Climate risk report for the Southeast Asia region

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FOREWORD

Southeast Asia

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The Southeast Asia region is critical to global climate objectives. Of the ten countries comprising the Association of Southeast Asian Nations (ASEAN), more than half are considered amongst the world's most vulnerable to climate change, and all are facing increasingly frequent and more severe weather events. At the same time, ASEAN countries collectively represent the fourth largest source of emissions globally, with energy demands projected to triple by 2050. Heavy dependence on fossil fuels means that greenhouse gas emissions are growing at an alarming rate with CO2 emissions per capita expected to more than double in the next two decades. The region's lush tropical forests, mangroves, and natural environment not only represent some of the world's most important biodiversity hotspots, but also hold two thirds of the world's carbon stocks.

The challenges are significant, but so are the opportunities. COP26 in Glasgow marked a step change in climate ambition across the region, with countries increasingly seeing the enormous potential in decoupling growth from emissions and creating jobs in a new green economy. Currently 85% of the region's greenhouse gas emissions are covered by commitments to reach Net Zero by mid-century. Eight ASEAN countries have made commitments to reverse forestry loss and/or protect their oceans and other natural habitats.

We need to build on this momentum to drive further ambition and ensure commitments translate into action. The UK's relationship with the region is becoming closer and is a key component of our Indo-Pacific strategy. In 2021, the UK became the first new ASEAN Dialogue Partner in 25 years, and we are pleased to be using the ASEAN-UK Plan of Action to deepen our cooperation on this vital agenda. Our partnership is underpinned by a wide range of tools, networks and expertise. This includes collaborating with world-class institutions to produce critical analysis – like this report – to strengthen our collective understanding of climate risks to inform decision making. It also includes using the UK's considerable international climate finance contribution, global networks and influence to leverage funding from other public and private organisations to support climate resilience and adaptation, improve the natural environment, accelerate the energy transition and promote low carbon growth. Drawing on these tools, our unique network of climate, energy and nature advisors in each of our Embassies and High Commissions across the region are working in partnership with Southeast Asian countries to deliver low carbon, climate resilient growth and jobs, fulfil our collective climate commitments and explore opportunities to do more together. This risk report was commissioned to better understand the climate risks to development in the Southeast Asia region across these themes.

This next decade is critical if we are to take the collective action needed to tackle climate change and halt nature loss. Southeast Asia is on the front line of this effort and should grasp the opportunity that a clean and climate-resilient future offers for growth and prosperity.

Met Office Hadley Centre ODI UKaid from the British people

Image location: Bandar Seri Begawan, Brunei Darussalam

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Executive Summary

Southeast Asia is already exposed to a changing climate and its impacts under a business-as-usual scenario, and these must be considered to ensure climate resilient development planning. This report analyses key risks across the Southeast Asia region under a changing climate up to the 2050s. The risks are analysed under seven themes that have been identified as priorities within a development context for FCDO: (1) **agriculture and food security**; (2) **water resources and water-dependent services**; (3) **health**; (4) **infrastructure and settlements**; (5) **energy**; (6) **environment**; and (7) **the blue economy and the marine environment**. These themes are not a comprehensive list of all possible climate risks, additionally, there are also many interlinking risks between them signposted in the sections that follow.

In this report, Southeast Asia includes **Brunei Darussalam**, **Cambodia**, **Indonesia**, **Lao People's Democratic Republic (Lao PDR)**, **Malaysia**, **Myanmar**, **Philippines**, **Singapore**, **Thailand**, **Timor-Leste**, and **Viet Nam**. Climate change is just one of several risks to resources, livelihoods, economies, and ecosystems. Southeast Asia is a dynamic region, experiencing rapid population growth, urbanisation, and economic transformation, so an assessment of climate risk provides only a partial picture of the many drivers of change shaping development outcomes.

Key climate-related risks for Southeast Asia have been identified by considering how the current climate interacts with underlying socio-economic conditions, and then assessing how risks may develop to the 2050s as both climate and socio-economic conditions change. Seeing the 'bigger picture' where multiple risks compound, interact with one another, and drive change, will remain important for those charged with designing, monitoring, and evaluating development programmes. Section 2.1 and the contextual parts of Section 3 provide background information on socio-economic conditions and vulnerability. Importantly, most risks identified in this report are not new for the region. However, the frequency, severity, and distribution of those risks are evolving as climate conditions change and economies develop.

Southeast Asia experiences a maritime climate in the south and a tropical climate in the north. The far north of the region and north-east Thailand experiences a more temperate climate.

On average Southeast Asia has warmed by 0.5°C from 1980 to 2015. The frequency of warm nights has increased, and the frequency of cold days and nights has decreased. Temperatures will increase by an average of 1.1°C by the 2050s* under a medium emission scenario, with increases of up to 3.5°C possible under high emissions, compared to a 1981-2010 baseline. The intensity, number, and duration of very hot days will increase in the Southeast Asia region and moist heatwaves are likely to be an increasing hazard through Maritime Southeast Asia.

There has been a recent drying trend over most of the region, particularly over northern high elevation areas. The exceptions are southern Viet Nam, southern Myanmar, and southern Lao PDR which have experienced a wetting trend. In contrast to the drying trend, annual rainfall is projected to increase across the region, and this is most pronounced across Myanmar, northern Thailand, and northern Lao PDR through the southwest monsoon season (June to October). Some projections indicate a drying trend across Timor-Leste and southern

Indonesia outside of the main wet season (April to October). The frequency of intense rainfall events will increase.

Coastal regions are already exposed to rising sea levels, increasing sea surface temperatures, acidification and marine heatwaves, trends that will continue. Sea surface temperatures will increase by 0.7°C on average by the 2050s under low emission and by 1.2°C under high emission scenarios, relative to a 1995-2014 baseline. By the 2050s, sea levels will rise by 0.2 – 0.3m irrespective of emission scenario, compared to a 1995-2014 baseline. The strongest typhoons are projected to increase in intensity.

Agriculture and Food Security (Section 3.1) are vulnerable to climate change because most crops in the region are rainfed, and so the success or failure of farming is determined largely by the weather. Although agricultural production now accounts for a relatively low proportion of GDP in most countries, roughly 50% of the region's population still live in rural areas and make a living tied directly, or indirectly, to the agricultural economy.

Yields of most crops are projected to decline without adaptation due to rising temperatures, heat extremes, flooding, and, in delta areas, soil and water salinisation (3.1.2). Farming in much of Southeast Asia is based on rice production, often in multiple cropped systems, with the region accounting for 26% and 40% of global rice production and imports, respectively. However, rice yields are projected to decline by 3-10% by the 2050s, with the biggest reductions expected in Cambodia, Myanmar, and Viet Nam. Heat and humidity stress will also become a growing problem for agricultural workers, causing reductions in labour capacity that could undermine agricultural productivity (3.1.5). Nonetheless, Southeast Asia still produces a net surplus of rice, and there is scope for improving agricultural yields and reducing greenhouse gas emissions through improvements in agricultural systems and practices.

Aquaculture plays an increasingly important role in meeting food and income needs and generating export revenue, but is threatened by rising temperatures and cyclone-related storm surges (3.1.3). The transition from rice farming to aquaculture has been most pronounced in the region's deltas, partly in response to climate-related sea level rise and soil salinisation, exacerbated by land subsidence. Aquaculture production has increased between 7 and11-fold in Vietnam, Indonesia, and Myanmar over the last 20 years, but the clearance of mangrove forests for aquaculture ponds has increased coastal exposure to cyclones and storm surges (3.7.2). As a result, some 30% of aquaculture areas may become unsuitable for farming by 2050-70.

Food insecurity may increase as agricultural production and food prices become more volatile, with the potential for longer-term price increases that could undermine food affordability for the poorest groups (3.1.6). Those groups mainly comprise net consumers of food: subsistence-orientated farmers growing much of their food on small-plot rainfed lands, concentrated in Myanmar, Cambodia, and Indonesia, and increasing numbers of urban poor dependent on informal wage labour to buy essentials, vulnerable to fluctuations in the availability of work and the cost of food. Across the region, roughly 54% of the population cannot afford a healthy diet, estimated to cost around USD4/day. In Indonesia, consumers already pay among the highest prices in the region for staples and nutritious food, and price volatility has been linked to the prevalence of child stunting (undernutrition). Regionally, declining agricultural yields and higher food prices could hamper progress towards SDG2: *End hunger, achieve food security and improved nutrition and promote sustainable agriculture*.

Many of the impacts of climate change will be felt through the region's Water Resources and Water-dependent Services (Section 3.2) as greater rainfall variability and more intense rainfall events will make harnessing and managing water resources for different users and uses more difficult. Southeast Asia has abundant freshwater resources, but deficits in water storage and distribution needed to smooth out variations in supply over time, and between areas, will increasingly act as a drag on economic growth. In Indonesia, roughly half of the country's GDP is produced in river basins experiencing severe or high-water stress in the dry season; *periodic* water scarcity is projected to result in 2.5% lower GDP by 2045 in the absence of investment in water storage and distribution to buffer supply variability (3.2.2, 3.2.4).

Pressures to meet competing demands for water are already evident in the lower Mekong basin (Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam), expected to home 100 million people by 2050 (3.2.2). The basin is a globally significant rice and fish-producing area, and installed hydropower capacity is expected to roughly triple by 2050. Mekong waters also carry sediments and nutrients that play a key role in stabilising delta lands and livelihoods and flows help flush salt from the delta's soils. While future changes in river flows will be driven largely by dam construction and irrigation diversions, climate change will likely amplify flow variability across countries, with higher peak flows and more damaging floods to the 2050s. The average annual cost of flooding in the lower Mekong ranges from USD60-70 million, with Cambodia and Viet Nam typically absorbing two-thirds of the damages. As flow variability increases and demands increase, dam operations may need to shift toward flood control in addition to maintaining sediment and salt-flushing flows to the delta. This will require greater cooperation between upstream and downstream countries to manage trade-offs and allow nations to achieve SDG6: *Availability and sustainable management of water and sanitation for all.*

Water contamination caused by flash flooding and higher temperatures is a growing risk to drinking water quality and health, especially where access to safely managed water and sanitation is lacking, as in Lao PDR, Cambodia, and Indonesia (3.2.3, plus 3.3.4, 3.3.5). Groundwater provides over 60% of domestic water supply across Southeast Asia, and its role as a storage 'buffer' for all sectors will likely increase. Although groundwater resources are protected to some extent from contamination, more intense rainfall events and flash floods can damage or destroy latrines and spread faecal matter and other pollutants into poorly constructed water sources, rivers, and the wider environment. Higher water temperatures and more intense droughts also present risks: higher water temperatures stimulate the growth of toxic algae, for example, and droughts can reduce the capacity of rivers to dilute, attenuate, and remove pollution. Risks to water quality and health will grow most rapidly in fast-expanding urban areas exposed to higher flood risks, particularly in informal settlements lacking drainage and effective faecal waste management (see also Section 3.3 on Health).

The Health (Section 3.3) outcomes sensitive to climate change in the Southeast Asia region include heat stress and heat-related mortality, diarrhoeal and water-borne diseases, undernutrition, vector-borne diseases, and health conditions linked to air pollution. Risks will be unevenly spread, exacerbating health inequalities linked to economic status, location, gender, and age. Many of the pathways linking climate variables with human health are indirect and hard to quantify, but the most significant for the region are likely to be heat stress/heat-related mortality and undernutrition, with the latter linked closely to diarrhoeal and water-borne diseases. Combined, these risks could result in over 10,000 additional deaths per year and hinder progress towards SDG3: *Ensuring healthy lives and promoting well-being for all at all ages*.

Continental Southeast Asia will experience one of the highest cumulative exposures to heatwave events and heat-related mortality of any global region (3.3.6). Combinations of heat and humidity pose the biggest risks to health, with the elderly, infants, pregnant women, people living in informal settlements, and those engaged in outdoor manual labour the most vulnerable. Higher temperatures and heat waves may also contribute to the formation of dangerous air ozone, as well as the forest and peat fires – originating mainly in Indonesia and Malaysia - that cause transboundary haze and a range of respiratory, cardiovascular, and neurological conditions. Ambient and indoor air pollution is already one of the leading causes of death and illness in the region.

The prevalence of diarrhoeal and water-borne diseases, key contributors to undernutrition, is also expected to increase because higher temperatures and floods can accelerate the growth and spread of dangerous pathogens (3.3.4, 3.3.5). Southeast Asia already has one of the highest undernutrition (child stunting) levels in the world at 26%, with 14 million children under five facing a lifetime of physical and cognitive deficits as a result. The highest rates of diarrhoeal disease and undernutrition are found in Timor-Leste, Indonesia, and Lao PDR, closely linked to unsafe water, sanitation, and hygiene. Undernutrition is also caused by food insecurity linked to declining agricultural yields and the potential for higher and more volatile food prices (3.1.6). Collectively, the risks above will hamper progress on SDG2: *Ending hunger and improved nutrition.*

The seasonality, range, and reproduction of vector-borne diseases such as malaria and dengue will also be affected by rising temperatures and changing rainfall patterns (3.3.3), highlighting the need for improved public health surveillance and vector control. In most countries, cases of malaria infection and mortality have fallen in recent decades despite increasingly favourable climatic conditions for disease spread. Over the last decade, total (regional) malaria cases and deaths have fallen by 76%, with most remaining incidence in Myanmar and Indonesia. Suitable areas for dengue transmission are expected to increase throughout Asia, although infection is often asymptomatic or results in only mild illness.

Risks to Infrastructure and Settlements (Section 3.4) in Southeast Asia arise from climate extremes and slower onset changes in climate conditions that threaten assets, systems, and services. Impacts can cascade across economic sectors, areas, and population groups because of the interconnected nature of power, transport, and communications systems, highlighting the need to *Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation* (SDG9) while also *Making cities and human settlements inclusive, safe, resilient and sustainable* (SDG11).

Climate risk and poverty will increasingly coincide in fast-growing towns and cities, especially informal settlements exposed to more flooding and extreme heat. Just over 50% of the region's 690 million population now live in urban areas, and that share will likely increase to over 60% by 2050. At least 20% of the urban population live in informal settlements lacking one or more basic services, with the highest shares in Myanmar (58%), Philippines (37%) and Indonesia (20%). More intense rainfall events will increase the risks of flash flooding and environmental contamination in low-lying areas, especially those lacking adequate drainage and faecal waste management (3.3.4). Over 20 million urban residents are already at high risk from flash floods, mainly in Viet Nam (10 million), Cambodia (4 million), and Indonesia (3 million).

In densely populated coastal areas, risks to infrastructure and settlements are amplified by cyclones, storm surges, and sea level rise. Viet Nam has 300 low-lying coastal cities increasingly impacted by cyclones, storm surges, and river flooding, with roughly one-third located on eroding coastlines. Some 6-12 million people in Viet Nam's Mekong delta may be affected by coastal flooding by 2070-2100 without effective adaptation, potentially reducing GDP by over 2%. Roughly 18% of Indonesia's population live in low-elevation coastal areas, making it one of the largest 'at risk' areas globally. An additional 0.8 – 2.5 million people in Indonesia could be affected by extreme river floods compounded by high tides and storm surges by 2035–2044. The coastal cities experiencing the fastest changes in relative sea levels in the region, caused mainly by land subsidence but exacerbated by climate-driven sea level rise, are Ho Chi Minh City (Viet Nam), Yangon (Myanmar), and Jakarta (Indonesia).

Southeast Asia's transport networks, port infrastructure, and maritime trade are also vulnerable to climate extremes, especially intense rainfall, floods, and cyclones (3.4.3, 3.4.5). Floods, and to a lesser extent cyclones, already result in annual damages of around USD2.2 billion to regional road and rail infrastructure. In absolute terms, annual damages to transport attributable to floods and cyclones are highest in Indonesia, Viet Nam, and Philippines as a share of GDP damages are highest in Myanmar and Lao PDR. Coastal ports and maritime trade may also incur heavy losses, with many regional ports already exposed to climate-related hazards that exceed operational design standards. Current port-specific risks across 18 ports in Philippines amount to around USD196 million/year with knock-on effects on maritime trade, arising mainly from cyclones and their impact on port-shipping operations.

Climate-related shocks and trends can contribute to both increases and decreases in migration, with no clear overall trends for the region. Projections to the 2050s highlight the lower Mekong subregion as a potential *out-migration* hotspot, with sea-level rise and storm surges undermining agricultural livelihoods in the Mekong delta. However, population mobility is driven by many different factors, with no simple causal chain or robust estimates of climate *induced* migration widely agreed.

Access to Energy (Section 3.5) has improved across the region, but climate change will have broadly negative impacts on energy supplies and will increase overall and peak demands. All but two countries (Myanmar and Cambodia) have achieved near-universal access to electricity, but closing remaining gaps in clean cooking fuel provision, increasing the share of renewables in electricity generation, and minimising risks to power generation and distribution from climate change will be needed to achieve SDG7: *Ensure access to affordable, reliable, sustainable, and modern energy for all*.

Regional electricity production is dominated by thermoelectric generation from fossil fuels and by hydropower, with both based on major, long-lived investments in fixed infrastructure that are sensitive to changes in water availability (3.5.2). Electricity production from thermal power plants (mainly gas and coal) still dominates the energy mix in all countries except Lao PDR and Cambodia. Country-level data are scarce, but the region will likely experience a reduction in the usable capacity of thermoelectric generation because of water constraints, driven in part by more variable water supplies (3.2.2; 3.5.2). Hydropower plays an increasingly important role in electricity production in Lower Mekong countries, especially Lao PDR (70%), Cambodia (46%), Myanmar (40%) and Viet Nam (30%), with installed hydropower capacity along the Mekong expected to triple by 2040. Risks to hydropower arise from greater river flow variability to the 2050s, and the need to balance power generation with other (transboundary) priorities including the maintenance of environmental services, sediment and salt-flushing flows to downstream deltas, and flood management (3.5.2).

Solar and wind projects can be developed incrementally to meet demand, so the risks of locking-in climate vulnerabilities are less significant (3.5.2). Solar and wind remain comparatively under-developed in the region, though Indonesia and Viet Nam are among the countries looking to capitalise on their potential. Power outputs from solar projects, both land-based and floating, will be sensitive to changes in the frequency of very warm, cloudy, and/or hazy conditions, but regional impacts to the 2050s are likely to be minor (+/-5%). Solar infrastructure can be damaged by storms and high winds, although systems can be strengthened at a cost premium. Onshore and offshore wind power can also be disrupted or damaged by high winds associated with more intense cyclones although adaptations are available – again at higher cost. In Philippines, more expensive typhoon-class wind turbines will be needed for many locations; in some areas, however, very high wind speeds will likely preclude wind power altogether.

Electricity distribution infrastructure will be disrupted or damaged by rising temperatures, heat waves, floods, and strong winds (3.5.3). Climate extremes pose the biggest risks to electricity distribution. In 2022, Super Typhoon Rai damaged key power lines and disrupted electricity supply to over 116 cities and municipalities in Philippines causing outages that hampered relief efforts and shut down electricity-dependent water supplies. Rising temperatures and heatwaves will also lower the capacity of generators, substations, and transmission lines. Regional evidence is limited, but wider studies forecast capacity reductions of 2-27%, depending on the component, during more intense heatwaves. More resilient systems (for electricity, water, and sanitation) will increasingly be those with no 'network critical' points of failure, and that combine multiple energy sources spread across multiple grids - smart, mini, and hybrid.

Regional energy consumption is forecast to rise by over 250% by the 2050s, with demand for cooling expected to surge as temperatures rise (3.5.4). By the 2050s, demand for cooling may account for 30-40% of peak summer electricity loads, driven largely by the uptake of air conditioning linked to warmer temperatures, heat waves, and rising incomes. The number of air-conditioner units in the region could rise from 40 million (2017) to 300 million in 2040, with roughly half in Indonesia. Higher demand will require upgrading power system flexibility across the region to accommodate an increasing share of renewables, manage intermittency, and deal with peak summer loads. Whether government energy plans and projections account for rising temperatures and heat waves is unclear.

Pressures on the <u>Environment (Section 3.6)</u> in Southeast Asia arise mainly from agricultural expansion and urban encroachment but rising temperatures and heat extremes will place additional pressures on remaining habitats. Southeast Asia is one of the most biodiverse areas of the world, including large areas that fall within the global top 10 biodiversity hotspots for irreplaceability - Indo-Burma (Cambodia, Lao PDR, Myanmar, Thailand, Viet Nam), Sundaland (Indonesia), Wallacea (Indonesia), and Philippines (3.6.1). However, the same areas also fall within the top five for hotspot threats from agricultural expansion, urban encroachment, mining, biofuel production, and illegal wildlife trade. Across the region, forest cover decreased by over 10% between 1990 and 2015, and hotspot areas have become increasingly fragmented. The need to grow more food and compensate for climate-related reductions in crop productivity (3.1.2) could accelerate agricultural expansion into natural habitats.

Climate change, particularly rising temperatures and heat extremes, creates additional pressures on fragile ecosystems, although the evidence base on climate sensitivities and impact pathways – for individual species and species interactions/combinations – remains limited (3.6.2, 3.6.3). A northward shift of biome boundaries and an upward shift in mountain treelines in Southeast Asia are expected due to rising temperatures. Upward shifts in the elevation of bioclimatic zones, decreases around the highest elevation zones, and expansions of lower tropical and sub-tropical zones are projected for the 2050s. Ecosystems that are fragmented, either naturally or because of habitat destruction, are likely to be most at risk from climate-related losses. This is because species unable to survive changes in climate may become regionally extinct if they cannot disperse or migrate, for example by moving along elevational gradients which allow them to track changes in temperature.

The risks of drought-related forest dieback and forest fires will likely increase, amplifying pressures on more fragmented habitats (3.6.2, 3.6.3). Southeast Asia's forest cover has declined by around 13% between 1990 and 2015 because of land clearance for agriculture and other uses. Southeast Asia is home to nearly 15% of the world's tropical forests, supporting globally significant tropical biodiversity and above-ground forest carbon stocks, but the region is also among the world's major deforestation and biodiversity loss hotspots.

The role rising temperatures and heat extremes may play in affecting wetland coverage, wetland health and the density and duration of peat fires is uncertain, although dry weather conditions and heat associated with more intense ENSO events may increase threats (3.6.2, 3.6.3). Wetlands provide food and fibre for local communities, help regulate water flows and water quality, and capture and store carbon. Global studies indicate that the preservation and restoration of wetlands can reduce major greenhouse gas emissions. Indonesia accounts for almost 50% of Southeast Asia's total wetland area, including tropical swamp forests and their underlying peat bogs. The clearing and burning of trees, and underlying peat in Indonesia and Malaysia, has released large quantities of greenhouse gases and created transboundary haze. In Indonesia, peatland fires accounted for roughly 8% of global fire carbon emissions between 1997 and 2016. Forest and peatland conservation policies are now being implemented in Indonesia and Malaysia.

There is growing interest from governments and their development partners in nature-based solutions to a range of climate mitigation and adaptation problems, and countries such as Viet Nam and Cambodia have elevated nature-based approaches into national policy documents. However, **implementation across Southeast Asia appears slow**, and the **evidence base** for impacts at scale, and over time, remains **limited**. Singapore has a long history of implementing urban nature-based approaches to flood control in urban areas, offering lessons in urban planning for the region's rapidly growing urban settlements.

While many Southeast Asian countries are on track to achieve UN-Aichi targets for protected areas, boundaries may need to change to secure species habitats and facilitate species migration/dispersal as biomes shift northwards. The uptake of nature-based interventions and carbon credits offers one route forward, with estimates suggesting that roughly 58% of the region's forests threatened by loss could be protected as financially viable carbon projects. Without proactive environmental management and exploration of new opportunities for nature-based carbon credits, progress towards SDG15 to *halt and reverse land degradation and halt biodiversity loss* will likely be jeopardised.

Across ASEAN's 10 member states, some 625 million depend on the Blue Economy and Marine Environment (Section 3.7) for their livelihoods yet key habitats are being depleted or degraded by overfishing, deforestation, pollution, and unregulated coastal development, with pressures amplified by climate change. Southeast Asia relies significantly more on its blue economy and marine environment than most other global regions. ASEAN countries account for 15% of global fish production, 34% of coral reef cover, 35% of mangrove forests, and 33% of seagrass meadows (3.7.2). Despite the environmental and economic benefits these services provide, key habitats are being depleted or degraded by overfishing, deforestation, pollution, and unregulated coastal development. Climate hazards, particularly warming seas, rising sea levels, and ocean acidification, add to pre-existing pressures, undermining progress towards SDG14: *Conserve and sustainably use the oceans, seas, and marine resources for sustainable development*.

The region's coral reefs, mangrove forests, and seagrass meadows provide vital ecosystem services but are threatened by the combination of higher sea surface temperatures, marine heatwaves, rising sea levels, and ocean acidification (3.7.2). The Coral Triangle, located off the coasts of Philippines, Malaysia, and Indonesia, is a globally significant hotspot for reef habitats and biodiversity, provides jobs and incomes (including tourism) for over 100 million people, and coastal protection benefits estimated at USD19 billion annually. Major coral bleaching linked to El Niño events and marine heatwaves has already been recorded in the Coral Triangle and further afield in the Gulf of Thailand. The region's mangrove forests and seagrass meadows, some of the most extensive and biodiverse in the world, also protect coastlines, store carbon, and provide nursery habitats for fish, but are threatened by rising sea levels and storm surges. However, the key risk remains habitat destruction: roughly one-third of the region's mangrove forests have been cleared to provide land for aquaculture over the last 40 years, mainly around Indonesian coasts.

Marine fisheries, including marine aquaculture, provide a key source of employment, revenue, and food security, but fish catch potential will be negatively affected by higher sea temperatures and ocean acidification (3.7.3). ASEAN's 10 member states account for almost 20% of global fisheries production, with export earnings valued at around USD1.95 billion in 2018. Fish products also make a major contribution to regional food security. In Malaysia, Myanmar, and Thailand fish account for over 35% of dietary animal protein; in Indonesia, the figure rises to over 60%. However, the productivity of marine fisheries, including marine aquaculture, will be reduced by higher sea temperatures and ocean acidification, amplifying existing pressures from overfishing, pollution, and habitat destruction. Indonesia, Viet Nam, and Philippines are among the world's ten largest marine fisheries producers, but fishery potential in Indonesia could decrease by 13-29% by the 2050s. Fish unable to adapt to higher sea temperatures will likely migrate to higher latitudes, potentially reducing the traditional target species accessible to smaller, near-coast vessels operated by poorer, artisanal fishers - still numerous in Philippines and Indonesia. As a result, artisanal fishers, and the coastal communities they support may face the biggest risks from warmer seas as well as coastal habitat destruction, the loss of fish nurseries, and the intensifying 'squeeze' on coastal space.

Climate risks to marine species and fisheries in Southeast Asia remain **poorly understood**. Climate sensitivities and impact pathways are complex, and projections for fish productivity and distribution are **uncertain**. This is a **key evidence gap** given the importance of fish to regional economies, livelihoods and nutrition.

Southeast Asia Climate Risk Report

HEADLINE CLIMATE STATEMENTS

Between 1980-2015, average temperatures across the majority of Southeast Asia increased by around 0.5°C. Warming rates have been highest across the Malay Peninsula and Sumatra, where this increase was around 0.9°C. Conversely, the lowest rates of warming were across southeast Indonesia and Timor-Leste where little change has been detected.

Average temperatures across Southeast Asia will increase uniformly by around 1.1°C by the 2050s* under a medium emission scenario, compared to a 1981-2010 baseline, with increases of up to 3.5°C possible under high emission scenarios. Only under these high emission scenarios is significant regional variation expected, with the highest warming projected to occur across Thailand, northern Lao PDR, and southern Myanmar.

The intensity, number and duration of positive heat extremes will increase in the Southeast Asia region.

Moist heatwaves** are likely to be an increasing hazard through Maritime Southeast Asia.

Annual rainfall is projected to increase across the region, and this is most pronounced across Myanmar, northern Thailand, and northern Lao PDR through the southwest monsoon season (June to October). Some projections indicate a drying trend across Timor-Leste and southern Indonesia outside of the main wet season (April to October).

The frequency of intense rainfall events is expected to increase across the region. Conversely, the number of consecutive dry days*** are projected to increase across the Maritime Southeast Asia by 5-15 days per year by the 2050s.

The proportion of intense typhoons (those of Category 3-5) will increase.

Sea surface temperatures in Southeast Asia will increase by 0.7°C on average by the 2050s under a low emission scenario and by 1.2°C under a high emission scenario, relative to a 1995-2014 baseline.

Sea levels across Southeast Asia will continue to rise through the 2050s and beyond. By the 2050s, sea level will rise by 0.2 – 0.3m irrespective of emission scenario, compared to a 1995-2014 baseline.

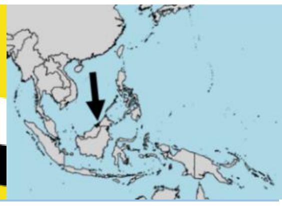
Southeast Asian seas will continue to acidify, and the frequency, intensity and duration of marine heatwaves**** will increase.

*The 2050s refer to the 2041-2060 time period.
**A moist heatwave is a typical heatwave (typically where maximum daily temperatures remain above the 90th percentile of what is typically expected during the season), combined with humidity above 66%.
***Consecutive dry days refer to the number of consecutive days where less than 1mm of precipitation is received across the area of interest within a year.
****Marine heatwaves are periods of extreme ocean temperature, where temperatures are above the 90th percentile of climatology.

Country Reference Tables

Analysis is conducted at the regional level using five zones. These country summaries are intended to help direct readers towards the relevant sections within the report by country; they are not a complete assessment of the full range of risks at a country level. These summaries do not provide a national level analysis and there will be additional climate risks pertinent at a national scale that should also be considered in a national or subnational development plan. Where relevant risks are identified, or where national or sub-national scale risk information is required, additional climate and socio-economic analysis would be required.

