerate renewable energy projects

The Philippines' Department of Energy (DOE) has introduced new monitoring protocols and guidelines aimed at accelerating the development of renewable energy projects. These updates will streamline administrative processes, reduce delays, and enhance accountability amongst developers.

In June, the DOE released revised omnibus guidelines for awarding and managing renewable energy contracts. These help identify non-serious developers, allowing legitimate developers to advance projects more effectively. Currently, 105 renewable energy projects are facing termination due to non-compliance with timelines, with most contracts awarded in 2017 and 2019. The primary causes for delays include issues with securing possessory rights and challenges with system impact studies (SIS). Of the stalled projects, 88 are significantly delayed, comprising 53 solar, 17 hydropower, 10 wind, 5 geothermal, and 3 biomass projects.

To combat delays, the department is implementing a contract termination process. Developers of solar energy contracts must complete the pre-development phase within two years. Failure to submit a declaration of completion or demonstrate reasonable efforts will result in a show-cause order, with potential termination recommendations to the Secretary of Energy if reasons for delays are deemed insufficient.

The revised guidelines also require developers to obtain a certificate of authority (COA) before signing contracts. This COA allows developers to secure permits and conduct essential surveys ahead of the official project start, enhancing preparedness and efficiency. Additionally, the guidelines simplify the process for obtaining incentives. Developers can now receive a certificate of registration (COR) after confirming project viability, and for biomass and solar projects, the COR can be obtained upon financing closure. The DOE is also enhancing its Energy Virtual One-Stop Shop (EVOSS) System to streamline permitting processes, aiming to reduce bureaucratic hurdles.

https://www.msn.com

REPUBLIC OF KOREA

Private-led cloud computing industry

The Republic of Korea will expand its private-led cloud computing industry to strengthen its competitiveness in the global artificial intelligence (AI) era, the science ministry said. The Ministry of Science and ICT announced the vision to boost local cloud companies by forming strategic partnerships with global entities, aiming to double the domestic cloud market's size to 10 trillion won (US$7.3 billion) by 2027 from 2022.

The Republic of Korea's cloud technology is more than a year behind global leaders, and AI cloud infrastructure remains underdeveloped, according to the ministry. To better foster the industry, the government plans to devise measures to adopt private cloud systems across education, finance, defense, and other public sectors, including easing network separation regulations and expanding tax benefits for AI and cloud companies. It will also work to develop a homegrown AI chip to be used for data centers and establish a national AI computing center with a capacity of more than 1 Exaflop, which means having a supercomputer that can calculate at least one quintillion floating point operations per second.

An AI innovation fund will also be created to support the transition to a private cloud ecosystem, with the government investing 45 billion won next year while inducing further investment from the private sector. Meanwhile, the country also plans to open an AI safety research institute under the Electronics and Telecommunications Research Institute to support the "safe" development and application of AI technologies and the global expansion of local AI companies, according to the ministry.

The envisioned launch of the institute comes as a follow-up measure to the global AI safety summit held in Seoul earlier this year, where leaders of major countries, including South Korea, Britain, and the United States, adopted a joint declaration on promoting safe, innovative and inclusive AI.

https://www.msn.com

Investment in the semiconductor industry

The Republic of Korean government will inject 8.8 trillion won ($6.45 billion) next year to advance the country's semiconductor ecosystem through low-interest loans while accelerating infrastructure construction and nurturing talent. Finance Minister Choi Sang-mok announced a slew of plans for comprehensive support for the chip industry while presiding over a ministerial meeting Wednesday, with firms in the sector clamoring for more concrete measures to catch up to global rivals. "We will provide solid support to secure global leadership, including providing 8.8 trillion won in support to the semiconductor industry by next year," Choi said.

This is a detailed follow-up to the 26 trillion won package to support the chip industry unveiled by President Yoon Suk Yeol in May, which was mainly designed to provide cheaper borrowing costs with more generous terms than market loans.

According to an announcement, the government will complete the offering of low-interest loans with a total value of 4.7 trillion won next year. In detail, the plan is to invest 250 billion won of capital in the state-run Korea Development Bank next year to secure low-interest loans of 4.25 trillion won. Since the launch of the loan program on July 1, a total of 824.8 billion won in facility investment funds has been loaned to 17 semiconductor companies, according to the Finance Ministry. Interest rates on borrowings will be further trimmed. The KDB has been providing rates 1.4 percentage points lower than its typical loan products.

Ministers decided to create a new semiconductor ecosystem fund of up to 800 billion won by 2027 and consider further expansion depending on future corporate demand. The government plans to

raise 420 billion won by creating a new fund of 120 billion won through an investment of 30 billion won next year.

The first company to benefit from the fund was CoAsia SEMI, a foundry design service provider that secured 20 billion won in investment to recruit more workers and expand overseas sales. Efforts to offer tax breaks to chipmakers and other firms in the sector will be continued.

In the 2024 tax revision bill drawn up by the government in July, it was proposed to extend the applicable period for research and development tax credits and integrated investment tax credits for national strategic technologies, including chipmaking, by 3 years until the end of 2027.

The government will support the tax code amendment bill to clear the last parliamentary hurdle and revise the ordinance and rules in March next year, including expanding the scope of application of tax credits for national strategic technologies and R&D. Some 2.4 trillion won will be allocated to build the infrastructure needed for an envisioned semiconductor cluster in Yongin, Gyeonggi Province. Preparations for constructing a highway that will pass through the Yongin Cluster, which will be built on a site of 4.15 million square meters, are underway to open the roads in 2030. Regarding power supply, detailed measures for power supply and cost-sharing will be prepared within the year amid growing concerns that Korean chipmakers face power shortages.

In the Yongin semiconductor cluster, 16 semiconductor production facilities, led by Samsung Electronics and SK hynix, will be built by 2047. Although a vast amount of electricity must be provided, detailed measures for cluster operation for mid-to long-term electricity supply have not yet been prepared.

https://www.koreaherald.com

Companies monetizing patents

In recent years, the Republic of Korean conglomerates have conducted several noteworthy transactions in monetizing their intellectual property (IP), including patents, according to Burford Capital, a global legal finance firm based in London. Their reasons may vary, it said, from reducing the financial burden of holding IP to gaining leverage in business negotiations. But regardless of the intention, monetizing patents has helped them unlock financial liquidity.

The Korea Times exclusively secured a report, on Wednesday, co-authored by Katharine Wolanyk, managing director at Burford Capital, and Chris Freeman, director with responsibility for assessing and underwriting legal risk at its patent group. It is set to be published in Burford Quarterly on Thursday (Korea time). The authors pointed out that already in 2024, there have been sizeable patent transactions involving sophisticated IP owners, including SK hynix. This year, the semiconductor giant sold over 1,500 patents to an affiliate of Korean patent aggregator Ideahub.

In November 2023, LG Electronics sold 48 standard essential patents related to codec technology to Chinese smartphone maker Oppo. The company no longer needed some of these patents after exiting the smartphone market in 2021. "This sale is part of LG's strategy to profit from its extensive portfolio of around 24,000 patents, particularly in 4G, 5G, and Wi-Fi technologies, as other Chinese smartphone makers like Oppo and Vivo have faced litigation over patent deficiencies," the report wrote.

LG Energy Solutions, another LG Group subsidiary, has announced that it "will spearhead efforts to create a patent licensing pool for electric vehicle batteries, an area where it has a world-leading patent portfolio." Samsung has also emerged as a key player in the IP landscape, leveraging its extensive patent portfolio for innovations in telecommunications, consumer electronics, and semiconductors.

"In 2023, Samsung entered multiple licensing agreements that generated immediate revenue and established long-term partnerships with other tech giants. These efforts highlight Samsung's strategic focus on robust IP management as a driver of profitability and innovation," the report said. These moves suggest Korean companies' growing recognition of patents as valuable financial assets, though the reasons behind monetization decisions vary by company, according to the report.

One reason is that owning IP is costly by itself. The R&D investment to develop technologies can run into millions of dollars or more, followed by significant legal expenses to obtain and maintain the related patent assets. Also, by affirmatively recovering money from their legal assets, companies can benefit from new revenue sources to supplement declining sales or shrinking profit margins. This reason particularly applies to companies that are long-established or operate in highly competitive industries. In other cases, companies like LG Electronics have exited a line of business and no longer see the need to retain IP that is no longer core to their operations. IP can also be leveraged to advance corporate objectives, such as gaining an advantage in business negotiations.

"In an uncertain economy, companies will need to be careful in their capital management and innovative in their pursuit of value. For many patent owners, financed divestitures may be the optimal solution. For little to no risk, with minimal operational burden, companies can reduce costs and generate new revenues by leveraging their IP assets," it said.

https://www.koreatimes.co.kr

VIET NAM

National blockchain strategy

The Ministry of Information and Communications (MIC) announced the strategy on October 23, outlining several key objectives to develop the country's blockchain capabilities. It aims to develop blockchain technology, establish relevant legal frameworks, and promote innovation in what it calls "the Fourth Industrial Revolution."

The strategy outlines five key areas, overseen by government agencies, including the MIC and the Vietnam Blockchain Association.

According to the official announcement, the five proposed actions include:

"(1) Perfecting the legal environment; (2) Developing infrastructure, forming

a blockchain industrial ecosystem; (3) Developing human resources for the Blockchain field; (4) Promoting Blockchain development and application; (5) Promoting research, innovation, and international cooperation."

Developing Viet Nam's blockchain ecosystem is a central goal of the strategy. The government plans to build 20 blockchain brands for platforms, products, and services. Additionally, the National Blockchain Strategy aims to also establish at least three testing centers in major cities to create a national blockchain network. These centers will play a crucial role in developing and deploying blockchain applications, ensuring security, and promoting innovation in the industry.

An important factor raised in the strategy announcement is the legal recognition of digital assets, as the country aims to formalize regulation around them: "The legalization of the definition of Digital Assets is one of the actions to realize the Vietnamese Government's commitment to preventing and combating money laundering, terrorist financing, and financing of proliferation of weapons of mass destruction." By aligning with international standards and recognizing digital assets as protected under civil law, Viet Nam is setting ambitious targets to strengthen its blockchain industry.

https://www.msn.com

Excess rooftop solar power to the national grid

Viet Nam has issued a new decree that allows excess rooftop solar power to be sold at up to 20 cent percent of the installed capacity to the state-owned utility Vietnam Electricity (EVN). The new rule is to promote the development of self-produced and self-consumed solar energy in the Southeast Asian country, which aims to cover half of government and residential buildings with this renewable energy source by 2030. However, despite Viet Nam's rooftop solar energy potential of 963 gigawatts (GW), such installations have barely increased since 2021 due to the lack of government incentives after the expiration of a feed-in tariff scheme.

"The 20 percent offtake will shorten the payback period for investors and accelerate self-use rooftop solar power installations at a moderate level while avoiding policy abuse and overdevelopment," said Do Quang Thinh, chief executive of The Sunergy, a Viet Nam-based energy consultancy.

Under the latest mechanism, the electricity purchase price will be set at the average market electricity price from the preceding year, as announced by the power system operator and the electricity market. Self-use rooftop solar power not connected to the national grid or with a capacity of than 100 kilowatts (kW) can be developed without limit and exempted from the need for electricity operation licenses.

Meanwhile, self-use systems with an installed capacity of 1,000 kW or more and which sell surplus electricity to the national power system must comply with registration requirements and the approved power planning, which stipulates that the total capacity increase of this source can be no more than 2,600 megawatts by 2030.

According to EVN, as at end-2023, over 103,000 rooftop solar projects with a combined installed capacity of more than 9.5 GW had entered power purchase contracts with the state-owned utility. Last year, the amount of this energy fed into the national grid – mainly in southern and central regions of Viet Nam – accounted for less than 4 cent percent of the country's total electricity output.

https://www.businesstimes.com.sg

ASIA-PACIFIC

BANGLADESH

Innovative climate smart mapping tool

As a part of the CGIAR research initiative on Asian Mega Delta, the International Rice Research Institute (IRRI), in collaboration with the Center for Environmental and Geographic Information Services (CEGIS) officially launched the Climate-Smart Mapping and Adaptation Planning (CS-MAP). The initiative was launched to enhance food security and climate resilience by empowering stakeholders with actionable insights and location-specific solutions.

This innovative tool integrates scientific research and local expertise to map climate risks, offering tailored adaptation strategies for sustainable farming to address the growing challenges climate change poses to agriculture in Bangladesh's coastal regions. Bangladesh, the seventh most risk-prone country for extreme climatic disasters in the world, faces the growing challenges of climate change. The risks associated with climate change include floods, droughts, salinity, rising sea levels, extreme temperatures, erratic rainfall, and cyclones. These challenges threaten agricultural production, food security, and rural livelihoods.

With changing weather patterns, field-level government officials must implement appropriate agricultural preparations and responsive actions. CS MAP can help them make appropriate and informed decisions. CS-MAP is a participatory mapping approach that has been implemented in 10 districts in the coastal area of Bangladesh, reads a press release.

Working with scientists and experts from BWDB, BRRI, BARI, DAE, and BADC, climate change-related risks in agriculture were identified by assessing the agricultural climate change risks in each area, the extent of each risk was determined, and these risks were mapped into an atlas. During the event launch, these atlases were formally handed over to 10 deputy directors of the Department of Agricultural Extension (DAE). The launch event featured informative presentations on the CS-MAP approach, potential applications, and a video demonstration. Approximately 75 key government officials, researchers, and stakeholders attended the initiative's launch, gaining valuable insights into the innovative tools and strategies developed under the CS-MAP initiative.

https://www.dhakatribune.com

CHINA

Next-generation radiative cooling technology

City University of Hong Kong (CityUHK) researchers have made a scientific breakthrough in developing next-generation passive radiative cooling technology. Their pioneering work on cooling ceramics, pavements, and textiles helps mitigate heat impacts without additional energy consumption. This innovation has promising application potential in buildings, roads, and clothing, addressing issues such as urban heat islands and greenhouse gas emissions to combat the challenges of climate change.

