HARNESSING THE POWER OF DIGITAL TECHNOLOGIES FOR CLIMATE ADAPTATION

The opportunity for social investors

avpn Dalberg

with support from Google.org ADB
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Report partnership

Supported by Google.org and ADB, AVPN collaborated with Dalberg Advisors to develop the report ‘Harnessing the power of digital technologies for climate adaptation: The opportunity for social investors’. Detailed research was conducted on the climate technology ecosystem, uncovering key insights including potential solutions and constraints across social sectors. This report aims to highlight innovative technological solutions addressing climate challenges and explore their impact on society. Additionally, it pinpoints opportunities for social investors and policymakers to advance solutions to address the impacts of climate change in the Asia-Pacific region.

AVPN is the largest network of social investors in Asia, comprising over 600 diverse members across 33 markets. Our mission is to increase the flow and effectiveness of financial, human, and intellectual capital in Asia by enabling members to channel resources towards impact. As an ecosystem builder, AVPN connects, learns, acts, and leads across key pillars and improves the effectiveness of capital deployed, bringing to bear the local field needs, regional expertise, and policy insights. For more information about AVPN and our work, please visit our website.

Google.org, Google’s philanthropy, brings the best of Google to help solve some of humanity’s biggest challenges combining funding, product donations and technical expertise to support underserved communities and provide opportunity for everyone. We engage nonprofits, social enterprises and civic entities who make a significant impact on the communities they serve, and whose work has the potential to produce scalable, meaningful change.

The Asian Development Bank (ADB) is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. It assists its members and partners by providing loans, technical assistance, grants, and equity investments to promote social and economic development.

Dalberg Advisors is a strategic advisory firm combining the best of private sector strategy skills and rigorous analytical capabilities with deep knowledge and networks across emerging and frontier markets. It has a dedicated climate practice to help clients—from governments to multinationals and financial institutions in reaching net zero, creating climate solutions, and catalysing a climate community. For more information about Dalberg and our work, please visit our website.
In the words of António Guterres, Secretary-General of the United Nations, “Climate change is the defining issue of our time – and we are at a defining moment... we need to do more and we need to do it quicker.” As we stand at this critical juncture, the urgency for innovative and scalable solutions to adapt to the accelerating impacts of climate change cannot be overstated. Supported by Google.org and ADB, and developed in collaboration with Dalberg Advisors, this report presents actionable strategies to integrate digital innovations into tackling the dual challenges of climate change and development in the Asia-Pacific region. While we recognise climate adaptation and mitigation as complementary approaches—where adaptation addresses the direct effects of climate variability and mitigation reduces future impacts through sustainable practices, including decarbonisation—this report focuses on climate adaptation. This focus underscores the urgent necessity for the region to adapt to the escalating climate impacts, both to protect current developmental achievements and to secure future progress.

The imperative for advanced technological solutions is clear: they are pivotal in enhancing our adaptive capacities, improving resilience, and ensuring that communities, especially the most vulnerable ones, can thrive in the face of climatic adversities. Digital technologies—ranging from IoT-enabled digital sensors for farm-level drought monitoring to AI-enabled integrated flood prediction and communication systems—offer unprecedented opportunities to optimise resource management, strengthen disaster response mechanisms, and foster informed decision-making processes that enable climate resilience.

The role of catalytic capital is indispensable in this equation. It serves as the cornerstone for initiating and scaling up climate innovations that might
otherwise be overlooked by traditional funding mechanisms. By providing the necessary financial backing and risk tolerance, social investors can unlock the potential of cutting-edge innovations that help anticipate and adapt to climate impacts. If done right, social investments can not only drive the development of transformative solutions but also ensure their widespread adoption and impact, especially in regions that need them most.

However, the adoption of such technologies cannot occur in a vacuum. It demands coordinated policy efforts that foster innovation while ensuring that these advancements are both accessible and equitable. Policymakers are crucial in this regard, as they establish clear regulations and frameworks that support responsible development and implementation of new technologies. This not only protects communities and economies from potential impacts but also boosts confidence among social investors, encouraging them to actively participate in the region.

As we chart the course forward, let’s embrace the challenge with a renewed sense of purpose and collaboration. The tools and capital to forge a resilient future are at our disposal. Only through a collective and focused effort can we hope to harness the full potential of these solutions to secure a resilient and prosperous future for the Asia-Pacific region.

Aravindan Srinivasan
Director | Thematic Collaborations, AVPN
Failure to adapt to growing climate risks poses significant economic and social threats to the Asia-Pacific (APAC) region—particularly given that APAC is home to seven of the world’s ten most climate-vulnerable countries. Warming rates in the region surpass the global average; in 2022 alone, extreme weather events in APAC affected over 50 million people and led to economic losses exceeding USD 36 billion. As temperatures continue to rise, the frequency and intensity of such events, along with corresponding losses, are anticipated to increase. Without swift action, climate-related losses could amount to ~5% of the region’s gross domestic product (GDP) by mid-century based on conservative estimates.

Efforts to adapt to climate impacts must take centre stage for APAC. Decarbonisation is pivotal for steering towards net zero greenhouse gas (GHG) emissions, but mitigation strategies alone fall short of addressing the immediate climate risks stemming from past and present emissions. This gap is particularly pronounced in APAC, where the tangible impacts of climate change are already intensifying existing socio-economic vulnerabilities. Despite contributing minimally to historical emissions, communities in small island developing states (SIDS) in APAC bear disproportionate risks and lack the resources to respond effectively. Given the region’s heightened vulnerability, it is imperative to prioritise actions that can help the region anticipate and adapt to climate risks while pursuing its net-zero targets. This is essential for ensuring climate equity in action.

Financing for climate adaptation falls short of what is needed by 14–20 times current funding levels. Social investors face hurdles in understanding the investment landscape and in identifying investment opportunities. Only ~9% of global climate finance is earmarked for adaptation (including projects with a dual focus on adaptation and mitigation); these funds predominantly flow from the public sector. Barriers to investing in climate adaptation solutions differ based on social investors’ investment approaches. Grantmakers often face challenges such as limited evidence and understanding of how to identify and apply a climate lens to their programming, as well as a lack of standardised outcome metrics. Impact investors, meanwhile, tend to find insufficient evidence of commercially viable adaptation projects.

Digital technologies help address adaptation challenges in ways that are cheaper, faster, and dynamic, presenting a clear opportunity for social investors to push the adaptation agenda forward:

- **Cheaper:** Digital technologies can significantly reduce the costs associated with implementing adaptation strategies. For instance, they enable scalable and cost-effective
ways to convey information to vulnerable communities in remote or hard-to-reach areas, particularly where infrastructure assets are highly susceptible to climatic disruptions. For example, Singapore’s Changi General Hospital’s pilot of a long-term Heart Failure Telehealth Programme not only cut care costs by 42% compared to traditional methods but also showcased telemedicine as a crucial adaptation strategy in healthcare. By minimising travel, it reduces carbon emissions and enhances patient access during extreme weather events, supporting resilience against climate impacts.  

- **Faster:** Digital technologies streamline data communication and coordination, leading to swifter (and in some cases, more proactive) responses to climatic events. Research suggests that deploying AI-based forecasting techniques could achieve reliability in predicting extreme riverine flooding events up to five days in advance. This rapid response is crucial in reducing the physical and financial burdens associated with loss and damage from extreme events. The World Meteorological Association estimates that damage from disasters could be reduced by 30% if early warnings are issued within 24 hours, exemplifying the benefit of speed.

- **Dynamic:** Enhanced by digital technologies, real-time data collection, analysis, and decision-making enable more effective and immediate responses in quickly changing environments. For example, mobile applications managing crop health can offer timely, climate-smart advice based on real-time local data to cope with drought forecasts and pest outbreaks, allowing for proactive adaptation measures.

Social investors are indispensable for catalysing change in under-invested impact areas—like climate and health—due to their unique ability to provide funding and market-building support to high-priority opportunities without the expectations of market-rate financial returns. As in other emerging sectors, social investors can contribute to driving innovation in digital climate adaptation technologies. They can use a range of financial instruments, from impact-seeking capital like fully concessional grants to return-seeking investments such as market-rate debt and equity investments. This includes leveraging innovative funding mechanisms that pool capital in ways that match their preferences for impact and returns with the maturity and requirements of the solutions in question.

This report aims to enhance the adaptation acumen of social investors by demonstrating examples across four themes—agriculture, water resources, disaster management, and public health—with a focus on emerging digital technology solutions. These thematic areas represent social sectors that are acutely susceptible to climate change impacts, and in turn affect the lives and livelihoods of vulnerable populations in APAC. The report provides a foundational framework for social investors to identify and support impactful digital technologies that contribute to the region’s adaptation and resilience goals.

Strategic investments in climate adaptation require a thematic understanding of climate risks and the corresponding opportunities they offer to investors. Social investors navigating the adaptation and resilience investment opportunities in APAC can engage via the following four steps.

1. **Understand climate risks and opportunities.** Begin by identifying and assessing climate risks and opportunities, prioritising among them and among target communities based on their exposure and vulnerability to climate hazards, and identifying adaptation needs accordingly.

2. **Identify climate solutions.** Assess opportunities to address these risks and whether technology has a role to play, such as by predicting real-time local climate risks or adapting to current and expected impacts using climate-related data and insights. Crowd in inputs from climate-vulnerable communities, and seek to understand the maturity and impact potential of the proposed solutions.

3. **Support impactful solutions.** Strategically allocate funds via relevant financial instruments to scale solutions per their respective stages of maturity, balancing the preferences for impact and financial returns with the affordability of solutions. At the same time, foster an enabling environment by investing in ecosystem-building initiatives such as capacity building and policy advocacy.

4. **Measure and communicate impact.** Collaboratively develop and adopt common frameworks for measuring adaptation impact across investments in APAC. This not only helps ensure transparency and accountability in quantifying the impact of adaptation investments but also can guide the investment of future resources towards solutions with demonstrated effectiveness and scalability.

In this report, we profile five use cases that show potential for digital technologies to address climate adaptation risks. These include weather forecasting and modelling, resource monitoring and management, disaster preparedness and response, agricultural optimisation, and climate and health intelligence systems. Digital technologies for these use cases, if deployed at scale, have the potential to greatly enhance the region’s climate resilience. Social investments have an opportunity across all five use cases to support their widespread development and adoption.
Weather forecasting and modelling

Utilises digital technologies to provide accurate predictions of and insights into changing weather patterns and climatic conditions, addressing the growing uncertainty in weather patterns. For instance, artificial intelligence (AI) algorithms now actively enhance the precision of predictive analytics in integrated weather forecasting and communication systems, leading to higher accuracy in predicting weather-related extreme events.7

**Trends:** The deployment of weather data collection and forecasting models is mature. However, localised applications with enhanced predictive capabilities to capture climate risks and real-time communications are still evolving. Deployment in APAC is moderate with early evidence of commercial viability in Japan, Indonesia, and India.

**Way forward:** APAC receives less than 5% of global commercial flows for developing weather forecasting and modelling, and execution is driven by government stakeholders. Social investments can play a pivotal role in advancing the granularity of weather data by prioritising infrastructure deployment. Additionally, they can promote cross-regional stations for weather monitoring, forecasting, and sharing.

Resource monitoring and management

Integrates advanced digital technologies to ensure the sustainable overseeing of critical resources including soil, water, and air.

**Trends:** Surface-level monitoring systems are advanced, but subsurface systems like groundwater monitoring are still in the early stages. Urban air quality monitoring is deployed in several urban centres and can be scaled into remote, climate-vulnerable regions. However, there is a need to ensure that monitoring leads to action, especially by the government.

**Way forward:** Social investments play a significant role in financing innovations and data infrastructures. However, there is a gap in funding initiatives for next-generation technologies, including predictive analytics and real-time communication tools for at-risk communities.

Disaster preparedness and response

Integrates cutting-edge digital technologies to enhance the efficiency and effectiveness of detecting and responding to climate-related disasters, thereby reducing their destructive impact, despite their increasing frequency and intensity.

**Trends:** Integrated flood forecasting systems are commercially ready and already deployed in some countries. AI algorithms for forecasting different types of disasters need to be refined.

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7 Remi Lam, *GraphCast: AI model for faster and more accurate global weather forecasting*, in Google DeepMind, 2023

using locally available data, which requires initiatives to strengthen data collection at local scales. Optimisation models for relief responses and supply chain resilience are in early stages.

**Way forward:** Social investors need to collaborate closely with state authorities. This partnership is crucial for building investor confidence in sustainable business-to-government (B2G) models that can attract commercial capital flows.

**Agricultural optimisation**

Leverages precision agriculture technologies for comprehensive data-driven approaches to inform on- and off-farm activities.

**Trends:** Agricultural optimisation has attracted the most commercial funding in the region across all use cases. Internet of Things (IoT)-based devices, offering real-time crop health data, demonstrate commercial readiness and are widely integrated into precision agriculture.

**Way forward:** Innovations in APAC require the co-creation of affordable solutions with agrarian communities. Social investments need to facilitate early-stage collaborations with women and smallholder farmers to address last-mile perspectives.

**Climate and health intelligence systems**

Gather real-time climate and health data from diverse sources and track parameters like temperature and disease outbreaks, addressing the escalating health threats exacerbated by climate change.

**Trends:** Globally, health tech innovations have made progress and received significant funding in recent years, but these solutions lack climate-specific progress.

**Way forward:** New innovative climate–health intelligence systems are in the early stages regionally and globally. Urgent development, testing, and deployment in APAC are critical due to the substantial health burden posed by climate change.

As social investors consider their approach to supporting tech-forward innovation for climate resilience in APAC, they can consider the following areas for impact, categorised broadly as investments in innovations, and investments in ecosystem building.
Financial interventions

To invest in innovations directly, social investors can consider the following financial interventions:

1. **Offer foundational support for early-stage solutions** focused on generating evidence on the impact of climate change on social sectors, such as research and development (R&D) and local data collection. This can include research grants, innovation funds, and other pre-seed capital.

2. **Promote solutions that refine AI-driven predictive analytics for climate data** and enable their seamless integration into local-scale data collection and relaying systems. This may require concessional debt, early-stage equity, or blended instruments depending on the maturity of solutions.

3. **Validate and scale proven digital solutions in lower-income regions of APAC, focusing on remote and resource-limited communities.** This could include performance-based grants or return-seeking debt and equity for more scale-ready solutions.

4. **Fund the building and strengthening of digital infrastructure for climate resilience as well as digital infrastructure that is climate-resilient**, focusing on at-risk communities. This could include concessional capital provision in coordination with public authorities.

To support the growth of a vibrant ecosystem for digital technology in support of climate resilience, social investors can direct resources towards the following:

Policy advocacy

1. **Integrate digital technology deployment into national climate strategies**, while acknowledging their role in climate action within information and communications technology (ICT) policies.

2. **Develop robust sectoral policies and initiatives that encourage open data generation and sharing** among state agencies, private sector innovators, and local communities.

3. **Establish ‘regulatory sandboxes’** for more dynamic policymaking, to streamline the development, testing, and deployment of climate adaptation-focused digital innovations.

4. **Define and enforce regulations governing AI and other emerging technologies** to tackle risks such as data privacy breaches, algorithmic biases, and reliability issues in climate-related applications.

5. **Implement policies that emphasise data quality assurance and standardisation** in data collection processes, including hardware specifications and data management protocols.

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8 Refers to a controlled framework where innovators can experiment with and test new technologies under relaxed regulatory conditions. Essentially, this environment allows developers to trial new ideas without the usual constraints of full regulatory compliance, which can be slow and restrictive.
Other ecosystem-building initiatives

1. **Facilitate improved access to open data** to support advancements in climate informatics and data-driven decision-making.

