Official Journal of the World Water Council
Water Policy

Water Policy Vol 23 No S1, 10 doi: 10.2166/wp.2021.232

Towards pragmatism in climate risk analysis and adaptation

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ABSTRACT

The Asia-Pacific region is extremely vulnerable to climate variability and change. This reflects high exposure to hydroclimatic hazards such as tropical cyclones, floods, droughts, and heatwaves. Rapidly growing cities and low-lying coastal zones/estuaries also face threats from sea level rise and storm surges. However, climate model projections remain very uncertain about most of these risks, so water infrastructure and operations need to consider a range of plausible futures. Against this background, the Asian Development Bank (ADB) has been developing frameworks, tools, and capacities in climate risk and adaptation assessment and management. Project teams are often operating in data-scarce situations and under significant time constraints, so the emphasis has been on creating pragmatic guidance and training resources. This paper charts the transition of climate risk management (CRM) within the ADB from a predominantly scenario-led to decision-led approach to adaptation. Examples are given of light-touch procedures for screening climate risks, strengthening the transparency and rigour of scenario analysis, raising awareness of a broad range of adaptation options, streamlining identification of CRM options, and embedding allowances for climate change in detailed engineering designs. Such practical innovations would benefit communities of practice beyond the Asia-Pacific region.

Key words: Adaptation, Asia, Climate allowance, Climate change, Risk management

HIGHLIGHTS

- Water infrastructure and operating rules must be adapted such that they continue to deliver intended benefits despite climate change.
- The Asian Development Bank has been developing frameworks, tools, and capacity for climate risk assessment and adaptation investments.
- Pragmatic procedures for screening climate risk are particularly helpful in information- and resource-constrained situations.

INTRODUCTION

The Asia-Pacific region is extremely vulnerable to the impacts of climate variability and change – threats that could undermine progress towards sustainable and inclusive economic growth of the region and beyond (Auffhammer, 2019). Over recent decades, some areas have experienced a significant rise in direct physical losses caused by extreme weather events such as tropical cyclones, floods, droughts, and heat waves. Annual average economic losses from floods, droughts, and tropical cyclones in the Asia-Pacific region are ~US$575 billion per year, and the number of people impacted has more than doubled in 40 years (UNESCAP, 2019). Economic costs from climate change in the region, as a percentage of GDP, are expected to be twice the global average by the 2050s (OECD, 2015a). This partly stems from high exposure to hydroclimatic hazards (Jongman *et al.*, 2012). Many cities and megacities – Shanghai, Mumbai, Ho Chi Minh City, and Jakarta among them – are in low-lying coastal areas exposed to rising sea levels, tropical cyclones, and extremely humid heat (Hallegatte *et al.*, 2013; Matthews *et al.*, 2017). In addition, rapid urbanization in many parts of Asia is exacerbating this vulnerability by placing more people, their assets, and infrastructure potentially in harm's way. Even small changes in climate hazards could translate into discernible changes in impacts within these 'hot spots' (Schleussner *et al.*, 2018).

Asia's vulnerability to climate change impacts also matters internationally because it is a key region for multinational businesses and industries to manufacture in, source from, and sell to. Therefore, with the global economy increasingly dependent on the free flow of goods along international supply chains, impacts of climate change in the Asia-Pacific region have attracted global attention. For example, the 2011 floods in Thailand highlighted the fragility of international supply chains for the electronics and automotive industries under extreme weather (Haraguchi & Lall, 2015).

The gravity of the adverse impacts of climate change and disaster risks in Asia-Pacific and the need for concerted action to address them are fully recognized at all levels. For example, the Asian Development Bank (ADB) Strategy 2030 (ADB, 2018a) identifies 'Tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability' as one among several operational priorities. All countries in the region have committed to taking action to reduce greenhouse gas emissions and to adapt to climate change, as outlined by their Nationally Determined Contributions (NDCs), in line with the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change. This is within the broad context of ADB's mission to achieve prosperity, inclusiveness, and resilience while sustaining efforts to eradicate extreme poverty in the region.

Delivering economic growth, eradicating remaining poverty, and responding to climate change in Asia and the Pacific will require significant investment in infrastructure – an estimated $26 trillion, or $1.7 trillion per year, over the period 2016–2030 (ADB, 2017a). This is concentrated in power, transport, telecommunications, water, and sanitation. There is an urgent need to ensure that this investment takes account of rising and future climate risks, because of the long lifetime of many investments, and because infrastructure decisions can lock in development patterns for decades. At the same time, there will be an increasing demand for investment in adaptation projects. However, there are formidable challenges which have previously hindered progress in managing climate change risks in the region.

First, there are often limited policy requirements or technical guidance in countries, and across or within sectors, for factoring climate risk management (CRM) into investment planning and infrastructure design. Second, climate change involves deep uncertainty and, until relatively recently, there has been a lack of technical guidance and capacity on how to address this in CRM (Hallegatte *et al.*, 2012). This is critical when it comes to the planning and design of water resource infrastructure, given the long lifetime of such investments, but also the profound uncertainties related to the regional and local characteristics of the hydrological cycle in a changing climate (Clark *et al.*, 2016). Third, the appraisal of different climate risks and adaptation options, as part of investment project analysis, is hampered by the challenges of economic appraisal of options (OECD, 2015b). Finally, financial resources are not always available to implement CRM interventions: the additional investments required to make water resource infrastructure climate-resilient may be contingent on the success of efforts to secure concessional or grant finances from 'third-party' entities, such as the Green Climate Fund (Tanner *et al.*, 2019).

Meanwhile, there has been a marked shift in the conceptual approach to CRM and adaptation planning within the water sector (Brown & Wilby, 2012; Ray & Brown, 2015). Formerly, the opening question might have been 'What are the expected climate risks and associated impacts at the project site, and what can be done to counter these threats?' Invariably, this approach focused effort on quantifying regional climate changes, and less so on evaluating adaptation options. A decade ago, this science-first approach was the preferred method of researchers and practitioners alike (IEG, 2012).

More recent practice is to invert this thought process by asking 'What are the project objectives and measures needed to ensure intended development outcomes are achieved, regardless of climate change?' In this new framework, climate model-based information is used to stress test and evaluate the efficacy of different adaptation options and project designs (e.g., Ray & Brown, 2015; Yates *et al.*, 2015; Poff *et al.*, 2016; IHA, 2019). The approach has been variously described as 'bottom-up', 'decision-centric', or 'vulnerability-led' but is essentially a decision-making procedure that embraces the inherent uncertainty of climate projections (Wilby & Murphy, 2018). Similar decision-making under uncertainty approaches is centred on principles of flexibility, robustness, and hedging strategies (e.g., real options analysis and portfolio analysis) or dynamic adaptation decision pathways and adaptive management (Watkiss *et al.*, 2015). Other considerations are important too – such as the evaluation principles used for project design/justification (Stakhiv, 2011).

Given the above context, this paper traces the evolution of pragmatic approaches to climate risk analysis and management by the ADB. This progress reflects a deeper sense of the development context and climate risk profile of the Asia-Pacific region, as well as the gradual assimilation of a new conceptual framework for adaptation planning. We begin by charting advances in CRM procedures within the ADB, including efforts to strengthen the enabling environment. We then explain how the ADB has moved to a more decision-centric approach that is focused on delivering project outcomes *despite* climate change. This is being achieved through the development of guiding principles and tools that are intended to embed climate resilience within the designs of new investment projects, i.e., to ensure that the ADB investment portfolio is 'climate smart'. However, implementing such activities may require policy and institutional reforms, and an example is provided by emerging techniques for adjusting national standards used in detailed engineering designs. We conclude by identifying opportunities for transferring insights about CRM from the Asia-Pacific region to wider communities of practice.