The team established the start-up i2Cool in 2021 under the incubation of CityUHK's HK Tech 300 programme and developed a cooling paint for roofs and walls. The recent approval of funding from the Hong Kong government's "Research, Academic and Industry Sectors One-plus Scheme" (RAISe+ Scheme) marks a significant step forward in accelerating the commercialisation and application of this groundbreaking innovation. The CityUHK team plans to establish manufacturing facilities and production lines by the end of 2026.

Space cooling energy consumption has more than tripled since 1990, resulting in a strain on electricity grids, increased greenhouse gas emissions, and the prevalence of urban heat islands. Extreme heat events and record-high temperatures worldwide have left many people around the world vulnerable to heat stress, adversely affecting thermal comfort, labour productivity, and even human health.

To address these challenges, a research team led by Professor Edwin Tso Chi-yan, from CityUHK's School of Energy and Environment, has been focusing on developing passive radiative cooling (PRC) technology. "PRC technology is a universal solution to global warming, as it leverages high solar reflectivity and high mid-infrared emissivity to cool surfaces naturally by reflecting incoming sunlight and emitting thermal radiation to the cold universe, potentially reducing the surface temperature by at least 2°C," explained Professor Tso. "This technology offers an electricity- and refrigerant-free cooling solution, mitigating the heat impact without additional energy consumption."

https://www.cityu.edu.hk

INDIA

Resilient, cost-efficient semiconductors

Researchers from IIT Guwahati, along with IIT Mandi and the Institute of Sensor and Actuator Systems at Technical University Wien have developed a breakthrough technique for growing ultra-wide bandgap semiconductors, IIT Guwahati has said. Named gallium oxide, this semiconductor has the potential to significantly improve the efficiency of power electronics used in high-power applications.

The main advantage of this new technology is that it can withstand extreme

temperatures as high as 200 degrees Celsius. This is ideal for high-power electronics, which are used in a variety of areas such as electric vehicles, high-voltage transmission, traction, and industrial automation.

Power semiconductor devices are the heart of every power electronic system. They are responsible for switching on and off the main supply voltage, and this can cause significant losses in terms of efficiency. There is a considerable amount of research into improving the efficiency of power electronic systems by using materials like Gallium Nitride (GaN) and Silicon Carbide (SiC). However, these materials have some limitations, such as high cost.

The new research team has successfully developed superior-quality ultra-wide bandgap compound semiconductors by incorporating gallium oxide with tin. This has improved the conductivity and thermal performance of the material, making it ideal for use in high-power applications.

The findings of the study have been published in multiple research papers in the *Journal of IEEE Transactions on Electron Devices and Thin Solid Films*. The researchers hope that this breakthrough technology will pave the way for the development of more efficient and sustainable power electronics that can support a range of high-power applications.

https://www.msn.com

JAPAN

Turning carbon dioxide into a green fuel

Researchers from Tokyo Metropolitan University have made strides forward in realizing the industrial conversion of bicarbonate solution made from captured carbon to a formate solution, a green fuel. Their new electrochemical cell, with a porous membrane layer in between the electrodes, overcomes major issues suffered in reactive carbon capture (RCC) and achieves performances rivaling energy-hungry gas-fed methods. Processes like theirs directly add value to waste streams and are key to realizing net zero emissions.

Carbon capture technology is a big part of the global strategy to reduce emissions and fight climate change. But the important question of what we do with the captured carbon dioxide remains an open challenge. Do we simply push it underground, or is there more to it? Scientists certainly think so. Using state-of-the-art catalysts and chemical processes, work is underway to try and convert the captured product into something more useful for society.

One particularly enticing application is the conversion of carbon dioxide into an environmentally friendly fuel. Technology has been developed for using electrochemical cells to reduce the carbon dioxide to a formate compound, which itself can be used in formate fuel cells to generate power. However, a significant roadblock is the need for pure carbon dioxide: pressurizing carbon dioxide can be highly energy-intensive. The gas is not converted very efficiently, and the cells do not last very long. Enter reactive carbon capture, where carbon dioxide dissolved in alkaline solutions, like bicarbonate solutions, can be directly used to create formate ions without the losses associated with providing pure gas. The key challenge facing researchers here is the design of a better electrochemical cell that can selectively produce formate ions from bicarbonate ions without losing out to side reactions, like the production of hydrogen.

Now, a team of researchers led by Professor Fumiaki Amano from Tokyo Metropolitan University has created a new cell with excellent selectivity for the conversion of bicarbonate ions into formate ions. In the new cell, electrodes made of catalytic material are separated from a polymer electrolyte membrane by a porous membrane made of cellulose ester. Hydrogen ions produced at one electrode pass through the electrolyte membrane and make it to the porous layer, where they react with bicarbonate ions to efficiently produce carbon dioxide in the pores. The gas is then converted to formate ions at the other electrode, also in contact with the porous membrane. When they put their cell to work, they found that the faradaic efficiency of their cell, the proportion of electrons converted to formate instead of other compounds, was 85%, even with very high currents. Not only does this outperform existing designs, but the cell was found to operate smoothly for over 30 hours and realize nearly complete conversion of bicarbonate to formate. Once the water has been driven off, all that is left is solid, crystalline formate fuel.

https://www.eurekalert.org

EUROPE

GERMANY

Laser technology for accurate climate monitoring

According to a study published in APL Photonics, scientists at the Max Planck Institute for the Science of Light (MPL) have developed an enhanced laser technology designed to accurately detect and monitor climate pollutants in the atmosphere. A high-power ytterbium thin-disk laser powers an optical parametric oscillator (OPO), which generates steady, high-power pulses in the short-wave infrared (SWIR) spectral band. This enables researchers to detect and analyze a wide range of atmospheric compounds. This innovative technology plays a crucial role in tracking greenhouse gas cycles and understanding the impacts of climate change.

Short-lived pollutants have a notable impact on global warming. Methane, for instance, is especially relevant to the greenhouse effect, as its warming potential is 25 times greater than that of carbon dioxide. However, detecting and monitoring these pollutants is challenging for two main reasons.

Firstly, the absorption spectra of many gases in the conventional infrared wavelengths often used for detection overlap and are interfered with by water vapor. Secondly, because these pollutants are volatile in the atmosphere, they are difficult to trace. The new laser technology overcomes these challenges by focusing on the SWIR band, where pollutants like methane absorb strongly, but water vapor has minimal absorption.

The ytterbium thin-disk laser, which generates high-power, femtosecond pulses at megahertz repetition rates, is central to this breakthrough. This enables the laser to pump an OPO, which transforms pulses into the SWIR region with exceptional intensity and power. The OPO produces steady, adjustable SWIR pulses that are ideal for high-sensitivity spectroscopic applications while operating at twice the repetition rate of the pump laser. Furthermore, the team's innovative approach incorporates broadband, high-frequency modulation of the OPO output, enhancing the signal-to-noise ratio and enabling even more precise detection.

Field-resolved spectroscopy and femtosecond fieldoscopy, techniques that enable researchers to detect and study a wide range of atmospheric compounds with minimal interference, are enhanced by the laser's ability to produce high-power, steady pulses in the SWIR band.

https://www.azooptics.com

Method to boost zinc battery lifespan, energy storage

Researchers at the Technical University of Munich (TUM) have developed a groundbreaking method that significantly extends the lifespan of zinc-ion batteries, potentially enabling them to endure several hundred thousand charge cycles. This advancement, achieved through a specialized protective layer for the zinc anodes, prevents common issues such as zinc dendrite formation, hydrogen generation, and corrosion, which have previously limited battery durability. The protective layer, a porous organic polymer called TpBD-2F, forms a stable, ultra-thin film on the anode, allowing efficient ion flow while keeping water away from the zinc surface.

Lead researcher Da Lei, suggests this innovation positions zinc-ion batteries as a viable, cost-effective, and sustainable alternative to lithium-ion batteries for large-scale energy storage applications tied to renewable sources like solar and wind power. Prof. Roland A. Fischer emphasized the research's scientific impact, noting, "This chemical approach has proven controllable and effective. We believe it has immense potential for scaling up beyond the lab."

This development builds on interdisciplinary work by TUM researchers in chemistry, physics, nanotechnology, and data science, supported by the e-conversion Excellence Cluster. The research, published in Advanced Energy Materials, opens new pathways for engineers to advance production processes for zinc-ion batteries.

https://news.europawire.eu

NORWAY

Large-scale carbon storage

SINTEF researchers are applying methodologies used to transport oil and gas in their efforts to upscale a technology for carbon capture and storage. This is good news for the climate. It now seems that crucial research, conducted by SINTEF and targeted at the oil and gas sector, can also be applied in the battle to mitigate climate change.

The simulation model called LedaFlow has made it possible for us to understand how we can transport both oil and gas along the same pipeline. This multiphase flow technology has helped the Norwegian oil and gas sector save billions, and the model is now about to be further developed so that we can investigate how CO2 behaves in similar pipelines.

Technologies involving the capture and storage of CO2 (abbreviated to CCS) are crucial to the reduction of greenhouse gas emissions to the atmosphere. In the future, we must learn how to handle and store large volumes of CO2. We must therefore also find out the best ways of transporting the gas and injecting it into huge subsurface reservoirs.

Here in Norway, a great deal of effort is being put into the industrial-scale application of CCS technologies in the oil and gas sector. Among other initiatives, leading sector companies have been utilising the Northern Lights project with the aim of sequestering up to 1.5 million tonnes of CO2 in subsea reservoirs during 2024 and a total of five million tonnes by 2026.

At present, there are only very few CO2 storage projects in operation in Norway, and all are based on the injection of gas derived from a single source and using a single well. The Northern Lights project is aiming to store CO2 at a much larger scale, involving more complex operations by which gas from multiple sources will be transported and injected using a network of different wells. The CO2 will be captured from processes such as waste incineration and cement manufacture. This innovation research project has been given the name CO2Flow.

"The project will directly apply the expertise we have accumulated in the field of flow behaviour modelling at the SINTEF Multiphase Flow Laboratory at Tiller outside Trondheim. It will also utilise the knowledge obtained from the oil and gas sector during the development of the LedaFlow model", says SINTEF researcher Ivar Eskerud Smith.

The use of innovative experiments, combined with the development of new data models, will make it possible to predict CO2 flow behaviour in pipelines. This in turn will enable us to achieve large-scale CCS for application in the oil and gas sector. Results from the data models will help to optimise pipeline design, in particular with a view to the selection of important aspects such as materials and pipe diameter. The results will also contribute towards cost-effective and safe pipeline operation – preventing unwanted occurrences such as unstable flow or low temperatures with the consequent formation of dry ice, which may block the pipelines.

For the most part, the development of the new data models will be carried out at the SINTEF Multiphase Flow Laboratory at Tiller. Additional experiments will be conducted at NTNU's DeFACTO underground testing facility at Gløshaugen in Trondheim. Testing, quality assurance, and commercialisation activities will take place at the offices of the LedaFlow model development partner Kongsberg Digital.

https://www.sintef.no

NORTH AMERICA

USA

Ultra-clean combustion of biofuels

Researchers in the US have developed a method for the efficient combustion of biofuels using a Swirl Burst injector to burn glycerol/methanol blends with near-zero emissions. Detailed in Fuel, the Swirl Burst (SB) injector at Baylor University's Cornerstone Atomization and Combustion Lab (CAC) is claimed to enable ultra-clean combustion for fuels that are typically difficult to burn due to their high viscosity.

According to the Texan University, conventional injectors struggle to burn glycerol – an abundant byproduct of biodiesel production – due to its high viscosity, though it has moderate energy density. In contrast, the SB injector's ability to handle glycerol without requiring costly fuel preheating or processing could transform biofuel economics. The process allows the SB injector to achieve a complete and clean burn by producing fine droplets, significantly reducing emissions of harmful pollutants like carbon monoxide (CO) and nitrogen oxides (NOx).

Lead author Lulin Jiang, Ph.D., principal investigator of the CAC Lab, said this novel technology also enables biodiesel producers to convert glycerol waste into a viable fuel source, promoting a circular economy and reducing the carbon footprint for generating power.

According to the university, the SB injector's flexibility allows the combustion of various glycerol/methanol ratios without hardware modifications, making it ideal for power plants aiming to meet emissions regulations. "Being able to transform waste, such as waste glycerol, into cost-effective renewable energy promotes energy resilience and energy equity for economically disadvantaged groups in a changing climate," Jiang said in a statement.

The research team tested three different fuel blends – 50/50, 60/40, and 70/30 glycerol to methanol ratios by theoretical heat release rate – at multiple atomising air-to-liquid mass ratios (ALR). All blends are said to achieve over 90 percent combustion efficiency including complete combustion by the 50/50 blend, with near-zero CO and NOx emissions, even in non-preheated, uninsulated combustion setups. This is claimed to be a significant improvement over conventional air-blast or pressure-swirl injectors, which often generate high emissions with high-viscosity fuels.

"The demonstrated high viscosity tolerance and fuel flexibility of the technology signifies that not only waste glycerol, but also the viscous source oils of biodiesel, and other waste-based bio-oils can be directly utilised for energy generation without further processing, significantly reducing biofuel cost and thus potentially stimulating its broad application," said Jiang.

https://www.theengineer.co.uk

Reactor for direct air capture

Rice University researchers have developed an electrochemical reactor that has the potential to drastically reduce energy consumption for direct air capture, the removal of carbon dioxide directly from the atmosphere. The new reactor design could be a part of the solution to the pressing problem of emission impacts on the climate and biosphere by enabling more agile and scalable carbon dioxide mitigation strategies.

A study in *Nature Energy* describes the specialized reactor as having a modular, three-chambered structure with a carefully engineered porous solid electrolyte layer at its core. Haotian Wang, a Rice chemical and biomolecular engineer whose lab has been researching industrial decarbonization and energy conversion and storage solutions, said the work "represents a big milestone in carbon capture from the atmosphere."