2. **Build climate adaptation knowledge and capacity among investors** and disseminate proofs of concepts.

3. **Enhance the capacity of local authorities and decision-makers** to incorporate adaptation considerations during their planning and procurement stages.

4. **Partner with local communities** to understand their needs and foster local community engagement with resilience-building technologies.

In summary, there is vast potential for digital tools to transform the climate resilience landscape and enable even low-resource communities to harness the power of technology to adapt to a changing climate. Social investors have a key role to play in directly investing in innovations and driving other initiatives that enable the development of a vibrant and tech-forward ecosystem to drive climate adaptation and resilience outcomes for APAC.
CHAPTER 1

INTRODUCTION
Asia-Pacific (APAC) nations\(^9\) are highly exposed to the growing impacts of climate change. Rising temperatures heighten the risk of heat waves across Asia, causing droughts in arid regions, delayed and weakened monsoons in South Asia, floods in monsoon regions in South, Southeast, and East Asia, and glacier melting in the Hindu Kush Himalaya region.\(^{10}\) Over the past 60 years, temperatures in APAC have increased faster than the global average, resulting in more intense and frequent unpredictable weather events and climate-related hazards (Figure 1.1).

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<th>Countries at greatest risk from climate change(^1)</th>
<th>Likelihood of exposure to climate-related extreme events(^2)</th>
<th>Likelihood of &gt;5% grain-yield decline in 2050 relative to today(^2)</th>
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<td>APAC 0.6–1.0 B</td>
<td>Globally APAC 6x</td>
<td>Globally APAC 1.4x</td>
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<td>Globally 0.7 – 1.2 billion (B)</td>
<td>APAC USD 2.8–4.7 T</td>
<td>APAC 32.6 M</td>
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<td>Displacement due to climate-related disasters, 2022(^2)</td>
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<td>APAC 49.4 million (M)</td>
<td>Globally 49.4 million (M)</td>
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Data sources:
(1) Intergovernmental Panel on Climate Change, Chapter 10: Asia, in Climate Change 2022: Impacts, Adaptation, and Vulnerability, 2022;
(2) Centre for Research on the Epidemiology of Disasters, EM-DAT: The International Disaster Database, accessed in 2024;

Note: In this report, Asia-Pacific is defined as the combination of countries of the World Bank’s regions of East Asia-Pacific and South Asia.

\(^9\) Intergovernmental Panel on Climate Change, Chapter 10: Asia, in Climate Change 2022: Impacts, Adaptation, and Vulnerability, 2022.
Collectively, weather events in APAC in 2022 affected more than 50 million people directly, resulting in more than 5,000 deaths and upwards of USD 36 billion in economic losses.\textsuperscript{11} Given that global temperatures are projected to breach the 1.5-degree threshold by 2030,\textsuperscript{12} socio-economic losses will continue to increase. By mid-century, climate change impacts are expected to cause substantial annual economic losses in APAC, significantly affecting regional gross domestic product (GDP). The extent of these losses will vary across the region. Even if temperature increases are kept below 2°C (above pre-industrial levels), advanced Asian economies are expected to experience GDP losses of 3.3%; in a business-as-usual scenario, in which no mitigating action is taken, losses could reach 15.4% of GDP. In the same scenarios, the Association of Southeast Asian Nations (ASEAN) countries are expected to encounter GDP losses of 4.2% and 37.4%, respectively.\textsuperscript{13}

These impacts cut across all economic sectors and jeopardise the region’s developmental gains. More than 60% of the working population in APAC is employed in sectors like agriculture, water resources, fisheries, and construction, which are highly susceptible to livelihood disruption due to changing climatic patterns. Consider the example of the agriculture sector—one of the sectors most adversely affected by climate change both in the region and globally. APAC is projected to experience increasingly frequent and/or severe crop yield losses, soil degradation, and water stresses, to the great detriment of food availability, commodity trade, and farmer incomes. In Indonesia, the Philippines, Thailand, and Vietnam, projections for 2100 indicate that rice yields may decline to as little as 50% of 1990 levels—a critical concern for Asia, which accounts for over 90% of global rice consumption.\textsuperscript{14} Moreover, extreme heat caused by climate change could lead to a loss of up to 3.1% of all working hours in the region by 2030—roughly equivalent to the loss of 62 million full-time jobs. The agriculture and construction sectors are expected to bear the brunt of this employment loss.\textsuperscript{15} Failure to swiftly adapt to climate change could exacerbate poverty and inequality, limiting future development gains while potentially reversing progress made to date.

Efforts focused on adapting to climate impacts must take centre stage for APAC. Decarbonisation efforts are pivotal for steering us towards net zero greenhouse gas (GHG) emissions. However, while mitigation strategies primarily focus on reducing emissions, they fall short of addressing the immediate climate risks stemming from past and present emissions.\textsuperscript{16} This gap is particularly pronounced in APAC, where the tangible impacts of climate change are already intensifying existing socio-economic vulnerabilities. Despite contributing minimally to historical emissions, communities in APAC small island developing states (SIDS) bear disproportionate risks and lack the resources to respond effectively. Given the region’s heightened vulnerability, it is imperative to prioritise actions that can help the region anticipate and adapt to climate risks while pursuing its net-zero targets. Therefore, emphasising adaptation measures with mitigation co-benefits becomes essential to address climate impacts, safeguard economic growth, and enhance social well-being while building resilience against future challenges (Figure 1.2).\textsuperscript{17} Consequently, robust support from developed economies is crucial for strengthening the adaptive capacities of developing economies within APAC, considering the former’s historical contributions to the current climate crisis. This is essential for ensuring climate equity in action.

\textsuperscript{12} Reuters, \textit{Global Warming Will Reach 1.5°C Threshold This Decade - Report}, 2023. The ‘1.5-degree threshold’ refers to limiting global warming to 1.5 degrees Celsius above pre-industrial levels, as per the Paris Agreement, to avoid severe and irreversible impacts of climate change.
\textsuperscript{13} Swiss Re Institute, \textit{The Economics of Climate Change: No Action Not an Option}, 2021.
\textsuperscript{14} International Monetary Fund, \textit{Boiling Point}, 2018; Asian Development Bank, \textit{Climate Change, Rice and Asian Agriculture}, 2012.
Despite the clear need, climate adaptation remains severely underfunded. Current adaptation finance flows fall short of the need by 14–20 times for developing nations within APAC (Figure 1.3). The overwhelming majority of global adaptation finance flows from the public sector in the form of debt; in 2021–22, 70% of global adaptation finance was in the form of low-cost project debt (21%, USD 13.4 billion) and project-level market rate debt (59%, USD 37.5 billion). Approximately 98% of the total tracked flows for the same year came from public sources—primarily states, multilateral development banks (MDBs), and development finance institutions (DFIs)—while grants from philanthropies accounted for less than 1%. The proportion of philanthropic funding is likely to be even lower within APAC given the predominance of global north philanthropies in climate adaptation grantmaking. Closing this gap will require mobilisation of climate funding from local philanthropy in APAC, particularly in the form of high-risk, patient capital. Innovative financing models can spur creative solutions and demonstrate viability in adaptation across the region.

Climate adaptation also represents an opportunity. The global market for climate adaptation solutions could reach a value of USD 2 trillion annually by 2026, with the Global South poised to reap the greatest benefits.\(^{20}\) Despite demonstrated impact and, in some cases, returns of USD 2–10 for every dollar invested,\(^{21}\) capital providers often perceive adaptation projects as challenging to allocate resources to or as lacking bankability for a variety of reasons:

- **Misconception of adaptation as purely reactionary.** Adaptation is often viewed as an ex post facto response to climate change.\(^{22}\) This narrative, aggravated by limited awareness of what constitutes climate adaptation, undermines the deployment of proactive, forward-thinking adaptation measures, and hinders adequate financing for them.

- **Localised and costly nature of solutions.** Adaptation innovations often demand localised solutions that can take longer to design and implement.\(^{23}\) In these contexts, achieving effective adaptation requires high upfront funding to support on-the-ground customisation and alignment among stakeholders. This may not align with commercial investors’ risk appetite and hence requires funding from more patient and less risk-averse investors.\(^{24}\)

- **Information asymmetry on climate risks and viability.** Significant information asymmetry exists between climate experts and investors. Investors do not always understand country-level climate risks and are not familiar with vulnerability data.\(^{25}\) There is also limited research establishing the business case and impact case for adaptation investments specific to APAC.\(^{26}\)

- **Diverse and non-standardised impact metrics.** Unlike mitigation efforts, which target the singular outcome of reducing GHG emissions, adaptation actions are multifaceted, aiming to improve a range of interconnected climate and socio-economic outcomes. The benefits of these actions are often seen at hyper-local levels, which makes it challenging to measure and compare their impact with actions across different scales and locations. Due to the absence of standardised metrics, investors may hesitate to commit resources without clear evaluation criteria in place.

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22 Expert interview.
24 Expert interview.
25 World Resources Institute, *With Patchy Guidance, Companies May Have Climate Risk Blind Spots*, World Resources Institute, 2021.
Digital technologies that address adaptation challenges present an opportunity for social investors to drive the adaptation agenda. In contrast to engineered technologies, digital technologies include tools and systems designed for data handling and information management (see definition in Glossary). Broadly, these technologies streamline data collection, analysis, and communication. In the context of climate change, these tools offer powerful means to pursue scale and dynamism in driving climate adaptation and resilience outcomes for the region (Figure 1.4).
Digital innovations can help overcome existing barriers in adaptation response through a range of channels:

- **Enabling low-cost development of tailored adaptation solutions.** Crowd-sourcing platforms can enable localised data collection and participatory mapping, to ultimately inform adaptation responses to climate events like flooding.\(^{30}\) Such approaches can reduce implementation costs while enabling impact at scale. For example, Japan-based Spectee.ai deploys AI-based algorithms on social media data to identify crisis situations, such as floods or earthquakes, and send alerts through email and phones.\(^{31}\)

- **Enhancing real-time capabilities for response to climate hazards.** Real-time data collection, analysis, and enhanced decision-making facilitated by digital technologies empower swift responses in dynamic environments. Digital ecosystems additionally bridge information gaps by providing standardised data-driven insights on climate risks, thereby addressing information asymmetry for investors and enabling informed decision-making on adaptive strategies and related investments.\(^{32}\) For example, Blue Sky Analytics is a climate analytics company that utilises artificial intelligence (AI) and machine learning (ML) to analyse satellite data and provide real-time insights on climate impacts on water availability and air quality for businesses.\(^{33}\)

- **Enabling proactive solutions to climate risks through advanced predictive analytics and decision support tools.** By harnessing data-driven insights, stakeholders can anticipate and mitigate climate risks before they escalate.\(^{34}\) Taking a proactive rather than reactive approach can also help reduce financial burdens associated with loss and damage caused by extreme events. An example is Google Flood Hub, which uses AI to provide critical flood forecasting to over 1,800 sites worldwide.\(^{35}\)

The adoption of digital technology for climate adaptation is still in its early stages in APAC; yet its demonstrated impact highlights the opportunity for targeted investments. Climate tech funding has surged by a factor of 40x over the past decade; most solutions that have received financing incorporate some form of digital innovation. In 2022, investments in climate tech soared to over USD 70 billion, marking an 89% increase over the previous year. Yet, just 11% of these funds were allocated outside the USA, Europe, and China; of this portion, the majority of investments focused on mitigation.\(^{36}\) As of 2023, APAC receives just 16% of total climate tech investments globally.\(^{37}\) Given the emerging nature and potential of digital technologies in climate adaptation, targeted and customised investments are crucial to support their development and deployment. This needs to be complimented with market building across the region to fully harness their potential.

Social investors have a unique and pivotal role to play in supporting innovations in digital technologies that enable adaptation and resilience outcomes for APAC. Social investors, such as philanthropies, corporate foundations, and impact investors, have a relatively

\(^{30}\) Expert interview.
\(^{32}\) Ibid; World Economic Forum, *Innovation and Adaptation in the Climate Crisis: Technology for the New Normal*, 2024.
\(^{34}\) United Nations Economic and Social Commission for Asia and the Pacific, *Digital for Climate Change Adaptation in Asia and the Pacific*, 2021.
\(^{35}\) Google Research, *Flood Forecasting*, accessed Feb 2024.
This report serves as a toolkit for social investors to help them navigate climate adaptation challenges and sets out guidelines on investing in digital technologies for climate adaptation. In Chapter 2, we present a four-step adaptation investment framework designed to guide social investors in identifying and supporting solutions for climate adaptation that align with their programmatic areas. Chapters 3 through 5 illustrate the framework’s application, with a focus on digital innovations. Chapter 3 highlights the impacts of climate change in four major thematic areas in which APAC is particularly exposed: water, agriculture, disaster, and public health. It provides insights into the risks arising from climate change and the necessary solutions to address them. Chapter 4 highlights the status and applications of digital solutions across cross-cutting use cases aligned with the impact areas identified in Chapter 3. Finally, Chapter 5 offers actionable recommendations for social investors, outlining strategies to effectively develop and deploy digital technologies for climate adaptation in APAC that will ultimately foster sustainable and climate-resilient outcomes.

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**BOX 1.1**

**Defining social investors and investments**

**Who are social investors?**

Foundations, grantmakers, impact funds, family offices, banks, wealth management firms, private equity (PE) and venture capital (VC) funds which seek impact outcomes. This category includes impact investors.

**What are social investments?**

AVPN sees social investments as a continuum of capital; that is, the range of financial, human, and intellectual capital that are invested with the expectation of measurable results and cover the entire spectrum of social investing, from impact-only to a combination of impact and environmental-social-governance (ESG)-themed investing and financial returns to risk-minimisation through ESG screens and integration.


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CHAPTER 2
THE ADAPTATION ACTION FRAMEWORK FOR APAC
Strategic investments in climate adaptation require awareness of climate risks and the corresponding opportunities they offer. The importance of climate adaptation and resilience as central tenets of the fight against climate change has been established for more than two decades\(^{39}\); yet guidance on investing for adaptation remains sparse, resulting in incremental action and funding. Given the interconnected nature of climate impacts across different sectors, such as water and public health, it is essential to adopt a holistic approach. Taking a thematic lens provides a strong foundation for guiding investments in climate adaptation, directing resources towards climate-proofing the relevant social sectors. Additionally, leveraging cross-thematic opportunities for social investments can bring together diverse funders and stakeholders, enabling the pooling of capital and resources and driving more transformational impact.

This chapter presents a four-step approach to guide social investments in identifying and supporting digital solutions that contribute to APAC’s adaptation and resilience (Figure 2.1).

**FIGURE 2.1**

**Adaptation action framework for APAC**

1. Understand climate risks and vulnerabilities for relevant themes
2. Identify solutions for anticipating and/or adapting to the risks
3. Provide customised support to scale impactful solutions
4. Measure and communicate the impact of investments

Communicate findings on results to help refine how investors identify risks
Prioritise solutions to invest in based on their impact potential

---

\(^{39}\) The establishment of the Adaptation Fund in 2001 during COP7 was a pivotal moment in global climate adaptation and resilience efforts. This initiative, accompanied by strengthened UNFCCC support to Least Developed Countries (LDCs) in adaptation pilot projects, underscored a shift towards a unified global approach to addressing the physical impacts of climate change through strategic planning and implementation of adaptation measures.
First, social investors need to understand the climate risks that affect the impact areas they work in. This entails conducting a comprehensive assessment of regional climate risks pertinent to the social investors’ impact focus areas. The outcomes of the assessments should steer the identification and prioritisation of the most critical risks, centring on the vulnerabilities of the communities that social investors serve. Social investors should also consider realigning their focus areas in light of the evidence, and to take into account intersectionality with other issues.