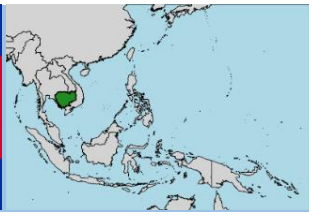
Brunei Darussalam country profile



Summary of climate analysis to Brunei Darussalam	Report section
Brunei Darussalam experiences a tropical climate. Brunei Darussalam has already experienced warming of 0.2 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Brunei Darussalam experiences a slightly pronounced, but highly variable, annual cycle of rainfall, peaking October to April. Precipitation trends over recent decades lack consensus with either a wetting or drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) being plausible. There is, however, high confidence in a future wetting trend on average throughout the year. Extreme rainfall will also increase. Brunei Darussalam experiences frequent typhoons and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks to Brunei Darussalam	Report section
Projected increases in the intensity and frequency of hot extremes pose significant risks to health. High overnight temperatures already occur in Brunei Darussalam, further impacting health.	3.3
Droughts, high temperatures and dry weather conditions associated with El Niño events may increase the severity of fires, impacting air quality and health.	3.3
Climate hazards, such as heat, storm damage, flooding, and excessive wind, pose physical risks to energy transmission and distribution networks with different lifetimes, also impacting economic losses.	3.5
Warmer sea surface temperatures lead to more frequent and intense heatwaves. Iincreasing ocean temperatures are likely to lead to changes in the distribution of marine species. Species living close to their thermal tolerance are particularly at risk.	3.7

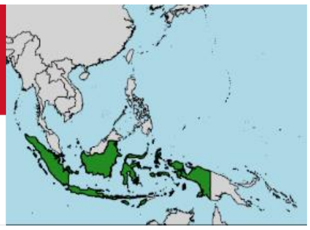
Cambodia country profile



Summary of climate analysis relevant to Cambodia	Report section
Cambodia experiences a tropical climate. Cambodia has already experienced warming of 0.1 to 0.3 °C per decade from 1980 to 2015. However, temperatures will rise in the future with an increased frequency and intensity of heatwaves. Cambodia has experienced a drying trend in recent decades. However, future projections show medium confidence in a wetting trend (predominantly in the monsoon season June to October) (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)). Extreme rainfall will also increase. Cambodia experiences frequent typhoons and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Cambodia	Report section
Cambodia is a major rice-producing country in Southeast Asia. Rice yields are projected to decline due to higher temperatures and the prevalence of rainfed (vs irrigated) cropping.	3.1
Cambodia is one of the biggest aquaculture producers in Southeast Asia and therefore stands to lose significantly in terms of production and income due to typhoons, storm surges, flooding, and heatwaves – hazards that are projected to increase in intensity.	3.1
Cambodia's labour productivity could decline significantly, due to increasing high heat-humidity stress, where large numbers of people are engaged in agriculture and other exposed occupations.	3.1
More frequent intense rainfall events and associated flash flooding, alongside rising temperatures, pose risks to water quality and health especially where access to safely managed water and sanitation is lacking, such as Cambodia.	3.2
Increasing temperatures, rainfall and humidity will lead to increases in vector-borne diseases, significantly impacting health.	3.3
For Cambodia, the country faces a transition to a state of permanent heat stress because of increases in temperature and humidity to levels which regularly surpass those safe for people.	3.3
Increased evapotranspiration driven by higher temperatures, as well as sea-level rise will reduce coverage of wetlands, change their composition, and reduce their functionality in Cambodia.	3.6

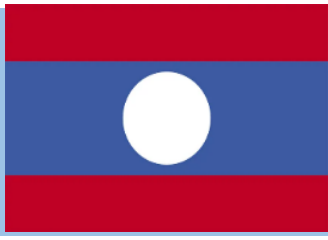
Indonesia country profile

Summary of climate analysis relevant to Indonesia	Report section
Indonesia experiences a tropical climate. Indonesia has already experienced warming of 0.1 to 0.3 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Rainfall trends in recent decades show either a wetting or drying trend for central Indonesia, and no observed change during the dry season for southern Indonesia. However, there has been a notable drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) across southern Indonesia in all seasons in some datasets. Future projections indicate high confidence in a wetting trend throughout the year for central Indonesia, but some models show a drying trend. There is some evidence that southern Indonesia will be wetter on average during November to March but there is a lack of consensus during June to October with both wetter and drier scenarios plausible. Indonesia experiences frequent typhoons and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Indonesia	Report section
Indonesia is one of the major rice-producing countries in Southeast Asia. Higher temperatures and the prevalence of rainfed (vs irrigated) cropping will reduce rice yields significantly.	3.1
Higher risks of crop, livestock and fishery damage from extreme events will increasingly hit farm incomes and raise prices, at least periodically. In Indonesia, consumers already pay among the highest prices in Southeast Asia for staples and nutritious food. Price rises/volatility could further affect nutrition outcomes and the prevalence of child stunting.	3.1
More frequent intense rainfall events and associated flash flooding, alongside rising temperatures, pose risks to water quality and health especially where access to safely managed water and sanitation is lacking, such as Indonesia.	3.2
Projected increases in the intensity and frequency of hot extremes threaten health.	3.3
Corals are threatened by rising sea surface temperatures and extreme weather events.	3.7
The existing pressures on fish stocks, such as overfishing and habitat destruction, exacerbate vulnerabilities from rising sea surface temperatures, potentially causing a decrease in fisheries' catch potential in Indonesian waters.	3.7

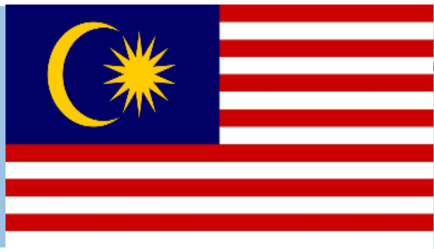
Lao People’s Democratic Republic (PDR) country profile

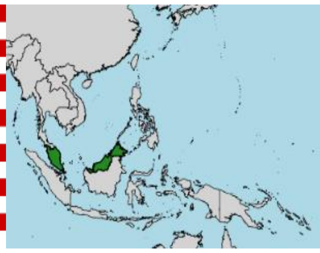


Summary of climate analysis relevant to Lao PDR	Report section
Lao People’s Democratic Republic (PDR) experiences a temperate climate in the north and a tropical climate in the south. Lao PDR has already experienced warming of 0.2 to 0.4 °C per decade from 1980 to 2015. Temperatures will rise in the future across both northern and southern Lao PDR, with an increased frequency and intensity of heatwaves. Lao PDR has generally become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) over recent decades, particularly over higher elevation areas. Lao PDR will become wetter on average in the future, mainly through the monsoon season June to October. Lao PDR experiences typhoons and these will continue to be a feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons.	2

Regional risks relevant to Lao PDR	Report section
Increasing temperatures and higher rainfall variability (subsequent combination of heat stress, water stress, and flooding) with other environmental pressures, is leading to a decline in rice productivity and rainfed croplands. Crop heat stress is a key risk, with temperatures across the monsoon belt approaching critical levels for rice, as well as wheat and maize. This risk will increase in the future as temperatures rise further.	3.1
More frequent intense rainfall events and associated flash flooding, alongside rising temperatures, pose risks to water quality and health especially where access to safely managed water and sanitation is lacking, such as Lao PDR.	3.2
Despite an overall contraction in risk, new areas of *potential* exposure to malaria may open at the fringes of current transmission zones, particularly at higher elevations where cooler temperatures have hitherto restricted transmission including the areas of Lao PDR that are currently malaria free.	3.3
Warming is projected to increase heat-related mortality and decrease cold-related mortality, redistributing mortality rates. Impacts will be overwhelmingly heat-related particularly in tropical continental Southeast Asia such as Lao PDR.	3.3

Malaysia country profile

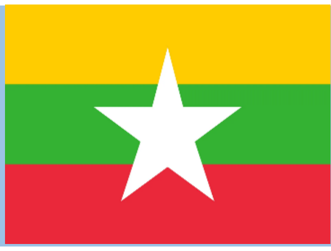


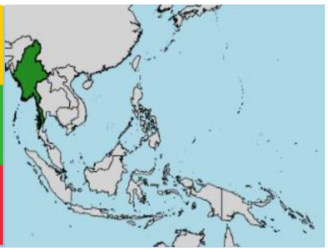


Summary of climate analysis relevant to Malaysia	Report section
Malaysia experiences a tropical climate. Malaysia has already experienced warming of 0.1 to 0.4 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Rainfall trends for recent decades have shown considerable differences, with some datasets indicating a wetting trend and others a drying trend. However, there is high confidence that Malaysia will become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) on average throughout the year in the future, although some models project a drying trend. Malaysia experiences frequent typhoons and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Malaysia	Report section
Increasing temperatures, rainfall and humidity will lead to increases in vector-borne diseases, significantly impacting health.	3.3
Projected increases in the intensity and frequency of hot extremes across the region pose significant risks to health. Combinations of heat and humidity pose the biggest risks to health and are exacerbated when overnight temperatures remain high.	3.3
Coastal settlements, especially coastal cities, face major threats from typhoons, storm sures and floods, as well as sea-level rise exacerbated by land subsidence. Malaysian coastal cities have high populations further enhancing risks.	3.5
Climate change is driving warmer sea surface temperatures which lead to more frequent and intense marine heatwaves. Species living close to their thermal tolerance are particularly at risk, such as corals in Malaysia.	3.7
Coral survival in the Coral Triangle, a one million square kilometer area between Philippines, Malaysia and Indonesia and global hotspot of coral reef habitats and biodiversity, is threatened by rising sea surface temperatures and extreme weather events.	3.7

Myanmar country profile

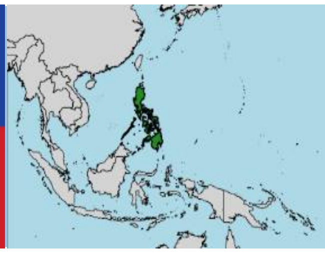




Summary of climate analysis relevant to Myanmar	Report section
Myanmar experiences a temperate climate in the north and a tropical climate in the south. The Irrawaddy River is the principal river of Myanmar at about 2200km long, running through the centre of the country. The Salween River also forms a short section of the border between Myanmar and Thailand. Myanmar has already experienced warming of 0.2 to 0.4 °C per decade from 1980 to 2015. Temperatures will rise in the future across the whole country, with an increased frequency and intensity of heatwaves. Precipitation trends over recent decades show a drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) in northern Myanmar, particularly over higher elevation areas, while there has been a wetting trend in southern Myanmar. Both northern and southern Myanmar, however, will become wetter on average in the future (medium confidence), primarily during the monsoon season June to October. Myanmar experiences frequent typhoons, and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Myanmar	Report section
Myanmar is one of the major rice-producing countries in Southeast Asia. Higher temperatures and the prevalence of rainfed (vs irrigated) cropping will reduce rice yields significantly.	3.1
Increasing temperatures and higher rainfall variability (subsequent combination of heat stress, water stress, and flooding) with other environmental pressures, is leading to a decline in rice productivity and rainfed croplands. Crop heat stress is a key risk, with temperatures across the monsoon belt approaching critical levels for rice, as well as wheat and maize. This risk will increase in the future as temperatures rise further.	3.1
Agricultural droughts significantly impact rainfed crop production in central Myanmar and while projections of dry spells are uncertain, there is evidence that they may increase, exacerbating existing issues.	3.1
Despite an overall contraction in risk, new areas of *potential* exposure to malaria may open at the fringes of current transmission zones, particularly at higher elevations where cooler temperatures have hitherto restricted transmission including the areas of Myanmar that are currently malaria free.	3.3
More frequent intense rainfall events and associated flash flooding, alongside rising temperatures, pose risks to water quality and health especially where access to safely managed water and sanitation is lacking, such as Myanmar.	3.2
Rising temperatures and heavy rainfall, typhoons and floods associated with climate change will increase risks from diarrhoeal disease which is one of the leading causes of under five-year-old deaths in Myanmar.	3.3

Philippines country profile



Summary of climate analysis relevant to Philippines	Report section
Philippines experiences a tropical climate. Philippines has already experienced warming of 0.1 to 0.3 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Rainfall trends in recent decades shows a drying tendency in the dry season and a significant wetting trend in the wet season. There is medium confidence that Philippines will be wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) on average, especially during the southwest monsoon (June to October). Philippines experiences the highest exposure to typhoons across the whole Southeast Asia region. Philippines experiences frequent typhoons, and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Philippines	Report section
Increasing temperatures and higher rainfall variability (subsequent combination of heat stress, water stress, and flooding) with other environmental pressures, is leading to a decline in rice productivity and rainfed croplands. Crop heat stress is a key risk, with temperatures across the monsoon belt approaching critical levels for rice, as well as wheat and maize. This risk will increase in the future as temperatures rise further.	3.1
Philippines is one of the biggest aquaculture producers in Southeast Asia and therefore stands to lose significantly in terms of production and income due to typhoons, storm surges, flooding, and heatwaves – hazards that are projected to increase in intensity.	3.1
Higher risks of crop, livestock and fishery damage from extreme events will increasingly hit farm incomes and raise prices, at least periodically. Price rises/volatility could further affect nutrition outcomes and the prevalence of child stunting as well as increase the number of people at risk of periodic hunger.	3.1
Rising temperatures and heavy rainfall, typhoons and floods associated with climate change will increase risks from diarrhoeal disease which is one of the leading causes of under five-year-old deaths in Philippines.	3.3
Coral survival in the Coral Triangle, a one million square kilometer area between Philippines, Malaysia and Indonesia and global hotspot of coral reef habitats and biodiversity, is threatened by rising sea surface temperatures and extreme weather events.	3.7

Singapore country profile

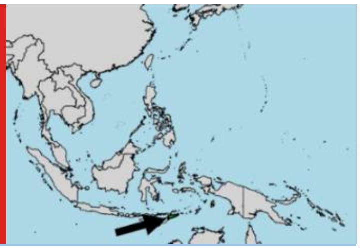
Summary of climate analysis relevant to Singapore	Report section
Singapore experiences a tropical climate. Singapore has already experienced warming of 0.1 to 0.4 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Rainfall trends in recent decades show considerable differences, with some datasets indicating a wetting trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)), and others a drying trend. However, there is high confidence that Singapore will be wetter in the future on average throughout the year, although some models project a drying trend. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Singapore	Report section
Projected increases in the intensity and frequency of hot extremes across the region pose significant risks to health. Combinations of heat and humidity pose the biggest risks to health and are exacerbated when overnight temperatures remain high.	3.3
Although the contribution of climate change to air pollution-related mortality and morbidity remains uncertain, pollution *generally* is a growing threat and a leading cause of mortality and morbidity across Southeast Asia.	3.3
Coastal settlements, especially coastal cities, face major threats from typhoons, storm sures and floods, as well as sea-level rise exacerbated by land subsidence.	3.4
Climate change is driving warmer sea surface temperatures which lead to more frequent and intense marine heatwaves. Species living close to their thermal tolerance are particularly at risk, such as corals in Singapore, are most at risk.	3.7

Thailand country profile

Summary of climate analysis relevant to Thailand	Report section
Thailand experiences a tropical climate. Important rivers include the Salween River which has a short section forming the border of Thailand and Myanmar. Thailand has already experienced warming of 0.2 to 0.3 °C per decade from 1980 to 2015. Temperatures will rise in the future, however, with an increased frequency and intensity of heatwaves. Precipitation in recent decades show a drying trend. However, Thailand will become wetter (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) on average in the future (medium confidence), mainly during the monsoon season June to October. Thailand will continue to experience infrequent typhoons, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2
Regional risks relevant to Thailand	**Report section**
Thailand is one of the most at-risk areas for crop heat stress especially where temperatures are already approaching critical levels, and which are projected to continue rising both in averages and extremes, during susceptible stages of plant growth and grain filling.	3.1
The combination of heat and water stress because of increasing temperatures and higher rainfall variability, impacts rainfed agriculture. Droughts already cause significant yield losses in northern Thailand, therefore further temperature rises and rainfall variability in the future will increase yield losses, impacting food insecurity.	3.1
Hot extremes in summer are expected to increase in frequency in the future in Thailand, which will increase the risk of heat-related mortality.	3.3
As temperatures rise and rainfall variability increases, high temperatures and low rainfall events will increase the risk of drought. This may be associated particularly with El Niño events. These drought conditions may increase the risk of fire events with fire events becoming potentially more severe.	3.3
As rainfall variability increases, heavy rainfall events will increase the risk of flooding in places such as Bangkok, causing economic losses.	3.4
Sea-level rise will significantly impact Thailand with Bangkok already being the topmost vulnerable city to sea-level rise in the world. Sea-level rise also threatens the sustainability of tourism throughout Thailand. Sea-level rise combined with sea surface temperature increases and ocean acidification will impact the natural marine environment.	3.4, 3.6, 3.7

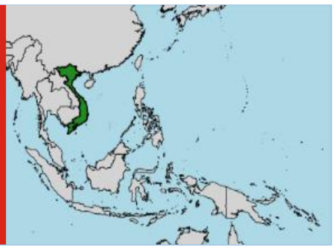
Timor-Leste country profile



Summary of climate analysis relevant to Timor-Leste	Report section
Timor-Leste experiences a tropical climate. Timor-Leste has already experience warming of 0.1 to 0.3 °C per decade from 1980 to 2015. Temperatures will continue to rise in the future with an increased frequency and intensity of heatwaves. Rainfall trends show a notable drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) for Timor-Leste, which is consistent through all seasons. There is some evidence that Timor-Leste will become wetter on average during November to March (the wet season) but there is a lack of consensus during June to October (the dry season) with both wetter and drier scenarios plausible. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Timor-Leste	Report section
Rising temperatures and heavy rainfall, typhoons and floods associated with climate change will increase risks from diarrhoeal disease which is one of the leading causes of under five-year-old deaths in Timor-Leste.	3.3
More frequent intense rainfall events and associated flash flooding, alongside rising temperatures, pose risks to water quality and health especially where access to safely managed water and sanitation is lacking, such as Timor-Leste.	3.2
Projected increases in the intensity and frequency of hot extremes across the region pose significant risks to health. Combinations of heat and humidity pose the biggest risks to health and are exacerbated when overnight temperatures remain high.	3.3
The extremely low-lying capital city Dili is particularly at risk of coastal flooding from sea-level rise.	3.7

Viet Nam country profile



Summary of climate analysis relevant to Viet Nam	Report section
Viet Nam experiences a temperate climate in the north and a tropical climate in the south. Important rivers include the Mekong River which stretches nearly 5000km from source on the Tibetan Plateau in China to the Mekong Delta in southern Viet Nam. Viet Nam has already experienced warming of 0.2 to 0.4 °C per decade from 1980 to 2015. Temperatures will continue rise in the future across the country with an increased frequency and intensity of heatwaves. Precipitation trends for recent decades show a drying trend (wetting/drying trends refer to increases/decreases in precipitation (rainfall and snowfall)) for northern Viet Nam and a wetting trend for southern Viet Nam. However, both northern and southern Viet Nam will become wetter on average in the future, especially during the monsoon season June to October. Viet Nam experiences frequent typhoons and these will continue to be a significant feature of the climate, although there may be a small reduction in frequency but an increase in the intensity of the strongest typhoons. Sea levels will continue to rise in the future. Marine heatwaves will become more frequent as sea surface temperatures continue to rise.	2

Regional risks relevant to Viet Nam	Report section
Increasing temperatures and higher rainfall variability (subsequent combination of heat stress, water stress, and flooding) with other environmental pressures, is leading to a decline in rice productivity and rainfed croplands. Crop heat stress is a key risk, with temperatures across the monsoon belt approaching critical levels for rice, as well as wheat and maize. This risk will increase in the future as temperatures rise further.	3.1
Sea-level rise will significantly impact Viet Nam with Ho Chi Minh city already being the second most vulnerable city to sea-level rise in the world (2050 Climate Change City Index[Error! Bookmark not defined.]). Sea-level r ise also threatens the sustainability of tourism throughout Thailand. Sea-level rise combined with sea surface temperature increases and ocean acidification will impact the natural marine environment.	3.4
Asia's deltas, including the Mekong and Red River deltas in Viet Nam, account for major shares of rice production for export and domestic consumption in Southeast Asia. They are threatened by rising sea levels, saline intrusion, and more intense typhoons.	3.1
Despite an overall contraction in risk, new areas of potential exposure to malaria may open at the fringes of current transmission zones, particularly at higher elevations where cooler temperatures have hitherto restricted transmission including the areas of Viet Nam that are currently malaria free.	3.3
Warming is projected to increase heat-related mortality and decrease cold-related mortality, redistributing mortality rates. Impacts will be overwhelmingly heat-related particularly in tropical continental Southeast Asia such as Viet Nam.	3.3

Image location: Langkawi Island, Malaysia

Met Office Hadley Centre

ODI

UKaid from the British people

1 Introduction

Lead author: Luke Norris, Met Office

1.1 Purpose of this report

The current climate has already undergone significant changes to which some aspects of human and ecological systems are not well adapted. This report provides an evidence base on the Southeast Asia region's changing climate and highlights some key climate risks these regions will or may face up to the 2050s[1] within the lens of pre-existing and future socio-economic risks and stressors.

It forms part of a series of climate risk reports which aim to contextualise climate variability and change in the context of the socio-economic exposure and vulnerability in ODA-eligible regions of Africa and Asia, produced through a collaboration between the Met Office and ODI, and funded by FCDO. The reports provide accessible and authoritative evidence to the UK Government on climate risk in support of adaptation and resilience planning and investments. They present a top-level regional overview of potential risks to development associated with climate and climate change out to the 2050s, signposting key issues and complexities.

The reports look at climate risk as a combination of hazard, exposure, and vulnerability. Each report captures critical information about the weather and climate which is evaluated in the context of the lives and livelihoods of the populations affected. This risk-based approach helps to frame the challenges of climate change in a way that can best inform action. The climate risk reports frame evidence to inform UK development programming and actions that support climate resilience in current and future climate and in current and future complex human-environment systems.

These reports aim to inform UK Government's long-term planning and design of development programmes, including supporting the compliance of these programmes with mandatory climate risk assurance. For the geographic scope of this report, Southeast Asia includes Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Viet Nam (Figure 1). Key aspects of the region, such as the elevation of the region and population densities, are also shown in Figure 2 (topography and population maps).

[1] In climate modelling, 2050s refers to the period 2041-2060.

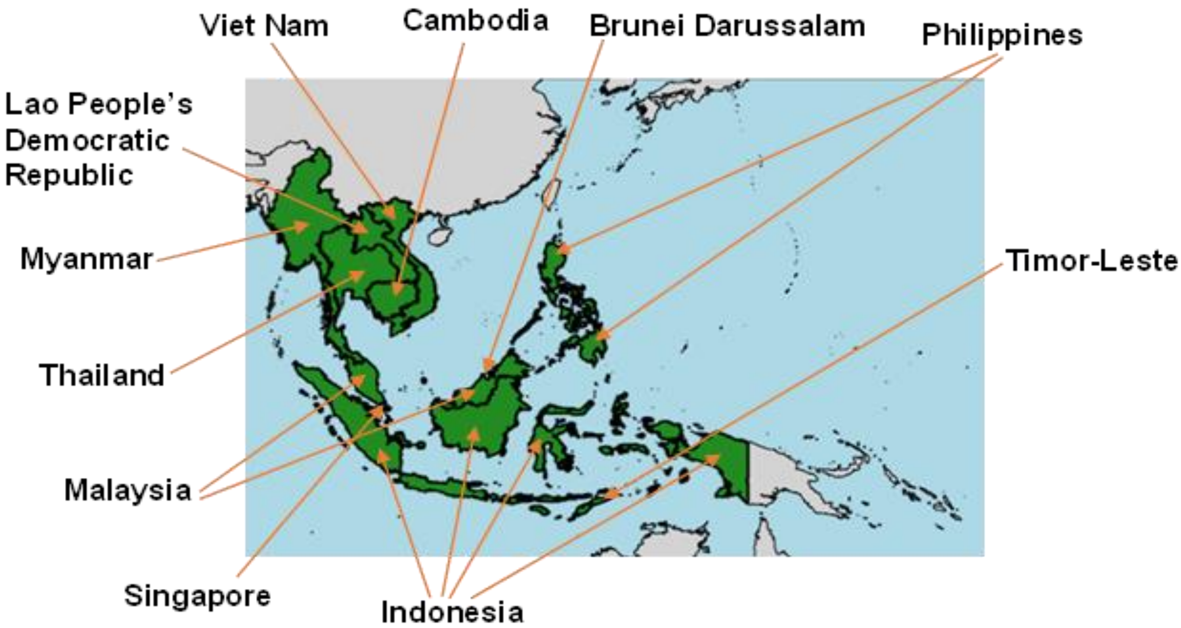


Figure 1: Countries included in the Southeast Asia region for this report.

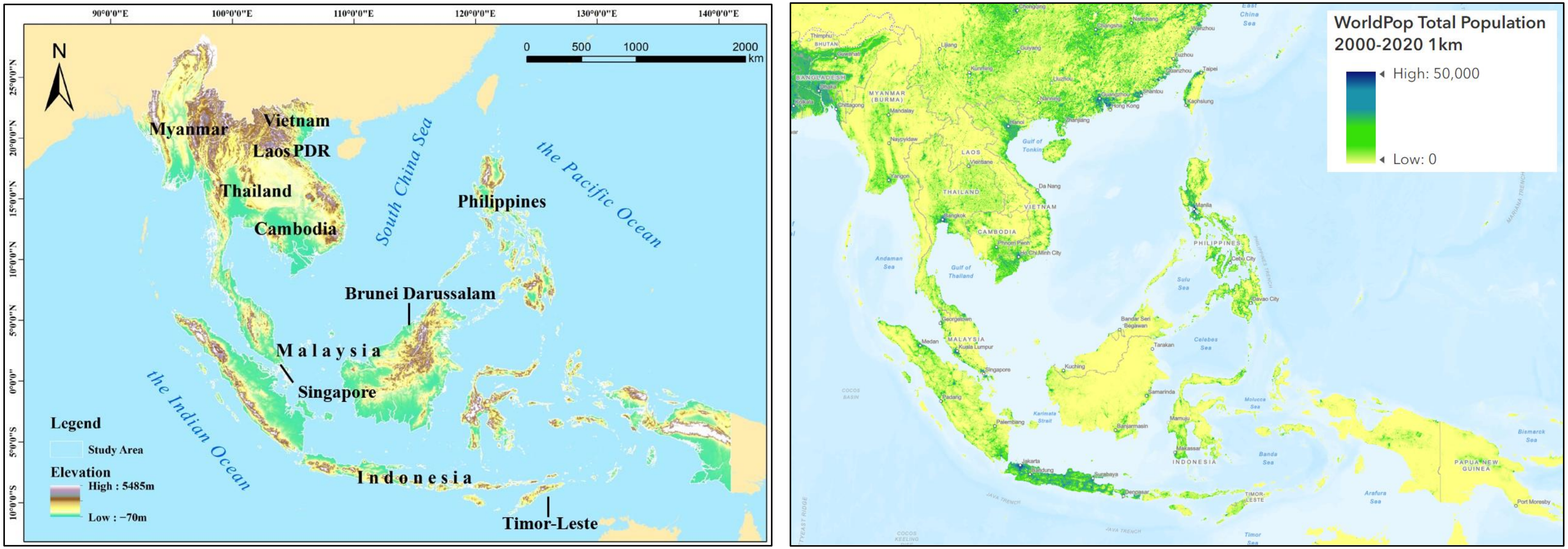
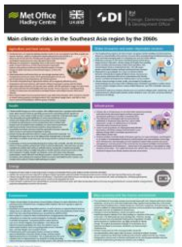


Figure 2: Topographic map (left; adapted from Liu et al., 2023) and total population map (right; data from WorldPop, 2018) of Southeast Asia and the Maritime Continent. Population data shows number of inhabitants per 1km grid square.

1.2 Report structure and risk-informed development

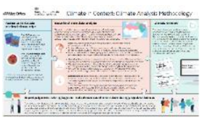
The Executive Summary outlines headline risks per theme, with context drawn from the report sections. This summary provides an overview of key climate related risks across the region. The summary is translated into 2 languages for ease of sharing with regional partners.



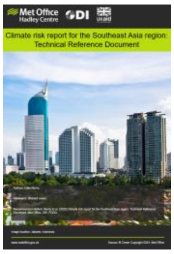
The Headline Risk Infographic contains standalone statements on headline key risks across the region. This infographic can be used to identify the key risks by thematic area. This infographic is translated into 2 languages for ease of sharing with regional partners.

Country Profiles outline prominent climate risks for individual countries. The tables signpost to relevant sections in the report with more detail.

Section 1 outlines the purpose, methodology and the regional development context through which this report has been framed. This section can be used to understand the lenses through which the report has been written.



Section 2 provides an assessment of the region's climate. It begins with an overview of climate resilience and vulnerability of the region and then it provides a summary of knowledge about the current climate and its future evolution at the regional scale.



The Technical Reference Document (TRD) accompanies this report to provide more detail on the methods, data and analysis supporting the assessment in this report. The TRD also contains a glossary of terms and a table of acronyms.

Section 3 assesses future climate risk by bringing together future climate analysis with socio-economic analysis of future resilience and vulnerability across seven key themes: agriculture and food security; water resources and water-dependent services; health; infrastructure and settlements; energy; environment; and blue economy and the marine environment. This section provides headline statements about key climate-related risks.

Figure 4 (page 28) shows an infographic depicting the Climate in Context Methodology for the Climate Risk Reports. Further information regarding the data used and detailed methodology can be found in Section A of the TRD and on the Met Office website here.

Focus Box 1 explains why it is necessary to consider both exposure and vulnerability to climate hazards and the need for an interdisciplinary approach when interpreting compound risks associated with, or exacerbated by, climate change. Information on risk-informed development can be found in TRD Section A.

Focus Box 1: Exposure, vulnerability, response, and development

Risks are created by the interaction between physical climate hazards and individual or community exposure and vulnerability to those hazards, as well as people's ability to respond (Figure 3, Begum et al., 2022). Exposure and vulnerability are separate, yet both emerge from socio-economic contexts and are exacerbated by uneven development dynamics such as: rapid urbanisation and demographic change, environmental degradation, weak governance, and lack of economic opportunity. IPCC AR6 also now considers response as an important component of risk and examines the effectiveness of adaptation solutions, the management of risks at higher levels of warming if climate change mitigation is unsuccessful, and the benefits of mitigation and emissions reductions (Begum et al., 2022).

The components of risk (hazard, vulnerability, exposure, and response) interact in complex ways (Figure 3, Begum et al., 2022). They can compound in single or multiple directions, cascade (e.g., with one event triggering another) and aggregate (e.g., more than one component occurring simultaneously).

Climate vulnerability and poverty are often mutually reinforcing. A growing body of evidence highlights the role climate risk plays in generating poverty and creating poverty traps (Hansen et al., 2019; Sachs et al., 2004), a problem often exacerbated by the political marginalisation of many poor and climate vulnerable people (Wisner et al., 2003).