"Our research findings present an opportunity to make carbon capture more cost-effective and practically viable across a wide range of industries," said Wang, the corresponding author of the study and associate professor of chemical and biomolecular engineering.

The device has achieved industrially relevant rates of carbon dioxide regeneration from carbon-containing solutions. Its performance metrics, including its long-term stability and adaptability to different cathode and anode reactions, showcase its potential for wide-scale industrial use.

"One of the major draws of this technology is its flexibility," said Wang, explaining that it works with different chemistries and can be used to cogenerate hydrogen. "Hydrogen co-production during direct air capture could translate into dramatically lower capital and operation costs for downstream manufacturing of net-zero fuels or chemicals."

The new technology offers an alternative to the use of high temperatures in direct air capture processes, which often involve running a mixed gas stream through high-pH liquids in order to filter out carbon dioxide, an acidic gas. This first step of the process ties up the carbon and oxygen atoms in the gas molecules to other compounds in the liquid, forming new bonds of varying degrees of strength depending on the type of chemical used to trap the carbon dioxide. The next major step in the process involves retrieving the carbon dioxide from these solutions, which can be done using either heat, chemical reactions, or electrochemical processes.

Zhiwei Fang, a Rice postdoctoral researcher who is a study co-first author, said conventional direct air capture technologies tend to use high-temperature processes to regenerate carbon dioxide from sorbent, or the carbon dioxide-filtering agent. "Our work focused on using electrical energy instead of thermal energy to regenerate carbon dioxide," Fang said, adding that the approach has several additional benefits, including it works at room temperature, needs no additional chemicals, and generates no unwanted byproducts.

The types of chemicals used to trap carbon dioxide have different drawbacks and advantages. Amine-based sorbents are the most widely used, in part because they tend to form weaker bonds which means less energy is required to take the carbon dioxide back out of the solution. However, they are highly toxic and unstable. Even

though basic water-based solutions using sorbents like sodium hydroxide and potassium hydroxide are a greener alternative, they require much higher temperatures to release the carbon dioxide back out.

"Our reactor can efficiently split carbonate and bicarbonate solutions, producing alkaline absorbent in one chamber and high-purity carbon dioxide in a separate chamber," said Wang. "Our innovative approach optimizes electrical inputs to efficiently control ion movement and mass transfer, reducing energy barriers," Wang said he hopes the research will motivate more industries to pursue sustainable processes and fuel the momentum toward a net-zero future. He added that this and other projects in his lab over the years reflect Rice's strategic focus on sustainable energy innovation.

https://www.sciencedaily.com

Technique to help build mangrove resilience

To help combat the loss of these vital ecosystems, researchers from UConn's Global Environmental Remote Sensing (GERS) lab are working to comprehensively monitor the health of mangroves. Their recent study published in Remote Sensing of Environment focuses on mangroves in Florida to see which areas cope with increasingly intense and frequent hurricanes and which mangroves may be at greater risk of being wiped out completely.

Lead author and Postdoctoral Researcher Xiucheng Yang says that thanks to remote sensing technology, decades of mangrove images are available, including images taken after disturbances like hurricanes. "After the disturbance, we can continuously track mangrove conditions, to see what happens due to extreme weather events and the ongoing recovery process of the damaged mangrove," says Yang. "We wondered if we could use this data to predict which mangroves could recover or not."

To see if this was possible, Yang and the GERS team paired a dense Landsat time series with a disturbance detection algorithm they developed previously called DEtection and Characterization Of the tiDal wEtland change (DECODE). They went a step further and included the element of Recovery and Resilience to automatically monitor mangrove conditions, in a method called DECODER.

The study focused on Florida since those coastlines are home to an estimated 96% of mangroves in the United States. Florida's mangroves are also under growing pressure, with increasingly frequent and powerful hurricanes. Using this method, the researchers mapped mangrove conditions and tracked the trajectories of recovery between the years 2000 to 2022 with an overall accuracy of over 97%.

Department of Natural Resources and the Environment Associate Professor and GERS Lab Director Zhe Zhu explains that monitoring recovery is an important element, as some mangroves recover naturally from disturbances while others decline, and some decline worse than others. By tracking the conditions over time using DECODER, the researchers hope to predict which areas are at greatest risk, to help pinpoint mangroves in need of intervention.

"We can provide critical information to identify hotspots for recovery and restoration efforts," says Yang. "Previously, researchers could only produce a binary map showing mangroves as present or absent. Our dense time series approach goes beyond simple distribution, offering insights into the dynamic health conditions of mangroves, especially their recovery processes following extreme weather events. This capability is unique."

Yang explains that their method differentiates mangrove responses to disturbance, categorizing them as healthy, disturbed, recovering, or declining. "High severity doesn't necessarily mean that a mangrove's recovery ability is compromised. Some highly affected areas can still recover naturally, while others may struggle. That's why we not only assess the immediate severity of events but also estimate the potential and pace of recovery," Yang adds. "For some areas, we indicate that without human intervention, mangroves may either never recover or recover very slowly."

This data is important because it can be used to direct restoration efforts to the areas that need it most. Zhu says that another important question they hope to address is how resilient mangroves are. This use of technology is an example of how humans can work with nature to build resilience in the face of climate change. The GERS lab has plans to apply the DECODER method broadly to aid in mangrove mapping and restoration efforts globally.

https://www.msn.com

AI creates accurate satellite images of flooding

Researchers at MIT have combined climate models with generative AI to create accurate satellite image predictions of areas impacted by flooding. Known as the 'Earth Intelligence Engine', the tool was developed as a visualisation aid to inform the public of the potential effects of impending storms. The MIT team has made the tool available online so that people can see its results in action. The work is published in the journal IEEE Transactions on Geoscience and Remote Sensing.

"The idea is: One day, we could use this before a hurricane, where it provides an additional visualisation layer for the public," said research lead Björn Lütjens, a postdoc in MIT's Department of Earth, Atmospheric and Planetary Sciences. "One of the biggest challenges is encouraging people to evacuate when they are at risk. Maybe this could be another visualisation to help increase that readiness."

Initially, the researchers used AI on its own to create the synthetic images. They applied a generative adversarial network (GAN), a type of machine learning method that can generate realistic images using two competing neural networks. While this model produced realistic images, it also generated 'hallucination' floods at locations where flooding was not currently possible.

"Hallucinations can mislead viewers," said Lütjens. "We were thinking: How can we use these generative AI models in a climate-impact setting, where having trusted data sources is so important?" To overcome this issue, Lütjens

and his colleagues reinforced the AI with segmentation maps of physics-based models that incorporate real, physical parameters such as an approaching hurricane's trajectory, storm surge, and flood patterns. The team was able to demonstrate that the physics-conditioned model outperformed the pure generative AI model.

"We show a tangible way to combine machine learning with physics for a use case that's risk-sensitive, which requires us to analyse the complexity of Earth's systems and project future actions and possible scenarios to keep people out of harm's way," said study co-author Dava Newman, Professor of AeroAstro and director of the MIT Media Lab.

https://www.theengineer.co.uk

Climate resilient infrastructure in the APAC region

Technologies, cases of their implementation, and the opportunities for SMEs

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Abstract

The Asia-Pacific (APAC) region accounts for the largest share of global greenhouse gas emissions while facing the most severe consequences of climate change compared to other world regions. Physical assets and infrastructure are projected to be severely damaged resulting in substantial economic losses. In most countries, adaptation and resilience plans receive less attention than mitigation actions. At the same time, several well-developed actioninitiatives and corresponding technologies may enhance the resilience of industry, transport, and energy infrastructure to facilitate disaster risk preparedness. These include predicting weather phenomena, increasing infrastructure resistance to heat and floods, and adopting new transport and building codes and standards, among others. There are successful cases in the APAC region that can serve as best practices. Small and medium enterprises (SMEs) can benefit from these initiatives and technologies by engaging in sustainable value chains, adopting green business models, and entering new markets with low environmental footprint.

Introduction

Over the next 20 years, the global impacts of climate change are forecasted to increase the cost of climate-related disasters to USD2.7 trillion, while the cost of resilient infrastructure is estimated at 3 percent of that amount (UNFCCC, 2021). The Asia-Pacific region (APAC) makes the highest contribution to climate change, accounting for the largest share of global greenhouse gas emissions and about half of the world's energy demand (Proskuryakova, 2023a). At the same time, the region experiences the highest impact from climate change with an average of six natural disasters per year, which is two to three times higher than in other world regions. By 2050, physical assets and infrastructure are projected to be severely damaged due to climate change. For instance, two-thirds of the global USD1.6 trillion losses associated with riverine flooding will occur in Asia (McKinsey, 2020). In 2002 alone in APAC extreme weather phenomena caused USD57 billion of economic losses affecting over 64 million people including 7,500 deaths. Other negative consequences include declining biodiversity, rising sea levels, and climate migration (UNDP, 2023).

All responses to changes that cannot be averted may be grouped into climate adaptation and climate resilience measures. Planning and implementation of these measures are coordinated by national governments that, in line with the Paris Agreement, are responsible for preparing National Adaptation Plans (NAPs). NAPs aim to magnify the resilience and adaptive capacity of countries and territories and have to be integrated into suitable sectoral and cross-sectoral policies, programmes, and actions. Measures that may be included in NAPs are capacity-building for stakeholders and acquisition of evidence-base for decision-makers, as well as sectoral plans with relevant programmes and policies. Evidence-base is especially important, as it is very difficult to forecast the actual manifestation of climate change (UN, 1992; UNICEF, 2020). The majority of NAPs underline the significance of future exposure and vulnerability trends, but only a few plans offer actual assessments of related risks. Thus, the existing uncertainty may lead to improper response assumptions and actions to address future resilience and adaptation risks (Garschagen et al., 2021).

Once adopted, NAPs need to be monitored, evaluated, and adjusted if necessary. However, governments, especially in the least developed countries, often lack resources and do not track their implementation (Leiter, 2021). NAPs design and implementation process should be participatory and include the most vulnerable groups and individuals. Due to the uncertainty of future changes and the complexity of possible responses, comprehensive full-scale climate change adaptation cannot be achieved in all countries. As adaptation will not be possible for all population groups, flora, and fauna species, some of the inevitable negative consequences will include degradation of ecosystems and biodiversity loss, destruction of infrastructure and homes, negative human development impacts, and submergence of some island states and territories into the sea. These forecasted impacts have to be identified and communicated to people and com-

panies well in advance so that they can increase resilience or adapt to these changes (UN, 1992; UNICEF, 2020).

The key national climate adaptation policy documents are NAPs and Adaptation Communications, and the documents that target mitigation and adaptation at the same time are Action on climate empowerment (ACE) and National Communication and Biannual Update Report. Global reports of the Intergovernmental Panel on Climate Change (IPCC), prepared based on inputs from many national teams, serve as an important information base for national actions (UN, 1992; Proskuryakova, 2024a).

In addition to the comprehensive picture offered by the IPCC, national future-oriented studies are necessary to foresee the projected changes and identify proper responses to mitigate changes and increase resilience. The strategic responses may be grouped into policy, disaster preparedness and emergency response, resilience planning, and risk and vulnerability assessments. . The key research tools in future studies are energy and climate models that offer macroeconomic (global, national, and sectoral), techno-economic (account for technology differences and can assess the appearance of new technologies, but suffer from path-dependency), and hybrid projections. The top-down models allow for long-term projections of energy supply and demand for at levels (Proskuryakova, 2023b).

There are other research approaches to foresee future resilience challenges. Of all approaches to future studies, foresight stands out. It allows for undertaking studies under the conditions of uncertainty that are often attributable to environmental changes and energy markets (Haarhaus, Liening, 2020). In addition, this participatory tool allows for collecting the opinions of a wide variety of stakeholders and experts, shaping the vision of a desirable future, and developing action plans based on research outcomes. Foresight methods allow for placing climate resilience issues in a wider context of natural resources, healthcare, territorial planning and construction, human development, and economic change (Proskuryakova, 2022). This approach is well suited to deal with the complexity that is associated with climate change by offering suitable non-linear approaches, including big data analysis, scenario planning, backcasting, horizon scanning, and various collective intelligence and expert tools (Sytnik, Proskuryakova, 2024).

The literature on technologies for climate-resilient infrastructure in the Asia-Pacific region available up-to-date is very scarce. If some research publications offer approaches to climate mitigation (Le et al. 2017; Zhang, Khan, 2024), very few studies look into solutions that offer increased climate resilience (Uchiyama et al., 2021; Pal et al, 2023). Both groups of studies most often aim at identifying key factors that are positively or negatively associated with climate change or climate mitigation.

Actions and technologies to increase infrastructure resilience

The UN definition of climate resilience contains three independent aspects: (1) resilient people and livelihoods; (2) resilient businesses and economies, and (3) resilient environmental systems (UN, 2020). Improvements in existing and construction of new infrastructure may be an issue in all three domains. Infrastructures and services, according to UNFCCC, cover industry, transport, and energy, and should be climate-smart and resilient (UNFCCC, 2021). Sectors of the economy have different likelihoods of natural hazard risk. Earlier studies indicated that over the past five years, climate-related disasters have had the highest adverse impact on the food and agriculture sector, especially in developing countries (Uchiyama et al., 2021). Other sectors that follow are the water, environmental, health, and industry sectors.

There are several types of interventions to foster climate resilience. The first group includes disaster risk reduction and management measures that may include risk and vulnerability assessments, information disclosure and monitoring, early action, and warning systems. The second group covers disaster risk preparedness measures that focus on climate-proofing infrastructure and services, as well as contingency plans, emergency response, capacity building, and nature-based solutions. The third group focuses on risk transfer and includes social insurance and care, knowledge and best practices sharing, and access to public and private finance (UNFCCC, 2021). Therefore, the technologies for climate-resilient infrastructure are mainly needed to facilitate disaster risk preparedness.