For example, a South-Asian philanthropy focused on agrarian livelihoods would be remiss not to prioritise the impacts of climate change on agriculture and water resources. This involves assessing climate risks from droughts, floods, and changing rainfall patterns, which directly affect crop yields, water quality, soil health, and freshwater availability for the region. These factors in turn increase the vulnerability of smallholder farmers to income and livelihood losses due to climate change. To address these risks and support agrarian livelihoods, the social investor could prioritise support for adaptation solutions such as drought-resistant crop varieties, water-efficient irrigation techniques, and early warning systems for extreme weather events.

Next, social investors should consider what solutions—including digital technology solutions—are most relevant for anticipating and adapting to future risks. One type of solutions to consider includes those that help anticipate real-time risks, vulnerabilities, and adaptation needs within the communities affected by climate change. In this context, digital technologies act as enablers, facilitating tailored, adaptive responses through tools such as real-time flood monitoring systems at the neighbourhood level and forecast-based early warning systems for vulnerable communities. A second set of solutions leverages climate information to co-pilot or automate actions on the ground, either in anticipation of or in response to climate impacts. For example, Internet of Things (IoT)-enabled irrigation technologies can automate watering cycles on drought-prone farmlands to improve water management efficiency and reduce farmers’ workloads, particularly during periods of extreme temperatures.

In identifying which solutions to support, social investors can incorporate parameters based on their investment approaches. For instance, AVPN’s APAC Sustainability Seed Fund, with the support of Google.org and the Asian Development Bank, evaluates projects based on three key parameters—innovation (both novel approaches and innovative applications of existing approaches), feasibility and track record of success, and potential for scale especially in serving marginalised populations. In doing so, the fund actively responds to on-ground needs of the affected communities in both defining the problem and the solution.

Once solutions are prioritised, social investors can tailor their support in accordance with preferences for impact and financial returns. Climate adaptation innovations require a diverse range of social investment types as they progress from development to deployment stages. Grant funding from philanthropies, corporate office foundations, and other investors is useful for supporting early product development of innovative climate solutions. A combination of grants and concessional debt can support the testing and validation of promising initiatives through location-specific pilot projects. Philanthropies, multilateral institutions like MDBs and DFIs, and impact investors, who prioritise social impact creation over significant financial returns, can provide this funding mix. Impact-focused venture capitalists
and other return-seeking investors can then support the scaling of those impactful solutions that show early commercial promise. Additionally, philanthropies and multilateral institutions could also play a part at this stage by de-risking investments for return-seeking investors. For instance, they can provide concessional debt and first-loss guarantees to demonstrate the commercial viability of early-stage solutions through innovative finance approaches, such as blended finance.

Concurrently, social investors should also spearhead ecosystem-building initiatives such as policy advocacy, capacity building, and knowledge transfer, in order to build a conducive environment within which solutions can take shape (see Chapter 5 for further discussion on ecosystem building). The type of ecosystem support required for each solution depends on its nature, development stage, and impact potential, as well as the policy environment and market dynamics in which it operates. Often, a single solution may necessitate various forms of support.

Finally, assessing impact using consistent approaches is essential for understanding and communicating the effectiveness of adaptation investments. Understanding the impact of adaptation investments presents a complex challenge for several reasons. First, adaptation initiatives address a diverse range of development and climate outcomes, often measurable only at hyper-local levels. Second, a lack of consensus on the definition of climate adaptation and its impact pathways has resulted in the proliferation of multiple impact measurement frameworks and approaches, each rooted in differing perspectives and priorities. Finally, there is an inherent challenge in designing measurement and reporting frameworks that are both adaptable to local conditions while remaining compatible with other related impact measurement frameworks.

40 Next Billion, The Emergence of ‘Resilience Credits’: How a New Asset Class Can Unlock Investment in Climate Resilience — And Why Impact Measurement Will be Key to its Success, 2024.
The development and deployment of clear and appropriate impact measurement methods is imperative for mobilising and harmonising investment.\(^{41}\) This can enable a shared understanding of results and ensure consistency and comparability across different programmes, regions, and investment categories. Further, by enabling the aggregation of impact achieved by diverse actors, it can also facilitate the monitoring of progress toward regional and global commitments, such as those outlined in the Sharm-El-Sheikh Adaptation Outcomes for 2030.\(^{42}\)

For example, within the private sector, 60 Decibels has developed a proprietary household-level resilience measurement tool, aimed at directing climate investments for social enterprises.\(^{43}\) This tool offers a streamlined approach to resilience measurement using standardised metrics applicable to diverse households, farming communities, and non-agricultural settings, with consistent resilience indicators that enable comparisons between various evaluations. This tool is an example of best practices and frameworks that social investors would need to adopt to ensure transparency and accountability in quantifying the impact of their adaptation investments.

The adaptation action framework below (Figure 2.2) summarises the steps described above. The chapters that follow utilise this framework to provide insights and guidance to social investors interested in investing in digital technologies to support climate adaptation in APAC.\(^{44}\)

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\(^{41}\) According to the findings of the Global Adaptation and Resilience Investment (GARI) working group, investors consider clear metrics as important to drive investments in adaptation and resilience, with a significant 67% recommending the development of metrics for resilience. GARI working group, *The State of Climate Adaptation and Resilience Investment: Where We Are, Current Investor Views, and Paths Forward*, 2022.


\(^{44}\) The scope of this report’s findings is limited to the first three steps of the framework.
**Adaptation action framework for APAC (expanded)**

1. Understand climate risks and community impact (illustrative)

2. Identify solutions

3. Support scale

4. Measure impact

Communicate findings on results to help refine how investors identify risks

Prioritise solutions to invest in based on their impact potential

<table>
<thead>
<tr>
<th><strong>A</strong> Identify relevant climate hazards</th>
<th><strong>B</strong> Map climate risks and community-level impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extreme weather events</strong></td>
<td><strong>Agroecology</strong></td>
</tr>
<tr>
<td>Floods, Droughts, Heatwaves</td>
<td>Dwindling crop yields owing to changing climatic conditions, including frequency of high heat.</td>
</tr>
<tr>
<td></td>
<td>Reduced crop health and nutritional levels because of warmer temperatures.</td>
</tr>
<tr>
<td></td>
<td>Anticipation of local climate risks and vulnerabilities</td>
</tr>
<tr>
<td></td>
<td>Identify solutions that predict or monitor real-time risks, tailored to specific community vulnerabilities.</td>
</tr>
<tr>
<td></td>
<td>Climate analytics often serve as enablers of other solutions.</td>
</tr>
<tr>
<td><strong>Slow onset events</strong></td>
<td><strong>Water</strong></td>
</tr>
<tr>
<td>Sea-level rise, Biodiversity loss</td>
<td>Reduced water availability due to droughts, rising temperatures, and saltwater intrusion into aquifers.</td>
</tr>
<tr>
<td>Glacial retreat, Sea level rise</td>
<td>Increased flooding caused by extreme rainfall events, cyclones, storm surges, and sea level rise.</td>
</tr>
<tr>
<td></td>
<td>E.g., limited resources prevent smallholder farmers from adapting to climate shifts, affecting crop yields and livelihoods.</td>
</tr>
<tr>
<td></td>
<td>Financial interventions</td>
</tr>
<tr>
<td></td>
<td>Provide appropriate financial instruments, e.g., grants, debt, equity, including innovative finance mechanisms where appropriate.</td>
</tr>
<tr>
<td></td>
<td>Measurement of solution-level impact</td>
</tr>
<tr>
<td></td>
<td>Adopt best practices to measure and report the impact of promising solutions.</td>
</tr>
<tr>
<td></td>
<td>Credible impact measurement can boost provider accountability and enable learning for other providers.</td>
</tr>
</tbody>
</table>

**Consensus on measurement standards**

| **Adaptation to climate impacts** | **Ecosystem building** |
| Identify solutions that co-pilot or support communication for on-the-ground implementation of adaptation measures, often utilising climate analytics as inputs. |
| Foster an enabling environment in which innovations can succeed. E.g., via: |
| • Policy advocacy |
| • Capacity building |
| • Knowledge exchange |

| **Co-develop consistent taxonomies and standards to assess impact.** |
| Unified systems of measurement enable consistent assessment and comparison |

| **Disasters** | **Public health** |
| Increased loss of life and property due to rising frequency and magnitude of climate-related disasters. | Increased frequency and spread of infectious diseases, due to shifts in habitat and seasonality for vectors. |
| | Higher fatality rates from NCDs including respiratory illnesses and heat strokes. |
| | E.g., people with special needs and the elderly are particularly vulnerable due to limited mobility and access to resources. |
| | E.g., elderly and children face heightened health risks, particularly from heat-related illnesses and poor air quality. |

*This framework highlights risks for the thematic areas covered in this report and is not exhaustive. According to IPCC, climate risks must be understood at the intersection of three factors: (i) hazard – refers to potential natural or human-induced climate events and chronic changes in weather patterns, (ii) exposure – factors through which an individual or system is exposed to climatic variations, e.g., infrastructure quality, livelihood type, proximity to at-risk geographical features such as coastlines, etc., and (iii) vulnerability – factors that predispose a person or system to risk, e.g., demographics, socio economic status, resilience of supply chains, etc. Vulnerability and exposure interact with hazards to generate risk and can be exacerbated by factors like poverty and lack of social support, regardless of the specific hazard (Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change).*
PRESSING CLIMATE RISKS AND TECH SOLUTIONS ACROSS KEY THEMES

CHAPTER 3

PHOTO BY RITTHICHAI

HARNESSING THE POWER OF DIGITAL TECHNOLOGIES FOR CLIMATE ADAPTATION
This chapter explores the intersection of climate impacts and digital technology solutions relevant to APAC by focusing on four key thematic areas—agriculture, water resources, disaster management, and public health. It highlights climate vulnerabilities within each of these thematic areas, their influence on well-being for populations that depend on them, and the role of technology in improving resilience in each area. Many other thematic areas are similarly affected by climate change in APAC, and the four themes profiled here represent only an illustrative starting point for addressing the knowledge gap among climate tech innovators and social investors in APAC.

45 The selected themes largely align with the priority adaptation themes for the region, as communicated to the UNFCCC through National Adaptation Plans and Technology Needs Assessments, 2020.
Agriculture accounted for 17% of the total GDP in South Asia in 2022—four times the world average—and is critical to ensuring food security.46 Across Asia, over 2.2 billion people rely on agriculture for their livelihoods.47 This is especially pressing for countries such as Cambodia and Myanmar, where over 60% of the population make their living in agriculture and forestry.48

Climate change impacts food systems through multiple pathways, reduced productivity due to altered precipitation patterns, soil degradation, and heat stress; yield loss due to increased prevalence of pests and diseases; interrupted production and supply chains due to natural disasters; and reduction of crops’ nutritional value (Figure 3.1).

First, climate variability can reduce crop, labour, and livestock productivity from altered precipitation patterns, soil quality degradation, and heat stress. Compared to 2010, total crop yields are expected to diminish by 18% by 2050 in South Asian countries.49 Shifts in rainfall patterns directly impact crop productivity, as rainfed farming produces more than 60% of the world’s cereal grains.50 Increased heat stress from more frequent and intense annual hot days significantly further contributes to declines in crop productivity by impacting agricultural workers.

In regions like sub-Saharan Africa and Southeast Asia, a global warming increase of 3 degrees could reduce labour capacity in agriculture by 30%-50%.51 Temperature increases and shifts in precipitation patterns also irreversibly change soil quality and threaten the health of livestock. In addition, anthropogenic pressures stemming from heightened use of agrochemicals, particularly inorganic fertilisers and pesticides, exacerbate the deterioration of soil fertility. In Sri Lanka, where farmers have been found to surpass recommended agrochemical application rates specified on labels, 61% of agricultural land grapples with diminishing soil quality.52

These climate and environmental risks can be addressed with improved water and soil monitoring, alongside more efficient irrigation and soil conservation practices. For example, the utilisation of solar water pumps allows for greater water availability and prevents water competition among smallholder farmers, improving overall productivity.53

Similarly, real-time heat stress detection can alert farmers to take suitable preventive measures, including enhanced ventilation and cooling with sprinklers to avoid reduction in livestock productivity.

49 The Chinese University of Hong Kong, *CUHK-led Study Estimates Over One-fifth of Staple Crops Will Be Lost by 2050 Due to Ozone Pollution and Climate Change*, 2023.
Increased prevalence of pests and diseases is already causing up to 41% yield loss in rice in Asia and affects other crops and livestock.\textsuperscript{54} Climate change has expanded some plant pests’ host range and geographical distributions—due, for example, to changes in temperatures, precipitation, and humidity levels—leading to increased infestations and hence, reduced yield. Additionally, climate change affects the conditions for pathogens and vectors of zoonotic diseases, impacting the health of both crops and livestock. The transmission of zoonotic diseases among livestock is a significant public health concern, considering the region’s high reliance on livestock-based products. At a farm-level, the emergence and spread of such diseases result in direct and indirect losses for farmers by introducing adverse shocks that affect overall farm productivity.\textsuperscript{55} Technology ventures are employing AI, drones, and remote sensors to provide farmers with precise pest detection and prediction. This also includes the use of sensors to monitor ambient temperature and related conditions that might result in their spread, enabling early adaptation measures.

Natural disasters lead to interrupted agricultural production and disrupt supply chains. For example, floods account for over 70% of supply chain losses in China, where agriculture incurs 18% of the total indirect loss.\textsuperscript{56} In addition to the disruptions to on-farm productivity and harvest schedules, climate change can reduce the efficiency of existing infrastructure to support post-harvest activities, such as storage and transportation of produce. The disruption of supply chains has cascading socio-economic effects, impacting jobs and incomes of individuals employed within the agricultural value chain.\textsuperscript{57} To address such risks, supply chain systems need upgrades to improve their predictions of and ability to adapt to disruptions. Start-ups are increasingly investing in AI and cloud-based digitisation of farm production data to support supply chain operations.