Climate change is interwoven with development challenges across the Sustainable Development Goals (SDGs). As factors such as economic inequality, education, gender, nutrition, and health shape the risk profile of individuals and communities, supporting sustainable development indirectly supports their capacity for managing climate risk (Wisner et al., 2003; Schipper and Pelling, 2006).

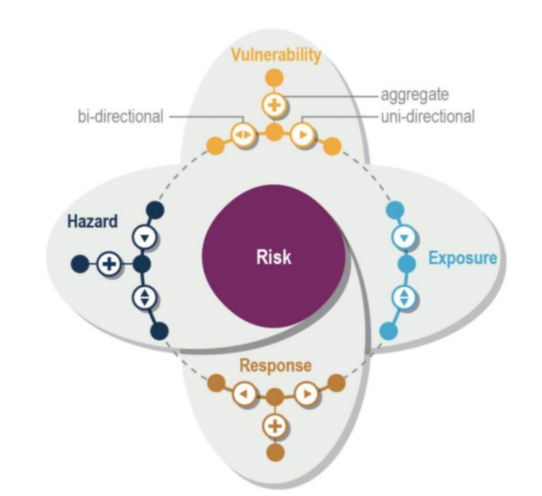


Figure 3: Climate risk is the product of the hazard, vulnerability and exposure to the hazard and the response to the hazard which interact in complex ways: compounding in single or multiple directions, cascading and/or aggregating. Image adapted from IPCC AR6 Working Group II (Begum et al., 2022).

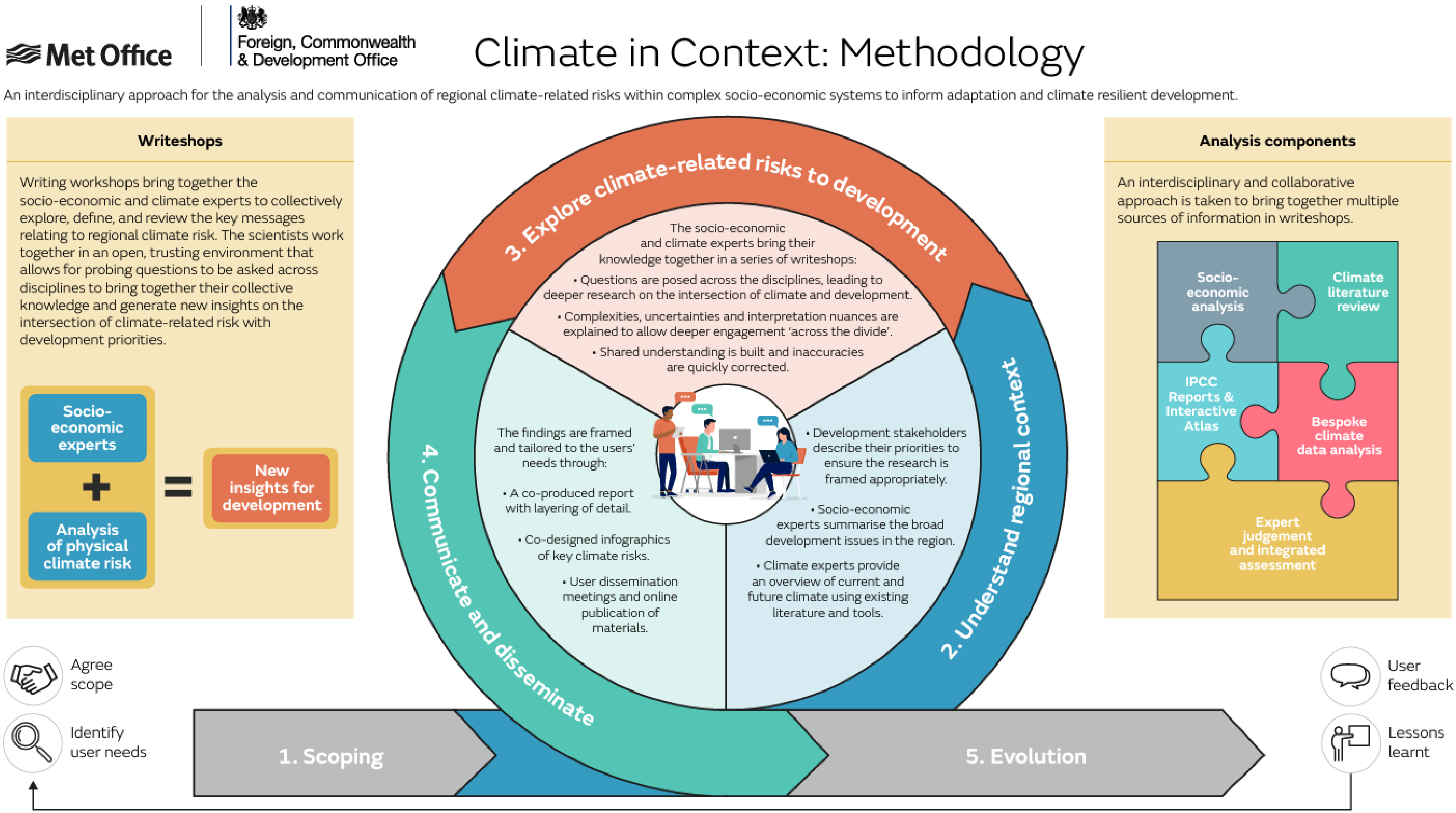


Figure 4: The Climate in Context Methodology for the Climate Risk Reports. Full methodology report citation: Richardson, K., Lewis, K., Osborne, R., Doherty, A., Mayhew, L. and Burgin, L. (2022) Climate in context: An interdisciplinary approach for climate risk analysis and communication, Met Office Hadley Centre. Further information regarding the data used and detailed methodology can be found in Section A of the TRD and on the Met Office website here.

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Image location: Hanoi, Viet Nam

2 Current and future climate in the Southeast Asia region

Lead author: Luke Norris, Met Office

2.1 Climate resilience and vulnerability overview for the Southeast Asia region

Vulnerability across the region is strongly associated with persistent poverty, high levels of inequality, and growing pressure on natural resources. Southeast Asia is home to roughly 690 million people – about 8% of the world population – with Indonesia, Philippines, and Viet Nam accounting for 70% of the regional total (UN World Population Prospects data for 2022 – see TRD Section F). Southeast Asian countries have experienced strong economic growth over the last two decades, in many cases doubling their GDP, and are now returning to growth after Covid-19 disruptions (IEA, 2022).

Just over half of the region's population (51%) currently live in urban areas, but the rapid pace of urbanisation driven by natural growth, rural-urban migration, and the transformation of rural villages/towns into urban centres will see that percentage rise to around 56% by 2030 and over 60% by 2050 (ASEAN, 2022). This will increase pressure on the fragile and overstretched infrastructure, alongside the expansion of informal settlements lacking one or more basic living conditions or services (e.g., improved sanitation, durable housing, water, electricity etc.) (World Bank, 2020).

Across Southeast Asia, there are concerns over the severe and persistent shortage of quality infrastructure, with existing and emerging climate hazards highlighting gaps in provision and posing threats to existing assets and services (Hallegatte et al., 2019; ESCAP, 2020). According to the EM-DAT database (the International Disaster Database), between 1995 and 2022, climate-related disasters[2] inflicted a total of 1,86,020 human fatalities in Southeast Asia (CRED-EM-DAT, 2023). On average, such disasters have affected (e.g., injured, displaced) nearly 13.5 million people annually and caused an average annual economic loss of USD 6 billion across the region over the same period (CRED-EM-DAT, 2023). A majority (more than 75%) of these impacts were caused by floods and typhoons. In 2023, a total of 79 disasters associated with hydrometeorological hazards were reported across Asia. Of these, 80% were associated with flood and storm events, with storms affecting the largest number of people and causing the most economic damage during 2023 (WMO, 2024). While trends in human lives lost have declined due to improvements in disaster preparedness and emergency response, such events still affect millions of people annually (disproportionately affecting poorer households) and cause large-scale economic losses and damages to infrastructure and economies (Panwar and Sen, 2019; Tasri et al., 2022).

Lower-income populations living in the region's informal settlements are most vulnerable to climate-related hazards, particularly intense rainfall, pluvial floods, and heatwaves (Shaw et

[2] Climate-related disasters include heavy rains and subsequent floods and landslides, storms, droughts, cold waves, and heat waves.

al., 2022; Caretta et al., 2022; Dodman et al., 2022), as they are more likely to be pushed into low-lying, flood-prone areas where land is cheaper and more easily accessible (Hallegatte, 2016; Dodman et al., 2022). Over 20 million urban residents are already at high risk from pluvial floods, mainly in Viet Nam (10 million), Cambodia (4 million), and Indonesia (3 million) (FAO, UNICEF, WFP and WHO, 2023). Farming is also becoming increasingly feminised as men (mainly) seek off-farm employment, leaving women more exposed to climate-related stresses, amplified by their lower incomes and reduced access to credit, property, extension services, and other resources creating a key source of vulnerability for the rural poor whose income is directly tied to the status of the agricultural economy (ADB, 2017; 2021a).

The countries of Southeast Asia have made significant progress on health and broader social development outcomes over the last three decades, despite recent disruptions from the Covid-19 pandemic and (in Myanmar) conflict and state fragility. Between 1990 and 2020, the rate of child (under 5 years old) mortality in the region declined by 70%, life expectancy increased by 10 years (IHME-GBD, 2019), and all countries graduated to middle-income status or, in the case of Brunei Darussalam and Singapore, high-income status, with major increases in health expenditure (WHO, 2019a). Regional trends obscure major disparities in health access and outcomes between and within countries, however, linked to economic status (e.g., poverty), location (rural, urban, informal settlement), age, gender and ethnicity. The safety nets that protect people from economic shocks remain precariously thin in some countries (Myanmar and Lao PDR especially – World Bank, 2019 data), and out-of-pocket health financing[3] exceeds 40% in Myanmar, Lao PDR, Viet Nam, Cambodia, and Philippines, increasing peoples' vulnerability to shocks (WHO, 2019b).

All Southeast Asian countries, with the exception of landlocked Lao PDR, are maritime nations. The region hosts one of the world's most extensive and diverse marine eco-regions and is considered a global hotspot for both its marine biodiversity and the potential of its blue economy to power economic growth (ADB, 2021b). Within the ASEAN[4] region, roughly 625 million people depend on the ocean for their livelihoods, significantly more than most other global regions. The compound effect of multiple climate hazards (sea-level rise, extreme weather events, marine heatwaves, and ocean acidification – see Section 2.2) and the impacts of pollution, coastal habitat destruction and overfishing, are putting the coastal economies of the region under growing pressures, impacting the livelihoods of the poorest communities (ADB, 2021b).

2.2 Climate overview for the Southeast Asia region

The Southeast Asia region experiences a predominantly maritime climate (where the influence from the surrounding ocean is strong) in the southern maritime countries (Philippines, Indonesia, Timor-Leste, Malaysia, Singapore, and Brunei Darussalam) and a tropical climate in the northern continental countries (Myanmar, Lao PDR, Viet Nam, Thailand, and Cambodia). The far north of the region and north-east Thailand experiences a more temperate climate. Southeast Asia is situated between the Indian and Pacific Oceans with annual mean sea surface temperatures around the region ranging from 25-32°C. The cooler sea surface

[3] Out-of-pocket payments are spending on health directly by households.
[4] The Association of Southeast Asian Nations (ASEAN), established in 1967, currently includes 10 member states: Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei Darussalam, Viet Nam, Lao PDR, Myanmar and Cambodia.

temperatures are situated to the far north and south of the region and the warmest temperatures along the equator.

Southeast Asia experiences high levels of climate variability on timescales of days, to months, to years due to many large-scale climate systems affecting the region. One example is the El Niño Southern Oscillation (ENSO) which has a 3–7-year cycle and affects the region during its Neutral, El Niño and La Niña phases (see TRD for more details). El Niño generally leads to drier, cooler conditions across Southeast Asia and conversely La Niña brings wetter and warmer conditions. Much of Southeast Asia is also affected by western Pacific and Australian typhoon seasons, with Philippines having the highest exposure to typhoons. Elevations above ~1500m, where average annual temperatures are cooler, are found throughout the majority of the region including mountainous areas of the Maritime Continent (here defined as the countries of Philippines, Indonesia, Timor-Leste, Malaysia, Singapore, and Brunei Darussalam) (Figure 2). Elsewhere, temperatures are very warm with the highest temperatures occurring in areas away from coasts.

Three major river basins are found in continental Southeast Asia: the Mekong, Salween, and Irrawaddy Basins. The Mekong River stretches nearly 5000km from its source on the Tibetan Plateau in China to the Mekong Delta in southern Viet Nam. The Salween River runs through southwest China and eastern Myanmar with a short section forming the border of Myanmar and Thailand. The Irrawaddy River is the principal river of Myanmar at about 2200km long, running through the centre of the country.

2.2.1 Regional climate overview and observed trends

Maritime Southeast Asia (defined here as Philippines, Indonesia, Timor-Leste, Malaysia, Singapore, and Brunei Darussalam) experiences a tropical climate which is affected by the East Asian and Indo-Australian Monsoons. These are the main broadscale drivers of rainfall which define the wet and dry seasons. The South West (SW) monsoon is active June to September which brings the wet season to western Philippines and dry conditions for the rest of the Maritime Continent, especially Java. The North East (NE) monsoon is active November to April and signals a reverse of these conditions. Seasonal variability in precipitation is also influenced by the migration of the Intertropical Convergence Zone (ITCZ) as it shifts north through Boreal summer and south again for Austral summer[5]. Much of the Maritime Continent of Southeast Asia experiences frequent typhoons.

Northern maritime Southeast Asia (Philippines) experiences a tropical climate with temperatures remaining around 20-30°C throughout the year. There is a pronounced, but highly variable, cycle of precipitation within the year with the majority of rainfall falling through May to October which is mainly due to typhoon activity (Matsumoto et al., 2020). Philippines has the highest exposure to typhoons across the whole Southeast Asia region.

Central maritime Southeast Asia (Indonesia, Malaysia, Singapore, and Brunei Darussalam) experiences a tropical climate. Temperatures have extremely low annual variability, remaining around 25°C throughout the year on average. Rainfall occurs all year round with the highest levels through October to April. It experiences lower annual precipitation variability without any

[5]For more information on the movement of the ITCZ see the Met Office website here: https://www.metoffice.gov.uk/weather/learn-about/weather/atmosphere/intertropical-convergence-zone

clearly defined wet or dry season, compared to northern and southern maritime areas which have more distinct seasons.

Southern maritime Southeast Asia (Indonesia and Timor-Leste) experiences a tropical climate. The annual cycle of temperature is very low with year-round temperatures typically remaining around 25°C. There is a pronounced annual cycle in precipitation with most rainfall occurring between November to March and a distinct drier season between June to September. However, there is moderate variability in the amount of precipitation year to year.

Continental Southeast Asia (Myanmar, Lao PDR, Viet Nam, Thailand, and Cambodia) experiences a temperate climate to the north, and a tropical climate in central and southern parts. Rainfall has a pronounced annual cycle with the East Asian and Indo-Australian Monsoons being the main broadscale drivers of rainfall which define wet and dry seasons. The Southwest monsoon from June to October, bringing the wet season to continental Southeast Asia. The Northeast monsoon (dry season) is active November to April. Continental Southeast Asia experiences frequent typhoons.

Northern parts of continental Southeast Asia (northern Myanmar, northern Lao PDR, and northern Viet Nam) experience a temperate climate. There is a very pronounced annual cycle for precipitation driven by the East Asian Monsoon, whereas temperature ranges are less variable and remain mostly temperate throughout the year (daily mean temperature annual range is 12˚C - 25˚C), rarely reaching below 10°C in the coldest months. Annual average temperatures are the lowest in the mountainous regions of these parts of Southeast Asia where (alongside northern Thailand) they have the highest elevations (between 2000-5000m). These mountainous areas also experience high annual precipitation.

Central and southern parts of continental Southeast Asia (southern Myanmar, southern Lao PDR, southern Viet Nam, Thailand, and Cambodia) experience a tropical climate. Mean daily temperatures ranging from 22˚C to 29˚C annually, rarely dropping below 20°C in the coolest months. Precipitation has a pronounced annual cycle driven by the Indo-Australian monsoon, with the wet season occurring between May and October and a dry season from November to March. The coasts of southern Myanmar, Thailand, Cambodia, and south Viet Nam experience particularly high annual average precipitation while inland areas generally experience lower precipitation in comparison. Northern Thailand, alongside northern Viet Nam and northern Lao PDR, have the highest elevations across Southeast Asia (between 2000-5000m) and experience high annual precipitation in particular with snowfall occurring at highest elevations. Annual mean sea surface temperatures around the coast of Viet Nam show some of the largest seasonal variability in the whole Southeast Asia region.

Observed trends in regional climate for Southeast Asia

A long-term warming trend in annual mean surface temperature has been observed across Asia during 1960–2015[6], and the warming accelerated after the 1970s (Shaw et al., 2022). Observational records show that Southeast Asia's average annual atmospheric temperatures over land increased by 0.5°C from 1980 to 2015. Warming rates range from 0.1-0.3° C per decade across most of the region (CRU TS data 1980-2015 from Harris et al., 2020), with southern regions such as Java and Timor-Leste showing little change or a slight

[6] Latest available reanalysis data for the IPCC Southeast Asia region.

cooling. Minimum temperatures have increased more rapidly than maximum temperatures. Rising minimum and maximum temperatures have resulted in more frequent warm days and nights, and less frequent cold days and nights (Shaw et al., 2022). Heat waves are becoming more frequent, longer lasting, and more intense in most parts of Southeast Asia (Li et al., 2022).

Between 1951-2007, a wetting trend, and an increase in extreme rainfall events (both frequency and intensity), especially during the winter monsoon period during La Niña episodes, has been observed across Continental Southeast Asia and central and eastern Philippines. Extreme daily rainfall values in these regions have increased by up to 30mm/day (Villafuerte and Matsumoto, 2015).

Numbers of typhoons of Tropical Storm strength (≥63 km/h) show no significant long-term trend during 1951–2017 (IPCC, 2021a). However, the average position of typhoon tracks in the region has shown a significant north-westward shift since the 1980s, increasing exposure to regions including Taiwan and eastern China. The average latitude at which typhoons reach their peak intensity in the western North Pacific has had a detectable poleward shift (or higher latitudes) since the 1940s (Lee et al., 2020).

Maritime Southeast Asia

In northern maritime Southeast Asia (Philippines), mean annual temperatures have risen by around 0.1- 0.3°C per decade, from 1980 to 2015 (ERA5 (Hersbach et al., 2020, APRHRODITE (Yatagai et al., 2012) and CRU TS (Harris et al., 2020)). There was a drying tendency in the dry season and significant wetting in the wet season in Philippines during 1951–2010 (Villafuerte et al., 2014). Philippines are particularly affected by typhoons and Takayabu et al., (2015) found that human induced climate change may have worsened the extent of storm surge during Typhoon Haiyan by 20%.

In central maritime Southeast Asia (Indonesia, Malaysia, Singapore, and Brunei Darussalam) mean annual temperatures have risen by around 0.1-0.4°C per decade, from 1980 to 2015 (ERA5, APRHRODITE, CRU TS). Precipitation observational datasets overall show a slight wetting trend, in the order of 0.1-0.5 mm/day per decade between 1980-2015 (APHRODITE), across all Southeast Asia. Between July and October 2015, a strong El Niño event combined with human-induced climate change substantially increased the likelihood of both heatwave and drought conditions across Indonesia (King et al., 2016).

In southern maritime Southeast Asia (Indonesia and Timor-Leste) mean annual temperatures have risen by around 0.1-0.3°C per decade from 1980 to 2015 (ERA5 and CRU TS). The occurrence of the marine heatwave of 2016 was shown to have been up to 50 times more likely as a result of human-induced climate change (Oliver et al., 2018). This marine heatwave persisted for 298 days, the longest on record for this region, with an average intensity of 2°C (Iskandar et al., 2021). Precipitation has generally increased by around 0.2-0.5mm/day per decade, although this trend is less evident across Java and southern Sumatra where there has been little change.

Continental Southeast Asia

In northern parts of continental Southeast Asia (northern Myanmar, northern Lao PDR and northern Viet Nam) mean annual temperatures have risen by around 0.2-0.4°C per decade from 1980 to 2015 (ERA5, APRHRODITE, CRU TS), with the largest increases during the dry season (November-March). Maximum average monthly temperatures have increased by approximately 3°C, and now reach a peak of 30°C in May. Observation datasets (GPCC and APHRODITE data, 1980-2015) show a drying trend, particularly over higher altitude regions and this is supported by ERA5 data (1981-2010) where reductions in monthly rainfall totals of around 50-100 mm (i.e., an annual reduction of 600-1200mm). Whilst overall rainfall is decreasing, extreme rainfall events have continued, and will continue to impact this region. For example, October 2020 brought persistent extreme rainfall to parts of central and northern Viet Nam, as a result of a series of cyclones (two of which were typhoon strength). Human-induced climate change had a negligible effect on the likelihood of this event occurring when compared to climate variability, illustrating that rainfall variability continues to be high (Luu et al., 2021).

Average mean temperature across central and southern parts of continental Southeast Asia (southern Myanmar, southern Lao PDR, southern Viet Nam, Thailand, and Cambodia) have risen by around 0.2-0.3°C per decade from 1980 to 2015 (ERA5, APRHRODITE, CRU TS). Similarly, maximum average monthly temperatures have increased by approximately ~0.4°C since 1981 and can reach a peak of 35°C in April. There is an observed wetting trend over much of the region, except for the central region of Cambodia and Thailand, where there is a drying trend (GPCC and APHRODITE, 1980-2015). There are some clear trends at seasonal timescales for some regions including slight wetting in Viet Nam during 1980–2017 (Stojanovic et al., 2020). Human-induced climate change has been shown to increase the magnitude and frequency of flooding events in the Lancang-Mekong river basin by 14% and 45% respectively, although the effective management of reservoirs as a buffer more than offset this effect (Yun et al., 2020).

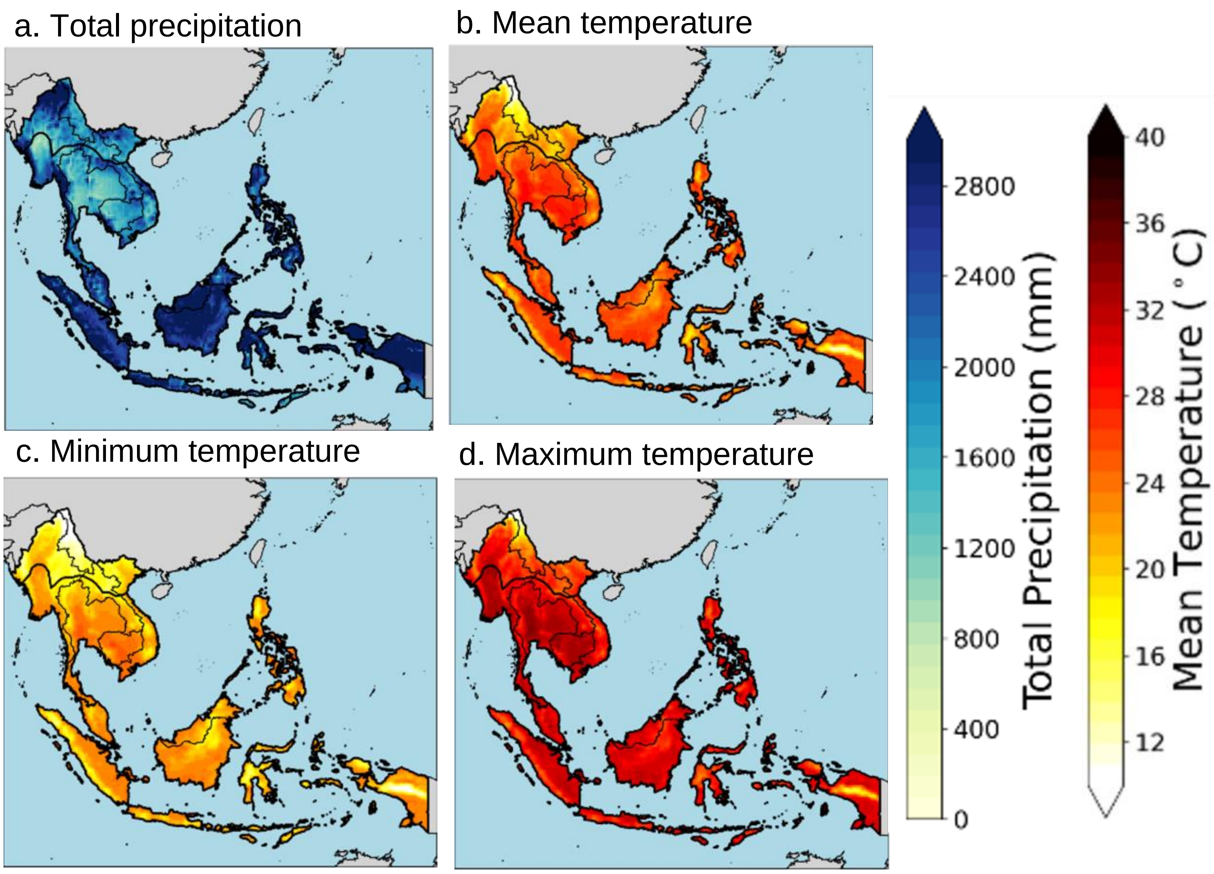

Figure 5: Baseline climate for the Southeast Asia region for the period 1981-2010. Maps show climatological average values of annual mean a) total precipitation (mm/year); b) mean temperature (°C); c) minimum temperature (°C); and d) maximum temperature (°C). Temperature and precipitation data come from ERA5 reanalysis dataset. These maps represent the average annual values over the 30-year baseline climate period.

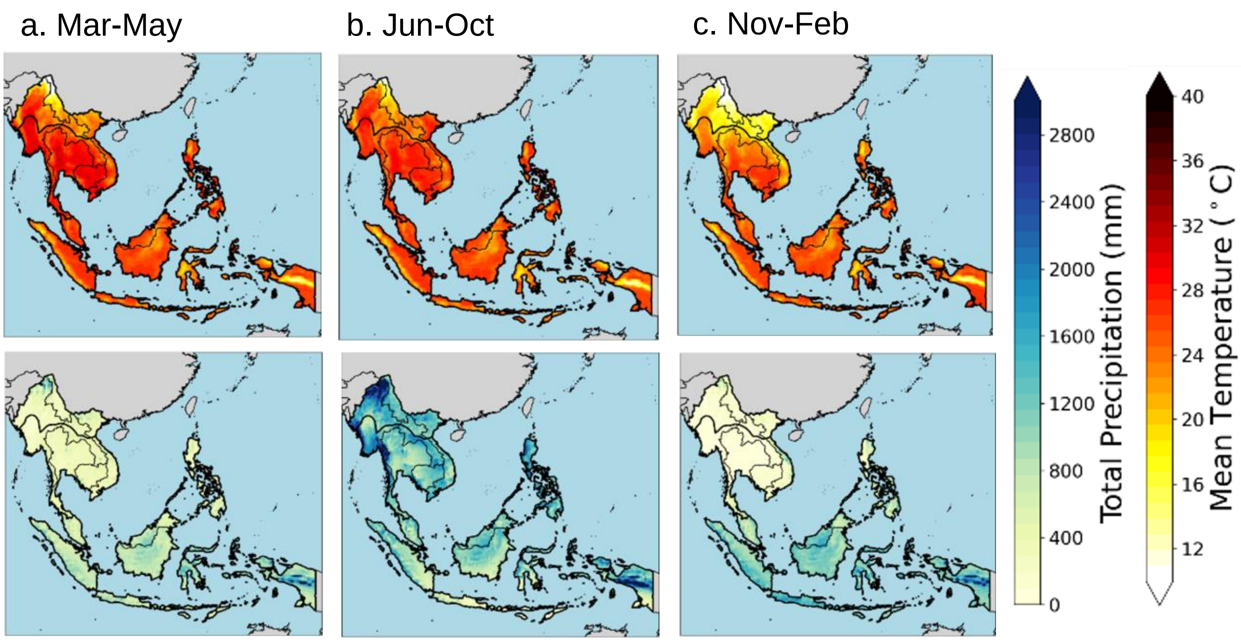

Figure 6: Seasonally averaged mean temperature (top) and total precipitation (bottom) for the Southeast Asia region over the baseline period (1981-2010) from the ERA5 reanalysis.

Focus Box 2: Event Attribution

Climate attribution of long-term trends or individual extreme weather events such as a heatwave, a flood, or a drought, identifies whether and to what extent human-caused greenhouse gas emissions are influencing weather and climate.

Geographical coverage of attribution assessments is uneven, and many more studies have been conducted for events in developed countries than for countries in the global south. Confidence in climate attribution analysis relies on high quality observational records, climate models' abilities to simulate a particular type of event, and scientific understanding of how natural variability and climate change may influence the processes that cause the event. The availability of this information varies for each extreme event and region, posing a particular barrier to attribution studies in the Global South.

There is currently a deficiency in longer time series observation records across Southeast Asia, which are essential to enable and inform such attribution studies.

The attribution of weather and climate-related events for Southeast Asia is discussed in more detail in TRD Section D.

2.2.2 Future climate over Southeast Asia

As stated in Section A of the Technical Reference Document, future climate over Southeast Asia is interpreted under a 'high greenhouse gas emissions pathway' (RCP8.5), or 'fossil-fuel driven development' scenario (SSP5-8.5) to model future climate evolution until 2050s unless otherwise stated.

The section below presents the projected trends applicable to the whole Southeast Asia region, then details further trends specific to either Continental Southeast Asia or Maritime Southeast Asia. To supplement the information below, readers are referred to the accompanying TRDs and the Country Reference Tables. For more detailed climate information at national level, a separate analysis would be required.

Mean temperature in Southeast Asia will continue to rise through 2050 (virtually certain, very high confidence) across the whole region, but likely by a slightly smaller amount than the global average (Gutiérrez et al., 2021b). Projected changes by the 2050s, relative to a 1981-2010 baseline and under both medium and high emission scenarios, are in the range of 0.5-2.5˚C and 1-3.5˚C across the region respectively, illustrating the sensitive relationship between greenhouse gas emissions and projected warming, even by 2050. Model projections for inland continental Southeast Asia (Lao PDR and northern Thailand) suggest a higher rate of warming compared to the rest of the region.