EVOLVING TO CRM IN THE ADB

The ADB *Strategy 2030* states that 75% of its committed operations will be supporting climate change mitigation and adaptation by 2030 (ADB, 2018a). To ensure this, climate finance from ADB's own resources will reach $80 billion cumulatively from 2019 to 2030. This commitment builds on an existing major investment base. In the year before the pandemic began, the ADB invested $1,536 million in adaptation from its own resources (Figure 1). The ADB also plays a key strategic role in the region in understanding and addressing the potential impacts of disaster risk and climate change in developing member countries (DMCs).

In 2014, it became mandatory for all ADB projects to be screened for climate risks, and a CRM framework was developed to facilitate these efforts at the corporate level (ADB, 2014). As illustrated by Figure 2, activities related to CRM are carried out across the project development cycle (with distinct concepts, preparation, and implementation phases). The CRM framework consists of the following steps that match this cycle:

1. Context-sensitive climate risk screening during the concept phase to identify projects that may be at medium or high risk.
2. For those projects identified as being at medium or high risk, a climate risk and adaptation (CRA) assessment is undertaken during the preparation phase of projects.

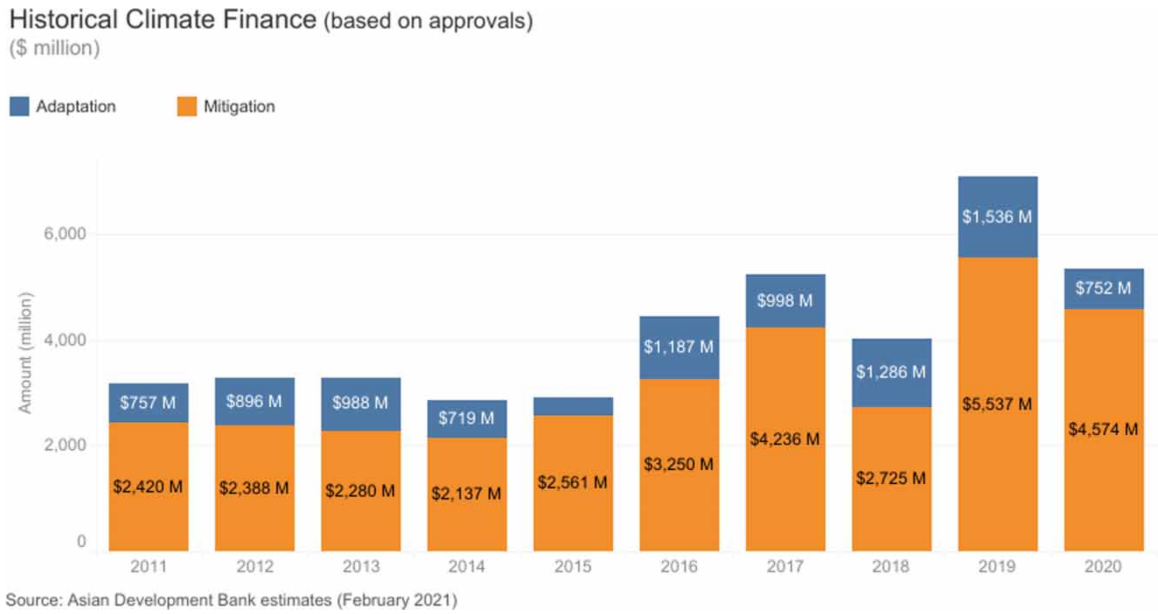

Fig. 1 | ADB finance for climate adaptation and mitigation projects 2011–2020. *Source*: https://data.adb.org/dashboard/climate-change-financing-adb.

3. The application and monitoring of selected climate risk measures are undertaken during the implementation phase.

Project teams have also been estimating and recording the level of adaptation finance, in line with the MDB methodology for tracking adaptation finance[1]. Furthermore, disaster risk concerns, including near-term disaster risks and risk emanating from geophysical hazards, have been incorporated into the CRM framework. Details on project climate risk assessment and associated risk management measures are captured in key project document(s), predominantly prior to project approval. These are made publicly available through the ADB portal[2].

For ADB projects, the Report and Recommendation of the President to the Board of Directors (RRP) includes specific placeholders for (1) reporting the assessed level of climate change impacts on the project and the amount of adaptation finance associated with the project (in 'Project at a Glance'); (2) describing the nature and severity of climate risks to the project and the proposed strategy to address these risks (usually in the 'Due Diligence' section); and (3) presenting a climate change assessment (as a 'Linked Document' to the RRP) for projects classified as at medium or high climate risk.

To support the implementation of the CRM framework, technical and financial support is provided, to the extent possible and mostly in a coordinated fashion. Technical and financial provisions for project-level CRM activities at the ADB are largely coordinated through the Climate Change team within the Sustainable Development and Climate Change Department. Financial support is made available internally (e.g., through the Climate Change Fund and various trust funds) to support the preparation of CRA assessments and related tasks. A large, searchable body of technical and sector-specific guidance notes has now been assembled to support ADB climate

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[1] https://www.ebrd.com/documents/climate-finance/-2018-joint-report-on-multilateral-development-banks-climate-finance.pdf.