As levels of atmospheric carbon dioxide climb, reductions in the nutritional value of major cereals and vegetables are expected by 2050—up to 10% for zinc, 5% for iron, and 8% for protein—exacerbating health issues.\textsuperscript{58} The decrease in crop nutritional value affected 465 million undernourished individuals in 2021, comprising 55% of the global undernourished population.\textsuperscript{59} Such events directly affect the nutritional well-being of populations in APAC, where two-thirds of the world’s poor reside. To address this, some companies are using AI to improve the identification and development of more nutritious crop and livestock breeds. Researchers are also using AI to identify genetic segments with preferred traits to develop superior crop varieties and are combining this with speed breeding technology to turn over multiple generations quickly.\textsuperscript{60}

\textsuperscript{56} Siyi Wei, Qi Zhou, Zi Qin Lou, Yunlei Shi, Qian Li Wang, Jia Yang Chen, Shen Qu, Yiming Wei, Economic Impacts of Multiple Natural Disasters and Agricultural Adaptation Measures on Supply Chains in China, 2023.
\textsuperscript{57} Anamika Malik, Mengyu Li, Hanfred Lenzen, Jacob Fry, Naveda Liyanapathirana, Kathleen Beyer, Sinad Boylan, Amanda Lee, David Raubenheimer, Arne Geschke, Mikhail Prokopenko, Impacts of climate change and extreme weather on food supply chains cascade across sectors and regions in Australia, 2022.
\textsuperscript{58} Harvard School of Public Health, Climate Change & Nutrition, 2023.
\textsuperscript{60} Queensland Alliance for Agriculture and Food Innovation, Turning Big Data into Better Breeds and Varieties: Can AI Help Feed the Planet?, 2023.
### Climate risks and digital solutions in agriculture and food security

<table>
<thead>
<tr>
<th>Issue areas</th>
<th>Impact of climate change</th>
<th>Digital technology needs</th>
<th>Examples of digital solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity loss due to input disruptions</strong></td>
<td>Reduced crop and livestock productivity due to reduced precipitation and water availability for agricultural use</td>
<td>• Real-time and remote monitoring of water and soil erosion rates • Remote sensors to monitor water levels and soil moisture • IOT-based sensors to improve irrigation efficiency (e.g., smart water pump)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced crop yields due to changes to soil quality</td>
<td>• Real-time and remote monitoring of water and soil monitoring • Improved irrigation and water use efficiency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduced crop yields and livestock productivity due to heat stress</td>
<td>• Real-time detection of heat stress • Auto cooling system via shade, ventilation, etc.</td>
<td>• Remote sensors to detect heat stress • Automation devices to manage heat stress in farm systems</td>
</tr>
<tr>
<td><strong>Productivity loss due to disease and disasters</strong></td>
<td>Loss of crops and livestock due to extreme weather events (incl. flooding)</td>
<td>• Prediction and early warning systems • Detection of pests, disease, and disaster events • Flood control and pest and disease management</td>
<td>• AI-enabled weather and disaster forecast • Drone-based disease/pest detection • Crowd reporting on disease and pests • Remote sensor and phone early warning for disaster, disease, and pests</td>
</tr>
<tr>
<td></td>
<td>Increased incidence of pests and diseases in crops and livestock</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Disruption to supply chains</strong></td>
<td>Increased complexity and cost of logistics due to climate disaster and change in production</td>
<td>• Real-time data collection and optimisation models to secure agro-food supply chains during disasters</td>
<td>• AI / cloud-based digitization of farm production data and supply chain operation</td>
</tr>
<tr>
<td></td>
<td>Reduction in crop nutrition due to climate change</td>
<td>• Improved crop and livestock breed with higher nutritious value</td>
<td>• AI-powered crop and livestock breed research</td>
</tr>
<tr>
<td><strong>Nutritional value loss</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Water availability in East Asia and the Pacific is 20% lower than the global average and 80% lower in South Asia. This impacts key livelihood outcomes in terms of food security, public health, and income-generation opportunities. Climate change can further exacerbate the scarcity of water resources in APAC by reducing overall water availability and lowering water quality (Figure 3.2).

Frequent climate events increasingly jeopardise water security. The worst droughts in South Asia are projected to occur 1.5 times more frequently in 2035–2100 compared to the previous century. Climate change also intensifies rainstorm patterns, leading to increased rainfall intensity and frequency. This poses a threat to water storage facilities, such as reservoirs, which may struggle to cope with the sudden influx of water. Consequently, the stable provision of water to communities can be compromised, further exacerbating the challenges surrounding water security in the region. To address these challenges, climate tech innovators are leveraging remote sensing, the IoT, and cloud computing to support the monitoring of water levels. Companies have also started using AI to support more accurate predictions of rainfall. With these insights, farmers and other water users can better manage water usage and reduce wastage.

In addition to the lack of water security, the quality of available water in APAC is also threatened by rising sea levels and unregulated wastewater discharge. Rising sea levels can lead to salinisation of freshwater resources, making them unfit for consumption and agricultural use. Since 2010, South Asia has already experienced an 11% reduction in freshwater resources. Furthermore, unregulated wastewater discharge is a significant contributor to the degradation of water quality in the region. Inadequate wastewater treatment systems and industrial pollution discharge lead to waterborne diseases and other public health concerns. To address these challenges, companies are using sensors to improve the monitoring of water quality; meanwhile, citizens are able to help prevent pollution at source by using mobile apps to report illegal wastewater discharge. Moreover, some companies are directly improving water quality in APAC through the use of robotics to remove waste from water bodies.

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61 Water availability is assessed based on ‘Renewable internal freshwater resources’, comprising yearly river flows and groundwater replenishment, accessible for domestic, agricultural, and industrial uses. This metric represents the maximum theoretical yearly amount of water available for a particular region at a given moment. World Bank, Renewable Internal Freshwater Resources Per Capita (Cubic Meters), 2023.


63 World Bank, Renewable Internal Freshwater Resources Per Capita (Cubic Meters), South Asia, 2023.

### Climate risks and digital solutions in water resources

<table>
<thead>
<tr>
<th>Issue areas</th>
<th>Impact of climate change</th>
<th>Digital technology needs</th>
<th>Examples of digital solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water security</td>
<td>Altered precipitation patterns and increased evaporation rates contribute to a decline in surface water availability</td>
<td>• Dynamic water resource monitoring</td>
<td>• Remote sensing-based real-time monitoring of surface and sub-surface water flows</td>
</tr>
<tr>
<td></td>
<td>Shifting aquifer recharge patterns lead to unpredictable and unreliable groundwater availability</td>
<td>• Predictions for water-related extreme events such as floods and droughts</td>
<td>• Cloud-based stormwater monitoring and management systems</td>
</tr>
<tr>
<td></td>
<td>Unpredictable, heavy rainfall events and glacial melting contribute to increased risks of inland flooding</td>
<td>• Efficient water usage systems</td>
<td>• IoT-based automated leakage control systems</td>
</tr>
<tr>
<td></td>
<td>Storm surges, rising sea levels, and intensified cyclones elevate the likelihood of coastal flooding</td>
<td>• Flood monitoring, including community-based flood reporting systems</td>
<td>• Satellite imagery and Geographic Information Systems (GIS) for watershed mapping and planning</td>
</tr>
<tr>
<td>Water quality</td>
<td>Climate-induced migration fosters unchecked urbanization, resulting in unregulated wastewater discharge</td>
<td>• Flood forecasting prediction and prediction</td>
<td>• AI algorithms for real-time flood prediction and early warning</td>
</tr>
<tr>
<td></td>
<td>Saltwater intrusion (accompanied by untreated discharge) affects freshwater sources and compromises water quality</td>
<td>• Tools for nature-sensitive watershed planning</td>
<td>• Community-based risk assessments and open mapping</td>
</tr>
<tr>
<td></td>
<td>Hurricane impacts lead to increased risks of coastal flooding</td>
<td>• Monitoring of wastewater discharges</td>
<td>• Sensor networks for continuous monitoring of effluent quality</td>
</tr>
<tr>
<td></td>
<td>Storm surges, rising sea levels, and intensified cyclones elevate the likelihood of coastal flooding</td>
<td>• Dashboards for freshwater quality</td>
<td>• Robotics for waste removal from water bodies</td>
</tr>
<tr>
<td></td>
<td>Saltwater intrusion (accompanied by untreated discharge) affects freshwater sources and compromises water quality</td>
<td>• Digitally enabled waste management</td>
<td>• Mobile app for reporting and tracking environmental violations</td>
</tr>
</tbody>
</table>
Climate disasters resulted in an estimated USD 67 billion in economic losses in APAC in 2022; under a scenario of 2°C warming, the region's estimated annual losses could reach USD 1 trillion.\(^{65}\)

The intensification of climate disasters drives three primary risks in disaster management. First, disaster forecasting becomes increasingly complex and uncertain. Second, communities and infrastructure systems face increasing stress from exposure to failure. Third, disaster response systems are stretched thin as the need for them grows (Figure 3.3).

Prediction of disasters is becoming more complex due to climate change, which brings uncertainties to the seasonal patterns of events like hurricanes, floods, droughts, and storms.\(^{66}\) Climate change is shifting long-established weather and climate patterns; for example, it is making India's monsoon more erratic.\(^{67}\) Unpredictable weather events can devastate even the most developed cities; in April 2024, a slow-moving storm in the United Arab Emirates brought an unprecedented amount of rain, surpassing a year's worth of rainfall in just one day. This record-breaking deluge resulted in flash floods that disrupted transportation and temporarily halted flights at Dubai International Airport, one of the busiest airports globally. The UAE's National Centre for Meteorology reported that the eastern regions received up to 250 millimetres (10 inches) of rain in less than 24 hours, close to two times its typical annual rainfall.\(^{68}\) Innovations are increasingly relying on localised, real-time weather monitoring and AI-based forecasting to improve the detection and prediction of disasters.

Communities and infrastructure systems are also increasingly at risk for damage as climate disasters grow in intensity and frequency, and occur in previously unaffected regions, undermining the ability to effectively anticipate and respond to climate-related events. The Asian Development Bank estimates that USD 26 trillion are needed to improve infrastructure resilience across the region.\(^{69}\) The need to build and fortify infrastructure in the face of stronger and unprecedented disasters is especially challenging for the urban poor, who generally live in the least maintained districts, and for rural communities that reside in overexposed areas with limited support.\(^{70}\) Technologies that detect vulnerabilities in infrastructure and community resilience are crucial in addressing these challenges by facilitating targeted reinforcement and development of infrastructure.

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\(^{66}\) Asian Disaster Reduction Center, Natural Disaster Data Book, 2022.

\(^{67}\) IndiaSpend, Climate Change Is Making India's Monsoon More Erratic, 2021.

\(^{68}\) NASA, Deluge in the United Arab Emirates, accessed April 2024.

\(^{69}\) Asian Development Bank, Disaster-Resilient Infrastructure Unlocking Opportunities For Asia And The Pacific, 2022.

\(^{70}\) Eco-business, South Asia's Poorest City Dwellers Bear Brunt of Worsening Floods, 2022; UNESCAP, Disaster Resilience for Sustainable Development, 2017.
Disaster response systems are severely strained and in urgent need of expansion. Several regions in APAC face significant fiscal and personnel constraints in their ability to plan and execute disaster management strategies due to limited state capacity. The costs associated with climate-related extreme events further exacerbate this deficit, reducing the efficacy of disaster response systems to accommodate the rising frequency and magnitude of disasters. For instance, 250 buildings collapse annually in Mumbai due to heavy rainstorms, but the government has yet to develop an effective communication protocol that can enable rapid response and build awareness to prevent future incidents. Technology can be leveraged to inform the public about such risks, adaptation measures, and the urgency of addressing vulnerabilities. Countries such as Bangladesh have improved their weather forecasting capability; however, challenges remain in disseminating information to at-risk communities with enough lead time to take early action. The same communication barriers persist in post-disaster scenarios, affecting rapid response and recovery. Disaster tech innovations are leveraging app-based alerting systems to help improve outreach and response time for communications in disaster-prone areas.

72 United States Agency for International Development, Strengthening Household Ability to Respond to Development Opportunities (SHOUHARDO) III Programme of Care Bangladesh, 2021.
### Climate risks and digital solutions in disaster management

<table>
<thead>
<tr>
<th>Issue areas</th>
<th>Impact of climate change</th>
<th>Digital technology needs</th>
<th>Examples of digital solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Disaster prediction and forecast</strong></td>
<td>Increased complexity and uncertainty in weather data and patterns</td>
<td>• Improved monitoring of weather patterns</td>
<td>• AI and machine learning algorithms to forecast future disasters</td>
</tr>
<tr>
<td></td>
<td>Shifts in disaster pattern in intensity, frequency, and geographical distribution of disasters</td>
<td>• Improved climate data collection and analytics</td>
<td>• Remote sensors for detecting sea levels and ocean activity</td>
</tr>
<tr>
<td></td>
<td>Increased exposure of infrastructure assets to disaster-related risks</td>
<td>• Improved prediction methods</td>
<td>• Satellite-based disaster detection</td>
</tr>
<tr>
<td></td>
<td>Increased community vulnerability in previously less-affected areas</td>
<td>• Improved detection of vulnerability in infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shift in climate zone and change in temperature and weather pattern</td>
<td>• Improved detection of weather patterns</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Satellite mapping to detecting vulnerable infrastructure and community</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Phone-based community support during infrastructure failure</td>
<td></td>
</tr>
<tr>
<td><strong>Disaster resilience</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increased demands to emergency response capacity and logistics</td>
<td>• Increased communications efficiency and effectiveness</td>
<td>• Mobile phone-based early warning system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Improved disaster response management, incl. supply chain</td>
<td>• Mobile app-based disaster response for victims and early responders</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• AI / ML algorithms for improving supply chain management</td>
</tr>
<tr>
<td><strong>Disaster response</strong></td>
<td>Increased stress to post-disaster recovery and reconstruction</td>
<td></td>
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</tbody>
</table>
Wide health outcome disparities across APAC are emblematic of inequality across the region. For example, the maternal mortality ratio in lower-middle- and low-income APAC countries is more than four times that of upper-middle income countries in APAC, and 14 times that of high-income APAC countries.\(^73\) Such disparities can be attributed to a combination of factors, from socio-economic inequality, to limited access to healthcare services, to inadequate healthcare infrastructure. Climate-related hazards threaten to further exacerbate risks to marginalised communities that already experience high vulnerability and exposure.

Climate risks that impact public health are spread across two broad areas: First, risks to human health, including rising incidence of infectious disease, non-communicable diseases (NCDs), physical and mental trauma, and malnutrition and dehydration. Second, reduced health system delivery capacity to health infrastructure, supply chains, and workforce (Figure 3.4).

In the first category, how infectious diseases spread is changing as weather patterns and changes in habitat affect the ways vectors such as ticks and mosquitos reproduce and interact with humans. The transmission of dengue, for instance, grew by 12% between the 1950s and 2010s due to climate change.\(^74\) In South Asia, the population at risk of malaria infection is estimated to increase by 134 million by 2030.\(^75\)

Rising incidence of NCDs is also closely linked to climate change. Air and water pollution and exposure to heat waves can cause or aggravate a range of NCDs, such as anaemia, stroke, pulmonary disorders, cancer, cardiovascular disease, and diabetes.\(^76\) More than 6.5 million annual deaths are attributed to air pollution, of which over 70% occur in APAC.\(^77\) Innovators have addressed these challenges with air quality and temperature monitoring mechanisms, integrated with surveillance systems that can better predict health risks. Governments can use these insights to develop more targeted policies and regulations to reduce pollution from hotspots or high-polluting activities. Telehealth platforms in APAC emerged during the COVID pandemic as triage for in-person services, including for NCDs, with great success—nearly 80% of users of one such platform were able to solve their medical issues through teleconsultations, thereby reducing the spread of infection at health centres.\(^78\)

\(^{74}\) The Lancet Infectious Diseases, Twin Threats: Climate Change and Zoonoses, 2023.
\(^{75}\) Forecasting Healthy Futures, Advancing the Discipline of Climate-Informed Malaria Prediction and Planning, and Supporting its Integration in Malaria Control Programmes Worldwide, accessed Feb 2024.
\(^{76}\) State of Global Air, Global Health Impacts of Air Pollution, accessed March 2024; WHO, Climate Change and Noncommunicable Diseases: Connections, 2023
\(^{77}\) UNEP, Restoring Clean Air, accessed Jan 2024.
Climate risks have caused widespread physical and mental trauma across APAC. This can occur through direct injury, such as during disasters like floods, landslides, cyclones, lightning strikes, avalanches, heat waves, and tropical storms. For example, since 1992, extreme heat has killed more than 24,000 people in India,79 and have led to at least 90 deaths across India and Pakistan in 2022 alone.