By the 2050s, both minimum and maximum temperatures are projected to increase by around 1.0-2.0˚C across Southeast Asia under medium and high emission scenarios (Gutiérrez et al., 2021b). The frequency and intensity of heatwaves across the whole of Southeast Asia are also expected to increase, and the frequency and intensity of cold waves (several days of temperatures below average) are expected to decrease. Compared to the baseline climate, the number of days above 35˚C is expected to increase by over 40 days per year across all but mountainous areas, while days above 40˚C are projected to increase by around 10-30 days per year across inland parts of Thailand, Lao PDR, and Myanmar. Most notably, there could be 300 heatwave days[7] per year in densely populated regions of Southeast Asia by the end of the century under a high emission scenario (Almazroui et al., 2021*)*. The level of regional warming primarily drives changes in the frequency and duration of heatwaves over Southeast Asia, but it is both warming level and the additional influence of ENSO that impact the amplitude (highest temperature of the hottest yearly heatwave event) of heatwaves (Dong et al., 2021). During strong El Niño episodes, the intensity of heatwaves is amplified, and conversely La Niña has a dampening effect on heatwave intensity. The level of future heat stress, which is a combination of heat and humidity, on populations is projected to increase significantly in frequency and severity through the Tropics including the Maritime Continent (Im et al., 2018) where moist heatwaves are likely to be an increasing hazard, but research is currently limited in this area due to data availability (Dong et al., 2021). Moist heatwaves occur when high temperatures coincide with higher than average humidity leading to an increase in heat stress which has negative implications for society ranging from health impacts (as human bodies struggle to effectively cool themselves) to increased energy demand (as air-conditioning usage increases, for instance).

For **Myanmar, Lao PDR and Viet Nam** warming between 1 to 3.5˚C by the 2050s is expected as annual temperatures increase with increased frequency and intensity of heatwaves. For **Philippines, Indonesia, Malaysia, Singapore, Brunei Darussalam and Timor-Leste** warming is expected between 1 and 3°C as annual temperatures increase with an increased frequency and intensity of heatwaves (for further sub-regional analysis, see section E in the accompanying TRDs, and country summaries).

Across Southeast Asia, overall confidence in projected average rainfall change by 2050 is low as higher resolution regional climate models project greater variability and a contrasting trend to the lower resolution CMIP global models. In short, both wetter and drier scenarios are plausible across much of the region.

Global climate models (CMIP5 and CMIP6) project an increase in annual mean rainfall across Southeast Asia by 2050, but only with strong agreement at higher warming levels (Gutiérrez et al., 2021b). This increase is most pronounced across continental Southeast Asia, especially northern Thailand, Myanmar and northern Lao PDR through the southwest monsoon season (June to October) where this seasonal rainfall is projected to increase by around 10-20%, or 100-300mm. There is some evidence that at higher warming levels, the average onset date of the southwest monsoon could be delayed, leading to an overall decrease of around 20-40% in during the March-May period, but with little impact in overall monsoon rainfall. Conversely, the strongest signal for a drying trend is found across southern Indonesia and Timor-Leste outside of the main wet season (May to October), where rainfall may decrease by as much as 50% (around 200mm) which is significant given the average total rainfall during this period being only 250-400mm. There are, however, equally plausible trends which show a similar increase in rainfall and as such, **the uncertainty in regional rainfall projections by the 2050s and beyond, presents a significant evidence gap and opportunity for future research.**

[7] The Heat Wave Frequency Index (HWFI) is calculated by counting the number of days for each event per year when daily maximum temperature remains higher than the 90th percentile of the historical period continuously for at least six consecutive days.

Projections of extreme rainfall (wettest day in a year) by 2050 show a 5-15% increase relative to a 1995-2014 baseline for most land areas across all model configurations, and closer to 30-40% increase across northern Thailand and Myanmar (Gutiérrez et al., 2021a). This strongly suggests that the intensity of intense rainfall events, and therefore associated flash flooding, is likely to increase. Conversely, the number of consecutive dry days (number of consecutive days where less than 1mm of rain falls) are projected to increase across the Maritime Continent by 5-15 days annually by 2050, although the signal is less clear across continental Southeast Asia and Philippines (Gutiérrez et al., 2021a; Supari et al., 2020).

For Myanmar, Lao PDR, Vietnam, Thailand, Cambodia and Philippines, there is at least medium confidence that these regions will become wetter on average, predominantly through the Southwest Monsoon (June-October). **Central and Northern Indonesia, Malaysia, Singapore and Brunei Darussalam** will become wetter on average throughout the year. There is some evidence that **Southern Indonesia (Java, and the Lesser Sunda Islands) and Timor-Leste** will become wetter on average during November to March, but there is a lack of model consensus through June to October (the drier months), with both wetter and drier scenarios equally plausible.

Sea-level rise is virtually certain to continue around Southeast Asia and lead to greater damage from typhoons, storm surges and coastal erosion along coastlines (IPCC, 2021b). By 2050, a 0.3m median rise is projected under RCP8.5, increasing to 0.7m by late century, relative to 1995-2014. Even under the lower emission scenario of RCP4.5, sea-level rise is projected to rise by 0.2m and 0.5m by 2050 and end-of-century respectively, indicating that there is relatively low sensitivity between emission scenario and sea-level rise (Fox-Kemper et al., 2021). These projected levels are relatively uniform across the region with the exception of east and west of Philippines where, under RCP8.5, the rise is closer to 0.5m by 2050 and 1.0m by late century. At the same time, it has been shown that cities across coastal Southeast Asia have been subsiding due to groundwater extraction, further heightening their vulnerability to sea-level rise (Wu and D'Hondt, 2022).

Sea surface temperatures are projected to increase in the coming decades across Southeast Asia (Gutiérrez et al., 2021a). The level of sea surface temperature increase is driven by the level of warming whereby under low emission (RCP2.6) and very high emission scenarios (RCP8.5), the median level of warming is 0.7°C and 1.2°C respectively. By the end of the century (2081-2100) sea surface temperature projections widen, whereby under the low emission scenario the median increase is unchanged at around 0.8°C whereas under the high emission scenario, the median increase is projected to be 3.0°C (Gutiérrez et al., 2021a, CMIP6). The world's oceans are the primary heat sink for the extra energy added via from global warming. During 1971-2018, they absorbed 91% of all energy added during 1971-2018 (Gutiérrez et al., 2021b, Table 7.1). The rise in ocean heat content is focused within the upper 2000m (with over half of this within the top 700m) and consequently, the occurrence of marine heatwaves[8] can only increase. The most extreme marine heatwaves are projected to occur most frequently in tropical Central and West Pacific and Indian Ocean by the end of the century (Figure 6.4 in Collins et al., 2019).

[8] Marine heatwaves are extremely warm, persistent sea surface temperatures anomalies that can persist for days to months and can extend to thousands of kilometres (Xu et al., 2022).

Typhoon frequency across the northwest Pacific basin is projected to decrease or remain unchanged, but the number of intense storms will increase. The number of typhoons that develop across the basin is expected to see little change compared with current climatology, but the proportion of the most intense typhoons (Category 4 and 5) is expected to increase, primarily impacting on north-central Philippines as well as Viet Nam, Cambodia and Thailand (Seneviratne et al., 2021, Qin et al., 2023). Over the past four decades, it is *very likely* that typhoons in the western North Pacific reach their peak intensity at higher latitudes. This trend is expected to continue, possibly reducing typhoon frequency at lower latitude locations, such as Philippines (Seneviratne et al., 2021). The peak intensity of typhoons, and therefore average and peak wind speed, is projected to increase worldwide, primarily due to higher ocean temperatures (Wehner et al., 2018; Knutson et al., 2020) which also enables storms to strengthen more quickly (known as rapid intensification). In addition, the speed of typhoon movement has decreased, and is projected to decrease further, probably leading to increased impacts (Yamaguchi and Maeda, 2020).

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Image location: Inle Lake, Myanmar

3 Climate risk impacts and interpretation for the Southeast Asia region

Lead author: Roger Calow, ODI

3.1 Agriculture and food security

Image location: Thailand

Summary of risks relevant to agriculture and food security

- Rice yields are projected to decline by 3-10% by 2050 due to heat extremes, flooding, and droughts, with the biggest losses projected for Cambodia, Myanmar, and Viet Nam. Rainfed production and lowland coastal areas (lower Mekong and Red River deltas) are most exposed. Southeast Asia currently accounts for 26% of the global rice production and 40% of global rice exports.
- Improvements in agronomic systems and practices, including climate-smart agricultural practices that can boost yields and reduce greenhouse gas emissions, could more than offset the impacts of climate change on yields and reduce environmental impacts - at least until the 2050s. In Cambodia, Myanmar, Philippines and Thailand, yields are roughly 50-70% of their exploitable potential.
- Inland aquaculture and livestock play an increasingly important role in meeting food and income needs, and in generating export revenue, but are threatened by rising temperatures and climate extremes. The transition from rice farming to marine aquaculture in the Mekong delta, an adaptive response to land-water salinisation, is largely responsible for mangrove clearance and the loss of natural coastal protection.
- The health and productivity of agricultural workers will be negatively affected by rising temperatures and heat extremes, with impacts falling increasingly on women and the elderly. Reductions in agricultural labour capacity from heat-humidity stress have been estimated at 30 to 50% for the region with a 3°C rise in temperature and could undermine agricultural employment and production.
- Food insecurity could increase to the 2050s as agricultural output and prices become more variable, with the potential for longer-term price rises that could undermine food affordability for the poorest groups. Poorer consumers, including growing numbers of urban poor, subsistence-orientated farmers, and landless tenants, will be worst affected. Roughly 54% of the regional population cannot *currently* afford a healthy diet, costing around USD4/day.
- Collectively, the risks above will hamper progress SDG2: *End hunger, achieve food security and improved nutrition and promote sustainable agriculture.*
- Most sectoral studies have focussed narrowly on crop yields and production. More research is needed on mixed farming systems (including livestock and aquaculture), agricultural supply chains (disruptions, storage), and shifts in food access and affordability for different groups of people.

3.1.1 Context

Agricultural production, including forestry, fishing, and livestock, provides a vital source of employment, income, and food security across Asia, even though its contribution to GDP is diminishing as economies diversify. Contributions to GDP range from 1% or less in Brunei Darussalam and Singapore, to over 20% in Myanmar and Cambodia, yet 50% of the region's population still live in rural areas despite rapid out-migration and urbanisation and maintain a link directly or indirectly to the agricultural economy (ADB, 2021).[9] As Asian economies develop and become more urbanised, food demand is increasing and shifting in composition, including towards animal products that are much more resource intensive (ADB, 2021; Lin et al., 2022).

Farming throughout much of the region is based on rice production, often in multiple cropped systems that include maize and vegetables for food and/or fodder, and important cash crops such as coffee and cashews. Over recent years, tree crops for palm oil production and rubber have also expanded, often at the expense of native forests. As demand for livestock products has risen (especially meat, eggs, and dairy), livestock numbers have also increased dramatically. Inland fisheries also play a vital role in agricultural production and nutrition. Across the region, the rapid growth of freshwater and marine (brackish water) aquaculture (see section 3.7.3) has served to lower prices in domestic markets, benefiting poorer consumers and contributing to export earnings (ADB, 2021).

Although irrigated agriculture is well developed in high-potential lowland deltas (roughly 70% of the world's irrigated farmland is in Asia – see also Section 3.2), and sometimes within urban/peri-urban areas[10], most countries are still heavily dependent on rainfed production linked to seasonal rains, and smallholder production based on the intensive farming of small plots of land. Close to 90% of Indonesia's farmers own less than two hectares of land (World Bank, 2023b); in Viet Nam the average farm size is 0.6 ha (Nguyen et al., 2017). Poorer farmers – landholders or landless tenants – operate in extremely small areas and rely on off-farm income in wider rural and (increasingly) urban economies to make a living (ADB, 2021). Farming is also becoming increasingly feminised as men (mainly) seek off-farm employment, leaving women more exposed to climate-related stresses, amplified by their lower incomes and more limited access to credit, property, extension services and other resources (ADB, 2017; 2021).

Agricultural productivity has increased markedly over the last 30-40 years, particularly following Asia's Green Revolution in the late 1960s. Nevertheless, productivity is now stagnating because of soil degradation and salinisation, diminishing returns from heavy fertiliser use, pesticide/herbicide resistance, water scarcity/salinisation in some areas, and climate change (ADB, 2021; Yuan et al., 2022). Across Asia, heavy use of fertilisers, particularly synthetic nitrogen, now accounts for roughly 12% of the region's GHG emissions from agriculture (ADB, 2021; Menegat et al., 2022).[11] Some of these problems have their root

[9] GDP data for 2022 from World Bank; population data from UN World Population Prospects. Source: World Bank World Development Indicators accessed July 2023 – see TRD Section F.

[10] Although urban growth is usually associated with the loss of farmland, growing food *within* cities can help make up the shortfall. Singapore, which currently imports over 90% of its food, aims to produce 30% of its nutritional needs locally by 2030 (The Straits Times, 2023).

[11] From nitrogen manufacture, transportation and field use (whole supply chain) in agricultural systems. South Asia and East Asia (including China) now have the highest nitrogen application rates of any

causes in policies designed to promote agricultural production in the past by subsidising water, energy, and other farm inputs. These subsidies have proved difficult to remove or reorientate despite their environmental impact and fiscal drain on governments (ADB, 2021).

3.1.2 Crop production

The regional evidence base linking climate change with impacts on crop production and food systems in Central and South Asia is limited (Shaw et al., 2021; Bezner Kerr et al., 2022). Most studies looking at slow onset shifts in climate have focussed on key staples (rice, wheat, maize) rather than food or farming systems,[12] and are based on a limited number of control trials and modelling projections. These typically hold non-climate variables constant: baseline technologies, varieties and farming practices are 'fixed' while climate variables change over time (Shaw et al., 2022; Bezner Kerr et al., 2022).[13] Projections are complicated by uncertainties around how different crops, in different conditions, may respond to higher levels of atmospheric CO_2 which can potentially boost plant growth and lower water uptake, but may also reduce some important plant nutrients (FAO, 2015; Bezner Kerr et al., 2022).[14]

Available evidence indicates that climate change has had broadly negative impacts on crop production and that future warming will have more damaging impacts (ADB, 2021; Shaw et al., 2022; Bezner Kerr et al., 2022). Rising temperatures, heat extremes and changing rainfall patterns all affect crop areas, suitability, productivity, quality and harvest stability, though crop sensitivities vary. Differences in projected impacts by 2050 for different climate scenarios are minor, but from then on adverse impacts become more pronounced, especially for rainfed crops under higher emission pathways (Bezner Kerr et al., 2022). Figure 7 highlights observed and projected impacts for key crops and crop categories for different regions of Asia, with South and East Asia showing negative trends for key staples. Individual country profiles on climate change and agriculture, including projections and policy options, are available from CIAT/World Bank.[15] Not all impacts are negative or certain, and opportunities exist to increase yields and mitigate some of the effects of climate change – issues picked up later in this section.

global region. Excluding China from the Asia region, India, Pakistan and Indonesia (in that order) have the highest country-level emissions from synthetic nitrogen use in agriculture, falling within the global top 10 emitting countries (Menegat et al., 2022).

[12] Impacts throughout the supply chain, from yields to supply chain disruptions, storage costs, quantity and quality of stored products, producer incomes and prices.

[13] In addition, modelling does not generally account for the wider functioning of ecosystems, including the balance between crops, weeds and pests, and effects on pollinators (FAO, 2015; Bezner Kerr et al., 2022).

[14] The effects of elevated CO_2 on plant growth and nutritional content are complex and depend on local growing conditions (temperature, soil conditions) and plant/cultivar type. Higher levels of CO_2 can increase biomass accumulation but can also reduce the content of key nutrients in some grains, fruit and vegetables (Bezner-Kerr et al, 2022 – *high confidence*).

[15] Climate-smart country profiles developed by the International Centre for Tropical Agriculture (CIAT), the World Bank and others available here: https://ccafs.cgiar.org/resources/publications/csa-country-profiles. These focus mainly on South and Southeast Asia. The World Bank's Country Climate and Development Reports and shorter Climate Risk Country Profiles also provide accessible summaries of agricultural risks.

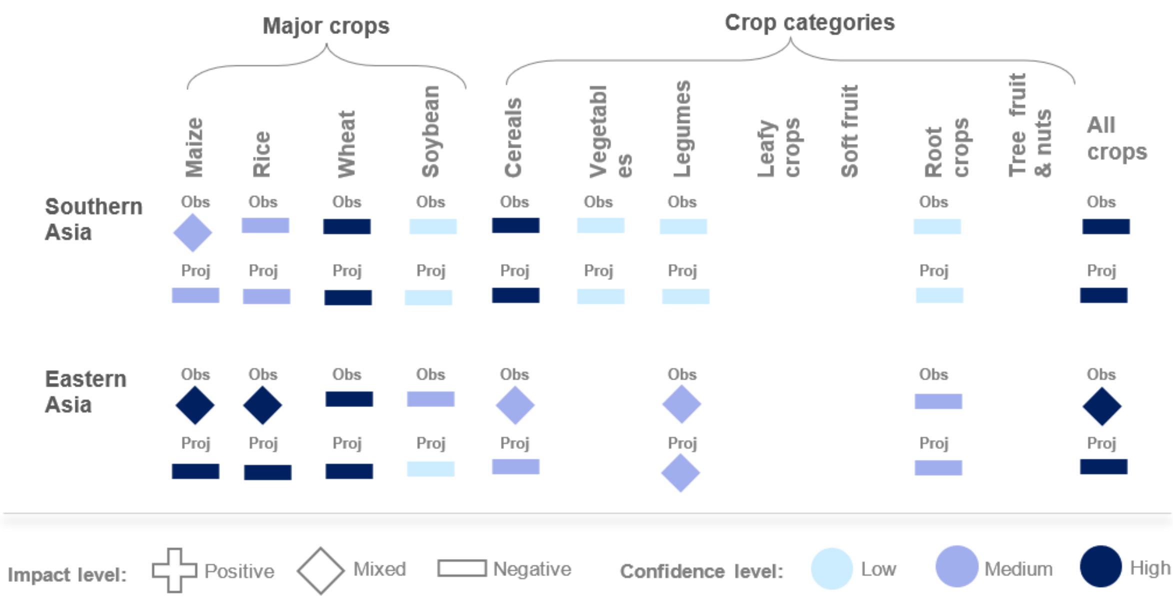

Figure 7: Observed (obs) projected (proj) impacts of climate change on crop yields in Southern and Eastern Asia. Source: based on Bezner Kerr et al. (2022). The impact level is identified with the following symbols: + means positive impact level; - means negative impact level; and ◊ means a mixed impact level. The confidence level is identified by the colour: dark blue means high confidence; purple means medium confidence; and pale blue means low confidence. Empty fields indicate areas that are not assessed or where there is insufficient data. Note: Observed impacts (from Bezner Kerr et al., 2022) are based on the synthesis of >150 articles published since AR5, though study timespans often extend prior to 2014. The projected impacts to the 2050 are the authors' own based on references listed for this section of the report.

Rice yields are projected to decline by 3-10% by 2050 compared with baseline scenarios, impacting global and regional food security as Southeast Asia currently accounts for 26% of global rice production and 40% of global rice exports (Li et al., 2017; Shaw et al., 2022; Bezner Kerr et al., 2022). The six major rice-producing countries in Southeast Asia - Cambodia, Indonesia, Myanmar, Philippines, Thailand and Viet Nam – collectively account for 97% of total rice production in the region. Demand for rice will increase by roughly 18% by 2050 due to population growth alone (Yuan et al., 2022). Over the same period, however, climate change is projected to reduce rice yields in major rice-growing areas by 3% - 10%, with the biggest impacts projected for Cambodia (-10%), Myanmar (-7%) and Viet Nam (-6%), even with positive CO_2 effects (Li et al., 2017).[16] The vulnerability of Cambodia and Myanmar's rice agriculture is linked to both higher temperatures and the prevalence of rainfed (vs irrigated) cropping (Li et al, 2017; World Bank, 2023a). For Viet Nam, the main vulnerabilities in rice agriculture are due to rising temperatures, flood risk and soil

[16] For an RCP4.5 scenario (see Section 2). Yield reductions reported by Li et al. (2017) are broadly consistent with those reported in wider literature reviewed by IPCC (Bezner Kerr et al., 2022; Shaw et al., 2022), although some projections including CO_2 effects report significant yield *increases* for rice production in the lower Mekong basin (e.g., Kang et al., 2021: 24-43% increase by end century).

salinisation in the Mekong delta where most of the country's rice is produced (Li et al, 2017; Nguyen et al, 2017 – see Focus Box 3).

Productivity is declining in major rice producing areas and rainfed croplands due to the combination of heat, water stress, and flooding, together with other environmental pressures, with rainfed systems being particularly exposed (FAO, 2015; ADB, 2021; Yuan et al., 2021; 2022). Crop heat stress is a key risk, with temperatures across Asia's monsoon belt approaching critical levels for wheat and maize grown over winter, and for rice crops grown during the summer monsoon season. Impacts are likely to be greater in rainfed cropping systems exposed to higher rainfall variability. Rainfed lowland rice accounts for nearly one-third of harvested rice area in Southeast Asia; despite growing in flooded soils for much of the season, rainfed rice is more exposed to rainfall deficits and/or excess flooding, leading to lower and less stable yields (Li et al., 2017; Yuan et al 2021; 2022 – see also Focus Box 3). Maize, grown increasingly for livestock fodder as well as a food crop, is more sensitive to heat and water stress than rice, hence yields are likely to fall further – by an estimated 5% with each degree of global warming in tropical regions (Franke et al., 2020). In Viet Nam, where maize accounts for 11% of the harvested area, maize yields may be 16% lower by 2050 because of the combined effects of pests, drought and higher temperatures (Nguyen et al., 2017).

Asia's deltas that account for major shares of rice production for export and domestic consumption are additionally threatened by rising sea levels, saline intrusion, more intense typhoons and storm surges. Asia's mega deltas, including the Mekong and Red River deltas in Viet Nam, are significant areas for rice production (over 50% of Viet Nam's rice output from the Mekong delta), with rice typically the only crop that can be grown during the summer monsoon (see Focus Box 3). Although heat, salt and flood-tolerant rice cultivars are available, floods, high winds and increasing salinity could increasingly damage crops and agricultural infrastructure.[17] In the Viet Nam Mekong delta, roughly 40% of the total rice area is already exposed to sustained flood risks, and the salinity-prone rice area already accounts for 44% of the total rice area (Wassmann et al., 2009). These problems have multiple causes. Increasing flood risk and saline intrusion (saltwater ingress into freshwater) are driven by groundwater over-exploitation, declining sediment deposition (upstream damming, downstream sand mining) and the destruction of natural sea defences, as well as by climate-driven changes in sea level and flood/storm intensity (see Focus Box 3).

Focus Box 3: Climate change and Southeast Asia's rice economy

Asia accounts for over 80% of global rice production and 75% of global consumption. In contrast to other major staples traded on global markets, most production and consumption occurs within the region. Excluding China, the biggest regional producers are India (24%), Indonesia (7%), Bangladesh (7%), Viet Nam (6%), Thailand (4%), Myanmar (4%), Philippines (3%) and Pakistan (2%) (FAO, 2019 data). The major exporters are Thailand, Viet Nam and India, accounting for roughly 60% of trade (Sekhar, 2018). Major importers are more widely distributed but include the two most populous

[17] In Myanmar, typhoon Nargis (May 2008) caused major damage to paddy fields and agricultural infrastructure in the Ayeyarwady delta, the country's main rice-producing area. Farmers needed 3-5 years to recover from the damage (Omori et al., 2021).

countries in the region – Philippines and Indonesia – with almost 400 million people (Yuan et al., 2022).

Although rice production will be less affected by climate change than wheat and maize (in part because more is irrigated), yields in much of Asia are still projected to decrease. Crop heat stress is a key factor in the monsoon belt (see Section 2) where most rice is grown, especially where temperatures are already approaching critical levels during the susceptible stages of plant growth and grain filling (optimum growing temperature range 25-30°C; maximum 35-38°C for common cultivars). Areas that are most at risk from this include: Myanmar, Thailand, Lao PDR and Cambodia (March-June), Viet Nam (April/August), Philippines (April/June) and Indonesia (August) (see Wassman et al., 2009; Sekhar, 2018).

The most vulnerable areas to combined heat and water stress are rainfed, where cropping cycles are tied directly to the timing and intensity of monsoon rains. These include southern Myanmar and northern Thailand where droughts already cause significant yield losses and food insecurity. In currently irrigated areas, declines in water availability and/or pressure to release water to other uses could potentially increase vulnerability (Yuan et al., 2022; Smolenaars et al., 2023).

Asia's deltas remain vital rice producing areas for Viet Nam (Mekong) and Myanmar (Irrawaddy, responsible for 54% and 68%, respectively, of each country's rice production (Wassmann et al., 2009, 2019). While rice is adapted to fluctuating water levels and partially saline conditions, sea-level rise, saline intrusion, more intense typhoons and storm surges (see Section 2) will increase flood risks, salinity stress and crop damage. Dam building and water diversion in the upper reaches of major rivers is also reducing sediment and nutrient flows to deltas, with the former also contributing to *relative* sea-level rise. The combination of climate change and land subsidence, rather than climate change alone, is causing these problems (Darby et al., 2020).

Adaptation options are available to mitigate some of these risks, and significant productivity gains in rice-based cropping systems in Asia are achievable (Li et al., 2017; Yuan et al., 2021; 2022). For example, rice cultivars with high heat tolerance are already grown in Iran and Australia, and changes in cropping practices, such as earlier planting, can reduce heat stress at later grain-filling stages of plant growth. Cultivars with much higher tolerance of flood conditions, including temporary submergence, are also available (FAO, 2015; Sekhar, 2018; ADB, 2021), as are more resilient (to heat) alternatives to rice such as millets (Chakraborti et al., 2023). In the Mekong delta, many coastal communities have turned to farming shrimp and other types of aquaculture as rice yields have declined (see also Section 3.7.3), but government targets for rice production in Viet Nam have acted as a brake on land conversion (Smajgl et al., 2015; Chau and Scrimgeour, 2023).

Agricultural droughts[18] also have a major impact on rainfed crop production in continental Southeast Asia, particularly in central Myanmar and the Lower Mekong region, although rainfall-based drought projections remain uncertain. The vulnerability of agriculture to drought is heightened by the region's reliance on rainfed agriculture. The distribution of drought impacts to date has been uneven, with central Myanmar experiencing the most frequent events (Ha et al., 2023). Cambodia has faced recent severe and prolonged droughts, while Thailand and Viet Nam have experienced the highest numbers of prolonged and damaging events between 2000 and 2021 (Kang et al, 2021; Chau et al, 2023; Ha et al., 2023). Evidence suggests a shift in historical drought patterns from northern central Myanmar towards the Lower Mekong Delta, disproportionately affecting the region between 2011 and 2021 (Ha et al., 2023). However, future projections (for consecutive dry days) in *continental*

[18] Agricultural drought refers to a lack of soil moisture content that causes vegetative stress and/or crop failure (Ha et al., 2023)

Southeast Asia remain uncertain (see Section 2.1.2). The Mekong River Commission (see Section 3.2) maintains a drought (and flood) forecasting and early warning system but is mandated to provide information products rather than specific drought/flood bulletins to member countries.[19]

Warming trends across Southeast Asia may create more favourable conditions for crop pests and diseases and increase the costs of control. However, the regional evidence base on impacts and trends remains limited. Global studies looking at the temperature response of insect pest populations indicate yield losses for rice, maize and wheat of 10-25% per degree of global warming, though with the biggest impacts in temperate zones (Deutsch et al., 2018). Negative impacts can also be expected because of the increased vulnerability of plants weakened by heat and water stress (FAO, 2015; Shaw et al., 2022). A concern for rice producing areas is the spread of the invasive golden apple snail, which eats young and emerging rice plants and causes major production losses. Although the snail is already endemic throughout most of Southeast Asia (in part because of warming trends (Lei et al., 2017).

Productivity gains may still be achievable *in spite of* climate change through improvements in agronomic systems and practices. These could boost rice yields and reduce the environmental footprint of rice farming (Li et al., 2017; Yuan et al., 2021; 2022). While rice yields are stagnating in four of the six major rice-producing countries (Indonesia, Myanmar, Thailand and Viet Nam), there is still significant room for improving yield, resource efficiency, or both (Li et al., 2017; Yuan et al., 2021; 2022).[20] Current yield gaps are larger than those in some other rice-producing countries such as China and the US, especially in Cambodia, Myanmar, Philippines and Thailand where yields are roughly 50–70% of their exploitable potential (Yuan et al., 2022). Closing these yield gaps through improvements in agronomic systems and practices could more than compensate for the negative effects of climate change outlined above, at least until the 2050s (Yuan et al., 2022 – see Focus Box 3). For example, rice intensification pilots[21] in the lower Mekong basin (Thailand, Lao PDR, Cambodia, Viet Nam) have demonstrated how significant increases in average yields and economic returns (52% and 70%, respectively) can be achieved with lower inputs and GHG emissions (Mishra et al., 2021). Irrigation development (see below) can also boost yields and increase resilience.

The importance of irrigation in sustaining crop production and supporting livelihoods will grow as rainfall variability and rising temperatures make rainfed agriculture more precarious. However, irrigation is a major consumer of water and may reduce water availability for other sectors. In contrast to large areas of South Asia, irrigation potential in Southeast Asia remains significant, with the ability to mitigate climate impacts and increase productivity. In Cambodia, for example, irrigated lands produce 60% greater yields than

[19] See MRC website: http://droughtforecast.mrcmekong.org/templates/view/our-product
[20] Resource use efficiency in terms of inputs of water, pesticides, nitrogen, labour, energy and GHG emissions (especially methane). See Yuan et al., 2021; 2022.
[21] With smallholders in irrigated and rainfed areas, focussing on seedling transplantation and spacing, retention of moist rather than waterlogged soils, and application of compost or manure instead of synthetic fertilisers to improve soils and reduce costs (Mishra et al., 2021). Measures such as these fall under the 'sustainable intensification' banner (see Pretty, 2018). More overtly *adaptive* interventions – earlier planting, and use of heat and/or flood resistant cultivars (see Focus Box 3) – are often called 'climate smart', though in practice the intensification/climate-smart distinction is blurred.

rainfed agriculture, and recent work commissioned by the World Bank shows that the adverse effect of drought on yields is entirely mitigated by households that irrigate their plots or rely on crop-rotation practices (World Bank, 2023a). Similar productivity gains could also be expected for Lao PDR, Myanmar, Thailand, Philippines and, to a lesser extent, Viet Nam, where irrigation is still limited despite the abundance of water resources (Li et al., 2017).[22] However, irrigation withdraws consumes a lot of water, and urban and industrial demands are also increasing, so robust water management will be needed to address trade-offs (see also Section 3.2).