According to the UNFCCC, estimations, technologies, and supportive capacity building for climate-resilience of all critical infrastructure and systems should be provided by 2040 (UNFCCC, 2021). This will require USD97 trillion of total investment in infrastructure, including nature-based solutions. By that time, emergency preparedness, anticipatory action, and response strategies in all countries should include climate risk management actions designed for critical infrastructure (UNFCCC, 2021). Anticipatory measures need to be taken by private and public sector actors and some technologies have already been suggested by experts and international organizations (Table 1).

Each of the APAC sub-regions faces a unique combination of natural disaster risks with significant impacts on the infrastructure planning, maintenance, and operations. In Southeast Asia,

countries are susceptible to frequent and severe floods following heavy rain, typhoons, and tropical storms. Other issues of concern are sea-level rise, salinity of soil, heatwaves, and drought. In South Asia, countries suffer from hydro-meteorological hazards (e.g., floods, glacial melting, and salinity). Pacific countries mainly suffer from floods and sea-level rise. *In Temperate East Asia,* the most frequent disasters are typhoons/storms, floods, heat waves, severe winters, and drought (Basnayake et al., 2021; Uchiyama et al., 2021).

Infrastructure resilience cases in the APAC region

Stakeholder engagement for energy infrastructure resilience in Australia

Energy systems are vulnerable to a wide range of climate change effects, including natural disasters. The

Table 1: Examples of actions and technologies that may be implemented by the private and public sectors to increase infrastructure resilience

AI Typology	Anticipatory actions	Examples of technologies
Private sector	Adapting industrial processes and transport systems to heat	Advanced cooling systems; Capturing and reuse of waste heat
	Changing the architecture of buildings - resilient construction	Green roofs that reduce the amount of wastewater and ambient noise, durable materials, and innovative construction designs
	Assessing hazard risks for capital and operational costs	Drones; Artificial intelligence; Future-oriented studies
	Devising new consumer products	Data-driven, evidence-based asset planning, design and management
	Resource efficient and cleaner manufacturing (limiting additional pressure on already stressed ecosystems or economies, adapting to resource limitations)	Technologies increasing process and resource efficiency: the Internet of Things, digital twins, biodegradable packaging; full or partial recycling of goods and packaging; lean production technologies
Public sector	Predicting weather phenomena, long-term modelling climate of change	Earth observation; Weather warnings, monitoring; surveillance, and risk mapping; Satellite-based remote sensing of meteorology and environmental conditions on the ground; Advanced computing
	Long-term evidence-based policy planning	Future-oriented studies (foresight, modelling)
	Installing early warning systems	Communication and IT Infrastructure; Remote senses
	Establishing new building codes	Requirements to account for current and projected future climate risks (draughts, floods, etc.)
	Establishing new transport infrastructure standards	Risk → assessments → for → all → new roads; Increased use of heat-tolerant streets and protection of landscape at highways; Shifting to the use of rut-resilient asphalt; Increasing → the → drainage capacity standard
	Increasing resource availability /security of supply during emergencies	Reliance on independent (local) water and energy sources Mini and micro smart grids
Public and Private sectors	Increasing infrastructure resistance to heat and floods	Developing → new, → heat-resilient materials (for example for paving roads); Developing new or upgrading the existing infrastructure → for higher maximum temperatures; Solutions for better flood protection

(Source: Composed by the authors based on (Ebinger, Vandycke, 2015; UNIDO, 2015; UNFCCC, 2021; Masterson, 2024; Shobande et al., 2024; WHO, 2024).)

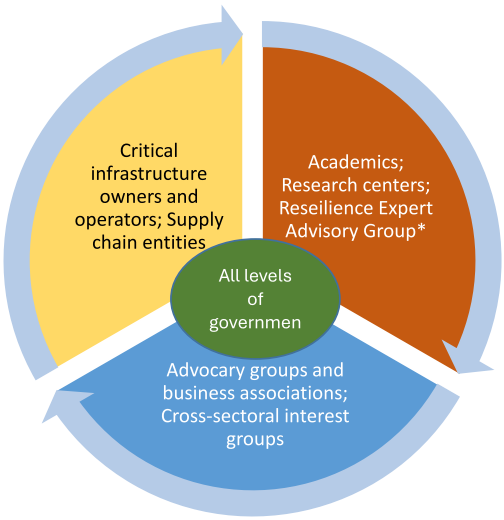

Figure 1: Composition of the Trusted Information Sharing Network

*Notes: * - The Resilience Expert Advisory Group (REAG) was established to support of Australian critical infrastructure owners and operators by providing strategic advice, guidance, and tools to mature security and resilience approaches. It consists of the national government and company representatives, and experts.*

(Source: Composed by the author)

impacts on one element of an energy system can potentially affect other elements of the system or the interconnected energy systems from other regions. In addition, energy systems interact and depend on water and transport systems and infrastructures.

The Australian Government implements activities to enhance the resilience of energy sector infrastructure and facilities to all types of hazards, including natural disasters, as well as other human and environmental threats. The Department of Climate Change, Energy, the Environment, and Water engages with industry on critical infrastructure by providing administrative support to the Electricity Sector Group (ESG) of the Trusted Information Sharing Network (TISN). Governments, owners, and operators of critical electricity infrastructure communicate within the TISN ESG platform to discuss security issues and exchange practical tools aimed at increasing the resilience of electricity infrastructure (Australian Government, 2021). TISN members (Figure 1) work together to:

- diagnose and address risks to critical infrastructure;
- identify security gaps and carry out mitigation strategies;
- contribute to the development of policies and programs related to critical infrastructure resilience;
- joint efforts to implement the 2023 Critical Infrastructure Resilience Strategy (Australian Government, 2023).

Scientific-based stormwater modelling in Japan

Most large cities in Japan, including Tokyo, have experienced periodic urban flooding. Due to urbanization processes, this problem has gained additional importance. Extreme rainfall can affect the quantity and quality of water, as well as damage water supply and stormwater facilities and infrastructure. Substantial research efforts have been applied to find solutions to urban flood risk in the country. The main approaches tested by Japanese scholars include the Storage Function Model in Urban Watersheds, Distributed Physical Models in Urban Watersheds, and experiments with AI-based simulations. Particular attention is paid to detailed hydrodynamic modelling with the use of high-resolution, vector-based Geographical Information System (GIS) data characterizing the urban environment in detail. Another promising model combines meteorological, hydrological, engineering, and socioeconomic data (Mishra et al., 2019; Uchiyama et al., 2021 Kawamura et al., 2023).

Of key importance for any modelling is to obtain real-life reliable and regular data from observations of precipitation and water level, such as the Tokyo Metropolitan Flood Control Integrated Information System (FCIS). At the national level, the data to all stakeholders is provided by the Ministry of Land, Infrastructure, Transport and Tourism through its Information and National Land Data Management Centre (Kawamura et al., 2023). As of 2023, real-time observations of river water level and streamflow were provided online at 7580, and rainfall observations at 10,619 stations (Water Management and Land Conservation Bureau, 2024).

Flood runoff models are an essential tool for increasing the resilience of water and other infrastructure by mitigating the impact of destructive floods, enhancing effective protection measures, and informing corporate management systems and policy-making. The adoption of integrated flood risk management (IFRM) is the recommended approach to planning and managing these natural disasters (Kawamura et al., 2023). It allows to take a comprehensive approach an

preview measures to prevent floods, reduce exposure, ensure evacuation, plan response, and facilitate recovery, thus, enhancing disaster resilience with the involvement of multiple stakeholders (Koike, 2021).

Sponge technology in urban water management in China

Climate change poses threats to the present-day and future water availability and water security due to the increased frequency and intensity of extreme weather phenomena, including heat waves and extreme rainfall, and drought. Floods or droughts lead to increased concentrations of pollutants posing risks of water contamination and pathogen proliferation and limiting access to clean and sanitation (UN Water, 2020). Densely populated small and medium-sized cities in developing countries are particularly affected by water-related disasters and water insecurity (IDRC, 2017).

The Ministry of Water Resources of China has put forward a guiding document to promote the design and construction of sponge cities to enhance water security and water conservation, better environment protection, and develop comprehensive solutions to water problems. "Sponge City" is a national stormwater management program that was put forward by the Chinese government to address urban water issues emanating from climate change sustainably (Guo et al., 2024). This is an inter-departmental and cross-sectoral initiative that requires a whole-of-the-government approach to combine natural and manufactured solutions; blue, green, and grey measures; and macro, meso, and micro level approaches. The national (macro level) sponge city concept was first applied to 30 pilot, and later to 60 demonstration cities (micro level) to test and advance the technology. As the program spread nationwide it became apparent that varied environmental conditions (such as rainfall, soil, terrain, and temperature) require regional (meso level) design strategies and assessment tools that will focus on specific low-impact development parameters tailored to local circumstances (Guo et al., 2024).

The 'blue' sponge technology focuses on rivers and lakes in terms of their protection, connection, and management. The 'green' sponge technology covers the installation of rain gardens, sunken green spaces, and grass ditches that collect surface water run-off or slightly contaminated water. The 'grey' sponge technology previews pumping stations and rainwater pipe networks. The 'Big Sponge' approach is applied in line with the information collected from systematic planning of the urban ecological pattern of various environmental elements, such as rivers and lakes, forests and mountains, fields and grasses. 'Small sponge' approach implies individual technologies and solutions, such as permeable paving, green roofs, and the construction of water storage facilities (ICLEI East Asia Secretariat, 2024).

Examples of sponge cities in China are Sanya, Hainan, Jiande, Hunan, and Changde which have transformed their varied territories from coastal lines and suburban areas to construct an environment-friendly cyclical water purification system (ICLEI East Asia Secretariat, 2024). This approach helps in designing climate resilient urban areas that overcome water deficit and pollution and offers people appealing places to live with vast community parks and green residential areas. Companies residing in such cities benefit from the absence of water shortages and lower cross-sectoral competition over water resources.

Small and medium enterprises benefit and contribute to resilient technologies

Small- and medium-sized enterprises (*SMEs*) can benefit from climate change adaptation and resilience trends and practices. However, there are challenges in this way that need to be accounted for and solutions have to be found. One such solution is pro-active participation in technology development and diffusion (Figure 2).

Their benefits from climate-resilient infrastructure include engaging in sustainable value chains, entering new local markets in countries that have constructed such infrastructure, and benefiting from new partnerships with knowledgeable and responsible organizations. The circular and resilience aspects of manufacturing networks have the potential to increase innovation in many sectors dominated by SMEs, such as consumer products, transport and energy services, and plastics. The adoption of the following business models may be beneficial for SMEs: circular supply, resource recovery, product life extension, sharing, and product-service system. These sustainable models are well suited for SMEs due to their higher reactivity, limited local footprint, and short distance to customers and end markets. They can operate in local markets that could be unattractive or out-of-reach to large companies (OECD, 2023).

However, SMEs suffer the most from climate change effects and related infrastructure disruptions, as they cannot cover losses in one market or region, affected by natural disasters, by a surplus in another. They often lack funds to increase the resilience of their capital assets and have less manoeuvre capacity in case relocation of facilities is required. Additionally, it is more difficult for small and medium enterprises to adapt their production networks to minimize negative interconnections, disruptions, and volatility caused by natural disasters.

At the same time, SMEs can contribute to the development and application of climate-resilient technologies. This can be done through participation in various platforms and networks that regroup various actors in search of responses to common challenges. Examples include European Technology Platforms (Proskuryakova et al., 2014) and the Australian Trusted Information Sharing Network. SMEs can also join various advisory and expert bodies created by government agencies to foster resilience and seek advice from the private sector. Through such channels, they can inform the policy process about the needs and difficulties faced by small and medium companies. Finally, SMEs can certainly benefit from the information provided by the governments, such as NAPs, weather phenomena predictions, and the outcomes of long-term climate change modelling. If SMEs are involved in national or global value chains, they could have ac-

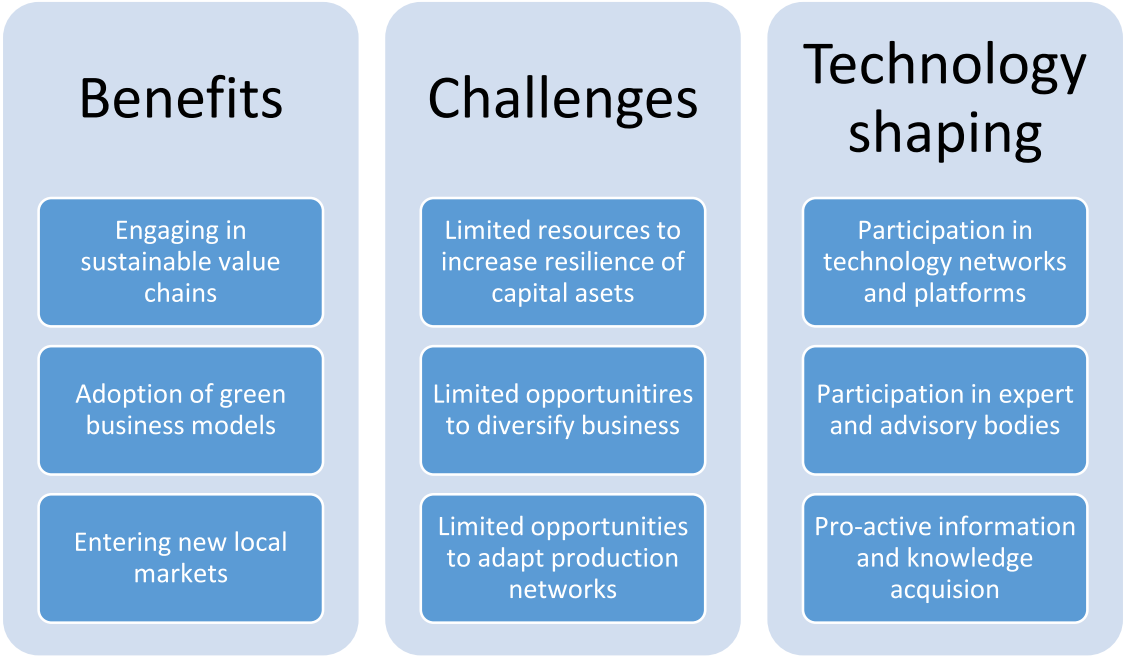

Figure 2: – SMEs' benefits, challenges, and participation opportunities associated with technologies for climate resilient infrastructure

(Source: created by the author)

cess to knowledge and resilience technologies created by other participants. SMEs' digital transformation, their shift to greener and more sustainable practices and business models, access to essential climate data, and raising the qualification of personnel, coupled with enabling policies, will be instrumental in their integration into global value chains along with increasing resilience to climate change.