Secondary trauma is also a significant driver of impact, including on mental health, community conflict, and gender-based violence. Extreme weather events, displacement, loss of livelihoods, and social unrest can directly impact challenges such as anxiety, depression, grief, post-traumatic stress disorder, substance abuse, and aggression.80 Farmer suicides are a well-documented example of the consequences of economic hardship from drought-induced crop failure.81 A recent study in South Asian countries observed that each 1°C increase in annual mean temperatures is associated with a mean increase in domestic violence prevalence of 4.4%.82 Even in comparably high-income communities, climate-related events play a role in mental health—for example, a 2022 study found that 21% of Australians who experienced climate-related disasters reported having a moderate to major impact on their mental health.83 Digital tools that help individuals gain access to information to plan, adapt, and access resources prior to and in the aftermath of climate-related disruptions can help reduce these secondary impacts. Some companies are also developing AI tools that offer mental health support at lower costs to bridge care gaps as wider populations seek support.84

Malnutrition and dehydration are closely linked with changes in weather patterns, resulting in disrupted food systems and water security, especially for marginalised communities. See sections on Agriculture and food security and on Water for further discussion.

In the second category of impact, climate change impacts healthcare delivery capacity in several critical ways. The increased frequency and severity of extreme weather events result in damage to healthcare infrastructure and disruption to sensitive supply chains, such as those for blood supply or pharmaceutical product stability. For example, seasonal flooding is a common occurrence in Cambodia, especially in provinces like Stung Treng and Kratie, where 31% and 20% of health facilities respectively are at risk of annual flooding.85 Moreover, healthcare workers are not only disproportionately exposed to direct climate-related hazards such as heat waves, or while working in disaster zones or on infectious disease outbreaks, but are also under increased strain as overall workloads rise in response to the rising incidence of health risks described above. This is especially acute during climate emergencies that cause surges in demand. Many health system administrators already rely on digital tools to enable risk monitoring, service delivery optimisation, and resource allocation; these tools will need to be resilient to increasing volatility as system outages and spikes in demand become more common.

80 Intergovernmental Panel on Climate Change (IPCC), Synthesis Report of the IPCC Sixth Assessment Report, 2023; World Health Organization (WHO), Mental Health and Climate Change, Policy Brief, 2022; Wellcome, Explained: How Climate Change Affects Mental Health, 2022.
82 Down to Earth, Domestic Violence to Rise as Subcontinent Heats Up, 2023.
84 Wysa, Mitsu
# Climate risks and digital solutions in public health

<table>
<thead>
<tr>
<th>Issue areas</th>
<th>Impact of climate change</th>
<th>Digital technology needs</th>
<th>Examples of digital solutions</th>
</tr>
</thead>
</table>
| Infectious diseases                  | Changes in the geography, seasonality, and incidence of bacteria and vector-borne and zoonotic diseases | • Air quality, precipitation, temperature monitoring, and nutrition tracking for agro-businesses and consumers  
• Predictive risk mapping, and syndromic surveillance  
• Improved access to digital diagnostic tools for climate-health impacts | • Remote sensors for hyperlocal mobile air quality monitoring  
• AI-assisted imaging for early diagnosis and treatment of health risks  
• AI-based digital genome sequencing  
• ML-powered symptom outbreak recognition software  
• Personalised e-assistant apps for monitoring nutritional intake |
| Non-communicable diseases            | Increased exposure to pollutants (e.g. via air and water)                                |                                                                                         |                                                                                               |
| Physical and mental trauma           | Rising incidence of weather-induced stressors, e.g., heat waves                           | • Predictive hazard mapping; algorithms to understand mental health risks  
• Real-time weather monitoring; data on climate-related health impacts during crisis  
• Communication networks for public safety and disaster response  
• Digital platforms for care provision | • Real-time climate-health analytics dashboards  
• AI-powered predictive models for identifying vulnerable populations and prioritising interventions  
• 5G-based geo-targeted multichannel citizen reporting and alerts  
• IOT-based sensors to monitor industrial safety and hygiene |
| Malnutrition / dehydration           | Direct injury and death due to extreme events (see Disaster management section)           |                                                                                         |                                                                                               |
|                                        | Incidence of secondary trauma, e.g. on mental health, community conflict and gender-based violence following extreme events, displacement, loss of livelihood, financial burdens, etc. | • Early warning systems for at-risk facilities  
• Optimisation models for service delivery  
• Digital healthcare services | • Mobile health (mHealth) applications for remote patient monitoring and teleconsultation  
• ML-powered and geotagged resource allocation optimisation |
| Health system delivery capacity       | Disrupted food systems and water security (see sections on Agriculture and food security, and Water) |                                                                                         |                                                                                               |
|                                        | Damage to health infrastructure and supply chains due to extreme events                    |                                                                                         |                                                                                               |
|                                        | Heightened health workforce exposure to poorer work conditions (e.g. heat), demand spikes during disasters, and higher ongoing utilisation |                                                                                         |                                                                                               |
This chapter spotlights high-potential use cases where digital technologies can strengthen climate adaptation and resilience across APAC. It outlines five promising use cases of digital technologies for climate adaptation and showcases specific applications within each. It offers insights into the technological development status and deployment across APAC. Each use case section compares global advancements with region-specific examples in APAC, emphasising the role of social investments and the gaps they can help fill.
Emerging digital technology use cases

We see five broad categories of digital technology use cases that can address the risks identified in the previous chapter (Figure 4.1).

Each use case varies in the level of maturity of the underlying technology and deployment in APAC. The following sections offer detailed insights into each of the use cases. Based on the technical readiness levels (TRLs) of the applications within each, we categorise these use cases as high, medium, or low in terms of technological readiness. Similarly, we rate the deployment status of technical applications across APAC based on the number of companies developing these applications in the region. To help social investors understand the significance of these technologies, each application is illustrated with a real-life example of a company operating within APAC and its potential impact.

Technical readiness level (TRL) is a measure assessing the maturity of a technology, ranging from concept (TRL 1) to deployment and operation (TRL 9). TRLs for various applications have been sourced from the World Intellectual Property Organization Green Database, a global innovation catalogue that includes user uploads, patented technologies, and expert profiles. In cases of unavailable TRL information, we conducted qualitative research to determine technology maturity at the use-case level.
Use cases of digital technologies for climate adaptation

<table>
<thead>
<tr>
<th>Digital tech use case</th>
<th>Description</th>
<th>Examples of digital technologies</th>
</tr>
</thead>
</table>
| Weather forecasting and modelling        | Accurate predictions and insights on changing weather patterns and climate conditions | • Satellite-based drought forecasting systems  
• Drone-based hyper-local weather forecasting |
| Resource monitoring and management        | Monitoring and managing crucial resources, including land and water, to inform sustainable practices | • ML and genomics for soil health analysis  
• Blockchain-based water ledgers |
| Disaster preparedness and response        | Advanced systems for early warning, preparedness, and efficient response to climate-related disasters | • AI and ML algorithms to forecast future disasters  
• App-based flood alerts utilising real-time crowd-sourced data |
| Agricultural optimisation                | Precision agriculture technologies that sense and automate on- and off-farm activities | • AI-powered automation to improve irrigation efficiency  
• IoT-based crop health monitoring |
| Climate and health intelligence systems  | Integrated climate and health information to predict, prevent, and respond to climate-related health risks | • Real-time dashboards for heat waves  
• ML-powered symptom outbreak recognition |
Based on Tracxn database, as of Jan 2024. The figures presented pertain to commercial capital including venture capital (VC) and private equity (PE) investments in climate technology. This excludes philanthropic or public financing, as available data on public finance for adaptation technologies lack appropriate tagging for digital tech. The figure aims to highlight the commercial readiness of the use case globally and in APAC, emphasising the volume dimension of private capital attracted to date. We distinguish China from the rest of the region due to its concentrated investor base and substantial domestic investments in climate adaptation technologies.

Despite demonstrating commercial viability in specific geographies such as Japan, Indonesia, and India, APAC continues to receive less than 5% of global commercial investments. Additional capital is crucial to scaling up existing commercial models, and testing is needed to validate advanced applications across the region.
### Overview of applications

<table>
<thead>
<tr>
<th>Regional weather monitoring and forecast</th>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focuses on analysing regional weather trends and patterns, utilising technologies such as satellites, weather stations, and geographic information system (GIS) analytics. Provides comprehensive insights for long-term planning and adaptation at regional scales.</td>
<td>Wasm, a Jordanian company, analyses regional weather patterns using satellite data and a digitally connected network of weather stations.</td>
<td>Impact: Allows clients to save up to 70% of their yearly costs associated with weather, with forecasting accuracy of up to 80%.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hyper-local weather information systems</th>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generates hyper-localised weather information using digital technologies, including drones and sensors. Offers detailed insights into immediate weather conditions, crucial for precision agriculture, disaster preparedness, and community decision-making.</td>
<td>Aerodyne, based in Singapore, deploys drones with advanced sensors for real-time weather and climate data collection.</td>
<td>Impact: Offers up to 200% increase in range and endurance of drones due to better awareness of weather conditions.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Communication platforms for extreme weather events</th>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrates advanced predictive algorithms with communication platforms through virtual dashboards and mobile-based apps during extreme weather events. Ensures timely relay of accurate and actionable information to stakeholders, facilitating efficient response and adaptation measures.</td>
<td>Piccard.ai’s AI flash flood alert system is an end-to-end, automated flood warning system. It predicts floods, visualises risk on a dashboard, and automates SMS/email alerts.</td>
<td>Impact: In 2019, the start-up secured a 12-month partnership with Melbourne Water to develop a flash flood warning for the city.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Long-term climate-weather observatories</th>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrates various digital technologies, such as GIS analytics, powered by ML and AI, to predict long-term climate impacts on weather. Translates complex spatial data into actionable insights, assisting decision-makers in comprehensive planning.</td>
<td>Blue Sky Analytics is an India-based climate analytics company that employs ML, AI, and satellite data to predict long-term impacts of climate.</td>
<td>Impact: Provides high-resolution air quality data at a low cost and has assisted in reducing air pollution in India by 30–50%.</td>
</tr>
</tbody>
</table>
Key Challenges

Limited data granularity in remote locations due to fewer weather stations inhibits accurate understanding of local weather patterns, impacting climate-related decision-making and adaptation strategies in these areas.

Ambiguous regulations around airspace management hinder local data collection using drones due to unclear standards on permitted airspace and operational specifications.

Limited data sharing between private and state actors obstructs the co-creation of solutions whereby private innovations can leverage existing state-owned data infrastructures to build advanced analytics and vice-versa.
Resource monitoring and management integrates advanced technologies to ensure the sustainable management of critical resources including land, water, and air. It involves real-time monitoring of resources through on-the-ground data collection via sensor networks, layered with advanced analytics, including AI technologies for data interpretation and predictive analytics. The integration of digital communication tools, such as virtual dashboards and phone-based applications, facilitates real-time communication of crucial information, aiding in data-driven resource management. This empowers businesses and communities alike to make climate-informed decisions promptly, thereby helping to preserve vital natural ecosystems and contributing to building long-term resilience to climate-related extreme events.

Surface-level resource monitoring technologies, such as stationary sensors and GIS systems, are highly mature. However, sub-surface monitoring tools for use cases including groundwater monitoring and soil analytics, and the integration of AI/ML models for predictive analyses, are still in their early stages.

Further advancements are needed to integrate real-time monitoring with advanced predictions, enabling a comprehensive understanding of the future impacts of climate on resource variability.

Most innovations for this use case relate to water, including applications for smart water metering and GIS-based leakage detection systems.

Blockchain-based data keeping is increasing data transparency in resource tracking and reporting, as demonstrated by innovations in water ledgers.

Funding overview (in billion USD as of 2024)

<table>
<thead>
<tr>
<th>Region</th>
<th>Amount (billion USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>7.377</td>
</tr>
<tr>
<td>North America</td>
<td>5.650</td>
</tr>
<tr>
<td>Europe</td>
<td>1.130</td>
</tr>
<tr>
<td>Other</td>
<td>242</td>
</tr>
<tr>
<td>China</td>
<td>5</td>
</tr>
<tr>
<td>Rest of APAC</td>
<td>350</td>
</tr>
</tbody>
</table>

APAC deployment status

Certain applications, such as urban air quality monitoring, are operational in major APAC cities. However, as a whole, this use case draws <5% of global commercial flows. Scaling investments can extend their reach into remote regions while supporting innovations that enhance predictive capabilities for optimising resource management.

88 Based on Tracxn database, as of Jan 2024. The figures presented pertain to commercial capital including VC and PE investments in climate technology. This excludes philanthropic or public financing, as available data on public finance for adaptation technologies lack appropriate tagging for digital tech. The figure aims to highlight the commercial readiness of the use case globally and in APAC, emphasising the volume dimension of private capital attracted to date. We distinguish China from the rest of the region due to its concentrated investor base and substantial domestic investments in climate adaptation technologies.
### Overview of applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Example</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harnessing advanced sensor networks and AI analytics, this application enables continuous monitoring of air pollutants. It empowers communities and regulatory bodies to proactively address air quality concerns.</td>
<td>Nafas relies on its proprietary network of 180 sensors across Indonesia to deliver hyperlocal air quality data via its mobile app.</td>
<td>Helps people reduce their exposure to hazardous air from urban air pollution.</td>
</tr>
<tr>
<td>By blending advanced ML-powered models with digital genomics, this innovative approach transforms soil quality analysis. By providing in-depth insights into soil conditions, it facilitates sustainable land management practices.</td>
<td>Singrow, based in Singapore, is the world's first genomic and precision agriculture transformation platform.</td>
<td>Proprietary genomics-based farming protocols allow Singrow's indoor farming technology to achieve at least 40% greater energy efficiency than other indoor farms.</td>
</tr>
<tr>
<td>Employs cutting-edge technologies such as contactless sensors and remote sensing for real-time monitoring of water quality and robotics for pollutant removal. It enhances the early detection and treatment of contaminants, ensuring healthy water bodies and safe consumption.</td>
<td>Taiwan-based Azure Alliance has developed the Azure Fighter—a fully electric and autonomous marine debris cleaning boat, capable of operating in both deep water and shallow water ports.</td>
<td>Between July and December 2023, Azure Fighter successfully removed 5,194 kilograms of marine debris from waterways.</td>
</tr>
<tr>
<td>Utilising advanced sensor networks, GIS-based systems, and ML algorithms, this application ensures efficient resource management through comprehensive monitoring, recording, and analysis of water levels and flows. These technologies foster sustainable water use and conservation practices.</td>
<td>WaterIQ, developed by Yayasan Solar Chapter, leverages IoT and cloud computing to monitor solar-powered water systems and anticipate pump maintenance needs in East Nusa Tenggara, Indonesia.</td>
<td>The device offers close to real-time updates by collecting and transmitting data every five minutes.</td>
</tr>
</tbody>
</table>
Key Challenges

**Retrofitting and integration of emerging innovations with conventional systems** is often not seamless, especially in densely populated areas (e.g. integrating digital sensors for real-time water flow and leakage detection with underground sewer systems in cities).

**High up-front investments are required to pay for infrastructure, equipment, and skilled personnel**, especially for regions and/or organisations with limited resources.

**The absence of standardised frameworks for data collection processes, including hardware specifications, impedes the integration of observations** from diverse monitoring systems at a resource level. For example, integrating data from privately deployed smart water devices and state-run agencies’ smart meters to assess the impact of climate change on water resources at a city level is challenging due to varying operational assumptions and reporting standards across these devices.