Some productivity gains may be possible *because of* climate change depending on local agro-ecological conditions, farming systems and climate variables, even though overall impacts at the regional scale will likely be negative. For example, projections for 2050 for rice yields in Lao PDR are mixed, with some models showing small gains of around 2% (Li et al., 2017). Some cash and industrial crops could also benefit: for example, coffee production in higher altitude areas of Viet Nam; palm oil production[23] in Indonesia and Malaysia; and coconut production in Philippines (Dikitanan et al., 2017; Savelli et al., 2021; World Bank, 2022a). Higher levels of atmospheric CO_2 associated with global warming can also boost plant growth, although as noted previously the relationship is complex and may result in lower nutrient content for some crops and cultivars (FAO, 2015; Bezner Kerr et al., 2022).

3.1.3 Freshwater fisheries and aquaculture

The sustainability and productivity of capture fisheries and aquaculture are threatened by rising temperatures and climate extremes in Southeast Asia (Allison et al., 2009; Shaw et al., 2022). However, research and evidence remain limited. Impacts occur due to rising water temperatures and chemical changes in the aquatic environment (salinity content, oxygen concentration, acidification), along with floods, droughts and storms that disrupt or damage aquatic environments and capture/processing infrastructure (FAO, 2015). Southeast Asia is vulnerable due to the growing importance of aquaculture in supporting rural livelihoods – particularly for women - and in improving diets (Suzuki, 2021).[24] In Cambodia, for example, fish provides roughly 80% of animal protein in household diets (World Bank, 2023a). Most production involves small-scale, artisanal operations that are more vulnerable to impacts, although larger commercial units are increasingly common (Shaw et al., 2022). Capture fisheries from rivers and lakes are also vulnerable, but their relative importance (vs aquaculture) is declining, and impacts are driven overwhelmingly by non-climate drivers such as over-fishing, pollution, and water diversions/withdrawals. The Inland capture (freshwater) fisheries of the Lower Mekong basin are the world's largest, valued at roughly USD11 billion/year, but production value is projected to decline to 2040 in all lower Mekong countries mainly because of hydropower development and its impact on fish habitats (MRC, 2017).

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[22] Rice yields in Viet Nam are already well above the regional average. Li et al. (2017) conclude that the combined effects of CO_2 fertilisation, irrigation and changes to planting dates could offset most of the negative impacts caused by climate change across the Indochina peninsula.

[23] Given the impact of palm oil production on the environment (see Section 3.6), expanding production has obvious risks, and government policies in both countries now emphasise productivity gains from smaller areas and native forest/peatland protection.

[24] All countries in Southeast Asia, with the marginal exception of Cambodia, now produce more from aquaculture than inland capture fisheries (FAO, 2023a; FAO, 2023b).

Indonesia, Viet Nam, Myanmar, Thailand, Cambodia and Philippines (in that order) are the biggest aquaculture producers in the region and stand to lose most in terms of production and income. Growth since the late 1990s has been remarkable, with production increasing between 7-and 11-fold in Viet Nam, Indonesia and Myanmar between 2000 and 2020 (FAO, 2023b). Aquaculture exports of shrimp are also significant, especially for Thailand and Viet Nam (Suzuki, 2021). However, farmers in coastal areas growing shrimp in brackish water are already affected by typhoons, storm surges, flooding and heat waves – hazards that are projected to increase in intensity (see Section 2.1.2). For regional marine aquaculture, including shrimp farming on coastal lands, around 30% of aquaculture areas may become unsuitable for farming by 2050-70, with production losses of 10-20% possible (Froehlich et al., 2018). While the transition to aquaculture out of rice farming in the Mekong delta is, in part, an adaptive response to climate change (see Focus Box 3), its expansion has also increased climate risks to coastal aquaculture, settlements and farming. Specifically, the conversion of mangrove forests into aquaculture ponds (also in Indonesia and Philippines) has lowered natural flood defences, and has also reduced biodiversity, impacted marine fisheries, and caused serious environmental pollution (WWF, 2017 – see also Section 3.7.2). [25]

3.1.4 Livestock

Livestock production and productivity are likely to be negatively affected by rising temperatures, although regional evidence remains limited (Bezner Kerr et al., 2022; Shaw et al., 2022; Thornton et al., 2022). Animal husbandry is integral to farming systems across Asia, particularly for smallholders, providing draft power, milk, hides, manure, meat and eggs, and an additional source of income/consumption alongside cropping (FAO, 2015; ADB, 2021). Demand for livestock products is also increasing, driving large increases in livestock populations (ADB, 2021). However, evidence (although limited) is accumulating that heat stress in domestic species is affecting productivity, with the biggest impacts on larger animals, especially cattle.[26] Most domestic livestock have comfort zones in the range 10–30°C, depending on species and breed, in a regional context where the number of days exceeding 35˚C is projected to increase by over 40 days per year across all but mountainous areas (see Section 2.1.2).

The distribution, incidence and severity of livestock diseases, and the availability and quality of fodder, may also be negatively affected by higher temperatures (Thornton et al., 2022). For infectious diseases, associations can be positive or negative depending on disease/vector type. Droughts and floods can also affect livestock populations and health, with droughts the largest contributor to livestock losses to date in Asia (ADB, 2021). This is because droughts affect access to water, but mainly because of the detrimental impact on fodder availability and quality (see comments on maize above). There is also some evidence linking higher levels of atmospheric CO_2 with reductions in fodder digestibility and nutritional content (Thornton et al., 2022; Bezner Kerr et al., 2022).

[25] Pollution from organic wastes, antibiotics and other chemicals. Since wild fish, both marine and inland, are typically used for aquaculture feed, the growth of aquaculture has also had a negative impact on wild fish stocks (WWF, 2017).
[26] Animals eat 3–5% less per additional degree of temperature, reducing their productivity and fertility, and heat stress also suppresses the immune system, making them more susceptible to disease. Larger ruminants are most vulnerable to heat-related impacts (Thornton et al., 2022).

3.1.5 Agricultural workers

Southeast Asia is one of the most vulnerable regions to labour heat stress globally, and the health and productivity of agricultural workers – increasingly women - will be negatively affected by rising temperatures and heat extremes (ILO, 2019; Lima et al., 2021). Projections by the International Labour Organisation (ILO, 2019) indicate that agriculture will account for 60% of global working hours lost to heat stress by 2030, with Asia and the Pacific most affected. Regional projections to 2030 suggest that for Southeast Asia as a whole, around 9% of agricultural working hours could be lost to heat stress (compared with 5% in 1995), with peaks in Cambodia (15%), Thailand (13%) and Viet Nam (10%) (ILO, 2019).[27] These are areas of high heat-humidity stress, where large numbers of people are engaged in agriculture and other exposed (largely informal) occupations (see also Section 3.3). More recent projections for Cambodia suggest that labour productivity could decline by 8-20% by 2041-50, with agriculture facing the biggest impacts (-10-20%) (World Bank, 2023a). Since agriculture is becoming increasingly feminised across the region, and the agricultural work force is ageing, impacts will fall disproportionately on women and the elderly (ADB, 2021).[28]

The impacts of heat stress on agricultural labour may have knock-on effects on employment, production, food prices and food affordability, though the evidence base remains limited. Looking beyond labour hours lost (ILO estimates – see above), recent research suggests that reductions in agricultural labour 'capacity' of 30-50% in Southeast Asia linked to heat stress[29] could cause growing (farm) labour shortages (Lima et al., 2021). This is because of the combined effects of lower labour productivity, rising demand for compensating labour, and the underlying regional shift to non-farm employment (see also Health, Section 3.3).

3.1.6 The bigger picture – climate change and food security

Impacts on agricultural production will likely lead to greater food insecurity in Southeast Asia, though pathways are complex and difficult to model (ADB, 2021; Shaw et al., 2022). Food security is shaped by access to and uptake of food, not just production and availability (FAO, 2015).[30] Food security may be threatened by a combination of (1) declining output and availability; (2) lower access due to declining household incomes and price

[27] No ILO projections were made for later dates. Numbers likely underestimates impacts since they relate to work in the shade rather than direct sunlight.

[28] In Cambodia and Lao PDR, where male migration is high, the share of females employed in agriculture now exceeds 50%. In Viet Nam, Indonesia and Thailand, over 40% of the agricultural labour force is now over 40 years old.

[29] Measures of heat stress and labour capacity adopted in the study are linked to temperature, humidity and radiation, with 30-50% capacity loss based on a 3°C rise in temperature (Lima et al., 2021). ILO estimates (ILO, 2019) are based on temperature only.

[30] Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). For further information on the four dimensions of food security flagged here (availability, access, utilisation and stability) see: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security For further information on the four dimensions of food security flagged here (availability, access, utilisation and stability) see: https://www.worldbank.org/en/topic/agriculture/brief/food-security-update/what-is-food-security

variability; (3) changing uptake/utilisation of food within the body affected by (for example) disease; and (4) lower stability as a result of more variable output, prices, and incomes (FAO, 2015). Pathways are complex because the number of contributory factors determining outcomes increases along the food production-access-use chain. However, a growing body of regional evidence indicates that production losses are likely to translate into higher agricultural prices and much greater output and price volatility (Cai et al., 2016; Bezner Kerr et al., 2022; Lin et al., 2022). These impacts will, in turn, affect the purchasing power and real income of households, undermining food security and increasing poverty, at least periodically (Hallegatte et al., 2016; FAO, UNICEF, WFP and WHO, 2023). These risks may hamper progress on *SDG2:*[31] *Ending hunger and achieving food security and improved nutrition* and *promoting sustainable agriculture* (United Nations, 2015).

Concerns about regional food shortages are nothing new although the region produces a net surplus of rice. However, longer-term changes in growing conditions and climate extremes will make productivity gains harder to achieve and could raise food prices. Southeast Asia continues to produce a net surplus of rice, and while there is limited scope to increase the harvested area, there is potential to raise productivity through improvements in agronomic systems and practices, particularly in rainfed areas (Lei et al., 2017; Yuan et al., 2021; 2022; Mishra et al., 2021). More concerning are projected increases in output/price volatility linked to climate extremes. Higher risks of crop, livestock and fishery damage from extreme events will increasingly hit farm incomes and raise prices, at least periodically (Jafino et al., 2020; Lin et al., 2022). Roughly 54% of the regional population cannot currently afford a healthy diet, reckoned to cost around USD4/day (FAO, UNICEF, WFP and WHO (2023). In Indonesia, consumers already pay among the highest prices in the region for staples and nutritious food, and price rises/volatility could further affect nutrition outcomes and the prevalence of child stunting (World Bank, 2023b). In Philippines, the number of people at risk of periodic hunger may increase 13% by 2050 (World Bank, 2022a).

The impacts of production and price volatility on food security and poverty will ultimately depend on how vulnerable households make a living. Net sellers of food *could* benefit from higher prices, though much depends on the interplay between prices, output and incomes. Net consumers of food will likely be harmed, while those who depend on agricultural wages and profits are likely to experience mixed impacts. Poorer consumers – the growing numbers of households living in informal urban settlements and subsistence-orientated/tenant farmers struggling to feed themselves from own (rainfed) production – will be worst affected (Hallegatte et al., 2016; Bezner Kerr et al., 2022). Poorer urban households typically spend 40% or more of their incomes on food (Wiggins, 2022), and malnutrition and health deprivation levels among the urban poor in Asia can be as high as among the rural poor (FAO, UNICEF, WFP and WHO, 2023). Food insecurity has increased in all countries except Indonesia (falling), Brunei Darussalam (data not reported) and Timor-Leste (not reported), based on a comparison of the most recent three-year averages (2017-19 vs 2020-22). Hence data reflect the more recent impact of Covid-19 restrictions on food production, supply chains, incomes and purchasing power, although regional food insecurity had been increasing in the five years prior to the pandemic (FAO, UNICEF, WFP and WHO, 2023; FAO, 2023 – see TRD). The prevalence of moderate or severe food insecurity for the period 2020-22 is highest in

[31] United Nations Sustainable Development Goals in relation to the 2030 Agenda for sustainable development adopted by all United Nation Member states in 2015 see: THE 17 GOALS | Sustainable Development (un.org)

Cambodia (51%), Philippines (45%) and Lao PDR (34%) (FAO, 2023 – see TRD). Section 3.3 on Health discusses undernutrition and other health outcomes.

Links between climate-induced ecosystem change, food security and poverty have not been systematically assessed but are likely to be important. Poorer rural households are more likely to depend on foraging and wild foods to meet food and income needs, smoothing consumption between season and years (Hallegatte et al., 2016). Ecosystems degradation or loss (see Section 3.6) can therefore remove a key safety net, potentially doubling extreme poverty rates in South Asia and East Asia when environmental incomes[32] are removed from household consumption data (Noack et al., 2015; Hallegatte et al., 2016).

[32] From forests, bushland, fallowed land, rivers etc.

3.2 Water resources and water-dependent services

Image location: Lao PDR

Summary of risks relevant to water resources and water-dependent services

- Managing water for competing users and uses will become more difficult as rainfall and river flow variability increases. Deficits in managed water storage and distribution needed to smooth-out supply over time and between areas will increasingly disrupt livelihoods and businesses and constrain economic growth.
- Future changes in river flows in the Mekong basin will be driven largely by dam construction, although climate change will also modify flows by amplifying variability across countries, with higher peak flows and more damaging floods to the 2050s. This may require a shift in dam operations, from maintaining low flows to reducing flood risks, and greater cooperation between upstream and downstream countries around water-electricity trades, and the maintenance of sediment and salt-flushing flows to downstream deltas.
- Dependence on groundwater as a source of climate-resilient domestic and agricultural supply will likely increase, although groundwater sources already provide drinking water to 60-65% of urban and rural households in Southeast Asia and the Pacific. However, groundwater resources remain poorly understood and natural contamination (with fluoride, arsenic) and anthropogenic pollution may constrain the development for drinking water in some countries.
- Climate-induced changes in water quality associated with more intense flooding and rising temperatures pose major risks to drinking water and health, especially in countries where access to safely managed drinking water and sanitation services remains limited and skewed to higher wealth groups (Myanmar, Lao PDR, Cambodia, Indonesia, Timor-Leste). Risks to water quality will grow most rapidly in urban areas, particularly informal settlements, lacking drainage and effective faecal waste management. Regionally, over 20 million people are already at high risk from pluvial floods in urban areas.
- To achieve SDG6, *Availability and sustainable management of water and sanitation for all,* risks to water availability and quality, within and between countries, will need to be addressed.
- Investments in both built (grey) grey and natural (green) infrastructure are needed to mitigate water-related risks, but more research is needed on how different *combinations* of green-grey infrastructure might mitigate risks at scale, over time, and in different urban and rural settings – a key evidence gap.

3.2.1 Context

Southeast Asia is a relatively water abundant region compared with South and Central Asia and other global regions. All countries, with the exception of Singapore, fall into the low or no 'water stress' category used for monitoring Sustainable Development Goal (SDG) 6.4.2[33], meaning that water availability far exceeds current use (FAO data for 2020, FAO AQUASTAT – see TRD Section F). The region's major river basins, including the Mekong (Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam) and Salween (Myanmar, Thailand), also fall into these categories (Biancalani and Marinelli, 2021). Singapore is an outlier: a city state on an island lacking freshwater lakes, the city meets its water needs by importing water from Malaysia, and through rainwater collection, wastewater reuse and desalination. Most importantly, it imports food rather than using water to grow its own.

Despite the relative abundance of water, however, water is distributed unevenly between areas and over time. Peaks and troughs are linked to the summer monsoon and much drier winter months, as well as wet and dry years linked to ENSO events and the strength of the monsoon. The ability to store and distribute water to buffer these effects then becomes more important, but most (poorer) countries face an infrastructure deficit. Groundwater systems providing natural storage provide a vital source of supply but remain poorly understood (Caretta et al., 2022; Bezner Kerr et al., 2022). Economic development, meanwhile, has been associated with rapidly increasing water demand, particularly for growing cities, although agriculture remains the dominant withdrawer and consumptive user of water in all countries except Singapore (FAO data for 2020, FAO AQUASTAT – see TRD).

By far the largest river basin in the region is the Mekong, with a basin area of roughly 800,000 km^2 spanning six countries (Zhang et al., 2023). From its source on the Tibetan Plateau in China, it flows south through Yunnan Province, China (known locally as the Lancang), and then through Myanmar, Thailand, Lao PDR, Cambodia and Viet Nam (collectively called the Lower Mekong), draining via the Mekong Delta into the South China Sea. The delta alone is home to around 18 million people (Shaw et al., 2022). In common with most river systems in the region, the Mekong is now heavily engineered, with dams and diversions influencing both its course and flows. One exception is the Salween River, flowing south from the Tibetan Plateau through Myanmar and Thailand and into the Andaman Sea, which *currently* has only a few small dams in its headwaters and tributaries.

In this section, we look at how the region's water resources – both surface and groundwater – may be impacted by climate change in the coming decades, with a particular focus on the Mekong basin given its importance. We also look at selected management risks as water supplies become more variable and demands increase. Hydropower development, touched on briefly, is covered in more detail under Energy (Section 3.5). Risks to freshwater fisheries and water-dependent ecosystems are addressed in Agriculture (3.1) and Environment (3.6), respectively. Water-related risks to health are discussed briefly here, but mainly under the Health Section (3.3).

[33] Water stress: water withdrawals as a percentage of available (renewable) water. Countries with low/no stress withdraw less than 50% of their renewable (replenished) water resources. Data for 2020 from FAO AQUASTAT – see TRD Section F.

3.2.2 Water resources and water-dependent services

The impact of climate change on the Mekong basin (Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam[34]), in combination with other pressures, is regionally significant because of the role Mekong waters play in supporting agriculture, food security, energy and environmental services, as well as domestic/municipal use. The basin is home to around 70 million people, with the population expected to reach 100 million by 2050 (Hoang et al., 2016). The basin is a globally significant rice and fish producing area, supporting both domestic production and exports.[35] Hydropower development - on the main river and its tributaries – is accelerating, with installed hydropower capacity along the Mekong projected to nearly triple by 2040 (Mekong River Commission – MRC, 2021 – see Section 3.5), and new thermal power plants that need water for cooling planned for lowland areas (Wang et al., 2021). The basin also hosts some of the most biologically diverse habitats in the world, supports the world's largest inland fishery, and its waters carry sediments and nutrients that play a key role in sustaining delta livelihoods and lands (FAO, 2011; Wang, 2021; Kang et al., 2021; Mohammed et al., 2022).

In contrast to some of Asia's other major rivers that drain the Asian Water Tower, meltwater contributions to the Mekong and Salween are relatively modest, meaning that flows are derived mainly from rainfall-runoff and baseflows – expected to increase by 2050. In the upper reaches, glacier contributions are minimal, and while snowmelt from the Tibetan Plateau is more significant (especially for the Salween), rainfall and groundwater-derived baseflows still dominate (Khanal et al., 2021). In the basins' lower reaches, the relative importance of rainfall and baseflows increase. This means that future climate-linked impacts in both rivers will be dominated by rainfall, derived mainly from the summer monsoon, and baseflows indirectly linked to rainfall-groundwater recharge.

Most studies indicate peak flows in the Mekong (Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam) will increase to 2050 and beyond, amplifying flood risks in the monsoon season, although hydropower operations could mitigate those risks. Most hydrological projections indicate increases in both seasonal and annual river discharges (annual changes of between +5 and +16 %, depending on location), with extreme high-flow events increasing in both magnitude and frequency (Hoang et al., 2016; Khanal et al., 2021). These findings are broadly consistent with the rainfall projections summarised in Section 2.1.2. Reservoir operations associated with hydropower developments could help moderate the higher flood 'pulse' associated with more intense (predominantly monsoon) rainfall (Lauri et al., 2012; Yun et al., 2020). To date, the development of water storage in the basin has increased low water levels in the dry season and decreased the high flow pulse in the wet season (LMC Water Centre and MRC, 2023).

Floods in the Mekong basin are associated with adverse impacts on agriculture, infrastructure and settlements, although they also bring some environmental benefits. In 2018, the collapse of the Xe Pian Xe Namnoy hydropower dam in Cambodia after heavy

[34] For the purposes of this report where locations are mentioned the related country of focus for this report is included in brackets, this is not an extensive list of countries relative to that location, instead is designed to help tag that location to the country of interest for this report.
[35] After India, Viet Nam and Thailand are the world's biggest exporters of rice, mostly to other countries in Asia. Over 50% of Viet Nam's rice production comes from the Mekong delta – see Section 3.1 (Sekhar et al., 2018; Wassmann et al., 2019).

rainfall caused the worst flooding in decades, displacing over 6,000 people (World Bank, 2022). Concerns over regional dam safety in light of the intensification of monsoon rains to 2050 (and beyond) can be expected to grow, especially since most hydropower schemes are built under opaque 'build-operate-own-transfer' arrangements that fail to spell out design standards and accountabilities (Mohammed et al, 2022). Increases in reservoir overflows could have major impacts on the structural integrity of further dams, with high flows seeing more water discharged over spillways and into stilling basins, both of which may require costly upgrades to remain safe (Mohammed et al, 2022 – see also Section 3.5). The average annual cost of flooding in the Lower Mekong Basin ranges from USD 60-70 million, with Cambodia and Viet Nam typically absorbing two thirds of the damages (MRC, 2023). The impacts of flooding are not all negative, however. Annual floods drive the basin's fisheries, maintain river morphology, deposit sediments and nutrients in the delta, and help flush salt from the delta, with annual benefits of around USD 8-10 billion (MRC, 2023).

Droughts in the lower Mekong are already responsible for major economic losses, but there is more uncertainty about future climate-driven drought conditions and their impact on water flows and water-dependent users. Specifically, droughts and extreme low-flow events in 2004–2005, 2015-16, and 2019–20 have caused major crop losses, reductions in fishery and livestock productivity, widespread shortages of domestic and industrial water, and harmful levels of salinity intrusion into the delta (Kang et al., 2021; Wang et al., 2021 – see also Focus Box 3 and Section 3.1). The 2015-16 drought alone resulted in significant economic losses for Thailand (USD1.7 billion), affecting over nine million people and damaging 30% of winter and spring crops (Kang et al., 2021). Future projections for drought frequency and intensity in the lower Mekong basin and continental Southeast Asia as a whole remain uncertain (see Section 2.2.2).

Dam releases and irrigation diversions, rather than climate trends, will likely have the biggest impact on dry season flows. Irrigation development remains limited (though still responsible for most *consumptive* water use) but will play an increasingly important role in meeting food demands, with the total irrigated area of the basin (mainly its downstream portion) expected to nearly double by the 2040s (MRC, 2011; 2021; 2023 – see Section 3.1). Cambodia, for example, has plans to expand the area of irrigated land by 50% over the next decade, increasing current water withdrawals by up to 80% (World Bank, 2023). Previous analysis conducted for MRC showed that water diverted for agriculture in the dry season can account for more than 45% of seasonal flows in 10% of years, so impacts could be significant (Nesbitt et al., 2004).

Focus Box 4: Multiple pressures in the Mekong delta

The Mekong delta in southern Viet Nam is the third largest delta in the world at 65,000 km^2 and home to roughly 18 million people. It produces over 50% of Viet Nam's rice for domestic consumption and export, is a major centre for aquaculture production (freshwater and marine) and supports rich biodiversity. However, the delta's population and economy are increasingly exposed to rising sea levels, storm surges and harmful saltwater intrusion into soils and freshwater aquifers.

Changes are driven by the combined effects of relative sea-level rise and reduced sediment accumulation on the delta. The former is driven by absolute or *eustatic* sea-level rise (from melting ice sheets, ocean warming and thermal expansion), and land subsidence (from groundwater overexploitation, sediment compaction). The latter is caused by upstream hydropower development and sand mining, trapping or removing sediment that would otherwise flow to the delta. The sum of these factors determines when a certain part of the delta will become submerged. However, sedimentation and subsidence rates vary across the delta, not all processes are fully understood, and uncertainties remain about the cumulative impact of upstream hydropower development in both the Lancang (China) and Lower Mekong.

Currently, rates of eustatic sea-level rise are ~3.3mm/year. However, land subsidence caused by groundwater over-pumping exceeds 25mm/year in some areas, while natural compaction of sediments may contribute up to 20mm/year in the coastal zone. Working in the other direction, sedimentation in coastal mangrove forests with sufficient sediment supply amounts to ~36 to ~67mm/year, countering also the risks of coastal erosion that has accelerated over the last three decades.

Climate-driven sea-level rise is now unavoidable for centuries to millennia, even if global temperatures recede towards the end of the century (IPCC, 2021). For submerging deltas, however, some of the key drivers of change have more proximal causes and policy levers, linked particularly to the design and operation of hydropower dams, and the protection of natural flood defences and sediment traps.

Sources: Smajgl et al. (2015); Minderhoud et al. (2019); Tamura et al. (2020); IPCC (2021); Kang et al. (2021); Shaw et al (2022).

Elevated flood risks, and water insecurity linked to rainfall-river flow variability and infrastructure deficits, will make water resources management a key priority across the region. Although the region as a whole is not water stressed in terms of basin and country-level averages (renewable water availability – see above), higher levels of rainfall and river flow variability will make water management more difficult. Global studies indicate that rainfall variability and the lack of water storage and conveyance needed to smooth-out spatial and temporal differences in water availability have a measurable impact on growth (Brown and Lall, 2006; Grey and Sadoff, 2007; IPCC, 2022). Regionally, the World Bank highlights deficits in water storage and conveyance as a drag on growth as rainfall variability increases. In Indonesia, for example, roughly one-half of the country's GDP is produced in river basins experiencing severe or high-water stress in the dry season; *periodic* water scarcity is projected to result in 2.5% lower GDP by 2045 in the absence of adaptation measures (World Bank, 2023). In Cambodia, investments in irrigation, reservoirs, tanks and 'natural/green' water conservation, in conjunction with water resource assessment and monitoring, are identified as critical resilience priorities (World Bank, 2023). In Philippines, increased storage capacity and stronger water resources management to reduce the impacts of more frequent climate extremes are also a priority (World Bank, 2022).

3.2.3 The groundwater buffer – benefits and risks

The role of groundwater in buffering more variable rainfall and stream flows will increase for all sectors, but regional resources remain poorly understood. Although groundwater resources in the region are largely unmonitored and poorly characterised, a growing body of evidence highlights their role in providing climate-resilient supply (Scanlon et al., 2023; Rodella et al., 2023). In particular, the natural storage groundwater aquifers provide makes the resource less sensitive to annual and multiannual rainfall variability, and groundwater is also shielded to some degree (see below) from pollution because of the protection afforded by overlying soils and rocks (Calow et al., 2018). For domestic users, groundwater resources are reckoned to provide drinking water to around 60-65% of urban and rural households in Southeast Asia and the Pacific, translating to roughly 80% of the overall population (Carrard et al., 2019).[36] Groundwater-based irrigation is also significant and likely to increase further, particularly in the Mekong delta (FAO, 2011) – see Section 3.1.

Across the region, more intense rainfall events and flooding, and potentially more hydrological droughts, will exacerbate risks to water quality. Risks will grow most rapidly in fast-growing urban areas lacking basic services (Caretta et al, 2022; Shaw et al, 2022). Although groundwater sources are less vulnerable to contamination than surface water sources, deteriorating water quality is a problem across Southeast Asia (Caretta et al., 2022; Shaw et al., 2022). Contamination of drinking water is the principal risk given limited progress in meeting 'safely managed' targets for WASH (Water, Sanitation, and Hygiene), especially in poorer countries with critical infrastructure gaps such as Lao PDR, Cambodia, Indonesia and Philippines.[37] In the densely populated Mekong delta (Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam), sources are now widely contaminated with faecal matter (Giao et al., 2023) as well as salt (see Focus Box 4). Populations with limited or no sanitation and safe water – predominantly rural, low income, but increasingly urban, informal – are most exposed to health risks because heavy rains can flood, damage or destroy latrines and spread faecal matter into poorly protected (unsafely managed) water sources (Howard et al, 2016; Calow et al, 2017). Where floods damage or destroy latrines, household demand for re-building may be compromised, undermining the commitment to open defecation free status explicitly targeted in SDG Target 6.2 (Calow et al., 2017; UNICEF and GWP, 2022). Urban WASH is increasingly vulnerable (see also Section 3.3), especially water and wastewater infrastructure in low-lying towns and cities such as those along the Mekong Valley (e.g., Stung Treng, Kratie, Kampong Cham in Cambodia). Within Yangon's informal settlements, over 90% of water samples at the point of use or consumption were found to be contaminated with E. coli in 2018 (FAO, UNICEF, WFP and WHO (2023).

Risk of outbreaks of water related diseases linked to poor and disrupted water and sanitation services will increase. There are clear causal links between flood events and outbreaks of water-related disease linked to unsafe water and sanitation services (Alderman, 2012; Howard et al, 2016). Common water-related diseases that spike during floods include cholera, hepatitis A and E, typhoid, polio and pathogenic E. coli (Alderman et al., 2012; Mora et al., 2018; Calow et al., 2018). Higher water temperatures can also encourage algal blooms and increase risks from cyanotoxins and natural organic matter in water sources, while higher runoff can increase contamination from fertilisers, animal wastes and particulates. Droughts can increase the concentration of pollutants in water bodies (Howard et al., 2016; Calow et al., 2018 – see Section 3.3.4), and saline intrusion can also render freshwater sources unhealthy or undrinkable (Howard et al, 2016).

[36] Study countries: Cambodia, Indonesia, Lao PDR, Myanmar, Timor-Leste, Viet Nam, Kiribati, PNG, Solomon Islands and Vanuatu. Indonesia had the highest groundwater-reliant population (more than 200 million) of the 10 countries investigated (Carrard et al., 2019).

[37] Access to safely managed drinking water (SDG 6.1) is 30% or less in Lao PDR, Cambodia and Indonesia. Coverage is generally lowest in rural areas, but low-income households in growing urban (informal) settlements are increasingly exposed to health risks associated with flooding, poor drainage and inadequate WASH (see also Section 3.3 and TRD Section F).