[2] http://www.adb.org/projects

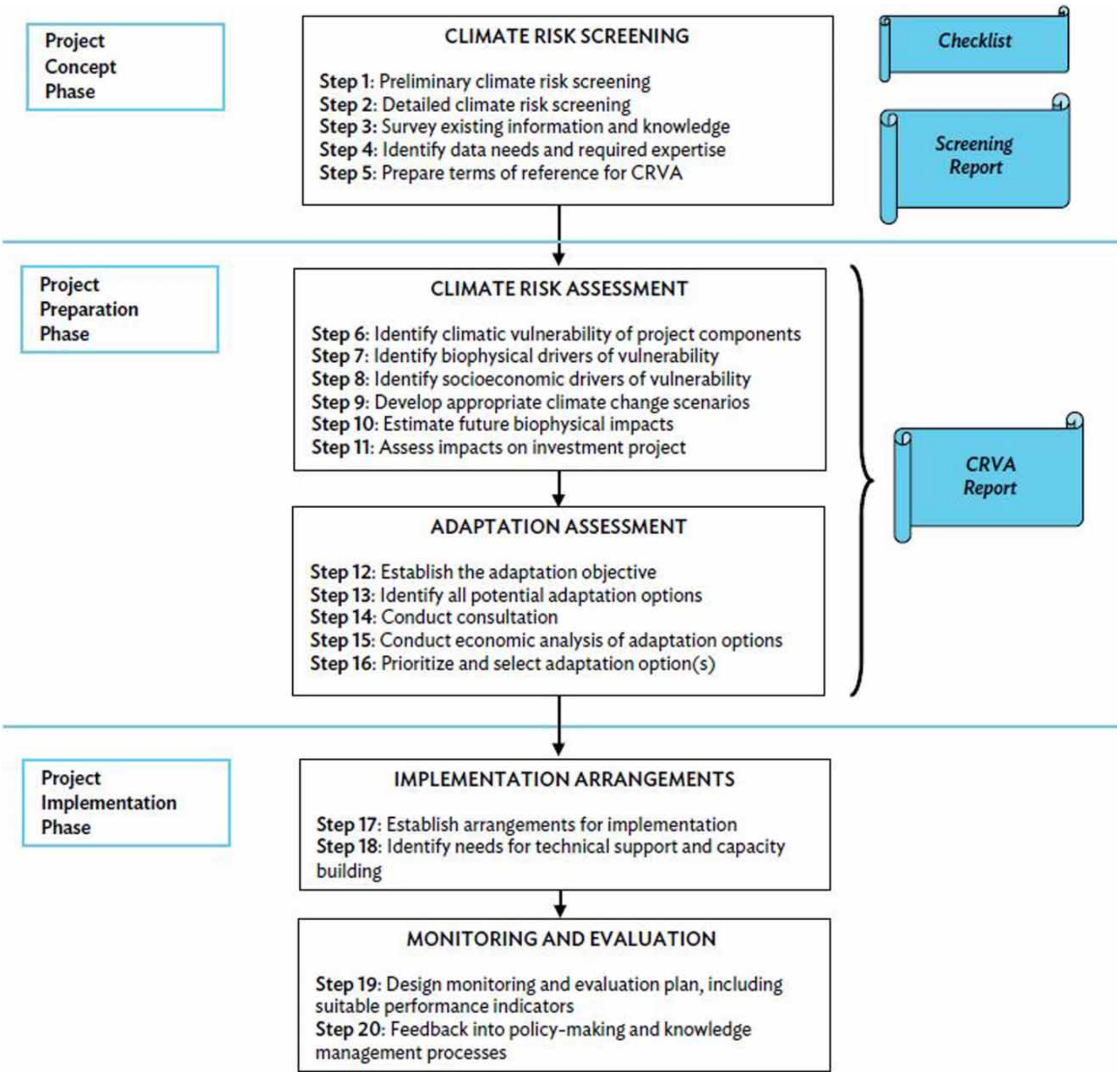

Fig. 2 | The ADB (2015) CRM framework for investment projects. CRVA, climate risk and vulnerability assessment.

risk assessments and adaptation planning[3]. For example, *Guidelines for Climate Proofing Investment in the Water Sector* (ADB, 2016) helps manage climate risks in water supply and sanitation projects. Similarly, knowledge products, such as *Information Sources to Support ADB Climate Risk Assessments and Management* (ADB, 2018b), have been developed to raise awareness of public domain data among project team leads and their CRA consultants (see Strengthening enabling environments for risk analysis, below). In addition, there are ongoing interactions and technical co-operations between the Climate Change team and project teams in operations departments within the ADB. Figure 3 illustrates the various engagements of the different teams across the

[3] https://www.adb.org/themes/climate-change-disaster-risk-management/publications-documents.

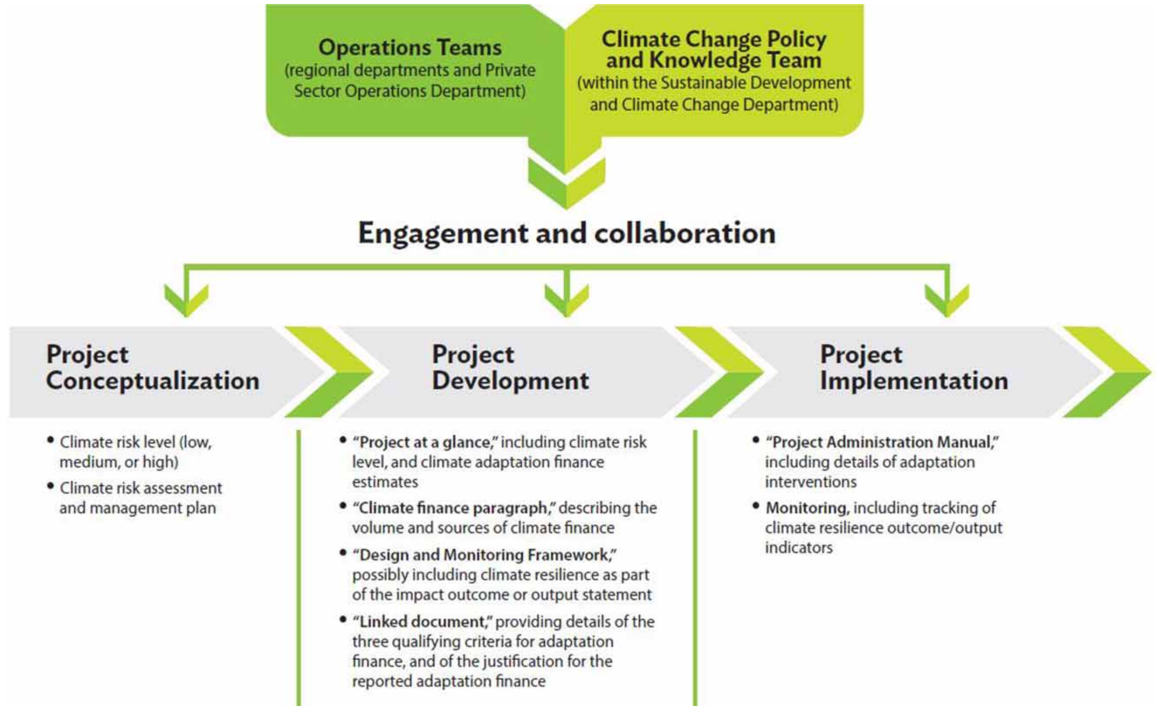

Fig. 3 | Collaboration and coordination for climate-resilient project development at ADB. *Source*: Lu (2019).

organization. This largely centralized CRM support mechanism enhances resource efficiency as well as technical consistency.

To take the stock of ADB processes and practices in implementing the CRM framework, a comprehensive review was carried out to assess how effective CRAs had been in helping teams to design and implement more climate-resilient projects (ADB, 2017b). This included a detailed technical evaluation of a large sample of CRAs for ADB investments. The primary criterion by which these CRAs were evaluated was *fitness for purpose*. In other words, to what extent had the CRAs assisted operations teams in designing and implementing more climate-resilient projects? The review found many positive aspects, even though the conclusions from the selected CRAs were often challenging to implement by project teams. Several specific insights were gained through this exercise. These included, among others: (1) ADB's approach was judged to be relatively pragmatic and proportionate; however, (2) there were opportunities to improve procedures and to strengthen the overall quality of project design to deliver climate-resilient projects; (3) the uptake of economic analysis of adaptation in CRA analysis could be strengthened; (4) bespoke guidance might be beneficial for adapting investments in the coastal zone and built environment given their high exposure and vulnerability to climate hazards; and (5) longitudinal analysis of completed projects could trace the value added and lessons learned by CRAs within the eventual design and delivery of resilience investments.

Following the recommendations of the above review, various initiatives were launched to strengthen CRM practices within the ADB, through streamlining procedures and building internal capacities through guidance and training. Work was carried out to re-orientate CRAs such that they focus more on project objectives and outcomes and consider risk management interventions, as opposed to top-down climate model-driven assessments. This was pursued through the development of *Principles of Climate Risk Management for Climate Proofing*

Projects (Watkiss *et al.*, 2020). The approach was light-touch (where feasible) and pilot-tested with live ADB projects before rolling out to staff via training sessions in 2018 and 2019.