Conclusions

Over the next decades, the frequency and intensity of global climate-related disasters are forecasted to increase, resulting in billions of damage costs, the largest share of which will be attributed to the APAC economies. Those most affected will be the poorer countries and communities that do not have the means and resources to foresee the projected changes and develop and implement effective mitigation and resilience strategies and plans. In particular, climate-related damage to infrastructure and services, including industry, transport, and energy, will have a higher impact on vulnerable social groups and smaller (local) market actors, whose resilience has to be reinforced in the first place.

It is a much smarter and more cost-effective solution to invest in resilient infrastructure today than to bare the economic consequences of climate-related disasters a few decades later. Future oriented studies and existing public and private initiatives in the APAC region could serve as the evidence base and a starting point for national governments to design, monitor, and adjust National Adaptation Plans, Adaptation Communications, and Actions on climate empowerment in a timely manner. Some of these initiatives covering cross-border environmental systems or economic areas may be elevated to the international level and included in bilateral and international agreements or coordinated by the Asia-Pacific International Cooperation.

It is important to design, evaluate, diffuse, and propel varied solutions, including climate-smart technologies, social projects, and policy actions. SMEs could be both beneficiaries and proactive contributors to such solutions. They may engage in existing sustainable business chains and adopt green business models, thus building competitive advantages to occupy new local markets. SMEs could also contribute to the planning, development, and implementation of resilient solutions through participation in technology networks and platforms, expert and advisory bodies, and knowledge hubs.

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Composite Adaptability Index

A framework for urban transportation resilience to urban flooding

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Abstract

This article explores the development of a Composite Adaptability Index (CAI), a framework that assesses the adaptability of urban transportation systems in response to climate change, particularly urban flooding. As Asian cities are facing the increasing risk of climate change impacts, the need for resilient transportation infrastructure is crucial. It is important to implement adaptation policies to improve the system's resilience and develop monitoring and evaluation measures to assess their effectiveness. The CAI relies on the main pillars of Environmental, Social, and Economic and sub-pillars of Exposure, Resilience, and Susceptibility. To understand the practical application of the CAI, a case study of Bengaluru, India, which is highly vulnerable to urban flooding, is presented. Results suggest that a policy bundle of land use and infrastructure instruments is extremely advantageous to increase system resilience. Compared to the other policy bundles and the Business-As-Usual scenario, the high CAI value of a bundle of land use and infrastructure instruments indicates its ability to improve the system's resilience. By adopting CAI, policymakers can proactively prepare the transportation system for climate challenges.

Introduction

Climate change has been a focal point of discussion in dialogues worldwide, including the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement. Climate change and its impact is significantly felt across various sectors, majorly in critical infrastructures, including transportation. Asia has been undergoing rapid urbanisation and economic growth in recent decades, leading to uncontrolled migrations and heightened demand for infrastructure, especially transportation. Its heightened vulnerability to climate change risks and resulting economic losses (Kurth et al., 2020) has made it essential to prioritise system resilience, especially in Asian countries, where many are particularly vulnerable to climate change In India, metropolitan cities like Bengaluru, Mumbai, and Chennai are severely affected by annual floods, and low-lying cities such as Ho Chi Minh and Jakarta are vulnerable to sea-level rise. Bangladesh's unique geographical profile makes it highly susceptible to flooding, tidal inundation risks, and the accelerated melting of Himalayan glaciers.

While resilience is gaining popularity in research and policy, the significant disparity between developed and developing nations is prominent. (Pan et al., 2021).India is notably vulnerable to climate change, facing extreme weather events like cyclones and floods in increasing intensity and frequency. The last few decades have seen unpredictable season changes and increased rainfall, leading to urban floodings threatening transportation systems. Uncontrolled urbanisation and unplanned developments have further complicated the matter with cities struggling to meet the socio-economic demands in these extreme conditions.

As the situation continues to deteriorate, particularly in developing countries like India, the urgency of adapting transportation systems becomes increasingly clear. Resilience is a big part of this step. Referred to as the "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner" by the United Nations Office of the Special Representative of the Secretary-General for Disaster Risk Reduction, resilience principles can help fragile systems become more stable and flexible. By prioritising resilience in transportation planning, countries can better prepare for the adverse effects of climate change, ensuring their networks remain robust and reliable amidst environmental changes.

To tackle climate change issues effectively, it is important to focus on the interconnection between adaptation and resilience strategies. Adaptation is the process that involves making changes to adjust to new conditions through modified practices and redesigning structures. Adaptation contributes to building resilience so that climate change impacts can be reduced or modified. While countries have identified and recognised the importance of adaptation and prepared national adaptation strategies, no recognised matrix or methodology exists to measure their effectiveness.

Measurement and evaluation of adaptation projects and programs leads to effective communication and public engagement, informed planning and

decision-making, solid justification of adaptation expenditures, accountability, governance, and management. The lack of monitoring and evaluation frameworks could be attributed to the challenges due to uncertainty and complexity, context specificity, lack of comparable indicators and resources, and the long-term horizon involved in collecting reasonable results.

This article is inspired by the work done by Dr. Harsha Vajjarapu as part of his thesis titled, "Evaluating Climate Change Mitigation & Adaptation Potential of Sustainable Urban Transport Measures in India" at the Indian Institute of Science (IISc), Bengaluru, and presents the development of an innovative index named the Composite Adaptability Index. The Composite Adaptability Index (CAI) is a context-specific framework developed to evaluate the adaptability of an urban city's transportation system against floods. The index is developed based on the Environmental, Social, and Economic pillars and considers the relationship between adaptation, exposure, susceptibility, and resilience. (Vajjarapu & Verma, 2021).

Composite adaptability index

You can think of the CAI as a progress report for the city's transportation system. Like how teachers assess the students through examinations, assignments, and seminars, the CAI index assesses the city's urban transportation network's adaptability to urban floods through various indicators. Similar to how blood pressure, pulse, and saturation level are indicators of the body's state of health, several indicators can be employed to determine the transportation system's performance. These indicators broadly fall under the three major pillars of adaptation - Environmental, Social, and Economic- the three sectors significantly affecting urban flooding and the sub-pillars of exposure, resilience, and susceptibility, which will provide a deeper understanding of how the system interacts with urban flooding. While the Environmental pillar considers aspects of rainfall, the social pillar looks at how individuals' travel decisions change. The economic pillar considers the economic impacts of urban flooding.

Exposure refers to the elements that increase the exposure of transportation systems to urban flooding; resilience denotes the ability of the system to return to its original state after a flooding event, while susceptibility reflects the possibility that the system has a chance of getting flooded in the event of urban flooding. The CAI development follows a systematic approach that starts with indicator identification and normalisation and continues through prioritisation and index calculation. The Composite Adaptability Index (CAI) development process for urban transportation systems facing urban flooding involves several key steps, as shown in Fig 1 and explained below.

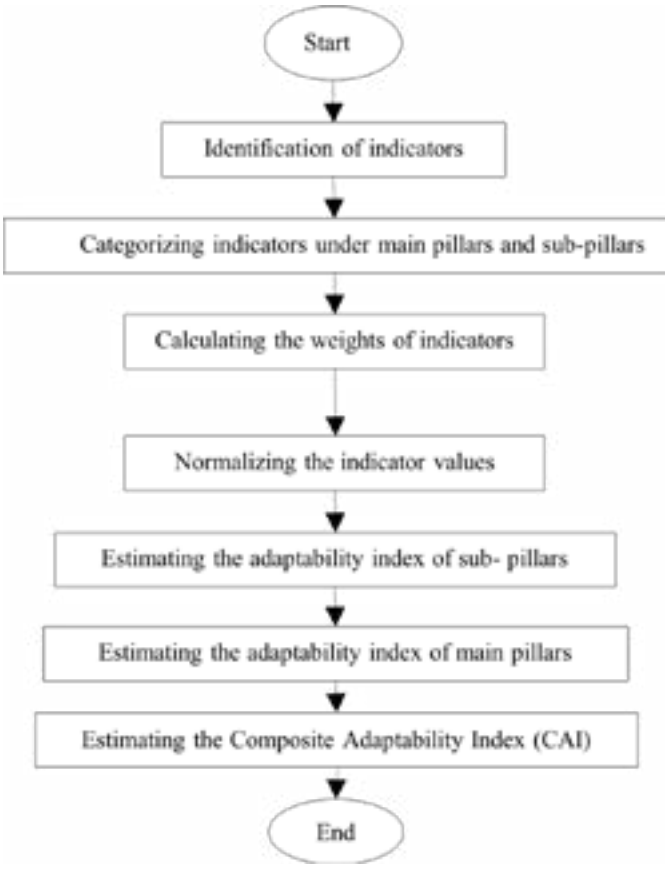

Figure 1: Development of Composite Adaptability Index (CAI)

(Source: Vajjarapu & Verma, 2021)

1. **Identification of indicators:** For the development of the CAI, indicators under each of these main pillars and sub-pillars need to be identified.
2. **Normalization of Data:** Normalization is carried out to ensure that indicator data collected on different scales can be compared meaningfully on a common scale. In simpler terms, normalisation ensures that apples are compared with apples and not oranges. Bringing all points to a common scale ensures their accurate evaluation and effective comparison without the influence of their differing measurement units.
3. **Prioritization of Indicators:** To ensure a structured evaluation of the indicators and development of the index, indicators should be prioritised based on their importance in contributing to the system's adaptability. This process identifies the significance of each indicator about its sub-pillar and assigns a numerical value, the weight, representing this importance. By doing this step, the influence of various indicators on system adaptability can be determined.
4. **Index Calculation:** The Composite Index calculation happens in three steps.

4.1 Adaptability index of sub-pillars

The adaptability index of sub-pillars is calculated by combining the normal value of the indicators with their assigned weight. Each indicator value is first adjusted to a common scale, and then its importance is factored in through its weight. The result is a weighted sum that reflects the overall adaptability of the sub-pillars. The mathematical formula for the same is given in Eqn [1].

$$AI_{sp} = \sum_{I=1}^{n}[NVI_i * WI_i], \quad [1]$$

where,
sp – Sub-pillars of adaptability
NVI – Normalized Value of Indicator
WI – Global Weight of Indicators

4.2 Adaptability index of main pillars

Examining the sub-pillars and their relation to the system's adaptability reveals that resilience positively influences adaptability; in other words, resilient systems are more adaptable, while exposure and susceptibility negatively impact adaptability. Considering these relationships, Eqn [2] was developed to determine the adaptability index of the main pillars of adaptation.

$$AI_{mp} = \sum \frac{[R_{sp}+(1-E_{sp})+(1-S_{sp})}{3}, \quad [2]$$

where,
mp – Main Pillars of Adaptability
R – Normalized Resilience
E – Normalized Exposure
S – Normalized Susceptibility

If the main pillar is entirely resilient to urban flooding with no exposure or susceptibility, then Eqn [2] gives the adaptation index of the main pillar as 1 with R_{sp} = 1, E_{sp} = 0, and S_{sp} = 0.

4.3 Calculation of Composite Adaptability Index (CAI)

Finally, the composite adaptability index for the entire urban transportation system is obtained from Eqn [3] as,

$$CAI_{system} = \frac{\sum AI_{mp}}{3} \quad [3]$$

The value of the composite adaptability index varies from 0 to 1, with 0 being the worst adaptability and 1 being the best adaptability.

Case study

The developed composite adaptability index was applied to the Bangalore Metropolitan Region (BMR), covering over 8005 sq. km. One of the fastest-growing metropolises in India, Bengaluru has a population of 12 million (World Population Review, 2020). With its population expected to reach 18 and 33 million in 2030 and 2050, respectively, Bengaluru presents an exciting challenge, with the city grappling with the demands of rapid urbanisation. These demographic shifts are reflected in city traffic congestion, air pollution, and changing land use patterns. The rise in impervious surfaces and the loss of wetlands and vegetation have significantly contributed to frequent urban floods (Ramachandra, 2017). Effect measures are urgently required to mitigate the issue.

Adaptation Policies: The study formulated adaptation policies through a comprehensive literature review, stakeholder interaction, and Intergovernmental Panel on Climate Change (IPCC) definition, additionally drawing inspiration from Western countries. Through the Delphi method, the most relevant adaptation policies were identified. A widely used technique, the Delphi method, is a way to get opinions from experts by asking them questions anonymously. They answer, see a summary of everyone's thoughts, and update their answers. The Delphi method filtered nine potential adaptation policies down to six. Identifying that policies are more effective when implemented in a package, the six policies were bundled to enhance each other in achieving better resilience. The study formulated three policy bundles to tackle urban flooding in Bengaluru and to restore the city to a business-as-usual (BAU) scenario without flooding.

Each policy bundle is composed of different policy instruments; Bundle 1 contains land use and infrastructure instruments, while Bundle 2 constitutes policies related to land use and information (traffic management). Bundle 3 integrates infrastructure and information instruments. These bundles were then critically analysed to assess their combined impact on improving system resilience, particularly in reducing flood levels. To evaluate their effectiveness, scenario analysis was conducted considering three cases: the BAU no-flooding scenario, the BAU flooding scenario, and various adaptation policy scenarios. The Composite Adaptability Index was employed to determine the policy bundles' effectiveness in improving the system's adaptability.