3.2.4 Water management and policy

Transboundary risk management will grow in importance as countries have to share more variable water supplies or share the benefits that flow from upstream diversions. Competition over shared waters can be a source of conflict or, more frequently, cooperation (Zeitoun and Warner, 2006; Caretta et al., 2022).[38] The combination of more erratic flows and investments in storage/diversions will increase the need for cooperation and investment in river basin organisations. Recent analysis in global transboundary basins supports the view that there is more potential for conflict in areas already under water stress, such as central Asia (Caretta et al., 2022 - *medium confidence*), although other factors – power asymmetries, pre-existing political tensions and rivalries – often dominate (Zeitoun and Warner, 2006; Milman et al., 2013; Caretta et al., 2022). The Lancang-Mekong could be characterised as a basin moving, rapidly, into a position of stress – between countries, water uses and water users – where trade-offs are inevitable and largely irreversible given investment in major hydropower schemes and downstream irrigation (Mohammed et al., 2022).

Greater cooperation between upstream and downstream countries to manage trade-offs is needed in order for Southeast Asia's nations to achieve SDG6: *Availability and sustainable management of water and sanitation for all*. The MRC, formed in 1995, works directly with the governments of Cambodia, Thailand, the Lao PDR and Viet Nam to facilitate information sharing and cooperation. The organisation serves as a regional platform for water diplomacy but has little control over infrastructure investment or water allocation decisions, despite publication of a comprehensive basin development strategy for 2021-30 (MRC, 2021). Emergency negotiation on a case-by-case basis has been the main form of cooperation to date, such as during the 2016 drought when the Vietnamese government submitted an emergency request to the Chinese government to release water (Zhang et al., 2023). Greater cooperation on the Lancang-Mekong rivers (Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam) could generate substantial benefits through coupling regional water and electricity trades, maintaining low flows and reducing flood risks (Zhang et al, 2023). However, power sharing between upstream and downstream riparians sharing the same basin runs the risk of concurrent power disruptions arising from shared rainfall deficits and low river flows, and dam building to date has not consinsidered other priorities aound maintaining salt-flushing and sediment flows to downstream deltas, or disruption to important fish habitats - see 3.2.2 above (Mohammed et al, 2022).

There is growing interest in the role nature-based solutions (NbS) could play in reducing inland flood risks across the region, but the evidence base for impact is limited. Over the last 10 years or so, NbS have been promoted as a way of tacking both climate mitigation and adaptation challenges at relatively low cost, while delivering additional benefits for people and nature (Seddon et al., 2020). A key focus is often flood mitigation – for example restoring forests in upland catchments to protect downstream communities from flooding while increasing carbon sequestration and biodiversity. Nature-based solutions now feature in many countries' climate resilience and Disaster Risk Reduction (DRR) strategies, as well as donor recommendations (e.g., the World Bank's Country Climate and Development Reports for the region – World Bank 2022; 2023; World Bank Group 2022; 2023). However, the empirical evidence linking NbS with flood mitigation and other benefits in Southeast Asia

[38] Disputes over water have historically been resolved through peaceful means, though the absence of violent conflict may still lead to inaction, increasing vulnerability to climate hazards (Milman et al., 2013).

remains limited, with most empirical studies conducted in Europe and the US (Hamel and Tan, 2022). Singapore is an exception, with a long history of implementing and monitoring 'blue-green' interventions, alongside 'grey' infrastructure, to address urban flooding.[39] The global evidence base, such as it is, points to complex site-specific relationships that do not always follow expected pathways or allow empirical evidence to be transferred from location to another (Calder and Aylward, 2006; Dadson et al., 2017).

Focus Box 5: Nature-based solutions (NbS) for catchment restoration and flood control

In broad terms, NbS involve working with and enhancing nature to address societal challenges. They include a wide range of actions that often assume, or explicitly prioritise, flood protection in the context of managing more extreme rainfall events.

Fluvial (river) floods, the most common, occur when the amount of water in a river exceeds the channel's capacity. They are caused primarily by the downstream flow of run-off generated by heavy rainfall on wet or impermeable ground. Recent years have seen growing interest in the role NbS can play in reducing the frequency, magnitude and duration of flood hazards. In broad terms, NbS aim to reduce flood hazards by modifying land use and land management, river channels, floodplains and reservoirs (where present) – restoring or sustaining catchment processes that have been affected by human intervention. Importantly, they also seek to sustain or enhance other 'co-benefits', including ecosystem services (aquatic, riparian, terrestrial) such as biodiversity, soil and water conditions, carbon sequestration, agricultural productivity and improved public health. Hence the close links with watershed restoration and management programmes that feature across Asia either as standalone initiatives or as part of public works/social protection programmes.

Despite their growing prevalence in policy documents, water-related benefits are often uncertain and/or difficult to assess. The evidence, such as it is, cautions against simplistic assumptions that directly connect changes in forest cover, land use, land management and storage with flooding, particularly in larger catchments. Indeed, the greater performance variability and uncertainty around NbS (compared with grey infrastructure), together with the sheer volume of flood waters and space limitations, means that purely 'natural' solutions will not be sufficient to deal with large floods in most catchments. In some circumstances, afforestation/reforestation may actually *increase* downstream flood risk. That said, NbS can play a key role in retaining water (and soils) in the landscape during small and moderate rainfall events, with soil moisture and soil stabilisation benefits that can increase the productivity and resilience of rainfed agriculture.

Monitoring the impacts of NbS interventions over the long periods of time needed to restore catchments and landscapes is tricky, and differences between areas makes it difficult to transfer empirical evidence from one location to another. However, remote sensing techniques are increasingly being used to monitor physical changes (e.g., vegetation cover, soil moisture conditions), reducing the need for on-the-ground monitoring of some indicators.

Sources: Calder and Aylward (2006); Dadson et al. (2017); Shiao et al. (2020); Seddon et al. (2020).

[39] Including river floodplain protection, and the construction or restoration of wetlands in low-lying areas. The Earth System Laboratory of Singapore is one of the few regional organisations conducting long-term, empirical studies of NbS interventions (see https://earthobservatory.sg/research/risk-and-society). Note: grey infrastructure refers to structures such as dams and dykes; green infrastructure refers to natural systems such as flood plains, wetlands and forests.

3.3 Health

Image location: Singapore

Summary of risks relevant to health

- The health outcomes sensitive to climate change in the region include heat stress and heat-related mortality, diarrhoeal and water-borne diseases, undernutrition, vector-borne diseases, and health conditions linked to air pollution. Impacts will be unevenly spread, exacerbating health inequalities linked to economic status, location, gender, and age.
- Southern Asia, including continental Southeast Asia, will experience the greatest cumulative exposure to heat-wave events (measured in person days), and heat-related mortality, of any global region. Combinations of heat and humidity pose the biggest risks to health, with the elderly, infants, pregnant women, people living in informal settlements, and those engaged in outdoor manual labour most vulnerable.
- Air pollution will be exacerbated by higher temperatures and heatwaves that increase the risk of forest/peat fires and transboundary haze, leading to a range of respiratory, cardiovascular and neurological conditions. The evidence base linking climate change to air pollution remains limited, but air pollution is now one of the leading causes of morbidity and mortality in the region, and among the top three risk factors for all-cause mortality in Myanmar, Lao PDR, Cambodia, and Timor-Leste.
- Climate change will undermine efforts to reduce undernutrition (stunting) in a region that already has one of the highest levels of child stunting in the world (26%), particularly in Lao PDR (28%), Indonesia (31%) and Timor-Leste (45%). Some 14 million children under five years old currently face a lifetime of physical and cognitive deficits as a result.
- Diarrhoeal and water-borne diseases linked to rising temperatures, seasonality and climate extremes could be expected to increase, especially where access to safely managed drinking water and sanitation is lacking. The highest under-5 death rates attributable to diarrhoeal disease are found in Myanmar, Lao PDR, Cambodia, Indonesia, Philippines, and Timor-Leste.
- The seasonality and spatial distribution of vector-borne diseases such as malaria and dengue will be affected by rising temperatures and changes in rainfall, with new areas of exposure, but interventions in most countries have thus far limited risks despite more favourable climate conditions. Over the last decade, total malaria cases and deaths have fallen by 76% in the WHO Southeast Asia Region.
- Progress towards SDG3, *Ensuring healthy lives and promoting well-being for all at all ages*, and SDG4, *End hunger, achieve food security and improved nutrition and promote sustainable agriculture*, could be undermined by the risks above.
- Many of the causal pathways linking climate variables with health outcomes are difficult to untangle, with different non-climate factors involved. Given the likely significance of heat and nutrition-related impacts in the region, further research on these topics is a priority.

3.3.1 Context

The countries of Southeast Asia have made significant progress on health and broader social development outcomes over the last three decades working towards SDG3 (United Nations 2015), despite recent disruptions from the Covid-19 pandemic and (in Myanmar) conflict and state fragility. Between 1990 and 2020, the rate of child (under 5 years old) mortality in the region declined by 70%, life expectancy increased by 10 years (IHME-GBD, 2019), and all countries graduated to middle income status or, in the case of Brunei Darussalam and Singapore, high income status, with major increases in health expenditure (WHO, 2019a).

Regional trends obscure major disparities in health access and outcomes between and within countries, however, linked to economic status (e.g., poverty), location (rural, urban, informal settlement), age, gender and ethnicity. The safety nets that protect people from shocks remain precariously thin in some countries (Myanmar and Lao PDR especially – World Bank, 2019 data), and out-of-pocket health financing[40] exceeds 40% in Myanmar, Lao PDR, Viet Nam, Cambodia, and Philippines, increasing people's vulnerability to shocks (WHO, 2019b).

In common with other global regions, the leading causes of morbidity and mortality are changing, with non-communicable diseases (NCDs) such as cancer, cardiovascular disease and chronic respiratory illnesses growing in importance, and communicable, maternal, neonatal, and nutritional diseases receding, albeit with significant local variations (IHME-GBD, 2019). Air pollution is now one of the leading causes of morbidity and mortality across the Southeast Asia region, from indoor cooking fuel in poorer areas to the transboundary haze caused by 'slash and burn' land clearance in Indonesia and Malaysia – see 3.3.7 below (IHME-GBD, 2019).

3.3.2 Assessing risks to health from climate change

Climate change is likely to amplify inequalities in health outcomes *and* increase risks to health from heatwaves, flooding, drought, air pollutants, vector and water-borne diseases, undernutrition, mental disorders and allergic reactions (Rocque et al., 2021; Cissé et al., 2022 – *high confidence*). This could further limit progress towards SDG3: *ensuring health lives and promote well-being for all at all ages* (United Nations, 2025). However, the evidence base remains incomplete, with relatively few empirical studies focused on low/middle income countries, and complex (often indirect) climate-health pathways to unpick.[41]

The most widely quoted[42] empirical assessment of climate-related health impacts looks at cause-specific mortality to 2030 and 2050, based on a mid-range (A1b) development/emissions scenario, roughly equivalent to RCP4.5 (see Section 2). Because of the long lead times between emissions of GHGs, changes in climate and health outcomes, the choice of scenario makes little difference to results for 2050 in contrast to projections to the end of the century (WHO, 2014). The study focuses on health outcomes known to be climate-sensitive (WHO, 2014; Jafino et al., 2020), with results for the Global Burden of

[40] Out-of-pocket payments are spending on health directly by households.
[41] Because (1) most health data e.g., from global burden of disease studies focus on current exposures and historical risk patterns; (2) attributing health impacts to climate change, rather than natural variability, remains challenging; and (3) many climate-health linkages are complex, with multiple interactions and feedback loops (WHO, 2014; Cissé et al., 2022; Di Napoli et al., 2022).
[42] Still cited in the latest IPCC AR6 reports, e.g., Cissé et al., 2022; Shaw et al., 2022.

Disease (GBD)-defined Southeast Asia region highlighted in Table 1.[43] Numbers for Central and South Asia are included for comparison. Results are for annual mortality attributable to climate change: additional deaths caused by climate change in 2050. In contrast to most climate impact modelling (e.g. for crop yields – see Section 3.1), results from the WHO study are generated by comparing two *future* scenarios (with and without climate change), rather than one future with climate change compared with an historical, static baseline (after vs before).

Table 1: Additional deaths attributable to climate change in 2050 under IPCC's midrange emissions and base case development scenario. Source: WHO (2014). Note: [a] undernutrition (stunting) estimates for children <5yrs; [b] diarrhoeal disease estimates for children <15yrs; [c] heat estimates for people >65yrs. Top number in each row is an average based on five global climate model runs. Numbers below (in brackets) show uncertainty intervals: lowest and highest estimates. For more information on assumptions and methods, see original report. SE Asia: Cambodia, Christmas Island, Cocos Islands, Indonesia, Lao PDR, Malaysia, Maldives, Mauritius, Myanmar, Philippines, Reunion, Seychelles, Sri Lanka, Thailand, Timor-Leste, Viet Nam. GBD groupings differ slightly to target countries reviewed in this report but exhibit similar cause-of-death patterns.

	Malaria	**Dengue**	**Undernutrit.[a]**	**Diarrh Dis. [b]**	**Heat [c]**
SE Asia	287 (265 to 334)	0 (0 to 0)	3049 (605 to 5494)	383 (172 to 575)	7240 (5883 to 10,290)
S Asia	9343 (2998 to 13,488)	209 (140 to 246)	16,530 (-1582 to 34,642)	7717 (3511 to 11,421)	24,632 (20,095 to 31,239)
C Asia	0 (0 to 0)	0 (0 to 0)	314 (66 to 563)	26 (12 to 38)	1889 (1077 to 2173)

While the numbers should be viewed as pointers rather than hard projections, and a more contemporary study might assess both morbidity and mortality[44], the results nonetheless highlight the growing importance of heat-related health impacts across South and Southeast Asia. Undernutrition (stunting) and diarrhoeal disease, closely linked, also remain important, though with complex causal pathways and uncertainties around attributing impacts to climate change. Although vector-borne diseases, in particular malaria, have been successfully addressed in most countries, outbreaks still occur and overall exposure in the future will likely increase. Flood and storm-related mortality were discounted in the WHO (2014) study due to inadequate data, but they are discussed briefly below, and elsewhere in the report (Sections 3.1, 3.2, 3.4, 3.5 and 3.7).

3.3.3 Vector-borne diseases

Rising temperatures and changes in rainfall will affect the seasonality and spatial distribution of vector-borne diseases, most importantly malaria (Cissé et al., 2022 – *high confidence*). Higher temperatures support faster development of the malaria parasite within mosquitoes and lead to more frequent bites, although the relationship is not linear. The optimal temperature for transmission of malaria is around 28-30°C. Beyond 35°C, the survival of the vector (malaria disease) declines (WHO, 2014). However, rising temperatures may bring other

[43] Global Burden of Disease (GBD) regions are grouped into seven super-regions that exhibit similar cause-of-death patterns.
[44] Because many of the impacts will be non-fatal. Assessing health outcomes by both mortality and morbidity (the prevalence of diseases) provides a more encompassing view on health outcomes, with the sum of both referred to as the 'burden of disease' measured in 'Disability Adjusted Life Years' (DALYs). One DALY represents one lost year of healthy life.

areas, previously too cold for malaria transmission, above a critical minimum temperature around 15-18°C, thereby potentially increasing overall transmission. Rainfall and humidity also affect case incidence, with the onset of the rainy season, high humidity levels and flooding associated with increasing cases (Sarkar et al., 2019). Most people who die from malaria are children under 5 years old (WHO, 2014).

Rising temperatures and changing rainfall patterns will create new areas of malaria exposure and contract others, with an overall estimate of 287 additional deaths per year attributable to climate change in Southeast Asia by 2050 (WHO, 2014 – Table 1). Projections are based on a combination of temperature and rainfall changes (mean temperature of the coldest month, maximum monthly rainfall) and changes in GDP per capita as a proxy for different aspects of welfare and economic status that correlate with prevention (WHO, 2014). Socio-economic development has a dominant influence on the long-term *contraction* of malaria risk (vs geographic exposure): without GDP growth and considering climate change effects and population growth only, the population at risk increases from 27 million to roughly 362 million in 2050 (WHO, 2014).

Despite an overall contraction in risk, new areas of *potential* exposure may open up at the fringes of current transmission zones, particularly at higher elevations where cooler temperatures have hitherto restricted transmission. For example, in the upland areas of Myanmar, Lao PDR and Viet Nam that are currently malaria free, or where current transmission is interrupted by the cold season. However, parasite prevalence and malaria transmission will remain more sensitive to non-climate factors, including land use change (e.g., deforestation, urbanisation), demographic shifts (e.g. rural-urban migration), and the efficacy of prevention and control strategies (including anti-malaria drug efficacy/resistance, vector insecticide efficacy/resistance, and the spread of invasive vector species) (WHO, 2015).

Other vector-borne diseases are also positively correlated with temperature and rainfall/humidity, including dengue fever, chikungunya, Japanese encephalitis, visceral leishmaniasis, and lymphatic filariasis. The WHO study summarised in Table 1 does not project any climate-attributable excess mortality to dengue fever (WHO, 2014), although dengue-suitable areas are found throughout tropical and sub-tropical climates, mostly in urban and semi-urban areas (in contrast to malaria). Infection is often asymptomatic or results in only mild illness. Nonetheless, suitable areas for dengue transmission are expected to increase throughout Asia as temperatures rise and rainfall patterns change (Cissé et al., 2022). Outbreaks in summer 2023, including in Thailand, Malaysia, and Cambodia, have resulted in high case incidence and a number of deaths (SCF, 2023). Outbreaks have been linked to floods, high temperatures, and the potential impacts of El Niño creating more favourable breeding conditions for mosquitos (SCF, 2023).

Whether elevated exposure to vector-borne diseases translates into higher morbidity and mortality will depend mainly on efforts to tackle vector breeding and transmission pathways. In the WHO Southeast Asia Region, including Indonesia, Thailand, Myanmar, and Timor-Leste, total malaria cases and deaths have fallen by 76% in the last decade, and 74% in the previous decade in spite of more favourable climate conditions (WHO, 2022). Excluding India, most remaining cases are in Indonesia and Myanmar. Between 2020 and 2021, there was an increase of roughly 400 000 cases in the region, with over half in Myanmar (WHO, 2022). Malaria incidence and mortality have also dropped significantly in the WHO western

Pacific region, although malaria remains endemic in Cambodia, Philippines, Lao PDR and Viet Nam (WHO, 2022).

3.3.4 Diarrhoeal and water/food-borne diseases

Diarrhoeal diseases are affected by temperature and rainfall and remains one of the leading causes of mortality and morbidity in Southeast Asia, especially in children (WHO, 2014; Cissé et al., 2022; Shaw et al., 2022). Children who die from diarrhoea (including cholera) often suffer from underlying malnutrition, which makes them more vulnerable to diarrhoea. Each diarrhoeal episode, in turn, makes their malnutrition worse. Diarrhoea is also a leading *cause* of malnutrition in children under five (WHO, 2017), with most infections occurring via faeces-contaminated water. The highest under-5 death rates attributable to diarrhoeal disease are found in Myanmar, Lao PDR, Cambodia, Indonesia, Philippines and Timor-Leste (IHME-GBD, 2019), linked mostly to unsafe water, sanitation and hygiene behaviours (Pruss-Ustun et al., 2019).

Rising temperatures will increase risks from diarrhoeal disease, with an estimate of 383 additional deaths/year attributable to climate change in 2050 (WHO, 2014; Cissé et al., 2022 – Table 1). The only climate variable considered in the WHO projection (Table 1) is temperature. Although current knowledge of temperature-diarrhoea relationships over time remains limited, most studies indicate that the rate of bacterial infections increase by 3-11% per 1^{o}C of temperature increase (WHO, 2014; Carlton et al., 2016). A growing body of evidence also highlights the combined effects of higher temperatures and rainfall (particularly heavy rainfall events and floods) on disease risk, with associations highlighted for Cambodia, Lao PDR and Philippines, as well as the wider Asia region (Cissé et al., 2022; Shaw et al., 2022). The additional mortality (Table 1) linked to climate change in Southeast Asia is much less than projected for South Asia because of higher income levels, better health provision and progress in extending access to safe water and sanitation (see Section 3.1 and TRD Section F), although progress is highly uneven between and within countries (see 3.3.1 above).

Evidence highlights a causal relationship between heavy rainfall, typhoons, flood events, and outbreaks of water-related disease, including cholera, hepatitis A and E, typhoid, polio and pathogenic E. coli (Alderman et al., 2012; Cissé et al., 2022 – *high confidence*). This is because rapid onset climate events can damage, destroy, or overwhelm basic health infrastructure, and flush pathogens into drinking water sources and the wider environment (Howard et al., 2016; Nijhawan and Howard, 2022). Indonesia, for example, has the highest diarrhoeal disease death rate in the region (IHME-GBD, 2019), and an estimated 95% of faecal sludge is still discharged (untreated) into the environment because of inadequate sanitation (World Bank, 2017). Flooding causes regular outbreaks of water-related disease, particularly in the poorer, informal settlements of Jakarta (World Bank, 2017). Lao PDR, with second highest diarrhoeal disease death rate (IHME-GBD, 2019), has the lowest levels of access to safe water in the region and experiences frequent floods and outbreaks of water-related disease, including leptospirosis. Within the region's urban areas, over 20 million people are *already* at high risk from pluvial floods, mainly in Viet Nam (10 million), Cambodia (4 million) and Indonesia (3 million) (FAO, UNICEF, WFP, WHO (2023). The combination of rising temperatures and more extreme rainfall events across the region (IPCC, 2021 – see Section 2) can therefore be expected to increase risks from a wide range of water-related diseases (Cissé et al., 2022; Shaw et al., 2022).

Increases in food-borne diseases are also associated with rising air and water temperatures although transmission pathways are complex (Cissé et al., 2022 – *high confidence*). Risks can occur throughout the food chain and involve a wide range of pathogens. Access to reliable, affordable energy for cooling is a key food safety concern, but also relates to the cooling needs of health services that require cold chains for transporting temperature-sensitive medical products. These include vaccines which typically require consistent cold storage at 2°C to 8°C to maintain their efficacy – for e.g., cholera, polio, tetanus, malaria, diphtheria, typhoid, Covid-19 (SDC, 2022). Rising temperatures and climate-related interruptions to electricity supply (see Section 3.5) could therefore compromise a wide range of public health interventions.

3.3.5 Undernutrition

Climate variability and change contribute to undernutrition and disease susceptibility, although pathways are complex and difficult to untangle (Phalkey et al., 2015; Leiber et al., 2022; Cissé et al., 2022 – *high confidence*). Climate variables such as rainfall, extreme weather events, seasonality and temperature have all been linked to nutritional outcomes via impacts on food security and health, although many non-climate drivers linked to location, wealth, age and gender are also important. Undernutrition itself has different dimensions, though the commonly used indicator is childhood (under 5) stunting.[45]

Climate change may increase the risk of undernutrition, with an estimate of over 3000 additional deaths per year attributable to climate change in 2050 (WHO, 2014 – Table 1). The estimate is based on a chain of model outputs that combine climate, crop production, food trade and nutritional variables. Uncertainty intervals are large, reflecting difficulties in isolating the climate signal in pathways to impact, but projected increases are driven largely by temperature-related reductions in agricultural production and food availability (see Section 3.1). More recent research, summarised by Lieber et al. (2022), highlights the impacts of droughts, floods and climate variability (adopted as climate change proxies) on nutritional outcomes, showing a strong positive relationship with undernutrition, especially for droughts. Longer-term reductions in agricultural yields and short-term production shocks associated with climate extremes could also increase food prices and affect food affordability for poorer groups, particularly the urban poor, vulnerable to fluctuations in the availability of work and the cost of food (FAO, UNICEF, WFP and WHO (2023) – see Section 3.1.6. Collectively, these risks will likely hamper progress on SDG2: *ending hunger and improved nutrition* (United Nations, 2015).

Southeast Asia already has one of the highest undernutrition (stunting) levels in the world (26%), with 14 million children under five facing a lifetime of physical and cognitive deficits as a result (UNICEF/WHO/World Bank Group, 2023). Prevalence is very unevenly spread, however. Lao PDR, Indonesia and Timor-Leste have the highest rates in the region (28%, 31% and 45%, respectively, in 2022), although they are not the poorest in terms

[45] *Stunting* refers to a child who is too short for his/her age, and results from a failure to grow both physically and cognitively. It is caused by chronic or recurrent undernutrition.

of GDP/capita (see TRD Section F). Indonesia and Timor-Leste also have the highest prevalence of under 5 child wasting in the region[46] (UNICEF/WHO/World Bank Group, 2023).

A combination of climate change, poverty, state fragility (Myanmar), and the enduring secondary effects of the Covid-19 pandemic are undermining efforts to tackle undernutrition and will continue to shape future trends. The impacts of climate change on undernutrition will be most apparent in the aftermath of extreme events – droughts and floods in particular – with heavy rainfall events and typhoons projected to increase in intensity across the region (IPCC 2021 – see Section 2). In Myanmar, for example, the combination of conflict, displacement, economic fragility and extreme events (most recently the impact of Typhoon Mocha and associated flooding in May 2023) has left over 25% of the country's population acutely food insecure. Around 2.2 million children and women in Myanmar were projected to need nutrition assistance in 2023 – a 10% increase compared to 2022 (WFP and FAO, 2023).

3.3.6 Temperature extremes

In Southeast Asia increases of heat-related mortality and heat-related health impacts are expected. This is due to large populations living in areas already experiencing high summer temperatures – particularly in tropical continental Southeast Asia (southern Myanmar, southern Lao PDR, southern Viet Nam, Thailand, and Cambodia). These regions are projected to experience even hotter summer temperatures of up to 40°C more regularly in the future. However, while there is a growing body of evidence linking climate change to extreme heat events in Southeast Asia (see Section 2), the number of studies that assess links between heat extremes and heat-related mortality remains small, albeit growing (Cissé et al., 2022). Recent systematic reviews examining the global evidence (e.g. Faurie et al., 2022) indicate that for every 1°C increase in temperature, direct heat illness morbidity and mortality increases by 18% and 35%, respectively.

Projected increases in the intensity and frequency of heat extremes across the region pose significant risks to health, with thousands of additional deaths/year estimated for Southeast Asia in 2050 (WHO, 2014 – see Table 1; Cissé et al., 2022). Extreme high temperatures affect mortality and morbidity through heat stroke, dehydration, and the exacerbation of respiratory and cardiovascular conditions, with the latter contributing most to excess deaths (Cissé et al., 2022; *very high confidence*). Heat stress occurs when the body is unable to regulate its temperature between 35-37°C. Projections for Southeast Asia indicate that the number of days above 35˚C will increase by over 40 days per year across all but mountainous areas, while days above 40˚C may increase by 10-30 days per year across inland parts of Thailand, Lao PDR, and Myanmar (see Section 2).

Combinations of heat and humidity pose the biggest risks to health and are exacerbated when overnight temperatures do not drop below 20°C (referred to as 'tropical nights') and allow sufficient cooling. These high overnight minimum temperatures already occur year-round in the maritime countries of Philippines, Indonesia, Malaysia, Singapore, Brunei Darussalam, and Timor-Leste and during the summer in continental

[46] Wasting is a relatively short-term condition, with data captured at the time of survey. Child wasting is the life-threatening result of poor nutrient intake and/or recurrent illnesses. Children suffering from wasting have weakened immunity, are susceptible to long-term developmental delays and face an increased risk of death (UNICEF/WHO/World Bank Group, 2023).

countries of Myanmar, Lao PDR, Viet Nam, Thailand, and Cambodia (Section 2). With projected future warming, tropical nights will occur more frequently, and during more months of the year. A threshold of around 35°C (wet bulb ambient air temperature)[47] is often cited as a 'survivability' limit, beyond which even short periods of exposure can cause serious ill-health and death (Im et al., 2017), although more recent research suggests the limit may be lower (Vacellio et al., 2023).

Southern Asia, including continental Southeast Asia, will experience the greatest cumulative exposure to heat-wave events (measured in person days), and heat-related mortality, of any global region (Jones et al., 2018; Cissé et al., 2022). This is because of the region's high (and rapidly growing) population, rapid urbanisation and combination of summer heat and humidity. In continental Southeast Asia, Thirumalai et al. (2017) show that all April heat extremes occur after El Niño years, and that global warming has significantly increased the likelihood of such events. For example, 29% of the 2016 extreme April heatwave was attributed to climate change (Thirumalai et al., 2017). For Cambodia, the World Bank (2021) conclude the country faces a transition to a state of permanent heat stress as a result of temperatures and humidity which regularly surpass levels safe for people.

Risks vary between rural and urban areas and between population groups. The most vulnerable to heat-related health problems are the elderly, infants, pregnant women, people living in cramped conditions, and outdoor workers. High rates of urbanisation, and particularly the growth of informal settlements within urban areas, will increase the risks of heat stress (Cissé et al., 2022; Shaw et al., 2022). Risks will be amplified for those without electricity or income for air conditioning or fans[48] to cool their homes (see Section 3.5). Over 30% of the urban population in Myanmar, Cambodia, Philippines and Timor-Leste live in informal settlements (see TRD Section F), and since many work as informal (outdoor) labourers, exposure to heat is particularly high. Evidence from South Asia (India), likely applicable to Southeast Asia, highlights links between occupational heat exposure and adverse pregnancy and foetal outcomes, with heat-exposed women experiencing a doubled risk of miscarriage (Rekha et al, 2024). Impacts on the agricultural labour force in terms of working hours potentially lost to heat stress are discussed in Section 3.1.

Risks are typically higher in urban areas because of the 'heat island' effect. Although urban-rural temperature differentials of 1-5°C are often cited in the literature, heat island effects can be much bigger. In Phnom Penh, Cambodia, daytime temperature differentials of 4°C between rural and urban areas have been recorded (World Bank, 2021). However, satellite observations and outdoor weather station data may under-estimate intra-urban hotspots shaped by settlement characteristics and the properties of residential structures, as well as the *indoor* heat exposure typically experienced by the urban poor living in cramped conditions with inadequate cooling (Tasgaonkar et al., 2022; Kim et al., 2023).

[47] A measure of humid heat stress, recognising that the body's ability to regulate temperature depends on humidity (and hence evaporative cooling through sweating), not just air temperature.
[48] Health agencies have historically cautioned against the use of electric fans in very hot weather because they can accelerate body-heat gain. More recent research indicates that fans can improve sweat evaporation in air temperatures below 35°C but should not be used at higher temperatures (Meade et al, 2024).

3.3.7 Air quality

Climate change can contribute to air pollution and also modify air pollution effects (Shaw et al., 2022 - *medium confidence*). For example, intensified droughts and heatwaves contribute to wildfires and dust storms across Asia, though mainly in Central and South Asia. In Southeast Asia, transboundary haze created by (deliberate) burning is much more an issue – see below.