**Limited data interpretation capacity among local authorities poses a challenge in translating data collection and analytics into decision-making and policy action.** For example, during a flood event, local authorities may have access to water-level data from monitoring stations. However, due to limited capacity in data interpretation, they may struggle to determine which specific areas or communities are at the highest risk of flooding and require immediate evacuation measures.
Disaster preparedness and response

Disaster preparedness and response integrates cutting-edge technologies to enhance the efficiency and effectiveness of detecting and responding to climate-related disasters. By harnessing advanced sensors, satellites, and real-time data analytics, this use case facilitates precise data collection in at-risk areas. Employing sophisticated algorithms, including AI and ML, disaster preparedness systems analyse these data to predict potential climate-related disasters, enabling proactive measures. The integration of digital tools ensures rapid relaying of critical information, including through early warning systems, to relevant state authorities, businesses, and at-risk communities. This aids timely response in the face of increasingly frequent and severe disasters.

Funding overview
(in billion USD as of 2024)

Disaster preparedness technologies are at various stages of development. While flood forecasting and early warning systems demonstrate commercial readiness, optimisation models for improving disaster responses and supply chain resilience are still in the proof-of-concept stage globally.

AI algorithms for disaster forecasting show early promise; however, more testing and refining to support local data availability is necessary before deployment.

ML applications for micro-logistics, with the potential to revolutionise relief distribution, are in early-stage development, highlighting the importance of additional testing.

Further regional testing on disaster communications is needed to improve access to relay systems for timely, easy-to-interpret information for at-risk populations.

Based on Tracxn database, as of Jan 2024. The figures presented pertain to commercial capital including VC and PE investments in climate technology. This excludes philanthropic or public financing, as available data on public finance for adaptation technologies lack appropriate tagging for digital tech. The figure aims to highlight the commercial readiness of the use case globally and in APAC, emphasising the volume dimension of private capital attracted to date. We distinguish China from the rest of the region due to its concentrated investor base and substantial domestic investments in climate adaptation technologies.
Utilising advanced AI and ML algorithms, disaster prediction systems analyse historical data and environmental indicators to forecast potential disasters. By integrating predictive analytics, these systems offer insights into the likelihood and severity of disasters.

**Example**

Google Flood Hub combines two AI models to predict the location and severity of flooding and then alert people in high-risk areas up to a week in advance.

**Impact:** Flood Hub currently covers river basins in over 80 countries worldwide, providing critical flood forecasting for over 1,800 sites and 460 million people.

**Application Example**

<table>
<thead>
<tr>
<th>Overview of applications</th>
<th>Application</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disaster prediction systems</td>
<td>Utilising advanced AI and ML algorithms, disaster prediction systems analyse historical data and environmental indicators to forecast potential disasters.</td>
<td>Google Flood Hub combines two AI models to predict the location and severity of flooding and then alert people in high-risk areas up to a week in advance.</td>
</tr>
<tr>
<td>Early warning systems</td>
<td>Integrating real-time data from sensor networks and AI capabilities, early warning systems provide timely alerts through mobile applications, incorporating crowd-sourced information for improved accuracy. This ensures swift communication and helps enable timely evacuation processes in disaster-prone areas.</td>
<td>Tokyo-based Spectee uses a cloud-based AI solution to analyse a variety of real-time crisis information, deliver situational awareness for risk response, and visualise potential damage, with notification via email and phone app.</td>
</tr>
<tr>
<td>Disaster relief and response</td>
<td>Integrating AI-driven and drone-based micro-logistics solutions optimise disaster response efforts. These systems enhance efficiency by coordinating real-time logistics for relief distribution, facilitating the deployment of resources where they are most needed during crises.</td>
<td>Nepal Flying Labs is a non-profit social enterprise building local capacity using drones and promoting their use for social good.</td>
</tr>
</tbody>
</table>

**Impact:** Following the 2023 6.4-magnitude Jajarkot Earthquake, Nepal Flying Labs led a team of drone pilots in affected villages and captured high-resolution photos and videos of almost 25 affected sites, successfully assessing ground damage and collecting evidence for reconstruction efforts.
Key Challenges

Limited access to reliable and affordable digital data infrastructure (e.g. hyper-local weather sensors) for collection and relaying in remote areas hampers the effectiveness of early warning systems.

Current disaster management plans and policies lack adequate integration of technological solutions, particularly the digital public infrastructure essential for real-time crowdsourcing of local disaster-related data and timely communication.

Limited collaboration between innovators and local organisations during the development phase hampers the effective design of solutions tailored to local disaster risk profiles and community needs. For instance, in a coastal community vulnerable to flooding, a lack of collaboration between climate tech developers and local environmental NGOs might result in the absence of crucial data points in flood risk assessment tools, limiting the accuracy and utility of these solutions for the community.
Agricultural optimisation

Agricultural optimisation refers to precision agriculture technologies that leverage digital tools for comprehensive data-driven approaches to on- and off-farm activities. These technologies employ sensor networks for continuous real-time data collection, capturing vital information related to soil health, irrigation, crop conditions, and other environmental factors. Advanced ML and AI algorithms analyse these data to provide detailed predictions and analytics for agriculture. The integration of digital technologies with predictive models for relaying timely, on-farm insights facilitate automation for precision agriculture. It also enables the sharing of critical information with farmers and other stakeholders through user-friendly dashboards and mobile applications, fostering supply chain resilience and boosting productivity and sustainability practices.

Applications reflect a blend of early prototypes and commercially ready solutions. While platforms for supply chain resilience are in ideation phases, AI-based predictive analytics and digitally enabled devices for automating crop management have demonstrated maturity in select geographies globally.

- **IoT-based devices** demonstrate commercial readiness and are widely integrated into precision agriculture, providing real-time data on crop health conditions.
- **AI algorithms** are being piloted for agricultural optimisation, focusing on predictive analytics for crop and irrigation management and yield estimation.
- **Automation technologies**, ranging from robotics to sensor-linked devices, hold promise in alleviating on-farm workload for farmers. However, their scalability hinges on thorough pilots and validation across diverse geographic regions.

### Relevant Themes

| Overall tech readiness | High |

### Funding overview

(Funding overview (in billion USD as of 2024))

<table>
<thead>
<tr>
<th>Region</th>
<th>Funding (Billion USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>2,657</td>
</tr>
<tr>
<td>North America</td>
<td>1,500</td>
</tr>
<tr>
<td>Europe</td>
<td>200</td>
</tr>
<tr>
<td>Other</td>
<td>181</td>
</tr>
<tr>
<td>China</td>
<td>69</td>
</tr>
<tr>
<td>Rest of APAC</td>
<td>557</td>
</tr>
</tbody>
</table>

### APAC deployment status

Most applications have been tested in APAC, as part of a proactive push for digital innovations for climate-smart agriculture. Advancing to the next stage requires initiatives to test and validate current innovations to make them implementation-ready while co-developing affordable solutions with communities vulnerable to climate change.

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Overview of applications

Crop health management

Application: Utilises IoT-based sensor networks for continuous real-time data collection to capture data on soil health and crop well-being. Layering of advanced ML and AI algorithms over collected datasets enables early detection of potential issues impacting crop health.

Example: Terraview is a Singapore-based firm that offers a comprehensive operating system for monitoring factors such as pruning and pest infestations.

Impact: Reduces crop loss by 10% by precisely identifying at-risk crops and achieves accurate yield estimates of up to 85%.

Irrigation efficiency

Application: Integrates AI optimisation models to assess and predict irrigation needs based on real-time on-field data monitoring. This data-driven approach ensures efficient water usage, minimises wastage, and enhances overall irrigation practices, contributing to sustainable agricultural water management.

Example: CultYvate’s SMART automated irrigation system provides predictive insights to farmers.

Impact: A case study demonstrated a 16% increase in yield, 50% reduction in labour, 29% water saved, and ~USD 1,000 per hectare in additional income.

Precision agriculture

Application: Deploys a suite of digital tools including sensor networks, satellite imagery, and AI algorithms to optimise resource use, enhance crop yield, and minimise the footprint of farming. Automated systems, including drones, are employed to act on these insights, ensuring timely responses to climate disruptions.

Example: Beleaf Farms, an Indonesian hydroponic farm start-up incorporates advanced IoT tech to provide high-quality produce with a lower water usage and carbon footprint compared to traditional farms.

Impact: Beleaf Farms’ technologies and techniques allow for 30% greater yield, 95% less water, and 99% less land used. They have over 61,000 square meters of farm across Indonesia.

Agri-related supply chain resilience

Application: Leverages end-to-end agricultural platforms integrating IoT sensors, blockchain for transparency, and AI analytics. These platforms enhance supply chain resilience by offering real-time visibility, streamlining logistics, and ensuring traceability from farm to market.

Example: Australia-based Uncharted Waters is a non-profit start-up building a digital twin of the global food system.

Impact: Simulates yield, water use, and other variables for 12 crop groups internationally, providing real-time data to support decision-making and resilience.
Key Challenges

Limited availability of user-friendly digital tools for small-scale farmers hampers the adoption of precision agriculture practices optimised for local conditions. For example, launched in 2015, India’s Soil Health Card scheme provided farmers with soil data, crop advice, and land management tips including via digital tools. However, the initiative faced criticism for its technical complexity, limiting usability for farmers in the absence of further assistance.

High upfront costs and limited access to affordable, green lines of credit create barriers for farmers when it comes to investing in and deploying advanced digital technologies for climate-smart agriculture.

The crowded and fragmented agricultural innovation landscape suffers from the absence of country-level data architecture frameworks that can help streamline them, leading to inefficient technology delivery to farmers.

Limited collaborations with small-scale farmers in the innovation ecosystem hinder need-based development and adoption of advanced technologies. Adoption of climate-smart agricultural technology (agri-tech) is generally low among small-scale farmers owing to their low levels of exposure to agricultural mass media, participation in extension programmes, and lacking agency to take risks/innovate.
Climate and health intelligence systems

Climate and health intelligence systems harness advanced technologies across the data collection, analytics, and relaying stages to enable proactive responses to climate-related health risks. These systems gather real-time climate and health data from diverse sources, tracking parameters such as temperature, air quality, and disease outbreaks. Using advanced ML algorithms, they predict climate-related health events and their impact, including the spread of infectious diseases and NCDs. The insights gleaned are disseminated to key stakeholders, including healthcare providers and emergency responders, enabling informed decisions during climate-related public health emergencies. This contributes to targeted health interventions and enhances preparedness against climate-related health risks.

Funding overview (in billion USD as of 2024)\textsuperscript{91}

The health tech sector has been experiencing an innovation boom, notably in AI diagnostics and disease outbreak pattern research. However, these innovations have yet to be widely adopted in climate-specific contexts to reduce the burden of climate impacts on the health sector. Progress requires a deeper understanding of the climate–health intersection itself.

Climate–health dashboards require localised, real-time data to guide targeted decisions around rising health threats from climate extremes, including heat waves.

AI models show promise for advancing climate–health warnings but require further refinement with on-the-ground data to boost localised accuracy.

Sensor-based innovations that track climate and health hazards through resource monitoring require further R&D to be contextualised at the climate–health intersection. Examples include digital sensors to trace and predict water-borne disease spread in flood-prone watersheds.

\textsuperscript{91} Based on Tracxn database, as of Jan 2024. Represents investments in healthcare tech overall and not for climate–health specifically. The database shows only 24 registered companies working at the intersection globally, none of which has managed to raise funding to date. To ensure a more balanced portrayal, the APAC summary does not cover China, given its concentrated investor base and substantial domestic investments in adaptation technologies. These numbers reflect only commercial funding from investor groups such as VC firms, PE firms, corporates, and angel investors.
Using advanced ML algorithms and real-time data analytics, disease prediction systems forecast potential outbreaks by analysing environmental factors, population dynamics, and health data. They enable proactive planning for public health interventions.

**Example**
In 2020, SingHealth started the 3D-DOSS project, which integrates anonymised patient data into a digital replica of the Singapore General Hospital.

**Impact:** The system enabled staff to visualise disease spread, detect infection clusters, and predict the risk of future infection.

Integrating AI-assisted imaging trained on climate–health data, early diagnostics identify climate-related health conditions before climate impacts intensify. These technologies analyse medical images and patient data, facilitating timely diagnosis, treatment, and preventive measures.

**Example**
Oxipit’s ChestLink is an AI-enabled imaging tool that analyses radiologist reports and corresponding medical images in near-real time.

**Impact:** In trials, the tool was able to screen chest X-rays for health hazards with 99.8% sensitivity. It has launched in multiple regions worldwide.

Utilising IoT-based sensor networks and cloud computing, real-time monitoring systems collect and analyse climate–health indicators. They provide actionable insights and early warnings to public health authorities for prompt responses to emerging health threats such as heat waves.

**Example**
The NGO-backed Geospatial Indicators Dashboard provides data across seven themes related to climate change and urban environment, including air quality, extreme heat, and flooding.

**Impact:** This tool covers 23 cities across nine countries, including India and Indonesia.

By employing wearable devices, remote sensors, and AI analytics, workforce safety systems monitor environmental conditions and health stress for workers. They enable real-time monitoring and predictive analytics to prevent accidents caused by extreme climatic conditions.

**Example**
UK-based firm PLINX has introduced TeamSense wearable, an IoT solution for construction workers that collects data including location and body temperature.

**Impact:** While the UK is its key market, in 2021, TeamSense was deployed on a large scale in Hong Kong and received high-value orders from Singapore.
Key Challenges

A lack of data collection and analytics platforms at the climate–health intersection hinders the rapid development of digital technologies that can effectively translate climate information into actionable insights. For example, the absence of open-data repositories to understand the local impacts of heatwaves on diverse populations hinders innovators from developing solutions that can effectively respond or adapt to these challenges, including tailored warnings based on specific local conditions rather than generalised regional forecasts.

Digital applications for climate–health use cases are largely at the R&D stage; a middle layer is missing in the form of late-seed grants and concessionary debt to test and validate pilots for products that demonstrate minimum viability.

Insufficient policy frameworks to define and address AI-related risks, including privacy concerns related to climate–health data, biases in AI models, and issues with accuracy, hinder effective deployment and utilisation of AI at the intersection of climate and health.
Digital technologies for climate adaptation demonstrate varying maturity levels. These technologies fall into four main categories: those that collect data, those that analyse data to make predictions, those that relay the data or predictions to decision makers, and those that integrate or perform more than one of the previous three functions. Across these categories, a few common trends emerge:

- **Increasingly, new technologies are designed to integrate multiple functions.** Applications for a range of use cases—such as weather monitoring and forecasting, early warning systems, precision tools for agriculture, and public health monitoring—can perform data collection and analytics to better inform adaptation decision-making.

- **Data collection technologies are being deployed most extensively compared to other functions.** For instance, within weather forecasting and modelling, applications that collect and relay data are being deployed in many parts of APAC, but those that perform advanced predictions are still being developed. Even across use cases, digital technologies for monitoring and conveying on-the-ground conditions and resource levels are far more ready for widespread use in APAC than are technologies for predicting disease outbreaks. However, there is room to expand data collection even further, as in cases of dynamic monitoring of sub-surface resources such as groundwater quantity and quality.

- **Weather forecasting and agriculture optimisation use cases are relatively more mature, while digital technologies for climate and health intelligence systems are still nascent.** Climate and health systems still require significant R&D support to enhance existing health technologies for monitoring and predictions. These systems can be built upon to introduce warning systems for disease outbreaks amongst other crises.