Indicators selection: Indicators for the analysis were identified under the three main pillars: Environmental, Social, and Economic. Multiple urban transportation-related indicators were also incorporated for the index estimation. Vehicle Kilometers Travelled (VKT), Vehicle Hours Travelled (VHT), Average speed of the vehicle (ASV), Cancelled trips (CT), and Average Trip Length (ATL) were the transportation indicators used in the study.

Scenario analysis: The values for the indicators selected above depend on the policies and vary across the policy bundles. Each of the policies affects different stages of planning a trip: determining where a trip starts and ends (Trip generation), determining how many people will travel from one place to another (Trip Distribution), choosing the method of transportation, such as car, bus, or train (Mode choice), and selecting the route to take (Trip Assignment). When combined, these steps are termed as the 'traditional four-step model' in transportation planning and are widely accepted for analysis. By using TransCAD, a transportation planning software with GIS and transportation modelling capabilities integrated with the four-step model, the three scenarios were analysed: BAU- no flooding, BAU- flooding, and Adaptation policy scenarios for years 2030 and 2050, and indicator values were extracted or estimated. (Vajjarapu et al., 2020)

Normalising and weighing: Since each indicator has different units, it is essential to apply data normalisation to bring them to a standard unit. Due to its simplicity, the min-max method is employed in this study, where it scales the data to fall within a range of 0 to 1. This helps transform the data to make it easier to compare and analyse.

$$NVI = \frac{(actual\ value - minimum\ value)}{(maximum\ value - minimum\ value)},$$

where,
NVI – Normalized value of the indicators
Actual value – Indicator value obtained from the model
Maximum and minimum value – Estimated Maximum and minimum values of indicators.

After normalising, the Analytical Hierarchy Process (AHP), a multi-criteria decision-making approach based on pair-wise comparison, developed by Saaty in the 1970s (Saaty, 1987) was used to achieve weights of the indica-

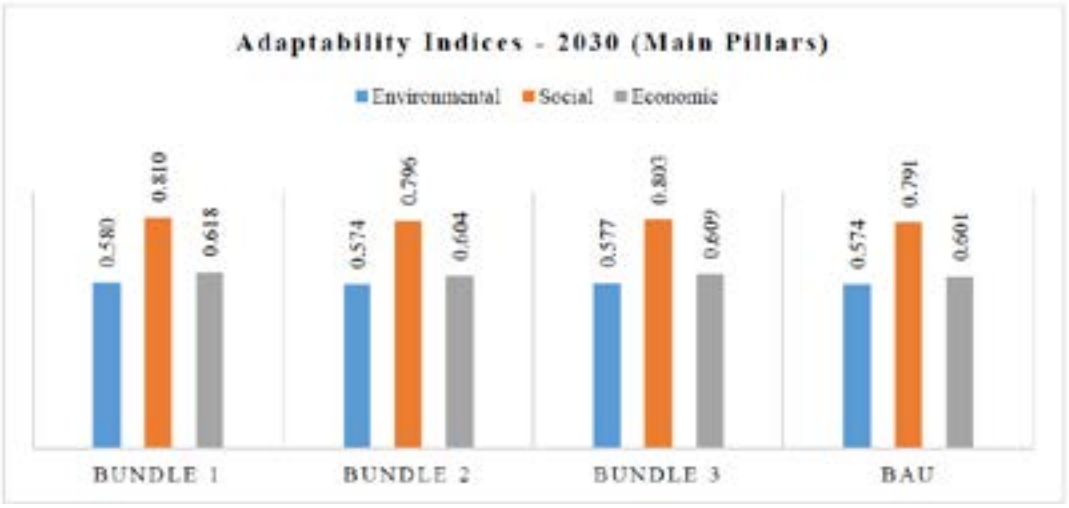

Figure 2: Adaptability Indices of Main Pillars for the year 2030

(Source: Vajjarapu & Verma, 2021)

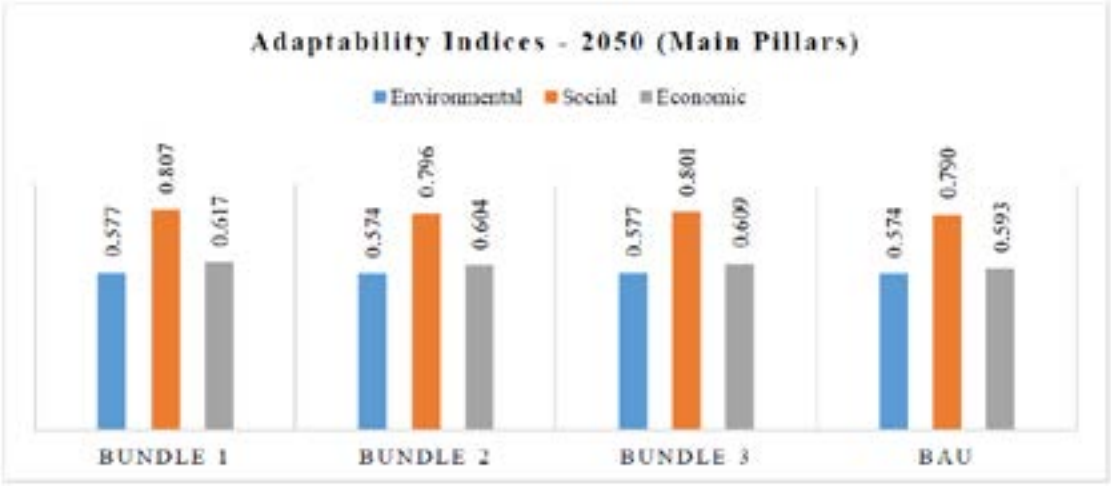

Figure 3: Adaptability indices of main pillars for the year 2050

(Source: Vajjarapu & Verma, 2021)

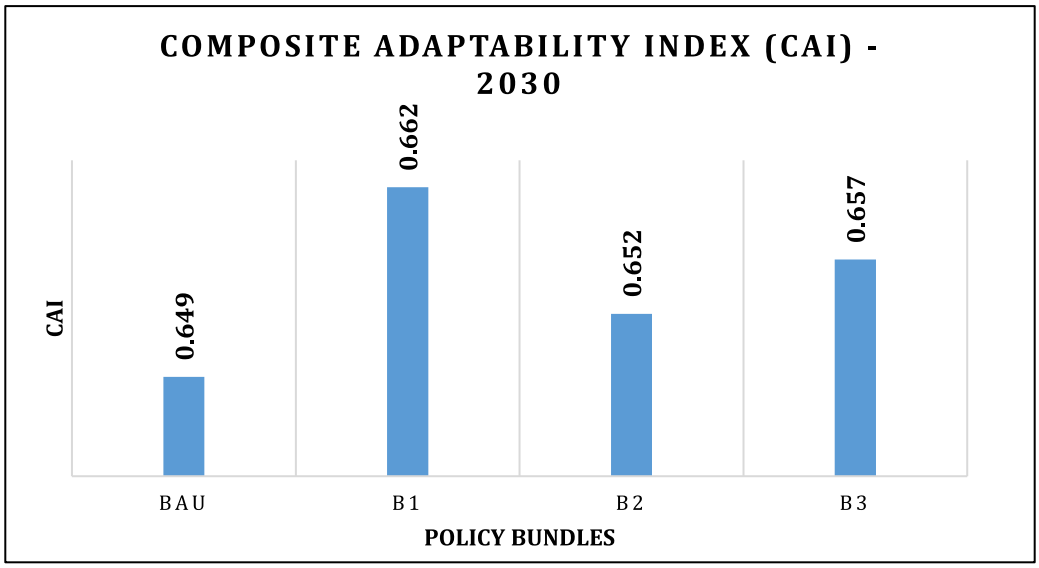

Figure 4: Composite Adaptability Indices for the year 2030

(Source: Vajjarapu & Verma, 2021)

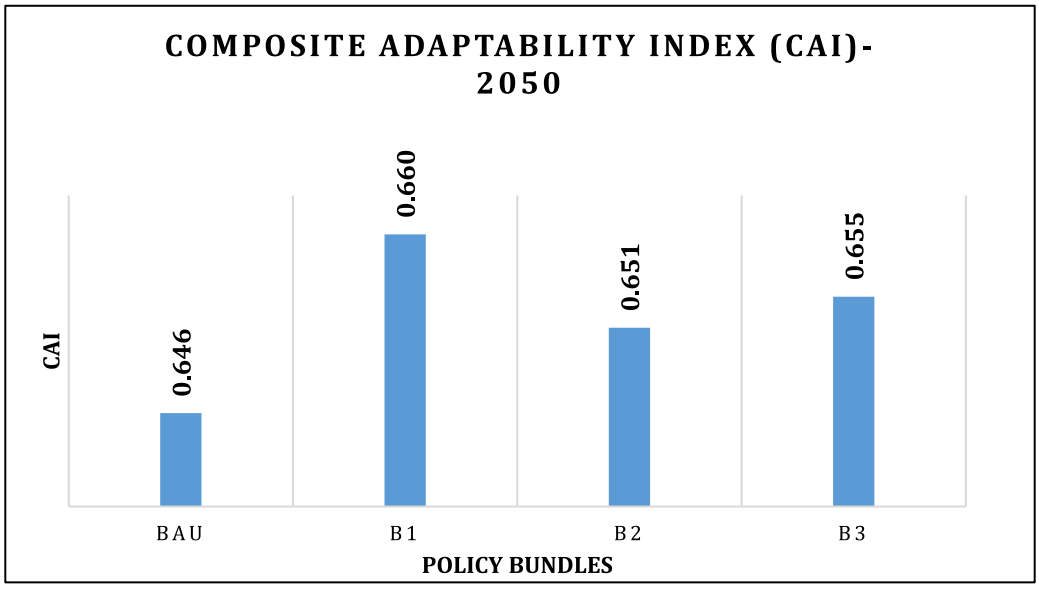

Figure 5: Composite Adaptability Indices for the year 2050

*(Source: Vajjarapu & Verma, 2021)*A comparison of the composite adaptability indices across the various policy bundles shows that bundle 1 achieves the best results. The higher CAI value of bundle 1, which combines land use and infrastructural instruments, underscores the importance of a well-informed resilience strategy that integrates these two sectors. This approach significantly increases the urban transportation systems' adaptability to urban floods and overall resilience.

tors. AHP utilises the decision-maker's expertise and breaks down the decision problem into a hierarchy of easily comprehensible sub-problems, which can then be analysed independently. The participants are asked to compare the indicators in pairs and rank them accordingly based on their effect on adaptability. In the study, to determine the weights of the indicators, inputs from 30 experts were considered. The experts included government officials, government officers from transport and urban planning, the meteorological department, disaster management, and professors from the Indian Institute of Science who are experts in Transportation Engineering. Once the results were calculated, a consistency ratio was used to ensure their reliability, allowing necessary adjustments to enhance decision-making.

Composite Adaptability Index: Once the normalised indicator values and their weights were obtained, the adaptability indices for the sub-pillars and the main pillars were calculated for the years 2030 and 2050. Fig.2 and Fig.3 represent the adaptation indices of various policy bundles and busi-

ness-as-usual scenarios with flooding. Compared with the BAU scenario for both years, the adaptability indices for the main pillars are increasing across all policy bundles, indicating that implementing the adaptation policies improves the system's adaptability level. Furthermore, to compare the effectiveness of policy bundles and identify the one with higher benefits, the composite adaptability index of the system for all policy bundles and the BAU were calculated, and the results are presented in Fig 4 and Fig 5 for the years 2030 and 2050, respectively.

Conclusion

The ever-present threat of climate change on the horizon and the demands for more and more infrastructure, particularly in the rapidly urbanising cities of Asia, have necessitated the incorporation of resilience strategies in long-term transportation planning. As climate-related risks become more frequent and intense across cities, the transportation system, one of the critical lifelines, is becoming severely vulnerable, especially in developing countries like India. While there are many adaptation policy initiatives to maintain the functionality and stability of the systems, the lack of a suitable measurement matrix reduces their acceptability.

This article presents the development of a Composite adaptability Index (CAI) an indicator-based approach that can be used to evaluate the adaptability of climate change adaptation strategies for the urban transportation sector, focusing on urban flood. The index is developed based on three main pillars – Environmental, Social, and Economic- and three sub-pillars or factors – Exposure, Susceptibility, and Resilience. Considering the relationship between adaptation and the three factors, a mathematical expression was developed for the index. The CAI offers a comprehensive approach by integrating various indicators across these pillars to understand how urban transportation systems can adapt to growing risks associated with climate change.

To highlight the practical application of the index, a case study of Bengaluru, one of India's fastest-growing cities, is also discussed in the article. Bengaluru faces frequent urban flooding due to unconstrained urbanisation and the loss of natural ecosystems. The CAI was applied to analyse the effectiveness of various policy bundles from infrastructural, land use, and traffic management instruments designed to reduce the effects of urban flooding on Bengaluru's transportation system. The Composite Adaptability Index developed in the study can be used to evaluate the effectiveness of adaptation policies. Though the application was restricted to adaptation strategies for Indian cities, the index is transferrable and can be used as an evaluation technique for adaptation policies. The model will act as a scientific tool for policymakers to make appropriate decisions in reducing the risk of flooding in urban areas.

Looking ahead, it is crucial for policymakers, researchers, and urban planners to adapt the CAI as a standard evaluation tool for adaptation policies. Through a holistic approach to urban resilience, it can be ensured that transportation systems are proactively designed to withstand future disturbances. The CAI applied in the Bengaluru case study was developed with a limited number of indicators; in the future, the CAI can be refined by incorporating more diverse indicators and testing its applicability across various contexts.