Higher temperatures and heatwaves can aid the formation of surface ozone, causing or exacerbating respiratory problems (Shi et al., 2020; Cissé et al., 2022). Surface ozone is created through the interaction between pollutants (e.g., car emissions) in the presence of heat and sunlight. Few studies have attempted to isolate the contribution of climate change to ozone-related mortality. One global analysis to the end of the century (Silva et al., 2017) projected increases across all global regions, but with deaths concentrated in East Asia, North America and India, albeit small in number compared with other causes.

Air pollution is now a leading cause of morbidity and mortality in the region, although the contribution of climate change to air pollution remains uncertain. Indoor and outdoor air pollution is among the top three risk factors for all-cause mortality in Myanmar, Lao PDR, Cambodia, and Timor-Leste (IHME-GBD, 2019). A growing social, economic, and political[49] issue is transboundary haze caused by the deliberate 'slash and burn' of peatland forests[50] to clear land for agriculture, mainly in Indonesia and Malaysia (Cheong et al., 2019; Tong, 2023 – see also Section 3.6). Fires have generated seasonal cycles of haze across much of the region since the 1980s, including in Singapore, Brunei Darussalam, Thailand and Philippines, as well as Indonesia and Malaysia. The role climate change might play in affecting the coverage, density and duration of these fires is uncertain, although droughts, high temperatures and dry weather conditions associated with El Niño events may increase their severity. Air quality and health data are limited but suggest a link between haze exposure and a range of respiratory, cardiovascular and neurological conditions (Cheong et al., 2019; Tong, 2023).

[49] Recognising the severity of the problem, ASEAN countries have now ratified the ASEAN Agreement on Transboundary Haze Pollution.
[50] Tropical peatlands coexist with swamp forests. Indonesia and Malaysia contain the largest tropical peatlands globally and are significant carbon sinks. Once drained and cleared they dry out very quickly, releasing large amounts of GHGs, and becoming fire prone. They can burn deep underground, making peat fires difficult to put out once started (see Tong, 2023).

3.4 Infrastructure and settlements

Image location: Phnom Penh, Cambodia

Summary of risks relevant to infrastructure and settlements

- Climate risk and poverty will increasingly coincide in Southeast Asia's growing urban areas where robust infrastructure provision lags behind urban expansion. Just over 50% of the region's population now live in urban areas; by 2050 the share will likely exceed 60%.
- Poorer urban households living in informal settlements are most exposed to climate hazards since land and housing markets push them into riskier places with inadequate housing, services, and drainage. Increases in extreme rainfall, flooding, and heat pose the biggest risks. Over 20 million urban residents are already at high risk from pluvial floods, mainly in Viet Nam (10 million), Cambodia (4 million) and Indonesia (3 million)
- Climate-related shocks and trends can contribute to both increases and decreases in migration, with no clear overall trends for the region. Projections to the 2050s identify the Mekong delta as a potential out-migration hotspot because of the impacts of rising sea levels and storm surges on agricultural productivity, but estimates of climate-induced migration may over-simplify drivers of change.
- Southeast Asia's transport and communications systems are vulnerable to climate extremes, particularly floods. Annual damages from existing natural hazards to regional road and rail networks are estimated at USD2.2 billion, mainly from floods and typhoons, and could be expected to increase significantly as hazards intensify.
- Densely populated coastal settlements, port infrastructure, and maritime trade face threats from more intense typhoons, storm surges, and floods, as well as rising sea levels. High-risk areas include Viet Nam with 300 low-lying coastal cities, and Indonesia where 18% of the population live in low-elevation coastal areas. Regional cities experiencing the fastest changes in relative sea level rise – mainly from land subsidence – are Ho Chi Minh City (Viet Nam), Yangon (Myanmar), and Jakarta (Indonesia).
- The risks to infrastructure and settlements highlight the need to *Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* (SDG9) while also making *Cities and human settlements inclusive, safe, resilient and sustainable* (SDG11).
- While the severity of climate-related impacts is often measured in terms of direct, short-term damage to infrastructure, longer-term impacts on the services, businesses, and people it supports receive less attention. Plugging this evidence gap would help identify priority investments in networks, not just assets.

3.4.1 Context

Infrastructure systems and the services they provide are critical for socio-economic development. Climate hazards can damage assets, disrupt network connectivity and trade over wide areas, and undermine progress on economic development and poverty reduction (Hallegatte et al, 2019). Across the region, there are concerns over the severe and persistent shortage of quality infrastructure, with existing and emerging climate hazards highlighting gaps in provision and posing threats to existing assets and services (Hallegatte et al., 2019; ESCAP, 2020).

Disasters linked to natural hazards, particularly floods, cyclones and heat waves, will likely increase in frequency and/or intensity (Section 2), although disaster-related mortality is declining (IPCC, 2022). According to the EM-DAT database (the International Disaster Database), between 1995 and 2022 climate-related disasters[51] inflicted a total of 1,86,020 human fatalities in Southeast Asia (CRED-EM-DAT, 2023). On average, such disasters have affected (injured, displaced and otherwise affected) nearly 13.5 million people annually and caused an average annual economic loss of USD 6 billion across the region over the same period (CRED-EM-DAT, 2023). A majority (more than 75%) of these impacts were caused by floods and typhoons. While trends in human lives lost have declined due to improvements in disaster preparedness and emergency response, such events still affect millions of people

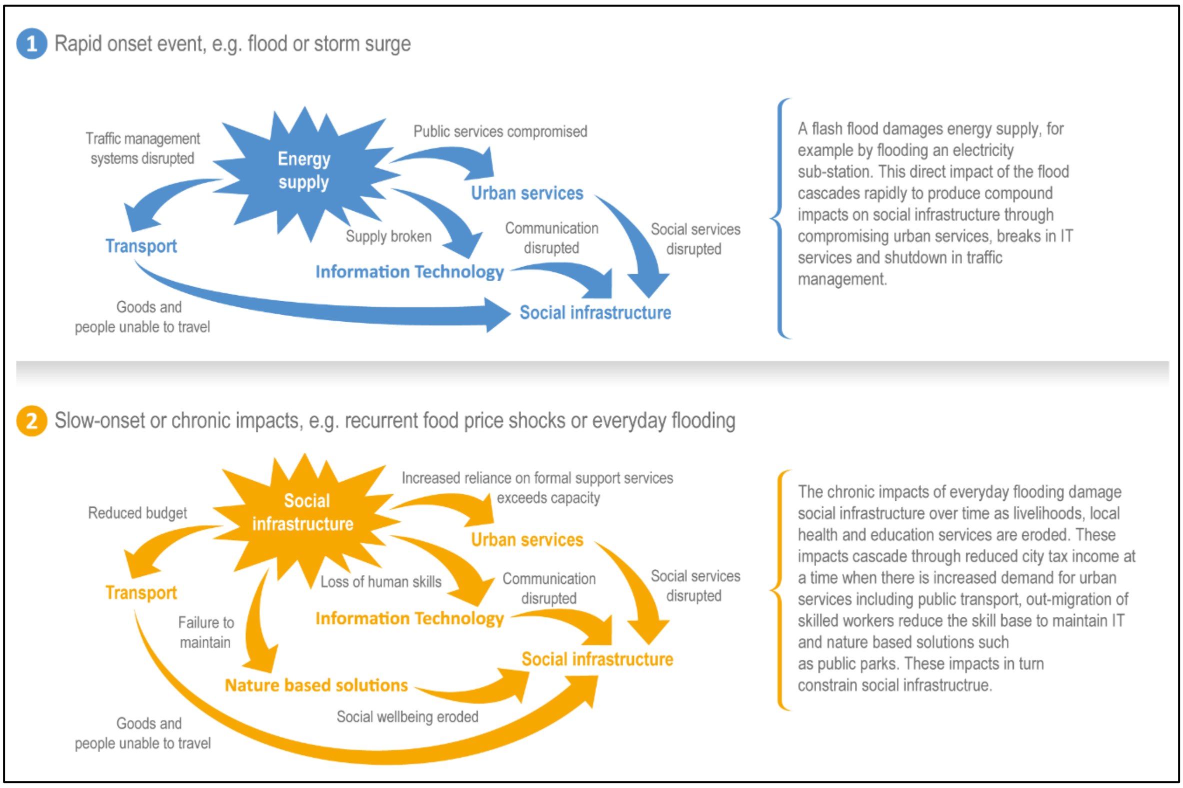

Figure 8: Climate impacts cascading through infrastructure networks. Source: IPCC (2022).

[51] Climate-related disasters include heavy rains and subsequent floods and landslides, storms, droughts, cold waves, and heat waves.

annually (especially poorer households) and cause large-scale economic losses and damages to infrastructure and economies (Panwar and Sen, 2019; Tasri et al., 2022).

Infrastructure networks have become increasingly interdependent. As a result, climate hazards cause direct physical damage to assets as well as indirect impacts that cascade through interconnected systems (Hallegatte et al., 2019; IPCC, 2022 – see Figure 8). For example, the failure of road networks can cause short-term travel delays and hinder the supply of emergency services to affected populations (He et al., 2022), as well as disrupting people's access to markets, jobs, health care and fuel over the medium to longer term (Hallegatte et al, 2017; He et al,2022). For this reason, more recent vulnerability and resilience assessments consider integrated systems and cascading risks (see, for example, Dawson, 2015; Thacker et al., 2017).

3.4.2 Housing and settlements

Rapid urbanisation in Southeast Asia is increasing pressure on fragile and overstretched infrastructure. Southeast Asia is home to roughly 690 million people – some 8% of the world population – with Indonesia, Philippines and Viet Nam accounting for 70% of the regional total (UN World Population Prospects data for 2022 – see TRD Section F). Just over half (51%) currently live in urban areas, but the rapid pace of urbanisation driven by natural growth, rural-urban migration and the transformation of rural villages/towns into urban centres will see that share rise to around 56% by 2030 and over 60% by 2050 (ASEAN, 2022). Within the region as a whole, however, there are striking variations between countries: Singapore (100%) and Brunei Darussalam (79%) are the most urbanised, while Cambodia (25%) and Myanmar (32%) are the least urbanised (UN World Population Prospects data for 2022 – see TRD Section F).

Rural-urban migration has already resulted in the growth of informal settlements and 'secondary' towns and cities where infrastructure provision lags behind urban expansion (IPCC, 2022; ASEAN, 2022)**.** Many of the fastest-growing urban areas are smaller 'middleweight' cities with 200,000 to two million people (ASEAN, 2022). Such settlements are often 'spontaneous' extensions and neighbourhoods emerging beyond or across administrative boundaries that are not officially recognised as urban. A key feature of urban growth – in secondary cities and larger urban centres and capitals – has been the expansion of informal settlements lacking one or more basic living condition or services (e.g., improved sanitation, durable housing, water, electricity etc.) (World Bank, 2020a). For instance, 58% of the urban population of Myanmar lives in informal settlements, the highest share in the region, followed by Philippines (37%) and Indonesia (20%) (UN-HABITAT, 2020 data – see also TRD Section F). One out of every four people in Metro Manila (capital region of Philippines) rely on informal housing (Singh and Gadgil, 2017). This highlights the need to *build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation* (SDG9) while also making *cities and human settlements inclusive, safe, resilient and sustainable* (SDG11; United Nations, 2015)*.*

Lower-income populations living in the region's informal settlements are most vulnerable to climate-related hazards, particularly intense rainfall generating pluvial floods and heatwaves (Shaw et al, 2022; Carreta et al, 2022; Dodman et al, 2022). Lower-income households are more likely to be pushed into more exposed (often low-lying, flood-prone) areas where land is cheaper and more easily accessible (Hallegatte, 2016; Dodman et al., 2022). Across the region, over 20 million urban residents are already at high risk from pluvial floods, mainly in Viet Nam (10 million), Cambodia (four million) and Indonesia (three million) (FAO, UNICEF, WFP, WHO, 2023). In Ho Chi Minh City (Viet Nam), for example, flood-prone areas are typically much cheaper than riskier places for the same quality of accommodation (Rentschler and Salhab, 2020). As a result, poorer households are disproportionately affected by floods and attendant health risks (see Sections 3.2.3; 3.3.4), and typically lose a much larger fraction of their wealth when they are impacted – pushing people into poverty and/or keeping them poor (Winsemius et al., 2018). Those living in overcrowded informal settlements with limited or no access to cooling are also more vulnerable to heat-related risks (see 3.3.6). While larger cities have the *potential* to draw on significant human and financial resources to address vulnerabilities and invest in resilient infrastructure – often receiving the lion's share of state revenue in Southeast Asia - this is often not the case in fast-growing smaller towns and villages lacking the resources, or political mandate, to deliver services (ASEAN, 2022).

Climate hazards could also drive internal migration, permanent or temporary, putting further pressure on housing and other infrastructure at growing in-migration hot spots. Scenario modelling by the World Bank focussing on the slow onset impacts of climate change on livelihoods[52] suggests that, by 2050, East Asia and the Pacific could see an additional 49 million internal migrants in the absence of concrete action on climate mitigation and adaptation (Clement et al., 2021). The Lower Mekong subregion is singled out as a potential *out-migration* hotspot, with sea-level rise and storm surges undermining agricultural livelihoods in the Mekong delta (see also Section 3.2; Focus Box 4). Climate *in-migration* hotspots are projected to emerge in areas where the population is already growing, such as the Red River Delta and the coastal central region of Viet Nam, with less risky climate and agro-ecological conditions (Clement et al., 2021).

Evidence to date on migration drivers and trends is mixed, however, with no longer-term, upward trend apparent. Climate-related shocks and trends can contribute to both increases and decreases in migration, with no clear overall trends for the region (Schwerdtle et al., 2020; Selby and Daoust, 2021). Most research indicates that while climate impacts shape the scale and nature of migration, climate change does not act in isolation to drive mobility (Fiddian-Qasmiyeh, 2019; Schwerdtle et al., 2020). Rather, the evidence highlights climate as one of many 'push' and 'pull' factors, with no simple causal chain or robust estimates of climate-induced migration based on commonly agreed methodologies – see Focus Box 6 (Gemenne et al., 2011; Fiddian-Qasmiyeh, 2019; Boas et al, 2019; Selby and Daoust, 2021). Over the longer-term (2050 onwards), and at progressive levels of warming, the IPCC conclude that involuntary, climate-influenced migration will likely increase from regions of high exposure and low adaptive capacity (IPCC, 2022 – *medium confidence*).

[52] Via shifts in water availability, crop productivity, and/or sea-level rise and storm surges.

Focus Box 6: Climate change and migration: global and regional evidence

The impact of climate change on the movement and distribution of people has been much debated. Globally, commonly cited articles have put the number of 'climate migrants' at 200-300 million by 2050 (e.g. Miller, 2017). However, the empirical basis for this scale of displacement is absent (Gemenne, 2011; Fiddian-Qasmiyeh, 2019; Selby and Daoust, 2021). Rather, the evidence points to climate as one of many possible drivers, with no simple causal chain or robust estimates based on commonly agreed methodologies (Gemenne, 2011; Schwerdtle et al., 2020; Selby and Daoust, 2021).

A rapid evidence review commissioned by FCDO (Selby and Daoust, 2021) reinforces the view that almost all forms of migration are multi-causal: affected by complex combinations of 'push' and 'pull' factors as well as by migrant agency, aspirations and capabilities. Climate change coincides with other transformations and hazards, many of which may be exacerbated by climate change but typically have roots elsewhere – job losses, land acquisition, land degradation, declining farm sizes, conflict and so on.

Drawing on the studies reviewed on migration in the Bay of Bengal (and other non-Asian regions), Selby and Daoust (2021) conclude:

- Climate-related shocks can contribute to increases and decreases in migration; there is no upward trend in migration linked to climate extremes.
- Movement in response to climate-related shocks is mainly internal or local rather than long-distance or international; evidence on whether it is mainly temporary or permanent is mixed.
- There is strong evidence that local experiences and attachments to place are often privileged over concerns about future climate change.
- Poorer individuals and households are particularly affected by both migration pressures and barriers to movement. Lower wealth accumulation in rural settings may hinder large-scale migration from marginal areas, contributing to spatial poverty traps.
- There is no evidence so far of global climate change-induced sea-level rise contributing to migration.
- A limited body of evidence indicates that climate change narratives among authorities and elites (e.g. around sea-level rise and displacement) may contribute to migration pressures.

To conclude, although the potential for climate change to disrupt livelihoods and contribute to migration decisions is clear, the attempt to distinguish between 'climate migrants' and 'non-climate migrants' and quantify 'new' mobility resulting from climate change is inherently flawed (Boas et al, 2019). Research needs to better explore the non-linear complexity of mobility in the context of climate change and include affected populations in the research effort (Boas et al, 2019).

Risks to housing infrastructure in Southeast Asia have been highlighted by numerous extreme events over in the last 20 years, including floods, heavy rains, landslides and typhoons (see Table 2). For instance, floods in Thailand in 2011 damaged nearly two million houses, causing an estimated loss of USD2.5 billion – some 59% of total infrastructure damages (World Bank, 2012). In 2013, typhoon Yolanda (international name: Haiyan) in Philippines caused over 6000 deaths and affected more than 16 million people (GoP, 2014). The typhoon destroyed more than one million houses, leaving millions of people homeless and causing an estimated economic loss of USD1.2 billion – over 80% of total infrastructure losses. Similarly in 2017, typhoon Damrey in Viet Nam affected more than 4.3 million people and caused USD162 million in housing damages (World Bank, 2018). However, while human-induced climate change is already affecting many weather and climate extremes across the globe, attributing human influence remains problematic given data constraints in the region (see Section 2.2), as does the attribution of impacts (see below).

While disasters are often framed as natural events, with causality that links climate extremes directly to damage, in practice impacts are shaped by the exposure and vulnerability of people and infrastructure. Simple 'natural disaster' framings can divert attention away from dynamic place-based vulnerabilities and their socio-political causes, reducing human agency to only the contribution it makes to the hazard part of risk (Hulme, 2011; Lahson and Ribot, 2021). In reality, risks are clearly influenced by (for example) the concentration of poor households in flood-prone informal settlements (see above), or the failure to build and maintain adequate flood defences (Lahsen and Ribot, 2021; Otto et al., 2023). Linking extreme weather events to climate change is one attribution step, and one that remains problematic for the region because of data constraints (Section 2.2); explaining an associated crisis and its costs is a very different one (Peterson et al, 2012; Lahsen and Ribot, 2021).

Table 2: Estimated economic losses to housing infrastructure caused by major disasters in Southeast Asia (in USD millions). Source: Authors' compilation from post-disaster needs assessment (PDNA) studies and government estimates for respective events; CRED-EM-DAT (2023). 'USD m' refers to United States Dollar in millions.

Extreme event/disaster	**Affected population**	**Total economic losses (in USD m)**	**Total infrastructure losses (USD m)**	**Losses to housing sector (USD m)**	**Housing sector losses as % of infrastructure losses**
Floods, Myanmar, 2015	1600000	1554	533	450	**84%**
Floods, Thailand, 2011	13570000	18300	3954	2346	**59%**
Floods, Viet Nam, 2016	659615	227	112	10	**9%**
Typhoon Sendong, Philippines, 2012	388319	150	114	69	**61%**
Typhoon Yolanda, Philippines, 2013	16078181	2912	1490	1222	**82%**
Typhoon Seroja and floods, Timor-Leste, 2021	33835	308	250	70	**28%**
Typhoon Damrey, Viet Nam, 2017	4330000	423	187	162	**87%**

3.4.3 Transportation

Extreme weather events can damage and disrupt all modes of transportation. Annual damages from existing natural hazards to road and rail networks in Southeast Asia are estimated at USD2.2 billion and could be expected to increase significantly to the 2050s[53] (Koks et al., 2019). Risks to livelihoods, businesses and economies are exacerbated where transport networks are fragile and have little redundancy (Hallegatte et al., 2019; Dodman et al., 2022). A global and regional analysis of transport exposure to natural hazards (typhoons, earthquakes, surface flooding, river flooding and coastal flooding) highlights the exposure of Southeast Asia's transport networks, overwhelmingly to floods but also cyclones, and the relatively low cost (vs damage costs avoided) of building in more resilience (Koks et al., 2019). Study estimates of expected annual damages (EAD – see Figure 9) did not consider climate futures, but costs could be expected to increase significantly given projected increases in extreme rainfall and typhoon intensity (Section 2). Impacts will vary depending on country size and economic status. For example, in absolute terms, EAD to transport infrastructure is substantially higher in Indonesia, Viet Nam and Philippines, while EAD as a percentage of GDP is higher in Myanmar and Lao PDR (Figure 9).

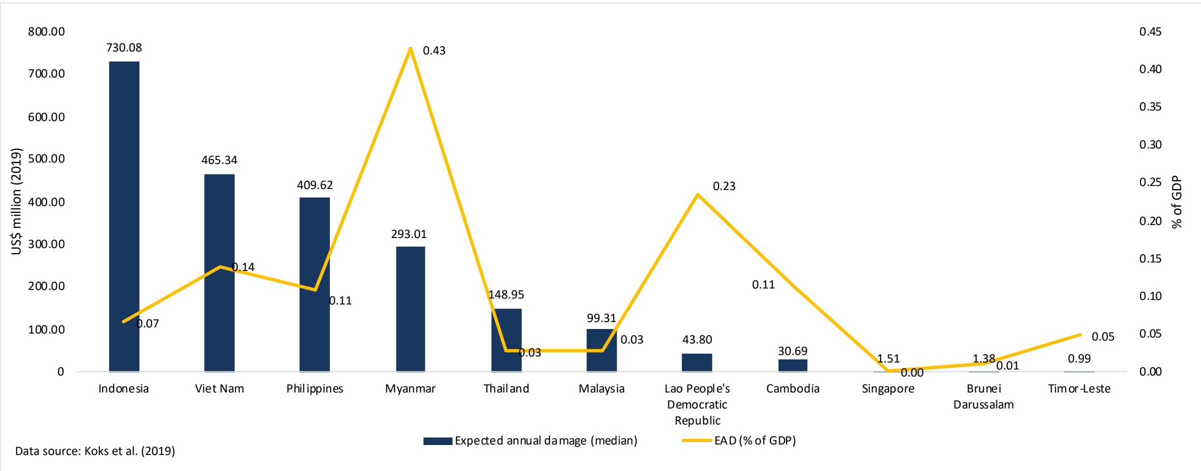

Figure 9: Expected annual damage (EAD) from multi-hazards to road and rail infrastructure in Southeast Asia (median values for 1 in a 100-year event).

Damage estimates typically underestimate the total economic cost of climate hazards because they do not consider indirect, cascading impacts through infrastructure networks (OECD, 2018; Hallegatte et al., 2019; Dawson et al., 2018). For example, He et al. (2022) demonstrate how the indirect impacts of floods on urban economic systems, and specifically mobility, far exceed direct infrastructure impacts. The study highlights Southeast Asia as a hotspot region where road networks are highly sensitive to flood impacts, and where floods of relatively low intensity can induce failure rates[54] of more than 50%. Viet Nam, for

[53] These are median estimates for 1 in a 100-year event. The study uses a variety of sources of cost data, fragility curves, and assumed parameters for each hazard to estimate infrastructure damages. This specifically includes direct damages to road and rail assets, and do not include the indirect costs from transport delays and disruption, or wider economic impacts.
[54] Exceeding a 30cm inundation threshold.

example, has expanded its road network significantly over the last two decades, but most of its 400,000 km network has not been built to withstand projected increases in extreme rainfall (Oh et al., 2019 – see Focus Box 7).

There is still limited evidence on the projected impacts of climate change on transport infrastructure particularly in low and lower middle-income countries. Further research is therefore required to generate robust evidence of such impacts. Analysis of the macroeconomic impacts of transport system failures due to natural hazards could be extremely useful given the interconnected nature of transport infrastructure within and across infrastructure systems. This would enable identification, comparison and prioritisation of transport resilience measures.

Focus Box 7: Economic impacts of climate risks on Viet Nam's transport networks

A World Bank study on multi-hazard risk analysis for Viet Nam examines the economic impact of climate risks on the country's national transport networks including roads, railways, civil aviation, inland waterways and maritime systems.

The study finds that exposure to extreme hazards would substantially increase for all modes of transports in Viet Nam under the low emission (RCP 4.5) and high emission (RCP 8.5) climate change scenarios. For instance, corresponding to 1000-year event, national road network exposure to extreme river flooding could increase to between 786 km to 1180 km under a future RCP4.5 scenario for 2030, as against the current exposure range of 720 km to 1163 km. The economic cost of road network failures due to extreme hazards could be up to USD 1.9 million a day under a high emission RCP8.5 scenario for 2030. For railway network failures, this cost could reach USD 2.6 million per day under same emission scenario. The macroeconomic impact of these combined losses could therefore be considerable.

National and province-level road networks in Viet Nam need adaptation planning and investment against future climate hazards, with significant resilience benefits. For example, based on the analysis of benefit-cost ratios (BCR) of adaptation investments for the top 20 national road links with highest BCRs, a cumulative investment of nearly USD 153 million over 35 years could generate benefits ranging between USD 651 million and USD 3.66 billion over the same period.

Source: Oh et al. (2019).

3.4.4 Information and communication technology (ICT)

Climate change poses significant risks to digital infrastructure and the continuity of services that ICT provides. Extreme weather events such as storms, floods, and heatwaves can cause damage to ICT infrastructure including 'first mile' infrastructure (e.g., submarine cables or terrestrial cross border links), 'middle mile' infrastructure (e.g., fibre optic cables, data centres) and 'last mile' infrastructure (e.g., mobile towers, WiFi and internet cables) (Sandhu and Raja, 2019; Dawson et al., 2018). Table F3 in the TRD summarises risks to these different elements.

Power generation and transmission for communication networks could be disrupted by localised water scarcity and higher temperatures. Thermal power plants (TPPs) that generate much of the region's electricity withdraw and consume significant amounts of water, exposing them to water shortages where other demands are increasing, and where reliable water supplies are threatened by more variable rainfall and drought (see Section 3.5.2). Higher temperatures can also lower the performance of power lines and other electrical equipment for transmission and distribution (see Section 3.5.2, 3.5.3).

Damages to ICT infrastructure can have significant system-wide economic and social impacts as many sectors of the economy rely on digital communication and data management (Dawson et al., 2018; Hallegatte et al., 2019). Damage to ICT infrastructure can disrupt financial transactions, transport services and supply chains, incurring large financial losses for businesses. In Myanmar for example, floods in 2015 and the communication outages that resulted reduced business revenues by an estimated USD1.2 million, excluding direct physical damages to telecoms infrastructure (GoM, 2015).

3.4.5 Coastal settlements

Coastal settlements face threats from more intense typhoons, storm surges and floods, as well as sea-level rise exacerbated by land subsidence. Coastal cities and settlements in Southeast Asia, especially in low-lying areas of Viet Nam, Malaysia, Indonesia and Singapore, have high populations and concentrations of economic assets (Figure 9). They will be increasingly exposed to compound risks as rising sea levels exacerbate the effects typhoons, storm surges and flooding linked to low elevation and constrained drainage. The 2050 climate change (global) city index[55] ranks Bangkok (Thailand) and Ho Chi Minh City (Viet Nam) as the two most vulnerable cities to relative sea-level rise (see below) and the most likely to experience major floods by 2050 under the RCP4.5 scenario.

Risks to coastal settlements from cyclones, sea level rise, storm surges, floods and saline intrusion, are already evident in some of the region's major coastal cities. For instance, among the 15 provinces in Viet Nam that were affected by typhoon Damrey in 2017, the two coastal provinces of Khanh Hao and Phu Yen alone suffered USD292 million in losses and damages – over 75% of total economic loss and damage from the event (World Bank, 2018). Viet Nam has 300 low-lying coastal cities frequently affected by cyclones, storm surges, floods, and saline intrusion, with roughly one-third located on eroding coastlines (World Bank, 2022). Roughly 18% of Indonesia's population live in low elevation coastal areas, making it one of the largest 'at risk' areas globally (ADB and World Bank Group, 2021b). The combination of high tides and river flooding in Greater Jakarta, January 2020, caused over 60 deaths and displaced more than 60,000 people (Barnes, 2020).

Future projections point to more flood and typhoon-related losses as climate hazards intensify. In low-lying Bangkok, for example, detailed climate-hydrological modelling by the World Bank estimated a 30% increase in the flood-prone area by 2050 under a high emission

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55 See: https://www.nestpick.com/2050-climate-change-city-index/

scenario (Ahmad et al., 2010)[56]. This could incur more than USD1.5 billion in economic losses, or nearly 2% of regional GDP. In Manila, the same study concluded that flood-prone areas could increase by 42% by 2050 (for a 100-year flood event) under the same scenario, with costs of USD1.5 billion – nearly 6% of regional GDP. Over 70% of the economic costs for both cities are for building and infrastructure (Ahmad et al., 2010). In Viet Nam, projections suggest 6-12 million people could be affected by coastal flooding by 2070-2100, depending on the emissions scenario, without effective adaptation (ADB and World Bank Group, 2021a). Indonesian coasts are also vulnerable to sea-level rise and storm surges that compound river floods (see above), with projections suggesting an additional 0.8 – 2.5 million people could be affected by extreme river floods by 2035–2044 (ADB and World Bank Group, 2021b).[57]

Coastal ports and maritime trade may also incur heavy losses, with many regional ports already exposed to climate-related hazards that surpass operational design standards (Verschuur et al., 2023). Based on estimates of Verschuur et al. (2023), current port-specific median risks[58] across 18 ports in Philippines could amount to USD196 million per year, and as much as USD698 million per year (95th percentile). The trade risk (loss of trade in monetary terms) for Philippines could be up to 3% of its annual maritime trade value. Similarly, ports in Viet Nam face an existing trade risk as high as 2% of their annual maritime trade value due to natural hazards (Verschuur et al., 2023), with typhoons the main risk to trade because of the downtime they cause in port-shipping operations.

The major driver of relative sea-level rise affecting Southeast Asia's coastal cities is likely land subsidence rather than climate-driven sea-level rise (Tay et al., 2022). Climate-driven sea-level rise is caused by melting ice sheets and ocean warming (IPCC 2021 – see Section 2). However, the main driver of localised sea-level rise affecting densely populated coastal settlements in Southeast Asia is likely land subsidence caused by groundwater overexploitation, loading from buildings and, in the Mekong delta, the combined effects of groundwater pumping and reduced sediment deposition (see Section 3.2, Focus Box 4). Based on high resolution satellite imaging, Tay et al. (2022) show that the cities experiencing the fastest changes in relative sea level (over 20mm/year) are in Asia, and for Southeast Asia include Ho Chi Minh City (Viet Nam), Yangon (Myanmar) and Jakarta (Indonesia). Significant variation within cities is also evident. This finding potentially provides an opportunity for local policy makers to identify high risk areas and take remedial action, irrespective of actions taken by the rest of the world to address climate-driven sea-level rise (Tay et al., 2022).