Other trends vary by use case (Figure 4.2), and levels of maturity across these digital technology types also vary for the applications and use cases discussed earlier in this chapter.
### Technological readiness across various applications

<table>
<thead>
<tr>
<th>Technology use-case</th>
<th>Technology readiness level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather forecasting and modelling</td>
<td>Low Medium High</td>
</tr>
<tr>
<td>Resource monitoring and management</td>
<td></td>
</tr>
<tr>
<td>Disaster preparedness and response</td>
<td></td>
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<tr>
<td>Agricultural optimisation</td>
<td></td>
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<tr>
<td>Climate and health intelligence systems</td>
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</tbody>
</table>

#### Technology use-case

- **Long-term climate-weather observatories**
- **Communication platforms for extreme weather events**
- **Hyper-local weather information systems**
- **Regional weather monitoring and forecast**

- **Groundwater quality monitoring**
- **Water resource management**
- **Nitrogen management**
- **Air quality management**
- **Soil quality management**
- **Surface water quality monitoring**
- **Air quality monitoring**
- **Soil monitoring**

- **Disaster relief and response**
- **Disaster prediction systems**
- **Early warning systems**

- **Crop health management**
- **Agri-related supply chain resilience**
- **Precision tools for agriculture**
- **Irrigation efficiency**

- **Real-time public health monitoring**
- **Early diagnostics for climate-health risks**
- **Disease outbreak prediction**
- **Workforce safety**

### Technology readiness levels

Technology readiness levels are determined through a combination of data sourced from the Wipogreen Database and qualitative assessments derived from secondary research and expert interviews. "Low" includes innovations in the proof-of-concept stage, "medium" includes those at the Minimum Viable Product (MVP) to prototyping stage, while "high" indicates innovations that demonstrate early commercial to commercial readiness in tested geographies.
CHAPTER 5

CALL TO ACTION
Unlocking the full potential of digital technology for climate adaptation in APAC necessitates tailored investments. Social investors can contribute to its development and deployment at scale through both financial investments in innovations, as well as ecosystem-building efforts (Figure 5.1).

Financial interventions
Social investors deploy a range of financial instruments to channel funding to innovators, from grants, debt (including concessional loans), and equity, to innovative mechanisms such as returnable grants. Each of these carries varying levels of risk and return, as well as different impact potential, and is typically utilised by different types of social investors. Blended finance instruments often involve collaboration among various social investors, pooling different interventions like grants and debt to support innovative initiatives. For instance, the World Economic Forum’s Giving to Amplify Earth Action (GAEA) initiative catalyses public-private-philanthropic partnerships (PPPPs) to jointly support solutions. PPPPs have been explored across several themes including nature, energy, clean air, the climate–humanitarian nexus, and industrial decarbonisation.92

Ecosystem-building initiatives
Ecosystem-building initiatives encompass a wide range of activities accessible to all types of social investors to cultivate an enabling environment for technological innovations to take shape and scale up. These efforts may involve advocating for policy, enhancing local and regional capacity, and facilitating knowledge transfer and collaboration across the ecosystem.

Social investors should combine various interventions across both these types to effectively support the scaling of impactful solutions. For example, collaborating with other funders to develop innovative financing mechanisms can help overcome barriers to impact at scale, as can working with policymakers to drive regulatory reforms that better facilitate the widespread development and adoption of digital technologies for climate adaptation.

The section below outlines recommendations for social investors on financial interventions for directing investments in innovations, as well as ecosystem interventions more broadly.

92 World Economic Forum, On GAEA Announcements: Frequently Asked Questions, 2024
Types of interventions by social investors

![Diagram showing different types of interventions by social investors, including financial interventions and ecosystem-building initiatives.]

**Financial interventions**

- **Grants**
  - Expect little or no return through patient capital
  - High tolerance of risk
- **Concessional debt**
  - Expect below-market to market-level return, balanced with impact
  - Moderate tolerance of risk
- **Debt**
  - Expect market-level return with consideration on impact
  - Moderate-low tolerance of risk
- **Equity**
  - Expect and prioritise market-level return
  - Low tolerance of risk

**Ecosystem-building initiatives**

- **Policy advocacy**
  - Advocacy with officials for enabling policies and regulatory environment; working closely with policymakers
- **Capacity building**
  - Capacity building for digital ventures, governments, local communities, etc.
- **Knowledge transfer**
  - Knowledge and best practice creation and dissemination within the sector

**Blended finance pools together various forms of capital to optimise for impact and returns across project cycles, often exhibiting a higher risk tolerance compared to traditional approaches.**
Social investors can strategically deploy different types of financial instruments—e.g. grants, debt, and equity, including via innovative finance mechanisms where appropriate—to support the development and scaling of digital solutions for climate adaptation and resilience. They can consider several priorities for investment to support innovators:

1. **Offer foundational support for early-stage solutions focused on generating evidence on the impact of climate change on social sectors.** This is particularly crucial for applications related to climate–health intelligence systems, which require R&D investments to build data tools and models showcasing the effects of climate change on public health. Currently, there is limited local-scale evidence at the intersection of health and climate, making foundational support crucial to build the data basis required for such tools.

   To facilitate this support, social investors can consider offering pre-seed capital with high-risk tolerance in the form of research grants and innovation funds. For example, providing pre-seed capital for predictive models on malaria proliferation under rising temperatures can help pinpoint high-risk areas and vulnerable populations. This information can aid in proactive planning for targeted interventions, particularly vital for vulnerable communities like the urban poor living near contaminated water sources, which are breeding grounds for disease vectors.

2. **Promote solutions that refine AI-driven predictive analytics for climate data and enable their seamless integration into local-scale data collection and relaying systems.** Investors should emphasise the development of solutions that not only prioritise real-time predictions but also improve the accuracy of predictive analytics over time. The next step of evolution for such solutions should involve their integration with...
communication tools, particularly in applications related to resource management and disaster response, to ensure swift information dissemination during climate-related emergencies. Additionally, investors should explore opportunities to retrofit these innovations into existing data systems and infrastructure to enhance their overall impact at scale.

Social investments to support such solutions may take the form of concessional debt, early-stage equity, or innovative blends of debt and equity, depending on the maturity and impact potential of the solutions. For example, seed capital to enhance predictive analytics for water resource management can improve the accuracy of drought predictions and flood risk assessments. Their integration with communication technologies and data-driven warning systems could provide early alerts and disseminate actionable information, such as water conservation measures or evacuation plans to residents and authorities. This integrated approach strengthens resource management and disaster response capabilities, particularly beneficial for coastal communities and those whose livelihoods are highly dependent on reliable access to freshwater resources.

**Spotlight**

ADB’s Water Financing Partnership Facility, established in 2006, supports ADB’s water initiatives in line with its ‘Strategy 2030 Water Sector Directional Guide’ for a resilient APAC. The initiative, facilitated by four trust funds including the Water Innovation Trust Fund and Water Resilience Trust Fund, focuses on innovative solutions such as digital tools for real-time monitoring of water-climate interactions. This aims to improve water resource management, ensure uninterrupted water service delivery, and enhance resilience against climate-related risks.

3. **Validate and scale proven digital solutions in lower-income regions of APAC, focusing on remote and resource-limited communities.** Collaborate with local stakeholders to pilot, customise, and deploy mature applications that have shown success in global and developed APAC contexts. This is especially relevant for applications related to early warning systems and agricultural optimisation, which demonstrate relatively high maturity in developed APAC contexts. Collaborating in this manner provides social investors with an avenue to transfer proven technologies to climate-vulnerable communities across the region, which face resource limitations in effectively anticipating and adapting to climate disruptions.

Social investors can deploy performance-based grants to support local organisations in testing and validating the efficacy of replicating solutions in new and more vulnerable geographies. For those ready to scale, social investments may take the form of return-seeking capital, such as market-rate debt and equity, given their proven impact and potential to generate returns. For example, piloting Japan’s advanced early warning systems in regions like Southeast Asia or the Pacific Islands—which are more vulnerable to climate risks due to their limited technological infrastructure—could help validate their efficacy and enable their deployment on a wider scale.

**Spotlight**

The Adaptation Fund Climate Innovation Accelerator (AFCIA), launched collaboratively by the Adaptation Fund, United Nations Environment Programme (UNEP) - Climate Technology Centre and Network, and the United Nations Development Programme (UNDP), fosters climate change adaptation innovation in developing countries. Established in 2020, AFCIA scales up local adaptation efforts, with a specific focus on local governments, civil society, non-governmental organisations, and innovative individuals among women and youth. Supported by contributions from the Adaptation Fund and the European Union, AFCIA has granted 44 awards totalling USD 16 million to locally led organisations in 33 countries, enhancing the resilience of around 910,000 individuals (48% women).

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**4. Fund the building and strengthening of digital infrastructure for climate resilience as well as digital infrastructure that is climate-resilient, focusing on at-risk communities.** Social investors should foster the development of digital infrastructure aimed at enabling resilience in communities through improved systems for real-time monitoring and response to localised climate risks. Additionally, they should also support the creation of basic digital infrastructure that is itself resilient to climate shocks, ensuring remote and vulnerable regions can maintain reliable electricity and internet access crucial for real-time data transmission and communication during climate emergencies. This dual approach not only strengthens early warning systems but also fortifies continuity in communities' abilities to adapt and respond effectively to climate hazards.

Social investors can allocate grants and concessional capital and work closely with state authorities to establish basic digital infrastructure, expand device accessibility, and promote digital literacy among at-risk populations. For example, funders could invest in installing a network of weather sensors in remote coastal villages susceptible to floods and cyclones; such investments would improve the granularity of weather predictions, providing accurate climate-related information and warnings to local communities. By ensuring reliable connectivity of basic infrastructure, such as internet access and mobile networks, residents can receive timely alerts and access essential climate-related data, enhancing their preparedness and resilience to climate challenges.

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**Spotlight**

The Internet Society Foundation’s Beyond the Net programme deployed grant capital in 2023 towards establishing internet connectivity in unconnected and underserved areas globally.95

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95 Internet Society Foundation, Beyond the Net Grant Program, 2023 Impact Report, 2024; calculated as 17% of the total grant value of USD 682,236 for the year.
Social investors should collaborate with other stakeholders such as policymakers, local nonprofits, and communities to enable a vibrant ecosystem for digital technology on climate resilience.

Policy advocacy

A priority for social investors should be to engage with policymakers to develop regulatory frameworks and other institutional mechanisms that enable digital innovations to support climate resilience in communities and economies at multiple scales. Several policy-level recommendations for social investors to consider in their advocacy strategies are outlined below:

1. **Integrate digital technology deployment into national climate strategies, while acknowledging their role in climate action within ICT policies.** By embedding digital solutions into climate adaptation plans, we can enhance the efficiency and accuracy of climate risk assessments, empower stakeholders with real-time data insights, and improve adaptive decision-making processes.

   **Spotlight**

   Iran's ‘Digital Iran – National Roadmap 2020–2025' aims to leverage ICT to address the country's water crisis by allowing for higher accuracy in assessing the region's water availability and variability over time.96 This is expected to result in real-time communication of data-driven insights for sustainable water resource management.

2. **Develop robust sectoral policies and initiatives that encourage open data generation and sharing among state agencies, private sector innovators, and local communities.** Encourage diverse methods and tools for data collection, including crowdsourcing information through open-data formats, to promote the generation of localised insights. In addition, strengthen data-sharing mechanisms to foster a more comprehensive understanding of climate risks, enable faster response to extreme events,

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and encourage multi-stakeholder collaborations towards building climate-resilient communities and economies.

**Spotlight**

Agri Stack, led by the Ministry of Agriculture & Farmers Welfare in India, leverages data and digital services to foster collaboration among stakeholders for improved agricultural outcomes. Through an open and federated structure, it keeps states at the centre of the design to enable participatory and inclusive engagement. One of its key objectives is to empower farmers with localised insights and advice for informed on-farm practices amidst changing weather and climatic patterns.

3. **Establish ‘regulatory sandboxes’ to streamline the development, testing, and deployment of climate adaptation-focused digital innovations.** By providing a controlled environment for experimentation, regulatory sandboxes encourage innovation and rapid iteration, driving the evolution of more effective and impactful solutions. This can support the development of scalable, interoperable design and facilitate technology transfer and adoption. Creating space to incorporate input from vulnerable communities during the design phase can further ensure that these technologies effectively address specific vulnerabilities and reach vulnerable communities across sectors.

**Spotlight**

In Kazakhstan, the implementation of a regulatory sandbox to support the development and testing of innovations in the energy sector is expected to enable decentralisation, digitalisation, and decarbonisation. This initiative aims to address the lack of commercial interest in the large-scale development of energy-efficient technologies, electrical grid capacity shortages, and the development of renewable energy that is accessible, reliable, and affordable.

4. **Define and enforce regulations governing AI and other emerging technologies to tackle risks such as data privacy breaches, algorithmic biases, and reliability issues in climate-related applications.** Specifically, ensure that AI models handling sensitive data (e.g. patient health records) comply with privacy regulations and are regularly reviewed for fairness and accuracy. Additionally, establish protocols for addressing algorithmic biases, especially in decision-making processes impacting vulnerable communities. This can be achieved by implementing measures such as techniques and datasets to avoid

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unfair, diversity in training data, and transparency in AI decision-making processes. Robust regulations are crucial to safeguard against potential risks associated with digital technologies, instil public trust in AI systems, and foster innovation within ethical and accountable frameworks for climate resilience.

### Spotlight

In late 2023, the European Commission established comprehensive AI regulations, including on transparency, AI usage in public spaces, and high-risk systems. Notably, it recognises healthcare as a high-risk system, stressing the need for rigorous testing of AI models prior to deployment. Innovators in this context must assess and reduce risks, maintain use logs, be transparent and accurate, and ensure human monitoring. This measure is essential to tackle privacy concerns regarding patient-health databases and curb misinformation stemming from inaccurate models.

5. **Implement policies that emphasise data quality assurance and standardisation in data collection processes, including hardware specifications and data management protocols.** Standardised data collection enhances accuracy, reliability, and comparability, crucial for effective climate adaptation measures and evidence-based decision-making. This is especially vital for resource monitoring and management applications, given the challenges in integrating data from diverse devices used by various stakeholders, from state agencies to industrial entities and households.

### Spotlight

Australia’s Terrestrial Ecosystem Monitoring (TERN) backed by the Australian Government under the National Collaborative Research Infrastructure Strategy, is a land observatory initiative that monitors the nation’s ecosystems to understand their vulnerability to climate change. Employing a robust data management structure, it features standardised data collection protocols, quality assurance processes, and open-access data-sharing platforms. This facilitates researcher and policymaker access to dependable data for decision-making concerning ecosystem preservation and adaptation measures.

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100 TERN, *TERN is Australia’s Ecosystem Observatory*, accessed March 2024.
Other ecosystem-building initiatives

In addition to policy advocacy, social investors should prioritise other ecosystem-building initiatives such as knowledge sharing and enhancing local capacity. Social investors can consider interventions including the following:

1. **Facilitate improved access to open data to support advancements in climate informatics and data-driven decision-making.** A 2023 study suggested that over 60% of APAC economies have insufficient data transparency. The lack of real-time, open-access, and harmonised datasets hinders the development of unified platforms for data-driven decision-making. Social investors are well-positioned to support initiatives that promote better access to current and historical data, including those owned by government departments and to support the collection of new data. Additionally, they can enable collaboration between data providers and innovators to build digital platforms that improve the sharing of climate-related data. For example, in Southeast Asia’s river basins, integrating observations from satellite imagery, weather stations, and river gauges is crucial for improving the accuracy of real-time flood forecasting.

   **Spotlight**

   The Climate Data Steering Committee, with members from the International Monetary Fund, International Energy Agency, United Nations Framework Convention on Climate Change (UNFCCC), and other entities, is pioneering the establishment of a publicly accessible climate data utility that provides accurate and verifiable climate data.