It is high time to integrate resilience into long-term transportation planning. By focusing on capacity building, stakeholder engagement, fund allocation, risk assessment, and stakeholder involvement, we can create robust and reliable transportation systems capable of withstanding disasters. Much as a band-aid on a broken arm does not solve the issue, ensuring adaptation does not result in maladaptation is crucial. Tools like the Composite Adaptability Index will serve as vital support systems for these initiatives, enabling informed decision-making and enabling policymakers towards effective strategies. Through collaborative efforts and strategic planning, we can ensure that transportation systems remain adaptive and resilient.

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Technology, innovation and governance

Building climate-resilient cities and addressing demographics crises

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Abstract

This article examines three Japanese smart cities—Toyama City, Fujisawa Sustainable Smart Town, and Tsuchiyu Onsen—to identify how technologies, policies, and practices contribute to climate resilience and address demographic challenges. Our findings show that smart cities require a balanced approach between technology adoption, innovation, and democratic governance rather than a one-size-fits-all solution. We emphasize that stakeholder management and transparent public engagement are essential for maximizing technological effectiveness. By fostering public understanding, running drills, and feedback mechanisms, smart city initiatives can ensure proper technology utilization, generate data for assessing governmental goals, and guide future technological and policy needs.

Introduction

With climate change damaging city infrastructure and straining budgets, governments and communities will look for ways to build more resilient cities cost-effectively. Cities worldwide, including Japan, are turning to technologies such as smart grids, mass transit, renewable energy, artificial intelligence (AI), and automation to build sustainable cities while addressing demographic and economic challenges. Equally important as identifying and implementing new technology, however, are sound governance and support for innovation among the public-private-academic sectors. In recent years, urban design philosophies, city development policies, and democratic government-citizen relations have fallen under the umbrella term of "smart cities."

This article examines the cases of Toyama City, Fujisawa Sustainable Smart Town (SST), and Tsuchiyu Onsen to identify technology, best practices, areas of opportunity, and challenges that must be overcome in smart city development. We find that even within a single country, a one-size-fits-all approach does not work, and climate-resilient infrastructure must be tailored to the strengths and weaknesses of each community. Moreover, we argue that consistent stakeholder management and transparent engagement with the public will allow the government to best leverage the technologies it seeks to implement. Gaining public understanding, running drills, and maintaining robust feedback loops will ensure that smart city technologies will be used as intended, provide valuable data to determine if the government is meeting its desired benchmarks, and provide insights on what technologies and policies are needed for long-term sustainability.

Smart cities in theory

There are numerous definitions of the concept of "smart city," with many developed by international organizations. Philip Bane, of the Smart Cities Council, identifies three core components of a smart city: 1) "'Cities' are any human community of any size and 'smart' can be technology, people and process," 2) "At the core of smart cities are people, and the human-centered needs of livability, workability, and sustainability are at the core of every smart city program or project," and 3) "Information and communication technology are core to technology development" (Bane, 2022). The European Commission defines a smart city as "a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of inhabitants and business" (European Commission, n.d.). The European Commission emphasizes that smart cities go beyond better resource management and less emissions through digital technology and highlights the importance of smarter urban transport networks, more interaction between the public and city administration, and meeting the needs of an aging population, among other urban planning advancements. Although intuitively, these smart technologies contribute to more climate-resistant infrastructure and can address climate change, they are not solely focused on environmental issues. More importantly, smart technologies can negatively impact the environment, as AI and battery technolo-

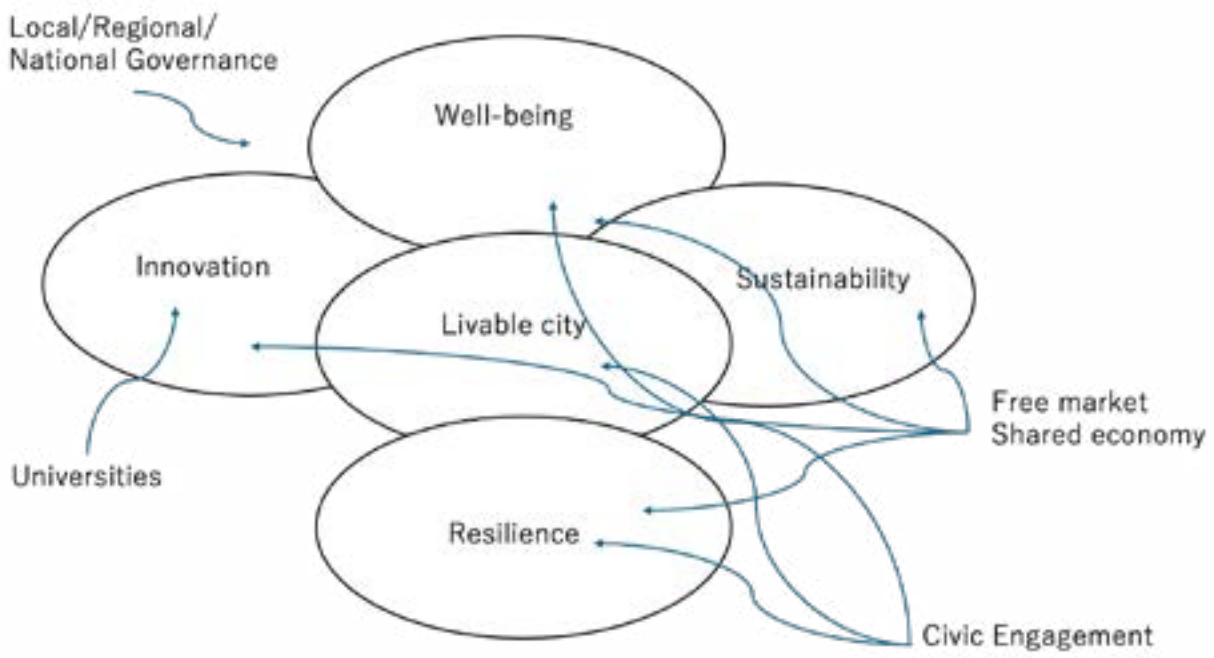

Figure 1. Core components of smart cities

(Source: Produced by authors based on Nagumo interview, Interview, July 3, 2024).

gies are resource-intensive and leave a noticeable carbon footprint (United Nations Environment Programme, 2024; Institute for Energy Research, 2023).

Although technology is a core component of a smart city, how it is selected and implemented, and how good governance, innovation, and development address the population's needs while maintaining community are equally important. Since smart cities go beyond technology, individual states implement smart city policies according to their capacity and constraints. Some cities utilize technology to address overpopulation in urban areas, whereas others, often found in Japan, utilize technology to address the consequences of an aging and declining population. Moreover, states may define a "smart city" in a manner that is more reflective of local norms. That is, for an international concept, it can be highly localized. The Smart City Institute of Japan, for example, approaches the smart city concept under the national "Digital Garden City Nation" policy, where the Government of Japan "aims to realize a 'fulfilling life' (Well-Being) by solving social issues and enhancing regional charm using digital technology" (Cabinet Secretariat's Office for the Council for the Realization of the Vision for a Digital Garden City Nation, 2022). The Smart City Institute of Japan has operated as a thought leader and agenda setter in Japan by:

1. Collecting, analyzing, and sharing the latest information on the world's leading smart cities and know-how for promotion;
2. Discussing, proposing, and advising for promoting smart cities in Japan; and
3. Promoting networking between various entities related to smart cities.

Takehiko Nagumo, founder and representative director of the Smart City Institute, contends the smart city concept is evolving and currently has five core components: 1) Well-being, 2) Innovation, 3) Sustainability, 4) Livable City, and 5) Resilience (Takehiko Nagumo Interview, July 3, 2024). Not all cities will have all five components and many smart city variations exist in Japan. Nagumo identifies at least three types of smart cities: Innovation-oriented, sustainability-oriented, and bed-town (sub-urban). As illustrated in Figure 1, different permutations of smart cities have different strengths and require different inputs. Innovative, sustainable, and resilient cities tend to lean on free market principles. Livable and resilient cities require strong civic engagement. And cities requiring high levels of innovation require inputs from the academic sector.

The FY2023-FY2027 Comprehensive Strategy for the Vision for a Digital Garden City Nation outlines four primary objectives: 1) create jobs in rural areas, 2) increase the flow of people to rural areas, 3) realize hope for marriage, childbirth, and child-rearing, and 4) enhance the attractiveness of every region.

The Ministry of Land, Infrastructure, Transport, and Tourism, especially its Urban Affairs Bureau, has also had a significant influence in promoting the smart city concept in Japan. This Bureau defines a "smart city" as "a sustainable city or district where management (planning, development, management, operation, etc.) is carried out while utilizing new technologies such as ICT to address various issues facing cities." The Urban Affairs Bureau further identifies the Internet of Things (IoT), robotics, AI, and big data as promising technologies for solving urban problems (Ministry of Land, Infrastructure, Transport and Tourism).

Of note, many of the cases in this article demonstrate how city governments

believe "green" cities will attract new residents, allowing them to address rural decline, aging populations, and other social issues. Japanese megacities, such as Tokyo and Osaka, are not often associated with the smart city concept, yet are innovation centers and promote climate-resilient infrastructure, technology, and green living. As a result, suburban and rural communities are using smart technologies and "green" marketing to attract residents away from major metropolitan centers. In a sense, environmentalism is imbued in smart city initiatives because they are attractive to younger Japanese and are not the end goal.

Smart cities in practice

Toyama City. Toyama City officially promotes itself as a "compact city," although official government documents use the term "smart city" regularly, if not interchangeably. A 2022 Smart City Vision Report, for example, introduced the idea of a "Toyama version of a Smart City." This tailored approach is common among Japanese smart cities as each aims to leverage its unique strengths to address the community's unique challenges. According to the *Resilient Toyama* report, resilience is measured in four categories: 1) resilient people, 2) resilient infrastructure, 3) resilient prosperity, and 4) resilient environment (Resilient Cities Network, n.d.). The report identifies two unique challenges to the region, demographic stresses and natural disasters.

Due to the anticipated decline in the overall population and growing aging population, government officials sought to shrink a city to better allocate resources to a needy population. Between 1995 to 2020, the population of Toyama city only decreased by less than 4,000 people (about 1%), but Toyama Prefecture's population decreased by 100,000 (about 9%) in the same period. Moreover, Toyama Prefecture has the 5th oldest population in Japan, with an average age of 48.6 in 2020 (City Population; Official Statistics of Japan, 2020). These trends also indicate that while a smart city aims to build a more attractive and citizen-focused city that reverses or at least limits population decline, this may come at the expense of surrounding communities as the smart city draws in population from them.

One of the main technologies implemented in Toyama City has been centralized public transportation (rail, taxi, bus, streetcars), with light rail transit (LRT) at its core, in part by taking over a defunct Japan Railways Group (JR) rail line. According to Shinji Honda (Senior Policy Supervisor, Toyama City), the city government sought to decrease reliance on cars and developed a public transportation system where public transportation was within walking distance; 300m from a high-frequency bus station and 500m from a train station (Shinji Honda Interview, July 18, 2023). The proximity to public transportation ensures that all residents, especially the elderly, have access to city amenities (Resilient Cities Network, n.d.). To determine where rail lines and bus routes should be placed, Toyama City utilized surveillance technologies to track where residents were traveling most. This data allowed the city to determine optimal operation times, and some routes started to operate on 15-minute intervals instead of the 30-60-minute intervals when they were run by the private sector.

Accessibility is also an important goal of Toyama City. For example, the city raised the platform on train and electric rail lines to ensure they were on the same level as the carriages. The leveled platforms helped the elderly and families use strollers to disembark more easily from trains. These changes have had a meaningful impact on public transportation use, with an increase of 2.1 times on weekdays and 3.3 times during weekends, with noticeably increased use from the elderly population (Shinji Honda Interview, July 18, 2023). LRT is not a new technology in Japan, but smarter leveraging of the technology and urban planning allowed the government to address the demographic crisis, place residents closer to city services, and increase the use of public transportation, all of which make the people and city more resilient to natural disasters and decrease their carbon footprint (Kriss et al., 2021).

Toyama City is a prime example of a smart city that utilizes existing technologies to develop an urban design plan sensitive to the city's large area, residents' habitual use of cars, and the aging and declining population. Moreover, according to Toyama City officials, the "compact city" concept begins with the city's needs, and the environmental benefits come second. This distinction is important because it reveals that environmental concerns do not exist in a vacuum, and cities are more likely to address them if they can also address economic and demographic concerns as well. These technologies are not aimed at climate resilience, but by drawing more residents to the core of the city, better understanding citizen behavior, decreasing reliance on vehicles, and making a city more "compact" overall, Toyama City is better positioned to address climate-related disasters.

To continue positive momentum, city planners must promote innovation and good governance. Developing new technologies ensures that cities have the latest tools to address a rapidly changing ecological environment, are economically competitive to attract residents and maintain a city's vibrancy, and strengthen public-government-private sector relationships. Smart cities have launched innovation hubs to allow each stakeholder to contribute their comparative advantages and synergize their interests. Toyama City, for example, launched an innovation hub that seeks to connect the public, academic, and private sectors to generate business opportunities and technologies for the future. Located near Toyama Station, the Sketch Lab is a moderately small space that regularly hosts workshops, talks, classes, and town development dialogues. In the Toyama City Smart City Vision interim report, city officials advocate for "citizen centrism," which is approaching the smart city vision from the service needs of civilians instead of contract obligations and interests of the state.

As Toyama City implements these bold technologies and initiatives, city officials must maintain good communication with the public to gain support for the smart city policies, justify expenditures, and ensure services are fully utilized. In Toyama City, the mayor held regular town halls to gain support and serve as a feedback mecha-

nism. The city also produces reports and communicates with the media to maintain high levels of transparency. As the population shrinks and budgets become increasingly strained, policies become more politically and economically costly because changing directions becomes more difficult. Climate change resilience, changing the direction of demographic decline, attracting new residents, and reinvigorating rural economies require multi-decade plans, and hence, sustained and robust engagement with the public.

