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 companies 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).)

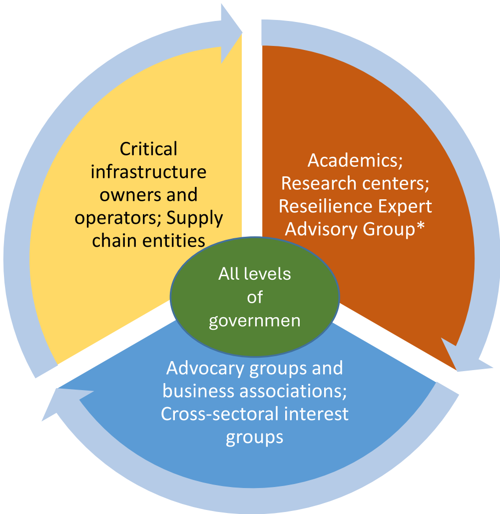

Figure 1: Composition of the Trusted Information Sharing Network

*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-

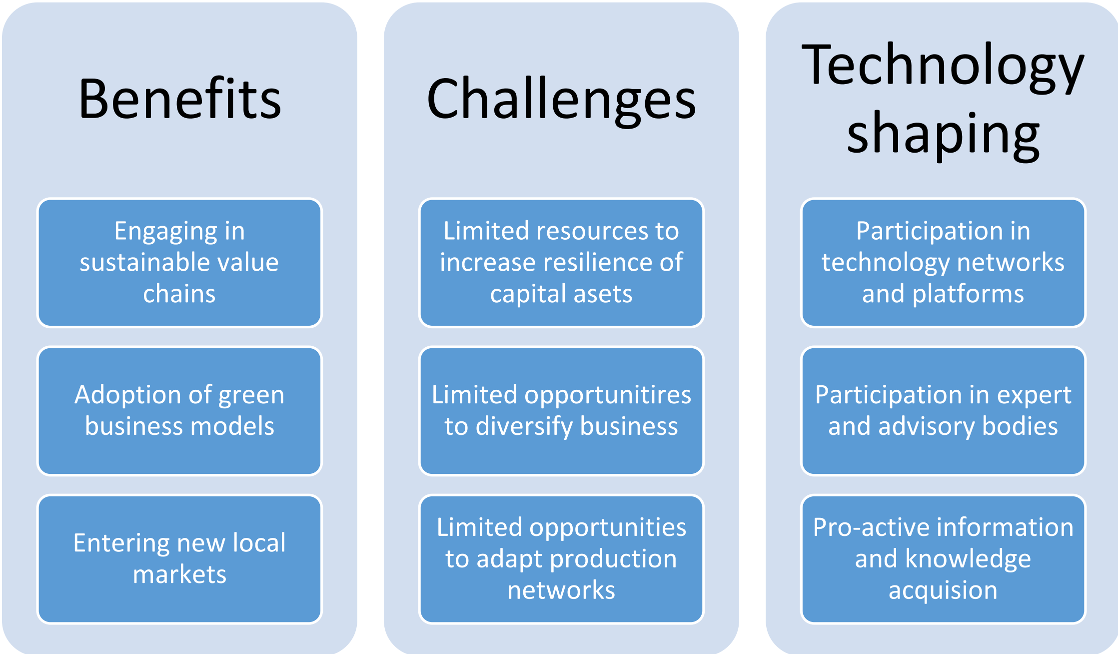

Figure 2: – SMEs' benefits, challenges, and participation opportunities associated with technologies for climate resilient infrastructure

(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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