STRENGTHENING ENABLING ENVIRONMENTS FOR RISK ANALYSIS

Project teams face many challenges when undertaking CRAs, including the climate risk assessment, adaptation options identification, and economic analysis ADB (2017c). Obtaining baseline climate data and contextual information at the project scale can be a significant obstacle to adaptation decision-making (Bhave *et al.*, 2016). Solutions may involve the use of unconventional data types, including technical reports, newspapers, indigenous knowledge, and even social media (e.g., Thompson *et al.*, 2021). Sometimes it is necessary to fill data gaps with brief field campaigns or to establish new data collection systems. The capacity to collate then interpret such diverse information streams and to recognize inherent quality issues or uncertainties (especially in climate model output) may also be in short supply. Likewise, tools for quantifying climate risks and evaluating adaptation option sets may be difficult to source or non-existent. Here, we recount some of the steps being taken by the ADB to address these practicalities.

Considerable attention has been paid to the procurement of climate risk information for adaptation and development planning more generally (e.g., Wilby *et al.*, 2009) as well as for specific sectors such as water (e.g., Fowler *et al.*, 2007). 'Country profiles' have been made available by organizations such as the World Bank and United Nations Development Programme for some time (see McSweeney *et al.*, 2010). Indeed, during the time of writing a new set of country profiles was released by the ADB and the World Bank[4]. These draw on climate scenarios from the CMIP5 ensemble associated with the IPCC Fifth Assessment Report, as well as indicators of climate risk and vulnerability. High-level profiles are helpful for situating projects within a national context and signposting useful resources but are typically insufficient for local-scale CRAs.

Portals like the KNMI Climate Explorer significantly improve access to baseline meteorological data and climate model projections for some variables (e.g., monthly mean temperatures and precipitation totals), extremes (e.g., annual maximum/minimum temperatures and 1-day rainfall totals), and impact indices (e.g., cooling and heating degree days). However, much of this information is also at low spatial and temporal resolutions – certainly too coarse to resolve past and projected conditions for a Pacific island or the specific locality of a project. Most Pacific islands are too small to be resolved as land surfaces (so are misrepresented climatologically as ocean spaces in climate models). More generally, there is still a disconnect between the outputs of the climate modelling community and the information needs of users, not least in terms of the formats and accessibility of climate model products. The Australian Bureau of Meteorology and CSIRO (2014) report on *Climate Variability, Extremes and Change in the Western Tropical Pacific* is a good example of a document that bridges this gap, so has received widespread uptake across the region.

Moreover, climate models struggle to represent important features of the local climatology (such as El Niño signatures in regional climate patterns of rainfall and temperature) (Yun *et al.*, 2016; Chen *et al.*, 2017). Key design variables such as storm surge height (for flood projects), potential evapotranspiration, and drought indices (for water resource and irrigation schemes) depend on post-processing and subsequent modelling with climate model outputs. Historic data that allow such assessments are scarce, difficult, or costly to obtain, or of questionable quality (especially for extreme values such as heavy rainfall). Compounding these concerns, for future climate projections, there is deep uncertainty from the combination of alternative representative concentration pathways (RCPs), and a large number of alternative climate models and

[4] https://www.adb.org/publications/series/climate-risk-country-profiles and https://climateknowledgeportal.worldbank.org/country-profiles.

simulations are available for each RCP. There is also uncertainty about future socio-economic change, which is usually at least as important as climate in determining future climate risks or levels of vulnerability. Hence, there may be a need to manage expectations about what climate experts can realistically supply to project teams. At the same time, there is scope to mainstream the use of climate risk information within the project life cycle (see below).

Efforts were made by the ADB to consolidate open information sources into a single document to save time and resources for project teams. As mentioned before, ADB (2018b) provides material to support CRA experts undertaking early stages of project development in the Asia-Pacific region. Approximately 70 sources of public domain data were compiled and evaluated. These resources were grouped into four categories covering: (1) inventories of national emissions, climate risks, vulnerability, and impacts; (2) historic weather, climate, and environmental change; (3) regional climate change projections; and (4) climate change impacts and adaptation. The ADB compendium also called for more investment in capacities for geospatial analysis, data testing and post-processing, climate downscaling, and impact assessment. Moreover, through closer cooperation between scientific and practitioner communities, access to publicly-funded, research-grade climate information could be much improved and made available to CRA teams.

Gridded satellite and reanalysis products are becoming more widely available (e.g., Beck *et al*., 2017). These information sources can be used in data-sparse situations or combined with available local measurements to infill and extend records (e.g., Wilby & Yu, 2013). However, remotely sensed data have recognized limitations – not least poor performance at estimating heavy rainfall (e.g., Alijanian *et al*., 2017). Furthermore, the skill of different precipitation products varies with information source, post-processing algorithm, region, season, and terrain (Sun *et al*., 2018). Where available, locally observed, point meteorological data can be used to bias correct gridded data but these procedures are not without uncertainties either (Teutschbein & Seibert, 2012). Hence, a key tenet when collecting and analysing baseline data for CRAs is complete transparency about all information sources and working assumptions. Giving the impression of undue precision should be avoided by rounding values and presenting confidence intervals as standard practice.

Specialist technical assistance in data gathering, post-processing, and downscaling is routinely procured by ADB project teams. This can help to fill skills gaps but presupposes that the in-house capacity exists to critically evaluate the quality of work undertaken by consultants (or indeed to develop the terms of reference to commission appropriate information). Simple steps can be taken to raise standards. For example, to encourage greater consistency and rigour in technical analysis of climate model information, the ADB could require that climate service providers complete a quick checklist (Table 1). This would drive greater transparency of implicit and explicit assumptions about climate information sources, so project teams are aware of any issues that could materially affect project design at later stages. This goes alongside the expected norms of carefully managing and quality assuring data at each stage of the information flow (see Wilby *et al*., 2017).

In-house training and capacity building are being pursued to better equip ADB project teams when developing terms of reference for consultants and quality assuring their deliverables. Pools of specialist advisers are used to provide independent peer reviews of CRA documents and ensure quality. Staff training has been provided on: shaping more explicit climate risk objectives, adaptation decisions, and eligibility criteria; understanding the project and what really matters (in terms of climate risks); smarter use of climate risk information in CRAs; hands-on experience of climate information portals; adaptation typologies; and economic analysis of adaptation costs and benefits. These elements have been integrated within a framework that is more focused on project outcomes than climate risk analyses. Looking beyond this, as the ADB contracts

Table 1 | Climate projection checklist for service providers.