2. **Build climate adaptation knowledge and capacity among investors and disseminate proof of concepts.** Investors and innovators alike note that the investor community is more familiar with mitigation actions than adaptation actions, which underscores the need to build awareness and capacity. Limited knowledge regarding the needs and complexities of adaptation solutions and the scarcity of demonstrated viable business models lead to a mismatch between investment terms and innovator needs. As social investors invest in and support digital ventures, evidence of commercial viability will also need to be captured and disseminated.

   **Spotlight**

   DRI Connect by the Coalition for Disaster Resilient Infrastructure is a knowledge exchange and global co-creation platform for multi-stakeholder collaborations, featuring e-learning modules and a marketplace for disaster-resilient solutions.

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103 Coalition for Disaster Resilient Infrastructure, DRI Connect, accessed March 2024.
3. **Enhance the capacity of local authorities and decision-makers to incorporate adaptation considerations during their planning and procurement stages.** For instance, longer procurement timelines and poor understanding of available technologies limit deployment. Capacity-building programmes for local authorities could enable them to effectively purchase and utilise the technologies. Success for many of the proven solutions depends on government procurement and engagement.

4. **Partner with local communities to understand their needs and foster local community engagement with resilience-building technologies.** Startups often lack the resources and networks to gather and integrate local community input needed for effective customisation of digital technologies. Social investors can leverage existing partnerships or forge new ones with grassroots organisations to crowd in user voices and build community buy-in. Furthermore, social investors can also support the capacity building of vulnerable communities to better understand and effectively deploy digital tools.

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**Spotlight**

Air quality enforcement officers in Cangzhou (China) lacked the capacity to identify pollution hotspots despite good coverage of air quality monitoring systems. Through a PPPP with the Environmental Defense Fund (EDF), the Beijing Huanding Environmental Big Data Institute, and the municipality, enforcement officers were supported to unlock the potential of the monitoring technologies.104

**Spotlight**

Mahila Housing Trust, an India-based non-profit, provides climate-targeted training to women from impoverished communities, enabling them to engage with governments and planning processes towards equitable adaptation and resilience outcomes.105

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**In summary, there is vast potential for digital tools and technologies to transform APAC’s climate resilience landscape** and enable even low-resource communities to harness the power of technology to adapt to a changing climate. Social investors have a key role to play in directly investing in innovations and driving other initiatives through impactful partnerships with other funders, policymakers, and local innovators. By doing so, they can enable the development of a vibrant and tech-forward ecosystem to drive climate adaptation and resilience outcomes across the region.

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ANNEX
Methodology

The analysis in this report employs a mix of qualitative and quantitative methods, including desk research, data analysis, and stakeholder interviews. Findings were refined through iterative discussions with philanthropies, impact investors, technology developers, ecosystem builders, and grassroots organisations, particularly focusing on those in the Global South. Taking a collaborative approach helped us develop representative and actionable insights for stakeholders navigating climate adaptation challenges in the region.

Adaptation gap estimations for APAC

Data for the adaptation funding needs and flows for developing countries have been sourced from UNEP’s Adaptation Gap Report 2023.

Adaptation financing flows. This refers to finance from developed to developing nations. Current data sources for the report enable analysis of international public finance exclusively, alongside private finance mobilised by public bilateral and multilateral channels. However, the report cites challenges in documenting finance from other private flows and domestic expenditures (both public and private).

Difference between modelled costs and adaptation needs. The modelled costs of adaptation refer to estimates of the resources needed to address incremental climate risks, compared to a reference period, without considering how these costs are financed. This approach relies on sectoral models and assessments to derive cost estimates but may not capture broader economic and cross-sectoral linkages. On the other hand, adaptation finance needs encompass the financial resources required by countries, both from international and domestic sources, to implement their adaptation plans. These needs are often based on programme- and project-level costing, with different definitions and sectoral considerations compared to modelled studies of adaptation costs. Consequently, disparities often exist between needs and modelled costs for the same country.

APAC estimates. The figures for the APAC region are derived by aggregating the data for East Asia, the Pacific, and South Asia regions. In cases where exact amounts in dollars are not available for regional or sectoral breakdowns, we estimate the resulting figure based on each region’s percentage share of the total.

Theme-specific digital technology needs mapping

This report centres on themes related to agriculture, water, disaster management and public health due to their heightened vulnerability to climate impacts in APAC. These four themes include many of the key sectors significantly affected by climate change, as communicated through UNEP’s Global Technology Needs Assessment Project and country-level National Adaptation Plans. These themes have also received increased attention in terms of adaptation investments within the region. While these thematic areas are crucial priorities, climate impacts also extend to other important sectors. The goal of this report is to initiate dialogue and action on the potential of digital technologies for climate adaptation writ large, in order to achieve broad impact across sectors.
Mapping of thematic impacts to technology needs. We started by analysing various literature sources, including academic studies, reports, and policy documents, to understand the impacts of climate change on the four chosen themes. We first mapped climate events to thematic impacts and vulnerabilities, identifying specific adaptation needs for each theme. These needs were then linked to the landscape of digital technologies that can effectively address them, providing insights into the technological solutions required for climate adaptation across the four themes. We identified the 20 prioritised technologies through stakeholder conversations aimed at pinpointing emerging technologies with high impact potential. We further segmented the prioritised technologies into five distinct use cases, each presenting specific thematic challenges addressed by digital technologies.

Technology maturity analysis. We conducted a technology maturity analysis across the five identified use cases, evaluating the readiness of each digital technology based on its TRL, which measures the maturity of a technology, ranging from concept (TRL 1) to deployment and operation (TRL 9), with 9 indicating readiness for scale or early commercialisation. The maturity levels were categorised as low, medium, and high based on the TRL scores across different applications. To ensure a comprehensive assessment at the use-case level, we sourced scores from the World Intellectual Property Organisation Green database where available; where these scores were unavailable, we supplemented our evaluation with qualitative research through the Tracxn database and with expert consultations.

We determined the presence of technologies in the APAC region by analysing the geographies of development and/or deployment tagged to various applications using the WIPO database. In instances where this information was unavailable, we conducted qualitative research to complement the data and ascertain the APAC presence of the technologies.

Use-case level funding flows. For the use-case level funding analysis, we relied on data from the Tracxn database as of January 2024. We chose this database as the primary source because it provides valuable insights into where funding interest exists, emerging trends, and areas where investment is lacking. While these data primarily represent commercial capital, including venture capital and private equity investments, they serve as a proxy for understanding market readiness. Given the lack of comprehensive documentation on social investments and the assumption that commercial flows reflect market dynamics, this approach helps to gauge market maturity and informs the roles social investors should undertake. It is important to note that the analysis excludes philanthropic or public financing, as available data on public finance lack appropriate tagging for digital innovations. Additionally, China is distinguished from the rest of the region due to its unique investor landscape and significant domestic investments in digital technologies for climate adaptation.

While these findings represent our best efforts to realistically capture the status of the APAC region, the findings are constrained by the scarcity of comprehensive data and initiatives at the intersection of digital technology and climate adaptation, as well as the absence of standardised terminology in documenting climate adaptation efforts at different levels. Therefore, this analysis does not claim to achieve precision, but rather aims to provide a directional guide for social investments in digital technologies for climate adaptation in APAC.
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td><strong>Adaptation</strong></td>
<td>In human systems, the process of adjustment to actual or expected climate and its effects, to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC 2022).</td>
</tr>
<tr>
<td><strong>Adaptive capacity</strong></td>
<td>The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences (IPCC 2022).</td>
</tr>
<tr>
<td><strong>Climate change</strong></td>
<td>A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the UNFCCC, in its Article 1, defines climate change as ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC 2022).</td>
</tr>
<tr>
<td><strong>Climate extreme</strong></td>
<td>Extreme weather refers to instances when a specific weather or climate condition surpasses a defined threshold, either unusually high or low. This can vary by location. When these extreme conditions persist over time (e.g. for a season), they are termed extreme climate events, often resulting in significant averages or totals, such as high temperatures, prolonged droughts, or heavy rainfall. Collectively, these are called climate extremes.</td>
</tr>
<tr>
<td><strong>Climate technology</strong></td>
<td>Technology built with the intent to mitigate or adapt to the negative impacts of climate change.</td>
</tr>
<tr>
<td><strong>Co-benefit</strong></td>
<td>A positive effect that a policy or measure aimed at one objective has on another objective, thereby increasing the total benefit to society or the environment. Co-benefits are also referred to as ancillary benefits (IPCC 2022).</td>
</tr>
<tr>
<td><strong>Decarbonisation</strong></td>
<td>Human actions to reduce carbon dioxide emissions from human activities.</td>
</tr>
<tr>
<td><strong>Digital technologies</strong></td>
<td>Digital technologies cover a wide range of tools and systems, including electronic devices and resources that handle data and information. This umbrella term encompasses subsets such as IT and ICT. IT involves computing technologies such as hardware, software, the internet, and related components. In contrast, ICT focuses on technologies that enable information access through telecommunication, emphasising tools such as the internet, mobile phones, and wireless networks for communication (ADB 2021). See next section for definitions of specific digital technologies featured in this report.</td>
</tr>
</tbody>
</table>
Glossary

**Disaster**
A ‘serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic, and environmental losses and impacts’ (UNGA, 2016).

**Drought**
An exceptional period of water shortage for existing ecosystems and the human population (due to low rainfall, high temperature, and/or wind).

**Early warning systems (EWS)**
Systems that encompass the technical and institutional capacities to predict, forecast, and communicate timely and meaningful warning information. This enables threatened individuals, communities, ecosystems, and organisations to prepare and take appropriate action to minimise harm or loss. EWS can utilise scientific, indigenous, and other knowledge types, tailored to specific contexts. They extend beyond human threats to include ecological applications like conservation, agriculture, and fisheries, addressing hazards such as coral bleaching, heavy rainfall, drought, and storms.

**Earth observation**
Remote-sensing (e.g. satellites) or in situ techniques (e.g. weather stations) for gathering information about activities on Earth.

**Exposure**
The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.

**Flood**
The overflowing of the normal confines of a stream or other water body, or the accumulation of water over areas that are not normally submerged. Floods can be caused by unusually heavy rain—for example, during storms and cyclones. Floods include river (fluvial) floods, flash floods, urban floods, rain (pluvial) floods, sewer floods, coastal floods, and glacial lake outburst floods (GLOF).

**Hazard**
The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. See also Impacts and Risk.

**Heat wave**
A period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from two days to months. Heat stress in mammals (including humans) and birds, both in air and on land, is exacerbated by a detrimental combination of ambient heat, high humidity, and low wind speed, causing the regulation of body temperature to fail.

**Impacts (of climate change)**
The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and wellbeing; ecosystems and species; economic, social, and cultural assets; services (including ecosystem services); and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial (IPCC 2022).
### Glossary

**Livelihood**  
Encompasses the resources and activities essential for people's sustenance, typically determined by their entitlements and assets. These assets include human, social, natural, physical, or financial resources.

**Mitigation (of climate change)**  
A human intervention to reduce emissions or enhance the sinks of greenhouse gases (IPCC 2022).

**Resilience**  
The capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend, or disturbance, responding or reorganising in ways that maintain their essential function, identity, and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning, and/or transformation (Arctic Council 2016).

**Risk**  
Risks in the context of climate change refer to potential adverse outcomes for human and ecological systems. These risks stem from both the impacts of climate change and human responses to it, affecting various aspects such as lives, livelihoods, health, economic assets, infrastructure, ecosystems, and species. They arise from the interplay of climate-related hazards with the exposure and vulnerability of affected systems, which themselves may vary in magnitude, likelihood, and uncertainty due to socio-economic factors and human decisions.

**Social investor**  
Foundations, grantmakers, impact funds, family offices, banks, wealth management firms, private equity (PE), and venture capital (VC) funds which seek impact outcomes. This category includes impact investors. AVPN sees social investments as a continuum of capital (i.e. the range of financial, human, and intellectual capital that are invested with the expectation of measurable results and cover the entire spectrum of social investing) from impact-only to a combination of impact and environmental-social-governance (ESG)-themed investing and financial returns to risk-minimisation through ESG screens and integration (AVPN 2018).

**Vulnerability**  
The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. See also Exposure, Hazard, and Risk (IPCC 2022).

**Well-being**  
A state of existence that fulfils various human needs, including material living conditions and quality of life, as well as the ability to pursue one's goals, to thrive and to feel satisfied with one's life. Ecosystem well-being refers to the ability of ecosystems to maintain their diversity and quality (IPCC 2022).
AI encompasses a range of advanced algorithms and techniques that empower machines to emulate human cognitive abilities. In the realm of climate adaptation, AI can analyse vast datasets of climate information, including historical trends and weather patterns. By learning from these data, AI can be used for predictive weather modelling, optimising resource management for climate resilience (e.g. water conservation in drought-prone areas) and designing infrastructure that can withstand future climate extremes. One of the current applications of AI is the development of early warning systems that anticipate floods and droughts, allowing for proactive measures to be taken.

Blockchain technology offers a secure and tamper-proof approach to record-keeping through a decentralised digital ledger system, i.e. a shared database that is constantly updated and synchronised across a network of computers, ensuring data integrity. Within climate adaptation projects, blockchain can be employed to track and verify data associated with the use of funds allocated for adaptation efforts. This can ensure the efficient and transparent use of adaptation funds, particularly when these funds are being distributed to developing countries, fostering trust and accountability.

Drones or UAVs are air-borne robots equipped with sensors and high-resolution cameras. These capabilities allow drones to collect data on various environmental factors, including crop health assessments, flood damage evaluations, and deforestation monitoring. These data are critical for assessing climate risks and formulating effective adaptation strategies. For instance, drones are deployed to map floodplains and pinpoint areas susceptible to inundation, enabling targeted interventions to mitigate flood risks.

GIS function as advanced digital maps. They integrate data from diverse sources, such as satellite imagery, census data, and climate projections, to create comprehensive geographic information. In climate adaptation, GIS are utilised to map climate risks (e.g. areas prone to wildfires or floods), vulnerable communities, and available resources (e.g. water sources or fertile land). This information is instrumental in identifying areas requiring investments in adaptation strategies. For instance, GIS are employed to map areas at risk from rising sea levels, allowing for the development of coastal protection measures.
IoT refers to a network of interconnected physical devices embedded with sensors that collect and exchange data. This may include a network of sensors deployed in fields, forests, or even within buildings, constantly monitoring environmental conditions. Within climate adaptation, IoT sensors can be deployed to monitor a variety of environmental factors, such as soil moisture levels, air quality, and water flow rates. These data can be harnessed to improve water management practices (e.g. optimising irrigation for crops), enhance crop yields through precision agriculture techniques, and improve disaster preparedness efforts through real-time data on environmental changes. An example is the utilisation of IoT sensors to monitor water levels in reservoirs, allowing for informed decisions on water allocation during droughts.

ML is a subfield of AI that focuses on algorithms with the capacity to learn from data without explicit programming. Essentially, ML allows machines to improve their performance on a specific task, such as identifying climate risks, as they process more data. Within climate adaptation, ML empowers researchers to analyse vast quantities of climate data, uncovering trends and potential risks associated with climate change. For instance, ML is being utilised to refine the accuracy of climate models, which are crucial tools for predicting future climate scenarios.

Satellite and remote sensing technologies utilise a network of sophisticated cameras constantly orbiting Earth to capture high-resolution images and measurements of the planet’s surface. This technology provides continuous monitoring of factors such as sea levels, deforestation rates, and drought conditions across vast geographical areas. These data are critical for comprehending the impacts of climate change on a global scale and developing effective adaptation plans. An example is the application of satellite data to track changes in glaciers and ice sheets, which play a vital role in regulating sea levels.
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