Fujisawa Sustainable Smart Town (SST). Fujisawa SST, located in Kanagawa Prefecture south of Tokyo, opened in 2014 on the site of a former Panasonic factory and is home to around 1,000 households. Developed through a partnership between Panasonic, Tokyo Gas, Mitsui Fudosan, and other organizations, the town was designed with a 100-year vision emphasizing sustainability and adaptability (Fujisawa City, 2024). After 10 years, in October 2024, Fujisawa SST was completed (Panasonic Group, 2024). As such, Fujisawa SST's technological infrastructure focuses on smart homes equipped with Panasonic's integrated systems, including solar power generation, battery storage, and energy management technology. The adoption of these technologies falls under the city's branding of "smart life," "smart space," and "smart infrastructure."

Safety, sustainability, and resilience are key concepts in Fujisawa SST's approach to community building. For example, a monitoring system, including public space surveillance, oversees community services, while electric vehicle charging stations and bike-sharing systems support sustainable transportation. Fujisawa SST has attracted a younger population (~30% under the age of 30), located in the popular Shonan area with its beaches and within easy reach of Tokyo and Yokohama. This has also made it an important case study for Japan's aging population. The construction of new housing complexes for the elderly and the integration of intelligent healthcare services, including telemedicine options, demonstrate how technology can improve daily life (Hornyak, 2022). The concept of 'machi oya' or 'town parent' illustrates this approach to building community across generations. The town is jointly managed by the Fujisawa SST Council and the Fujisawa Management Company, which oversee day-to-day operations, collect data, and guide the town's development through regular town meetings and digital platforms (Wang, 2023). But this also means that corporate involvement represents a main element in the town's governance.

In addition to these local governance and community features, environmental sustainability is central to the community's design and operation. For example, homes are equipped with renewable energy systems (such as vehicle-to-house [V2H] systems that allow for charging EVs off solar panels and using EVs to power homes) and smart grid technology, reducing dependence on external energy sources and increasing resilience to natural disasters. Green initiatives are also incorporated into the overall design of the SST, with houses, roads, and walkways built to allow fresh air to circulate through the city. City planners take advantage of the region's geographic location and reputation as a beach town and promote a "green" aesthetic to attract young families, such as keeping telecommunications cables underground, installing thin-film solar panels on residential balconies, and curating specific lifestyle books in the community's bookstore. Finally, city designers hope SST will serve as an important innovation hub to foster public, private, and academic collaboration.

Much of the innovation from Fujisawa SST comes directly from Panasonic, as it can implement technologies in the city before they reach the mass market. The city also announced an innovation lab called "Future City Lab," led by Keio University and designed to connect residents, academia, industry, and government (PR Times, 2024).

Despite thorough planning and strong support from the private sector, Fujisawa SST faces significant challenges, particularly in terms of cost. Development and maintenance costs are substantial, and housing prices are about 10% higher than the regional average. City planners will need to address concerns about the model's scalability, particularly in regions with limited resources. The city's reliance on advanced technology requires constant updating and maintenance, creating ongoing financial costs, while higher living costs and technological requirements may limit accessibility for lower-income residents, potentially creating social inequalities. According to a Fujisawa SST guide during a site visit, approximately 80% of residents were satisfied with the city, whereas 20% were dissatisfied, most citing strict restrictions of home design as the source of their dissatisfaction. Maintaining interaction with neighboring communities to avoid becoming a gated community also poses a challenge. Here, sharing renewable energy resources, engaging in joint disaster drills, and providing access to the SST's welfare facilities are key mechanisms for fostering integration with the surrounding areas. Moreover, previous studies have also shown that despite extensive data collection and feedback mechanisms provided to citizens, citizen participation and stakeholder dialogue to implement community-related decisions remain limited (Wang, 2023). Despite these challenges, Fujisawa SST is a valuable model for smart city development, demonstrating how public-private partnerships and active community engagement can create resilient, sustainable urban environments (Hornyak, 2022; PwC, 2021).

Tsuchiyu Onsen. Tsuchiyu Onsen is not a city, rather, it is a remote foothill hot springs resort community within the municipal boundaries of Fukushima City, Fukushima Prefecture. It had been an independent village until it merged with Fukushima City in the 1970s. Like many other rural parts of Japan, this small hamlet is suffering from depopulation, with the population dropping from 380 to 300 residents between 2013 and 2023 (Tsuchiyu Onsen Interview 1, 2023).

For the last 1400 years, this community's main industry has been hot spring tourism, specifically onsen (hot springs) hotels and inns. Onsen boiled

eggs, a popular delicacy, are another related long-term industry. This community has turned to renewable energy to try to revitalize an aging community whose economy was hit hard by the Great East Japan Earthquake of March 11, 2011, with five of 16 onsen inns closing due to a lack of tourists (Rivero & Inumat, 2024). The local onsen cooperative took advantage of the Feed-in-Tariff (FIT) for renewable energy enacted in the wake of this triple disaster and technological advance. Specifically, it has embraced geothermal electricity generation.

This embrace has set Tsuchiyu Onsen owners cooperative apart from nearly all others in Japan, where opposition to geothermal energy is the norm due to concerns that geothermal plants damage the hot water resource that onsen hotels and onsen egg boilers depend on. According to Sato Yoshiyasu, Vice President of the Japan Onsen Association, "if possible, we want the drive for geothermal energy developments to stop" (Japan Times, 2023). Hotel owners have often alleged and worried that geothermal plants will cause their onsen water to go cold, even though there is little evidence that this is actually the case (Balmer and Ozawa, 2023). In fact, the opposition of onsen associations has been one of the leading obstacles to developing geothermal electricity in Japan. Given that geothermal, unlike wind and solar power, is a stable base load of power and that Japan has the world's third-largest geothermal resource, Tsuchiyu Onsen has attracted wide attention domestically and internationally as a model for Japan on how the harmonious coexistence of onsen resorts and geothermal plants can be achieved (Dickie, 2012; Balmer & Ozawa, 2023; Rivera & Inuma, 2024).

The Tsuchiyu Onsen association has not only tolerated the geothermal plant, it has been its main investor and the initiator of the plant since 2012 (Dickie, 2012). It founded a company, Genki Up Tsuchiyu (GUT), to build and manage the plant. It turned to new technology, specifically a binary geothermal plant, which uses a fluid that boils at a lower temperature than water to drive the turbine. A binary plant thus needs far less heat to generate electricity than earlier technology. The Tsuchiyu plant runs on steam, and excess water runs off from a well that supplies hot spring water to local hotels. The Tsuchiyu plant can generate up to 440 kw, or 2.6 Gwh per year, enough to power 800 homes. It could have been bigger, but a 500 kw capacity limit on the line linking the town to the regional Tohoku Electric Power Company grid caused Genki to limit the plant size rather than negotiate with Tohoku EPCO to build a bigger line. Nearby, GUT also has invested in a small-scale hydropower plant (144 kw capacity; 900 Mwh per year) in the town, entirely rebuilding a 52 kw hydro plant that had been shut down when Tohoku EPCO connected the town with its regional grid one hundred years earlier. In addition to the geothermal plant, GUT uses run-off hot water from its geothermal plant to run a shrimp farm. It also runs a cafe where customers can catch these shrimps for lunch (Tsuchiyu Onsen Interview 1, 2023).

This cafe, the shrimp farm, and especially the geothermal plant are featured as tourist attractions, together with the geothermal plant. GUT provides paid tours to 1000 tourists a year on average, many of whom stay at a local onsen inn. Their geothermal plant and shrimp business has also attracted national and international attention beyond extensive media coverage, with two Japanese Ministers of the Environment visiting, and a delegation from the International Renewable Energy Agency (IRENA) paying visits (Tsuchiyu Onsen Interview 1, 2023). This tourism strategy can also be seen as a strategy for realizing urban and national engagement. It is less clear whether this could also be a strategy for attracting new residents.

The 3-11 Great East Japan Earthquake, tsunami, and nuclear accident not only prompted the Tsuchiyu onsen cooperative to search for a way to revitalize the town and stop its demographic decline, but it also removed obstacles and created opportunities for doing so. Specifically, regulatory reform after March 11, 2011, allowed for the building of geothermal plants in national parks for the first time, and Tsuchiyu Onsen inside the Bandai-Asahi National Park. Also, the Feed-in-Tariff (FIT) enacted by the Japanese government in 2012 for promoting renewable energy means that since the Tsuchiyu geothermal plan opened in 2015, it has received 40 Yen for each kilowatt-hour it sells to Tohoku EPCO. After this FIT rate runs out in 2030 and GUT only receives a much lower wholesale rate, it is considering establishing a local electricity company, purchasing some electric vehicles for local electricity storage, and building a smart micro grid for the community to ensure that more of its electricity is consumed locally and to enhance local disaster resilience, so that this community does not lose power for several days as it did after 3-11. GUT also has expansion plans, including an additional 100-kw of geothermal capacity and 360 kw of new small-scale hydro capacity, but needs to attract financing (Tsuchiyu Onsen Interview 1, 2023).

GUT and its geothermal and hydro plants resulted from community engagement, specifically through the onsen cooperative, and GUT, although a for-profit company, does provide for the community. Specifically, with local schools closed due to population decline, it funds bus travel for local children to schools outside of the community. It also covers public transportation expenses for the elderly. Nonetheless, a co-owner of a local onsen inn complained that GUT should pay out more of its profits to support the local community, such as by paying for the community's street lights (Tsuchiyu Onsen Interview 2, 2023). The founding goals of GUT in 2012 in many ways resemble those of a smart city. According to its website :

"1. To build a model future onsen tourism region. 2. To respond to the declining birthrate and aging population in society. 3. To create an eco-town using natural renewable energy. 4. To collaborate with industry, government, and academia." (Genki Up Tsuchiyu, n.d., author's translation)

GUT thus represents an attempt by a community, specifically a local onsen cooperative, to slow, if not reverse, local population and economic decline. To accomplish these goals it has turned to new renewable energy tech-

nology, specifically, binary geothermal technology, along with small-scale hydro, to create an electricity-generating business and related shrimp farming and tourism promotion business. It is now working on expanding its renewable electricity business, and in several years, establishing a smart microgrid and local power company. Some of its profits are returned to the community through subsidizing public transportation for the old and the young and providing profit to the onsen cooperative. It is thus an example of promoting social inclusion and community participation from its inception as a local initiative, through its support for the young and elderly, and through promoting social links with urban and other areas. In this sense, GUT can be said to represent a "smart community," one that embodies our policy recommendation about community involvement and communication.

Conclusion and policy recommendations

Japan provides several cases that are highly informative of the diverse ways cities implement technologies for climate-resistant infrastructure. Broadly speaking, Japanese cities are looking to develop resilient infrastructure as the country is highly vulnerable to natural disasters and climate change. Tokyo, which is usually not considered a "smart city," launched its SusHi Tech initiative, which leverages technology to build a more resilient infrastructure. However, climate change does not impact each city in the same way. Coastal cities are sensitive to rising water levels, whereas historically cold regions of a country will need to adjust to rising temperatures and new seasonal patterns. Despite the aggregative dangers posed by climate change, city design must also consider a region's comparative advantages (geothermal energy) and vulnerabilities (aging and declining populations). As a result, each city will need to tailor its infrastructure policies to its specific economic, political, and social contexts.

Toyama City, Fujisawa SST, and the Tsuchiyu Onsen projects demonstrate just a few of the technologies being tested in cities across Japan. They demonstrate how cities can cut costs, strengthen networks, revitalize economies, attract residents, and build climate resilience while tailoring their politics to specific economic, political, and social contexts.

Nevertheless, innovation and technology are not a panacea for all of Japan's demographic problems. A drawback of heavy reliance on technology is that communities may weaken if in-person interactions decrease. Using drones, remote work, and relying on digital communication may decrease the human resource requirements to run a city, but this can increase the sense of isolation among the elderly.

The challenges of social inclusion and participation can be addressed with participatory urban planning. For example, one digital twin project in Japan – Project PLATEAU – generates a large-scale simulation that can simulate various socioeconomic activities, such as human mobility and economic transactions so that planners can use the results for actual urban planning. However, this simulation is highly dependent on data. Thus, if these activities are poorly digitized, they are hard to simulate and include in future urban planning. Potential subgroups of populations at risk of losing from smart city projects include informal sector workers, homeless people, seasonal workers, and foreigners (Haraguchi et al 2024). These social groups are often underrepresented in data, posing challenges for data-driven planning and smart city development. Nonetheless, some projects in Japan, such as the Daimaruyu Project surrounding Tokyo Station, are beginning to address this challenge by incorporating these underrepresented social groups in their smart city project.

Another threat to communities is the violation of privacy. One of the key goals of the smart city project in Japan is to enhance preparedness and responses to natural disasters as the county is highly vulnerable to disasters. For example, real-time analysis of human mobility during disasters would provide city officials with valuable insight into chaotic post-disaster situations (Haraguchi et al., 2022). To prepare for this, human mobility data should be analyzed both during disasters and in normal circumstances. Yet, ensuring individual privacy remains a major concern in various smart city projects worldwide, and it has been a key factor in the failure of some smart city projects. For example, a high-profile project by a sibling company of Google in Toronto, Canada, was canceled due to privacy concerns raised by citizens and advocacy groups (Bilefsky, 2019). Common privacy concerns include data security, commercial use of data, government surveillance, consent and transparency, data retention, and access, among others. Approaches to address this include building trust among citizens through participation (Lucas and Simpson 2024) and using synthetic data with a task-based approach (Papyshev and Yarime 2021) and differential privacy techniques (Savi et al., 2023).

In sum, technology and climate resilience must come second to community and good governance. The tools will not be utilized effectively, and the objectives will not be achieved if stakeholders are not fully committed. The "smart" in smart cities comes from the people, not the technology.

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