Contextual information	**Check**
State the purpose(s) of the chosen climate projections at the start of the report	
Justify the choice(s) of emissions pathways and climate model sensitivity	
Justify the choice(s) of GCM(s) or climate model ensemble	
State and justify the choice of the baseline period	
Explain the choice of short-listed variables	
Historic data quality assurance and analysis	
State any recognized strengths and weaknesses of the data sources	
Provide complete details for historic data (e.g., site locations and years of record)	
Document any known changes in site, instrument, or observer practices	
Perform quality assurance, homogeneity, and stationarity checks on all data	
Sanity check extreme values against independent sources (e.g., media reports)	
State and justify any extreme value distributions (including for GCM output)	
Provide confidence intervals for all extreme value estimates	
Regional climate downscaling and derived indices	
State any recognized strengths and weaknesses of the chosen GCMs/RCMs	
Avoid mixing different scale GCM and RCM projections in the same ensemble	
Justify the choice of downscaling methods in terms of fitness for purpose(s)	
Provide full details and supporting references for all downscaling methods	
Provide full equations and supporting references for all derived variables	
Use GCM outputs in ways that are internally consistent (avoid pick-and-mix)	
Acknowledge when GCM/RCM ocean grid cells are used for terrestrial sites	
Itemize all components of regional sea level rise, justify omitted components	
Acknowledge uncertainty in derived indices (e.g., modelled evapotranspiration)	
State the percentile of extreme value estimates	
Compare historic data and GCM/RCM output using periods of overlap	
Presentation	
Proof-read documents for typographic errors and cite all literature sources	
State climate model details and emissions scenarios in figure and table legends	
Apply most appropriate quantiles (not just the mean) for the intended use	
Use 'could' rather than 'will' when referring to uncertain climate model projections	
Avoid undue precision when reporting climate change projections	

much of its technical work with consultants, there are opportunities to strengthen the climate service community more generally, whether by training, some process of certification[5], and/or by setting professional standards (e.g., Adams *et al.*, 2015).

[5] Such as the Global Center on Adaptation and World Bank 'Knowledge Module on PPPs for Climate-Resilient Infrastructure' https://gca.org/programs-infrastructure-and-nbs-knowledge-module-ppp/.

STREAMLINING AND REFOCUSING PROJECT-LEVEL CLIMATE RISK ANALYSIS

As discussed above, the ADB (2017b) review of CRM processes and practices revealed several recurrent issues within a sizeable sample of CRAs.

First, early CRAs tended to focus on model projections of the future climate for a limited number of variables (annual precipitation and temperature), i.e., climate hazard assessment, with significantly less time and resources devoted to project vulnerability, and even less on identifying adaptation strategies and options. This was due in part to the practice of engaging climate specialists, as opposed to sector specialists with CRA training. It also reflects the timing and nature of CRA studies within the project cycle, which are typically conducted in parallel with, but often independently from, project feasibility studies before the final design.

Second, these CRAs typically applied an impact assessment ('predict-then-act') approach. In such cases, the climate change analysis attempts to identify a set of climate change projections that 'best' characterizes the project location, which can lead to over-interpretation of projections from climate models, and time periods that rarely match the project design lifetime (such as the use of scenarios for mid- or late-21st century even in projects with a 30-year lifetime). As noted in the Introduction, this 'top-down' perspective is being superseded by approaches that pay greater attention to project objectives and outcomes with decision-making under uncertainty from outset.

Third, the nature of the ADB project cycle, and allocation of tasks across different teams, hinders the ability of CRA consultants to implement detailed recommendations concerning climate-sensitive design parameters. In many cases, the type and location of a project, and even some of the design elements, is decided upon by the time the CRA is underway. This means there is generally limited scope to re-design or alter a project significantly (to increase climate resilience) once the concept phase is complete. At the other end of the process, as the CRA consultants' work is completed prior to project Board approval, they are no longer available to consult with implementing agencies and design firms once project activities begin. To address these issues, there is now greater emphasis on improving the CRM process upstream (before the concept phase) and downstream (in the implementation phase).

Fourth, it is clearly desirable for CRAs to provide a 'menu' of risk management options to project teams, with each option evaluated (in terms of, e.g., economic costs and benefits, effectiveness, and technical feasibility). In practice, CRAs have tended to offer a narrow range of risk management options (in many cases only one), and these are usually focused on technical design options. This is being addressed through the development of searchable inventories of sector-specific adaptation options, with supporting literature and case studies (Georgi *et al.*, 2021). Other material showcases the integration of adaptation (and mitigation) solutions at city scales (e.g., ADB, 2018c). Even a one-page typology of adaptation options can be a powerful training resource and a reminder to project teams of the wider possibilities (Table 2). Importantly, this broadens the analysis of adaptation from hard engineering options to a suite of technical and non-technical options, including consideration of no- and low-regret activities, operational risk mitigation, green solutions, and other alternatives such as risk spreading, not just civil works and structures.

As mentioned before, the ADB is re-orientating CRM procedures to focus on achieving intended project outcomes *regardless* of climate change. This is part of wider efforts to simplify and streamline the existing CRM framework (Figure 2). The new workflow (Figure 4) is founded on several guiding principles that are elaborated in detail by Watkiss *et al.* (2020). In summary, they are discussed below.

Principle 1: move upstream

This entails activities before the development of project concepts, including (1) screening sector strategies and roadmaps to identify potential climate risks in relevant thematic and country operations to enable adequate time and resource allocation for climate-resilient project preparations; (2) identifying key climate risks in

Table 2 | Typology of adaptation actions: modified from Biagini *et al*. (2014).

Category	Sub-category	Description	Examples
Human and social capital	*Capacity building (C)*	Developing human resources, institutions, and communities, equipping them with the capability to adapt to climate change	Training/workshops for knowledge/skills development, public outreach and education, dissemination of information to decision-makers/stakeholders; identification of best practices, training materials
	Practice and behaviour (B)	Revision or expansion of practices and on the ground behaviour that are directly related to building resilience	Soil/land management techniques; climate-resilient crops or livestock practices, post-harvest storage, rainwater collection, expanding integrated pest management
Institutions and governance	*Management and planning (M)*	Incorporating understanding of climate science, impacts, vulnerability, and risk into government and institutional planning and management	Developing an adaptation plan, livelihood diversification, drought planning, coastal planning, ecosystem-based planning, changing natural resource management
	Policy (P)	Creation of new policies or revisions to policies or regulations to allow flexibility to adapt to changing climate	Mainstreaming adaptation into development policies, land-use specific policies, improvement of water resource governance, revised design parameters, ensuring compliance with existing regulations
Information and communication tools or technology	*Information (I)*	Systems for communicating climate information to help build resilience towards climate impacts (other than communication for early warning systems)	Decision support tools, communication tools, data acquisition efforts, digital databases, remote communication technologies
	Warning or observing systems (W)	Implementation of new or enhanced tools and technologies for communicating extreme weather and climate risks, and for monitoring changes in the climate system	Developing, testing, and deploying monitoring systems; upgrading weather or hydromet services
Infrastructure	*'Grey' infrastructure (HI)*	Any new or improved hard physical infrastructure aimed at providing direct or indirect protection from climate hazards	Climate-resilient buildings, reservoirs for water storage, irrigation systems, canal infrastructure, sea walls
	'Green' infrastructure (SI)	Any new or improved soft, natural infrastructure aimed at providing direct or indirect protection from climate hazards	Revegetation, afforestation, woodland management, increased landscape cover, wetland/mangrove restoration
Financing (F)		New financing or insurance strategies to prepare for future climate disturbances	Insurance schemes, microfinance, contingency funds for disasters
Technology (T)		Develop or expand climate-resilient technologies	Technologies that improve water use or water access, solar energy capacity, biogas, water purification, solar salt production

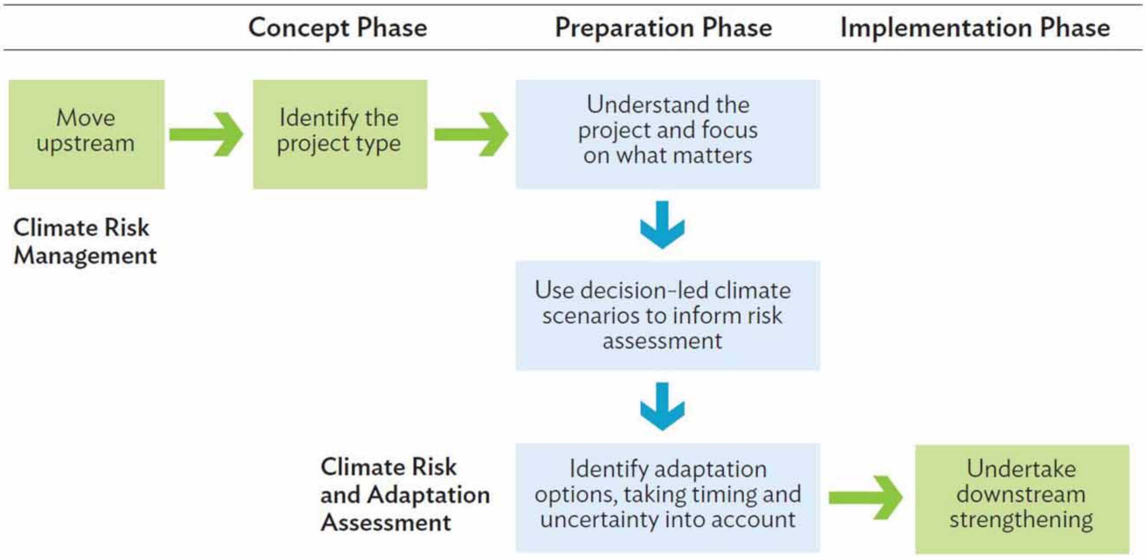

Fig. 4 | Guiding principles of CRM for climate-proofing projects. *Source*: Watkiss *et al*. (2020).

DMCs or sectors and hence opportunities to invest in building climate resilience in development plans and through targeted investments; and (3) enhancing the provision of key technical resources to support the identification of potential climate risks and opportunities for climate resilience investment (e.g., ADB's Urban Climate Change Resilience Trust Fund). Country Partnership Strategies (CPS) developed by the ADB with DMCs provide key entry points for mainstreaming climate adaptation at this more strategic and integrated level.

Principle 2: identify the project type

As projects are formulated and move towards the preparation phase, there is a need to differentiate investments and develop CRAs that match the materiality (proportionality) of climate change risks and adaptation needs. An initial checklist of five criteria has been developed to make these distinctions. The criteria are (i) amount of climate finance; (ii) project lifetime; (iii) risk of lock-in; (iv) warranted level of precaution; and (v) potential economic impact. The resulting project categories are the following:

Type 1a climate-proofing projects: where climate is a relatively minor risk to project performance, so the objective is to make the project more resilient with marginal adjustments for which a lighter-touch CRA approach would be sufficient. An example might be a standard roads project where drainage is a primary concern.

Type 1b climate-proofing projects: where climate change is a significant threat to project performance, so a greater level of adaptation and a more detailed CRA analysis are warranted. An example might be a large hydroelectric power and reservoir project.

Type 2-targeted adaptation investment projects: where addressing climate risks is the primary objective. An example might be a new coastal protection project to counter floods caused by rising sea levels. These types of investment may become a larger part of the ADB investment portfolio in the future with moves to scale up support to DMCs on climate action. Such projects require a more integrated approach in which CRA analysis are part of the core project design and outcomes. In many cases, this will involve more detailed climate and adaptation analysis, but it may also include lighter-touch situations (e.g., technical assistance projects or investments focusing on non-structural resilience solutions such as early warning systems and data analytics).

Principle 3: understand the project and focus on what matters

Moving into the main preparation phase of a project, this involves mapping the pathways through which climate variability and change could affect project objectives, outputs, and outcomes, as well as key project indicators. This can be used to narrow the list of risks for consideration, based on how material they are to the project performance and key indicators (including the economic and financial performance) and to identify adaptation objectives at an early stage.

Principle 4: use decision-led climate scenarios to inform risk assessment

Once climate impact pathways and key risks have been identified, the analysis of climate information and climate model projections can begin. This focuses on the appraisal of relevant climate impact and risk metrics. The approach here will differ. For light-touch assessment, as in Type 1a projects (Principle 2), sensitivity testing and rapid assessment methods are appropriate, rather than detailed analysis. However, for Type 1b projects, where climate change is likely to be material, a detailed assessment will be warranted but should still be decision-led.

Principle 5: identify adaptation options taking account of timing and uncertainty

It is recognized that the adaptation of long-lived infrastructure is challenging because of uncertainty. However, it is possible to identify promising measures by matching the type and timing of adaptation options to climate risks identified and placing greater emphasis on the economic rationale for adaptation (the costs and benefits). For Type 1a projects, this is likely to focus on low and no-regret regret options. A key focus is to introduce a wider consideration of adaptation options that extend beyond technical design changes (while noting these remain an important option). For projects that have more significant climate risks (Type 1b projects), low- and no-regret options are still important, but a greater focus on decision-making under uncertainty approaches, including iterative adaptive management, is recommended.

Principle 6: strengthen downstream (implementation, monitoring, and evaluation)

To ensure that benefits from the CRM are delivered, there is a need to enhance the programming of adaptation as projects move into the implementation phase (of the project cycle). This may require some changes in existing practice, especially to address additional challenges with flexible and iterative programming due to long-term implementation and governance arrangements. There is also a need to move towards implementation, monitoring, evaluation, and learning frameworks. This will require that resources be allocated for post-project climate evaluation and that institutional processes are in place to benefit from lessons learned. Occasionally, there may be covenants in loan agreements to ensure that climate-resilient features remain in contracts and bidding documents for civil works.

To illustrate these principles, consider a hypothetical irrigation project in southeast Asia. The overall objective is to improve rural incomes by increasing farm output from improved irrigation efficiency, leading to higher agricultural productivity, developed within an integrated water resources management approach that considers ecosystem services. Such a project might involve upgrading existing canals, installing new piped distribution systems and more efficient supply of water, introducing an improved management and operation (with water charging), and supporting farmers with extension services to enhance productivity and/or grow higher-value crops, as well as watershed management (e.g., slope stabilization and protected forests). The expected operating lifetime of the new infrastructure is 20–30 years, so the focus should be on risks from *climate variability* and emerging climate trends (rather than on long-term climate change). However, the project should not be in a water-scarce region and/or area where future climate or socio-economic development could exceed sustainable water use (i.e., to avoid lock-in and potential maladaptation). We may assume that the region faces possible climate risks from changes in average, minimum, and maximum temperatures (and evapotranspiration), average and seasonal precipitation, dry and wet season onset, and intensity and duration; changes in the frequency and intensity of tropical cyclones, the frequency and intensity of heavy rainfall, flash flooding, and erosion; and changes in the frequency and intensity of hot days and heatwaves. These would have implications for both water availability and irrigation demand, as well as for agricultural production (and crops and varieties).

Against this backdrop, there are prospects for mainstreaming adaptation thinking at an earlier stage (Principle 1) such as more strategic consideration of national and regional climate change and integrated land-water management in the ADB CPS and the Country Operations Business Plan. Since climate risks/opportunities are highly material to the project, an in-depth CRA is warranted (Principle 2) – this is a Type 1b project requiring more detailed analysis and closer collaboration with the core design team. The key risks affecting project outputs are identified (Principle 3) as changes in: (a) climate variability and abstraction levels, and thus the ability to meet the performance criteria for year-round irrigation supply – potentially affecting infrastructure design; (b) increasing temperature and evapotranspiration, as well as changing climate variability, affecting irrigation demand (total, seasonal, and peak) and design criteria (tolerance levels for inter-annual variability); (c) agroclimatic shifts and particularly possible changes in dry season and heat extremes, that might affect the choice of crops, timing of planting and harvest dates, crop pests, and diseases – potentially affecting the management and operation of the scheme and the farmer extension service components; (d) drought and fire risks to headwater forests, soil/slope stability, and downstream river flows – potential affecting the watershed management options; and (e) flooding and physical damage to irrigation systems, fields (and crops), and access roads from increased intensity of heavy precipitation (Table 3).

Next, the climate information needed to evaluate these risks is identified (Principle 4). This might begin with a detailed appraisal of historic temperature, evapotranspiration, and wet and dry seasonal rainfall totals, along with their inter-annual variability, compared to the water requirements of different crops. Indicators of extreme events, such as annual maximum daily rainfall amounts, dry-spell duration, and extreme heat could be analysed where data exist. Some basic water balance modelling and flood risks estimation might be performed too. The operating lifetime of some planned infrastructure could reach the 2050s, so changes in the same extreme values and water balance components could also be assessed using sensitivity testing or marker scenarios or from the climate model ensemble (such as CMIP5 or CMIP6).

A portfolio of adaptation options could then be developed and mapped against the identified climate risks and vulnerabilities (Principle 5) (Table 3). The options should include a mix of adaptation types. Importantly, these must target key risks, noting these affect project engineering as well as the services that are also included in the project (irrigation operation and farm extension services). The immediate priority is to identify no- and low-regret measures for early adoption (such as improved weather forecasts). Other measures, notably for possible changes to civil works and structures, should enable decision-making under uncertainty. For example, engineered options might include an appropriate allowance for climate change to harden critical assets, but alternatives that introduce the flexibility of design for later upgrade, or options that build robustness such as enhanced demand-side efficiency, should be considered too (see section Incorporating climate change within engineering design standards). Alongside this, it is important to strengthen monitoring within the project to enable adaptive management of emerging risks. For example, this might include a greater focus on measuring and correlating irrigation supply and demand with climate information but could also extend to enhanced pest and disease surveillance. Finally, roles and responsibilities should be assigned among project partners for

Table 3 | Intended project outcomes, climate risks, and adaptation options for a hypothetical irrigation scheme in southeast Asia.

Project outcomes	Climate risks	Adaptation options
Improved efficiency and reliability of irrigation supply	Change in precipitation and water (availability), increasing crop evapotranspiration (demand), change in variability, affecting system dimensions to meet peak supply (1 in 5 years)	• Increased irrigation capacity • Increased efficiency (e.g., drip irrigation) • Increased water storage • Supplementary water sources (conjunctive) • Improved demand-side management
Increased market-oriented agricultural production	Agroclimatic shift and change in the dry season, risk of weather extremes, impacts on the choice of crops, timing of planting and harvest dates, crop pests, and diseases, in turn affecting crop productivity and quality	• Weather and seasonal climate forecasts • Climate-smart extension services • Crops or varieties with shorter growing cycles or more resilient choices • Pest monitoring and management • 'Tall rice'
Enhanced watershed ecological services	Change in drought and fire risk affects headwater forests, soil/slope instability, downstream river flows	• Land-use zoning or buffer zones to deter encroachment into forest areas • Replant deforested areas with fast-growing tree species • Install live check dams
More productive rural infrastructure	Physical damage to irrigation system and access roads by flash floods, erosion, and sedimentation	• Early warning systems • Water management plans • Increase water storage (ponds and cisterns) • Strengthen emergency spillways, sluice gates, site drainage • Increase design standard with climate uplift for key access roads

long-term monitoring of project performance against expected outcomes and climate pressures (Principle 6). Taken together, these encourage adaptive management of emergent climate threats through a cycle of review that could be built into the management contracts for the project.

INCORPORATING CLIMATE CHANGE WITHIN ENGINEERING DESIGN STANDARDS

Although there is widespread expectation that extreme rainfall could become more intense (IPCC, 2018), and that the pace of global mean sea level rise will accelerate over coming decades (IPCC, in press), there is considerable uncertainty about the local values of these important design variables – even for the present climate. Nonetheless, engineers have to produce detailed designs for infrastructure that could have operating lifetimes of decades to centuries. Hence, the ADB, along with a few other agencies (e.g., CSIRO and Bureau of Meteorology, 2015; Environment Agency, 2016; United States Army Corps of Engineers, 2019), has been developing step-by-step procedures for incorporating adjustments for climate change within the detailed engineering design stage of a project. (Here, attention is on adjustments to *individual* project designs, rather than on facilitating an adaptive pathway comprised of *multiple* adaptation investments over time (e.g., Ranger *et al.*, 2013)).

The ADB approach seeks to strengthen the enabling environment (policy and regulatory) for adaptation upstream, as well as for individual projects. This may be achieved through national standards for detailed engineering design – noting that in the absence of such changes, these can act as a barrier to project-level adaptation (because projects comply with current, non-climate adjusted national standards). The ADB toolkit includes a technical report, user manual, and spreadsheets to guide users through a sequential process of updating design standards, with worked examples and data to aid understanding. In the ADB, these procedures were piloted in Viet Nam where national standards for roads and bridges require a design flood level of 1 in 100 years for expressways, and 1 in 25 years for categories 3, 4, or 5 rural roads. In Viet Nam, the 1-day annual maximum rainfall total (Rx1day) is a critical variable in provincial-level road design formulae for hydrologic calculations of design water discharge, flood level, and flow velocity. Parts of the Viet Nam coastline are also highly susceptible to storm surge, flooding, and erosion (Duc *et al.*, 2017). Therefore, a parallel set of procedures was devised for estimating local sea level for specified design periods. The two overarching philosophies are transparency and accountability – all sources of evidence and each calculation is made explicit. This means that as scientific understanding and climate modelling evolve, key data entries can be periodically reviewed and revised accordingly. For example, the IPCC (in press) *Special Report on the Ocean and Cryosphere in a Changing Climate* provides higher upper-bound estimates of global mean sea level rise than the previous point of reference which was the Fifth Assessment Report. These and other lines of evidence beyond the scope of IPCC reports are kept under review to ensure that guidance issued to project teams on design standards is sufficiently precautionary.

The ADB (2020) procedure for estimating design values for future extreme rainfall involves seven stages. Step 1: project objectives are specified as clearly as possible. These define the site(s), required design variable(s), return period, and operating life of the project. Step 2: a check is made for contextual risks. For instance, the design may be for a climate-resilient culvert, bridge, or road, but a coastal road might be more at risk from storm surge than flash flooding from the land. Step 3: design values are estimated from the annual maximum series of historic rainfall using established extreme value analysis. Quality assurance checks are applied to data and the choice of extreme value distribution (with confidence intervals) is made clear, along with reasons why. Step 4: equivalent climate model projections are obtained for the design variable (such as Rx1day) and operating lifetime of the asset. Again, decisions about the baseline period, choice of emissions scenario, climate model ensemble, and spatial domain of the scenarios are all made explicit. Step 5: the same extreme value distribution (as in step 3) is fit to the annual maximum series from the climate models for the baseline and future period. The design value is estimated at the required return period for these two periods. Step 6: the percent change in the design value is calculated by comparing the future and baseline estimates. To avoid undue precision and include some contingency, this change factor is rounded up to the nearest 5% (as in Table 4). Step 7: the change factor is applied to the historic extreme value estimate (from step 3) to give the new design value for the future, at the specified return period and confidence level.

This procedure captures non-stationarity in extreme rainfall (Cheng & AghaKouchak, 2014), but there are several points where the engineer makes an expert judgement. The most important decisions likely concern the choice of extreme value distribution (if any) guided by considerations of distribution fit, the short-listed climate model ensemble, and confidence interval. It is well known that extreme rainfall estimates are sensitive to the assumed distribution, geographic location, and length of record used (Papalexiou & Koutsoyiannis, 2013; Hu

Table 4 | Climate change adjustment factors for the 1-day annual maximum rainfall total (Rx1day) in Viet Nam.

	Return period (years)				
Future period	**2**	**5**	**10**	**20**	**25**
2016–2035	15	20	25	25	25
2036–2055	35	25	30	30	35
2056–2075	50	45	45	45	45
2076–2095	80	75	75	70	70

All values are expressed as percentage changes from 1986 to 2005 based on climate model experiments (CMIP5) under RCP8.5. Return-period estimates assume a Gumbel distribution and the 97.5th percentile of the credible ensemble, rounded up to the nearest 5%. *Source*: ADB (2020).

et al., 2020). There is little consensus about how best to judge the accuracy of a future scenario, but the ability to simulate key features and processes of the present climate system is regarded as a necessary but insufficient test (e.g., McSweeney *et al.*, 2015; Vogel *et al.*, 2018). The confidence interval should reflect tolerance for risk and economic considerations, which will vary by project. Since the results are sensitive to all these factors, the default position is to be totally explicit about what was done and why. At the very least, this leaves the calculations open to scrutiny and there is a clear audit trail leading to the design value.

A similar approach is proposed for the estimation of local mean sea level and high-water levels (ADB, 2020). As before, the first step is to be clear about the project objectives (S1). This specifies the design variable, time horizon, and location(s) for the flood and/or coastal erosion assessment. Once more, contextual risks should be identified (S2). For example, local rates of erosion may be influenced by changes in sediment supply from nearby rivers, as well as by sea level rise and storm surges. The *lower bound* (most optimistic) projection of future sea level rise is probably defined by an extrapolation of the historic trend from the nearest tide gauge (S3). A *central estimate* of sea level is derived by summing published values of global (e.g., thermal expansion and ice melt contributions), regional (e.g., gravitational fingerprint and vertical land movement), and local (e.g., tidal-range, wave, and surge) sea level components (S4) from sources such as IPCC (in press). A *high estimate* of sea level is obtained from the same components as in step S4, but now upper-bound uncertainty values for each constituent are blended into the calculation (S5). Finally, an *extreme estimate* of sea level is produced from the highest plausible values for each component/uncertainty bound in steps S4 and S5 to give a credible maximum water level under a high-end sea level change scenario with tide, storm, and wave effects (S6).

A key advantage of the components-based method of sea level estimation is that individual elements are accounted for and visible (Nicholls *et al.*, 2014). Moreover, the approach has been applied previously in some high-profile projects, not least in the long-term coastal protection plan of the Netherlands (Katsman *et al.*, 2011) and for planned nuclear power stations in the UK (Wilby *et al.*, 2011). Even so, the ADB (2020) procedures may encounter lack of information for some local components such as wave and storm surge heights – in which case, nearest neighbour or published values may be adopted. Choices must also be made about the numerical methods used to combine uncertainties in high and extreme sea level estimates. Simplifying assumptions may require that: maximum surge and wave heights remain unchanged (unless model evidence suggests otherwise); extreme surge, wave, and tide behave independently of each other; vertical land movements linked to changes in coastal sediment budgets can be neglected; and coastal morphology and beach profiles will be the same as present.

Finally, there are differing views about what constitutes a 'credible' upper-bound global mean sea level rise scenario. One expert elicitation attached a 5% probability of global mean sea level rise exceeding 2 m by 2100, and 7.5 m by 2200 in +5 °C world (Bamber *et al.*, 2019). Such judgements are clearly pertinent to risk assessments of long-lived assets such as power stations, ports, major flood defence assets, or other critical infrastructures in the coastal zone. It is also important to acknowledge that sea level rise is likely to continue well beyond 2100. Such high-end, multi-decadal scenarios are not needed for short-lived investments and/or where the risk of lock-in is low but, regardless of the project lifetime, all working assumptions should still be laid bare as a matter of principle.

CONCLUSIONS

The Asia-Pacific region has achieved major economic growth over recent decades. However, the region frequently experiences extreme weather events and is one of the most vulnerable globally to future climate change. The ADB has recognized these risks and become a regional leader on the CRM of its investment operations, by undertaking climate impact assessments from as early as 2005, then introducing mandatory risk screening of projects from 2014. Over time, the acquired experience has yielded valuable insights and led to an evolution of progressively more pragmatic CRM and adaptation within the organization.

Recent review work by the ADB, as part of a cycle of evaluation, led to a reappraisal of the current CRM processes, and a set of guiding principles for climate risk assessment have been developed, as summarized in this paper. These make the case for updating the CRM process and CRAs in the ADB. The tenets also provide a foundation for developing strategic and project-level guidance, as well as for enhancing the frameworks and processes needed to deliver the step change in climate finance envisaged by *Strategy 2030*. Alongside, there are new operational guidance and tools to embed climate change allowances in detailed project designs. These advances represent a welcome shift towards development outcome-orientated CRM. The latest work is reviewing the future possibilities offered by regional re-analyses (Mahmood *et al.*, 2018), ways of simulating unprecedented extreme events (Jain *et al.*, 2020), or the use of storylines to address highly uncertain climate risks (Shepherd *et al.*, 2018).

Many of the practical innovations made by the ADB would benefit communities of practice beyond the Asia-Pacific region. For example, there is a catalogue of resources aimed at CRA consultants, including project-level guidance, compendia of information sources, checklists for climate model scenarios and adaptation options, plus training materials. There are also manuals and tools for calculating hydrological extremes and sea levels for detailed engineering design – instruments that could fill a glaring gap internationally. Procedures are emerging too that will assist portfolio – rather than project-level adaptation strategies and thereby offer more integrated solutions. Above all, there are the conceptual advances that seek to rationalize the whole process of CRM and to focus resources on what really matters.

ACKNOWLEDGEMENTS

This work benefited from the authors' associations with the Asian Development Bank and from the helpful remarks made by Arghya Sinha Roy.

DISCLAIMER

The views expressed in this paper are those of the authors and do not necessarily reflect the views and policies of the ADB or its Board of Governors or the governments they represent.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 18 October 2021; accepted in revised form 18 October 2021. Available online 28 October 2021