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56 Under the conditions that currently generate a 1-in-30-year flood, but with additional rainfall projected for a high emissions scenario.
57 Based on modelling by Sven et al (2018). Figures represent an average of four RCPs and assume present day population distributions. Median projection is 1.4 million additional people affected.
58 The port specific median risk (50th percentile) includes risk to port infrastructure, critical infrastructure supporting ports (like roads and railways, etc.) and trade risks measured in monetary terms, for a 1000-year event.

3.5 Energy

Image location: Philippines

<u>Summary of risks relevant to energy</u>

- Closing remaining gaps in clean cooking fuel provision, increasing the share of renewables in electricity generation, and mitigating the risks to power generation and distribution posed by climate change will be needed to achieve SDG7: *Ensure access to affordable, reliable, sustainable and modern energy for all*. Access to energy has improved across the region, with all but two countries (Myanmar and Cambodia) achieving near-universal access to electricity in 2021.
- Electricity production from existing thermal power plants could be negatively affected by more variable water supplies (for cooling) and higher water temperatures, but evidence on current and potential impacts for the region is limited. The regional energy mix remains dominated by fossil fuels and their use in thermal power plants to generate electricity, although countries are seeking to transition to renewables.
- Risks to hydropower arise from greater river flow variability to the 2050s, and the need to balance power generation with other (transboundary) priorities including the maintenance of environmental services, sediment flow to downstream deltas, and flood management. Hydropower plays an increasingly important role in electricity production in Lower Mekong countries, especially Lao PDR (70%), Cambodia (46%), Myanmar (40%) and Viet Nam (30%), with installed hydropower capacity along the Mekong expected to triple by 2040.
- Power outputs from solar projects are sensitive to changes in the frequency of very warm, cloudy and/or hazy conditions, but impacts to the 2050s are likely to be minor. Very high wind speeds associated with more intense typhoons can damage wind infrastructure but adaptations for most (but not all) high-risk locations are available – at higher cost. Solar and wind remain comparatively (to other energy sources) under-developed, though Indonesia and Viet Nam are among the countries looking to capitalise on their potential.
- Electricity transmission and distribution infrastructure will be negatively affected by rising temperatures, heat waves, floods and strong winds. Transmission and delivery losses remain high in some countries (e.g. Myanmar), creating cascading risks that threaten electricity access and regional power integration.
- Climate risk assessments are required for all types of power generation and transmission infrastructure to support energy and wider economic resilience – particularly for long-lived investments in hydropower and thermoelectricity plants. How such assessments are being made under different public and private sector contracting arrangements is unclear.
- Higher cooling needs linked to rising summer temperatures and heatwaves will increase average and peak electricity demands, requiring greater grid flexibility, storage capacity, and peak generation capacity. Cooling is expected to account for 30-40% of peak summer loads by the 2050s, but it is unclear whether climate-related cooling needs are factored into government energy plans - an evidence gap.

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3.5.1 Context

Southeast Asian countries have experienced strong economic growth over the last two decades, in many cases doubling their GDP, and are now returning to growth after Covid-19 disruptions (IEA, 2022a). Economic and population growth has been accompanied by rising energy demand: IEA (2022a) estimates that primary energy demand for Southeast Asia will increase by 56% between 2020 and 2050; for the ASEAN region specifically, IRENA and ACE (2022) forecast that total final consumption will increase more than 250% by 2050, with energy demand growing by roughly 3% annually.[59]

Strong economic growth over the last decades supported the expansion of electricity access. Since the early 2000s, Southeast Asia has made great strides in increasing electricity access, achieving nearly universal coverage by 2021 in all but two countries. Around 50 million people gained access between 2015 and 2019 alone, though progress slowed amid the pandemic. In Lao PDR, grid extension and off-grid electrification increased access, making it universal (up from 45% in the early 2000s) (World Bank, 2018). However, in Myanmar and Cambodia just over 70% and 80% of the population, respectively, have access to basic electricity, with even lower rates – 62% and 77% – for rural areas. In Cambodia, however, many households without grid access have solar devices or rechargeable batteries (World Bank, 2018).[60]

While Southeast Asia has made impressive gains in improving access to electricity, major challenges remain across the region before it can achieve SDG7 and "*ensure access to affordable, reliable, sustainable and modern energy for all*" reflecting difficulties in providing clean cooking fuel, reducing CO_2 emissions and increasing the share of renewable energy (United Nations, 2015). Despite improved access to clean cooking fuel – which increased from 45% in 2010 to 70% in 2019 - around 100 million people will still lack access in 2050 under current policies (IEA, 2022a).

[59] Primary energy demand is the sum of all available energy sources, accounting for both imports and exports. Total final consumption is the sum of all end uses of energy, net of losses in transmission and distribution.

[60] With around 70% of households connected to the grid in a country experiencing frequent power shortages that often damage appliances, upgrading access to higher tiers, where households have access to electricity for 16 hours or more per day, requires further investments in the grid.

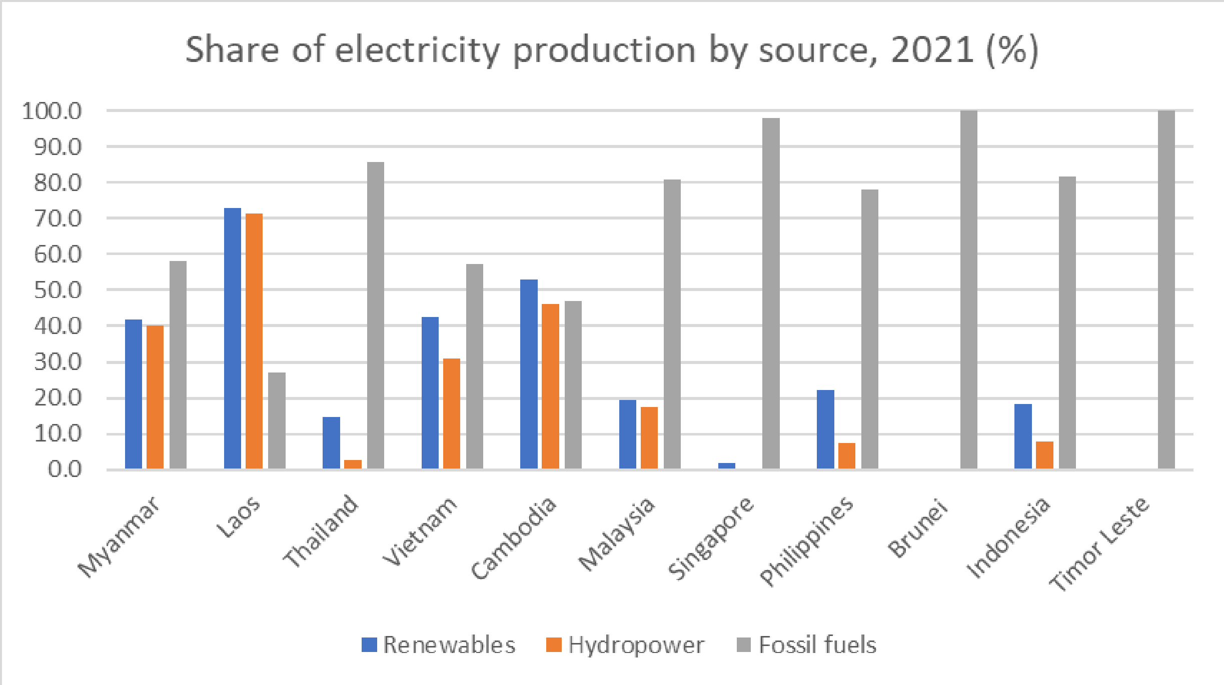

Figure 10: Percentage share of electricity production by source across Myanmar, Lao PDR, Thailand, Viet Nam, Cambodia, Malaysia, Singapore, Philippines, Brunei Darussalam, Indonesia, and Timor-Leste for 2021. Blue bars indicate renewable electricity production, orange bars indicate hydropower electricity production to highlight how much/little hydropower accounts for shares of renewable electricity production per country, and then grey bars indicate fossil fuel electricity production for comparison with renewables (and hydropower). Data source: Ember – Yearly Electricity Data (2023); Ember – European Electricity Review (2022); Energy Institute – Statistical Review of World Energy (2023) – with major processing by Our World in Data.

The region has a varied energy mix with high dependency on fossil fuels and thermal power plants (TPPs) for electricity generation, but also increasing use of hydropower in electricity production for some countries (IRENA, 2022). As net oil importers, many Southeast Asian economies like Thailand and Philippines, which accounted for 40% of regional imports in 2020, are exposed to high oil prices and supply chain disruptions (IEA, 2022a). The region is projected to become a net gas importer by 2025 though price hikes may lead to changing perceptions and policy priorities (IEA, 2022a). Many countries in the region, including Indonesia and Viet Nam, are signatories to the Global Coal to Clean Power Transition statement, committing members to transition away from using coal in power systems.[61]

Hydropower plays an increasingly important role in the electricity mix for Mekong riparian states, and installed hydropower capacity along the Mekong is expected to triple by 2040 (MRC, 2021). Hydropower currently accounts for over 70% of power generation in Lao PDR, 46% in Cambodia, 40% in Myanmar, and just over 30% in Viet Nam (Ember, 2023). Southeast Asia's renewable energy potential, particularly in wind and solar, remains largely untapped though the region aims to increase its share of renewables in power production to 35% by 2025 to help meet emission reductions goals (ACE, 2020).

[61] Southeast Asian signatories include Brunei Darussalam, Indonesia, Philippines, Singapore, and Viet Nam. The statement can be read here.

3.5.2 Power generation

Electricity systems, critical to global decarbonisation efforts, are under pressure from extreme and slow-onset weather and climate events such as heatwaves and sea-level rise (IEA, 2020). Power generation infrastructure has long lifetimes – 25 to 40 years for utility-scale solar, 60 to 80+ years for TPPs, and 80+ years for hydropower – and therefore needs to be resilient to future climate risks and other threats (Opitz-Stapleton et al., 2022). Thermal power plants and hydropower installations, in particular, involve major investments in fixed and largely irreversible/inflexible systems where the risks of 'locking in' climate vulnerabilities are higher. Solar and wind installations, in contrast, can be developed incrementally to meet demand and, if necessary, modified to account for new data and changing conditions.[62]

Thermal power plants that need water for cooling can contribute to, and are affected by, local water stress. Higher temperatures may also reduce their efficiency (Wang et al, 2019; Dodman et al, 2022). Thermal power plants account for the fossil fuel dependencies highlighted in all countries except Lao PDR and Cambodia (Figure 10), and more are planned for lowland areas to make the Mekong delta a thermal power centre (Wang et al, 2021). Thermal plants burn fuels such as coal and gas to make heat, with water used to generate steam (powering turbines for electricity production) and for cooling (Rodriguez et al, 2013). Most TPPs withdraw and consume much more water than other energy technologies, making them vulnerable to water shortages where other demands are increasing, and where reliable water supplies are threatened by more variable rainfall and drought (Rodriguez et al, 2013; Luo et al, 2018a). Country-level data on water demands and links with TPP operations are scarce since most countries do not collect or disclose information. For Southeast Asia as a whole, however, Wang et al (2019) conclude that TPPs will likely face greater water availability/reliability constraints as water supplies become more variable and competing demands grow (see Section 3.2), potentially decreasing the reliability and 'usable capacity' of future electricity production. Limited evidence from elsewhere in Asia indicates how periodic water shortages can significantly disrupt electricity generation (Luo, 2018b).[63] In addition, higher air and water temperatures expected to the 2050s could reduce TPP generation efficiency. Assessments vary, but a 1°C increase in the temperature of water used as coolant yields a decrease of between 0.1% and 0.7% in power output (Cook et al, 2015; Mima and Criqui, 2015).

Thermal power plants also face risks from floods since their cooling demands mean they are located close to rivers or coasts (Dodman et al, 2022). In Indonesia, different types of power plants are already vulnerable to flooding in low-lying tidal areas with, for example, floods prompting a 12-day shutdown of the 909 MW Muara Karang natural gas power plant on the northern coast of Jakarta in January 2013 (Handayani et al., 2019). Heavy rainfall can also reduce the quality of coal stored in open yards, affecting power output production, and leading to floods that disrupt coal mining and power production (Handayani et al., 2019). Meanwhile, heavy winds can also disrupt or prevent coal from reaching points of demand on Java Island, leading to the use of costlier oil-fired power plants (Handayani et al., 2019).

[62] General guidance around decision making under uncertainty for different kinds of projects/investments is provided by Ranger (2013).
[63] For example, 14 of India's top 20 largest TPPs experienced water shortage-related disruptions at least once between 2013 and 2016, losing more than USD1.4 billion in revenue as a result (Luo, 2018a).

Southeast Asia's solar potential, both ground-based and floating, is significant but underexploited. Viet Nam, where solar already accounts for 41% of renewable capacity, has led the region in installations. Indonesia's solar potential remains largely underexploited though the country has a target of 23% renewables capacity in 2025. Major projects like the 145 MW Cirata floating photovoltaic plant (FPV), currently under construction, signal a growing interest in developing the country's solar potential (IEA, 2022b). Cambodia plans to increase solar PV to 1,000MW by 2030 rising to 3,000MW by 2040, with major projects such as the 100MW National Solar Park already under construction (ADB, 2022).

Solar PV outputs can be expected to change with climate, but regional impacts to the 2050s and beyond will likely be minor, though evidence is limited (Feron et al, 2021; Dodman et al, 2022). Despite the growing importance of solar PV systems for electricity production, few studies have assessed the impact of climate change on PV output in Southeast Asia or other global regions (Wild et al, 2015; Feron et al., 2021; Dodman et al, 2022). However, PV outputs and intermittency are known to be sensitive to changes in the frequency of warm, cloudy and hazy conditions, with clouds and aerosols reducing power outputs, and high air temperatures reducing PV cell performance (Kaldellis et al., 2014; Wild et al, 2015; Feron et al, 2021). In their global study looking at PV outputs to 2036-2065 for RCP4.5, Feron et al (2021) conclude that impacts are likely to be relatively minor for Southeast Asia. Specifically, changes in average summer and winter PV potential are estimated at within +/- 5% to 2050, although the effects of atmospheric pollution were not considered.

Several countries including Indonesia and Philippines are looking to add floating solar projects to their power generation mix. Panels can be damaged by high winds and turbulent water although adaptations are available. Floating solar panels (on lakes, reservoirs, ponds) can be attractive for power generation where land is scarce, and can harness the evaporative cooling effect of water to address heat-related efficiency losses with PV cells (Joshi et al., 2023; Pouran et al., 2022). However, solar FPVs are potentially vulnerable to hazards such as extreme winds, with 120mph winds during Typhoon Faxai in Japan causing modules to tear and stack, resulting in fire damage at Kyocera's 13.7-MW FPV plant at the Yamakura Dam (Pouran et al., 2022). Meanwhile, high winds and cable friction led to a fire outbreak at the 17-MW FPVs in southern France (Pouran et al., 2022). Solar FPV projects in Southeast Asia could be similarly impacted by natural hazards, but exposure will be location-specific. Adaptations are available to strengthen both land-based and floating PV systems but at (currently) high cost. Depending on the 'hardening' measures adopted, the overall cost of solar PV systems could increase by up to 50-70% (Elsworth and Van Geet, 2020).

Many Southeast Asian countries have significant untapped wind potential, although very high wind speeds associated with more intense typhoons can damage wind turbines. Global investment in wind electricity rose by 20% in 2022 (IEA, 2023). In Southeast Asia, Viet Nam has 475GW of technical potential for fixed and floating offshore wind (ESMAP, 2019), with world class resources off the country's southwest coast of Binh Thuan and Ninh Thuan provinces, as well as onshore potential. The Government of Viet Nam plans to add 6GW of wind power by 2030 (Vu and Guarascio, 2023a). Philippines, which targets 35% and 50% renewables in the mix for 2030 and 2040, respectively, has 178GW of technical potential for fixed and floating offshore wind with the best potential in the country's north and centre (World Bank, 2022). Lao PDR, meanwhile, plans to add onshore wind farms to diversify its energy portfolio and increase export capacity, adding projects such as the 600MW Monsoon

Wind Farm due to begin operation in 2025 (Monsoon Wind Asia, 2022). Both onshore and offshore wind farms can be dmaged by high wind speeds, although adaptations are available – at a cost (see below).

Although expected lifetimes of wind installations are shorter than other power generation infrastructure, with a lifetime of around 20 years, they still need to account for future climate hazards (Duffy et al., 2022; Opitz-Stapleton et al., 2022). Heatwaves may lead to wind turbine shutdown if temperatures exceed standard operating temperatures between 30°C to 50°C (Opitz-Stapleton et al., 2022). Wind turbines also have different operational ranges for wind speed (typically 3 m/s to 25-30 m/s) and wind speeds that exceed design standards above this adds to the strain and physical loads, so extreme winds may pose challenges and lead to shutdowns (Duffy et al., 2022). During Hurricane Maria in 2017, a Puerto Rican wind farm experienced strong winds up to 70 m/s and was badly damaged unlike other wind farms that likely experienced lower wind speeds of up to 50 m/s (Duffy et al., 2022). Typhoon-Class offshore wind farms are available and are designed for more extreme conditions. Designing wind farms for resilience to typhoons and other hazards means that Levelized Cost of Energy (LCOE) for offshore wind in Philippines is over 30% higher than in established markets, and with typhoon-class wind turbines likely needed for many locations; development of the industry in the north and east where wind speeds can be over 110 m/s is too expensive and high risk (World Bank, 2022). High wind speeds similarly pose risks to onshore wind infrastructure in the region, identified as high-risk hazard, including in the context of projected increase in cyclonic (sustained) wind speeds for the Monsoon Wind Farm under development in Lao PDR (JICA, 2022). In a high-level climate risk assessment for a 88MW power project in Lao PDR's Ninh Thuan Province, flooding risks were identified due to heavy rainfall, thunderstorms and typhoons that may damage wind infrastructure (Arup, 2024). Proposed design solutions include drainage systems and stronger turbine foundations to ensure resilience (Arup, 2024). While the frequency of typhoons at lower latitudes such as Philippines may reduce in the future, typhoon intensity may increase (see Section 2.2).

Electricity generation from hydropower could be dirupted by more variable river flows but projections are uncertain. Hydropower accounts for most electricity generation in Lao PDR and over 40% in Cambodia and Thailand (Figure 10). With an extensive network of dams on both the upper and lower Mekong already in operation, and more planned that will bring the total to 189, the region will become increasingly dependent on hydropower (see Section 3.2). Capacity projections (electricity generation) for maritime and continental Southeast Asia under different emissions scenarios vary. IEA (2021) projects a decline through the century for hydropower in Cambodia, Lao PDR, Myanmar, Thailand, and Viet Nam, with a decline of up to 8% under RCP8.5 driven by changing rainfall patterns and a higher likelihood of droughts. However, our review of the evidence (Sections 2.2, 3.2) indicates peak flows on the Mekong will likely increase to the 2050s and beyond and hydropower storage could potentially 'smooth-out' high and low flow periods, at least over the short term. In maritime areas (Indonesia, Malaysia, and Philippines) the capacity factor is projected to decrease to the 2050s before recovering, though the degree to which it can increase from the 2050s is scenario dependent. Capacity may increase for Malaysia and Indonesia between 2060 and 2099 under RCP 8.5 but decline for Indonesia (IEA, 2021).

Most hydropower projects with a long design life are financed under opaque 'build-operate-own-transfer' arrangements that my not account for climate change. Global guidelines for factoring in climate change into hydropower design and operation have only recently been published (IHA, 2019), and whether safeguards apply will likely depend on project-specific negotiations around funding conditionalities and financing periods (Buckley et al, 2022). Hydropower dams in Lao PDR and Cambodia are largely financed under Build-Operate-Own-Transfer contracts (BOOTs) where a private company builds and ooperates the dam for a fixed period before transferring to government. However, contracts typically involve opaque processes and confidential documents, making it unclear whether designs factor in climate-related changes in river flow, or who will take responsibility for potential infrastructure upgrades during 'operate' and 'own' phases (Mohammed et al, 2022 – see also Section 3.2). A clear risk is that projects are designed for historical and poorly characterised climate-runoff-river flow conditions, exposing governments to expensive future upgrades to ensure safe operation (Mohammed et al, 2022). Moreover, individual project investments may not consider wider basin priorities, for example around balancing upstream power generation with downstream flood/drought management, the maintenance of sediment flows to deltas, and environmental flows for aquatic habitats.

Risk management strategies will rely increasingly on transboundary cooperation around information sharing, dam releases, power sharing and broader basin management, plus the development of different energy sources. Since the 1990s, several transboundary platforms have been established to ensure coordination in the region, including the Mekong River Commission (MRC) and, most recently, Lancang Mekong Cooperation (IEA, 2021).[64] The MRC has a mandate to promote, coordinate and manage sustainable development of regional water resources. The organisation has developed guidelines to facilitate sustainable hydropower development, including a Basin Development Strategy (2020-2030) which prioritises climate resilience through strengthening data management and sharing, forecasting, and hydropower operation (IEA, 2021; Mekong River Commission, 2021). In practice, however, major projects such as the Xayaburi dam (Lao PDR) have gone ahead despite concerns about downstream environmental and water security impacts (Soutillo, 2019). Poor capacity and enforcement mechanisms along with mistrust prevent more effective cooperation – see also Section 3.2 (Mekong River Commission, 2021; Soutillo, 2019). Risks embedded in energy infrastructure can cascade across national borders, especially where power sharing between upstream and downstream riparians in a shared basin all face concurrent power disruption arising from shared rainfall deficits and low river flows. The ability to mitigate these risks will therefore depend on developing diversified energy portfolios with multiple options spread across multiple grids – smart, mini, hybrid - as well as cross-border trading (Shaw et al, 2022).

3.5.3 Transmission and distribution

Climate hazards also pose physical risks to electricity transmission and distribution (T&D) networks with different lifetimes. This subsection highlights both direct risks posed by climate hazards (heat, storm damage, flooding, excessive wind) and also cascading impacts of blackouts/load shedding on households, businesses, and local economies.

Transmission and distribution losses have declined across Southeast Asia, but regional differences are large. Across ASEAN (Association of Southeast Asian Nations),

[64] MRC, initiated in 1995, members include Thailand, Lao PDR, Viet Nam and Cambodia with China and Myanmar as dialogue partners. Lancang-Mekong Cooperation Mechanism, established in 2016 and initiated by China, counts all riparian states as neighbours. See also Section 3.2.

T&D losses declined by 5% down to 7.2% in 2017 (UNESCAP and ASEAN Centre for Energy, 2020). However several countries record high losses including Brunei Darussalam (14%) and Myanmar (19%) (ASEAN Centre for Energy, 2017). In Myanmar, weak institutional capacity and market structures mean that investment in the energy sector remains limited (UNESCAP and ASEAN Centre for Energy, 2020). Reported T&D losses for Cambodia vary, with aims to decrease losses to 8% to support electrification (UNESCAP and ASEAN Centre for Energy, 2020).

Investment in new transmission infrastructure can help countries meet surging demand, improve their resilience to extreme weather events such as heatwaves, and manage the intermittency of renewable capacity added to the grid. Viet Nam, which several decades ago experienced days-long power outages, has invested in upgrading both its generation and transmission infrastructure, however, power cuts still occur (Lee and Gerner, 2020). In line with its socioeconomic priorities for 2018-2023, Cambodia will add four high voltage overhead and underground transmission lines and 10 substations in Phnom Penh, Kampong Chhnang, Kampong Cham, and Takeo provinces (ADB, 2023b). In Lao PDR, where private investment in transmission and distribution infrastructure has lagged investment in power generation, Greater Mekong Subregion Northern Power Transmission Project and similar projects have sought to help close the transmission and distribution access gap for poorer households and facilitate interconnections with the power grid in northern Thailand (ADB, 2023c). Meanwhile in eastern Indonesia, adding distribution lines and smart grids under the electricity grid development program has improved grid access on the islands of Sulawesi and Nusa Tenggara where electrification rates lagged and infrastructure was isolated, of poor quality, and underdeveloped (ADB, 2023d).

Electricty transmission and distribution networks will likely experience more damage from climate extremes, especially more intense storms and high winds. Electricity transmission and distribution networks span large distances, with overhead power lines often traversing exposed areas (Dodman et al, 2022). Transmission pylons are generally more susceptible to wind damage, while distribution lines are more likely to be affected by treefall and wind-blown debris (Hallegatte et al., 2019; Dodman et al, 2022). Across continental Southeast Asia and Philippines, mean wind speeds may increase in the future in the range of 2-8%, and potentially above 10% across Myanmar, while signals are conflicting in the maritime part of the region (see Section 2.2). Meanwhile, typhoons may decrease in frequency but increase in intensity (see also Section 2.2), potentially causuing greater damage and disruption to electricity networks. In 2022, Super Typhoon Rai hit Philippines and disrupted power supply to 116 cities/ municipalities, with eight of the country's 69 kV and four 230 kV transmission lines in affected areas of northern Luzon damaged and rendered out-of-action, causing an estimated USD420 million in economic losses (UN OCHA, 2022; Gallagher Re, 2023). Power outages had cascading impacts on water access since 80% of water systems were dependent on electricity, and relief efforts were hampered by the lack of power and telecoms (UN OCHA, 2022). The disruption to relief efforts highlighted the role of resilience planning, with back-up generators proving critical to ensuring connectivity as commercial power lines were being restored (Hamilton and Aranda, 2022).

Power transmission can also be reduced by rising temperatures and heatwaves, leading to the de-rating (lower performance) of power lines and other electrical equipment. Evidence from Southeast Asia is limited, but studies in the US indicate that by the 2050s higher ambient air temperature may reduce the average summertime transmission capacity by 1.9%–5.8% relative to a 1990–2010 baseline (Bartos et al., 2016). Higher losses have been projected in other US studies, with up to 20% capacity reduction for generators, substations, and transmission lines during more intense heatwaves by 2060 (Burillo et al., 2018). In the UK, transmission losses of between 6–10% have been estimated for the 2080s for a 4°C climate scenario, with reductions of up to 27% for some components (Dawson et al., 2018). For Southeast Asia the number of days above 35˚C is expected to increase by over 40 days/year across all but mountainous areas (Section 2.2), and similar reductions in transmission capacity could potentially cause power cuts and system outages when demand for cooling and pumping for irrigation water reaches a peak.

Cross-regional power sharing potential remains underutilised and holds potential for risk mitigation. Southeast Asian countries plan to capitalise on opportunities for power trading through the ASEAN Power Grid which includes the development of both physical and market infrastructure. Under the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) countries explored opportunities to trade up 100 MW of power through existing T&D infrastructure. In 2022 Lao PDR commenced exports of hydropower-generated electricity to Singapore via Thailand and Malaysia.

3.5.4 Demand

Southeast Asia's energy demand has grown significantly and will continue rising at roughly 3% per year to the 2050s. Primary energy demand for Southeast Asia is projected to rise by 56% between 2020 and 2050 (IEA, 2022a), with total final consumption of energy for ASEAN countries projected to increase by over 250% by 2050, growing at roughly 3% per year on average (IRENA and ACE, 2022). In Philipinnes, electricity demand is expected to triple over the next two decades, averaging about 6.6% per year, driven by population growth, rising standards of living and growth in manufacturing (World Bank Group, 2022). In Indonesia, power demand is anticipated to grow by at least 5% per year on average between 2021 and 2030 (IEA, 2022b). Higher demand will require upgrading power system flexibility across the region, particularly to accommodate an increasing share of renewables to the grid, manage intermittency, and connect solar and wind power installations to demand centers (IEA, 2022b). In Indonesia, for instance, power demand is concentrated on the island of Java (nearly 70%), but Java only has 3% of the country's solar potential, so successfully meeting its growing demand requires resilient connection to other parts of the country including Sumatra, Kalimantan and Nusa Tenggara (IRENA, 2022). Higher demand for imported fuels across the region can leave islands exposed to fluctuations in prices and supply, and contribute to power outage risks. It is unclear to what extent current energy demand projections account for increases in cooling demand linked to rising temperatures and heatwaves – see below.

Southeast Asia has done much to meet growing electricity demand but higher temperatures will increase demand for cooling, straining electricity supplies in countries with unreliable or patchy services (PwC, 2021; UN-Habitat, 2022). With reserve margins of around 30%, most countries are able to meet electricity demand although power outages are still common. Both Myanmar and Cambodia have underdeveloped electricity services and experience blackouts. In 2019, Indonesia experienced its longest blackout since 2005, leaving many areas without power for over 30 hours (Christina and Da Costa, 2019). Viet Nam, which several decades ago experienced outages lasting several days, has invested in upgrading both its generation and transmission infrastructure, but power cuts still occur (Lee and Gerner, 2020). A combination of technical issues, drought and high temperatures which curtailed hydropower generation and increased demand meant that Viet Nam experienced power cuts in summer 2023, leading many regional manufacturers based in the country to halt production (Vu and Guarascio, 2023b).

Only 15% of Southeast Asian households currently have air conditioning, skewed to higher income groups in urban areas.[65] Demand for cooling can be expected to surge to the 2050s although it is unclear whether regional projections account for higher cooling needs linked to rising temperatures. Demand projections highlighted above (IEA, 2022; IRENA and ACE, 2022) consider government energy plans, economic development and population growth, but it is unclear whether these also account for rising temperatures and more frequent and intense heatwaves. Across the region, however, IEA (2019) estimate cooling needs could account for around 30% of peak electricity demand by 2040. Projections for individual countries informed by warming trends point to expanding air conditioner (AC) ownership and higher 'peak' electricity demands. In Indonesia, household AC ownership is projected to grow from around 8% in 2017 to between 43-61% by 2040, depending on emissions and socioeconomic development pathways (Pavanello et al., 2021), with demand for cooling expected to account for over 40% of peak summer load (IEA, 2018). By 2040, the country could account for roughly half the number of AC units in the region (IEA, 2019).[66] Access to AC is linked to household income, with millions of less well-off households that may want to purchase ACs unable to do so, relying instead on fans (see also Section 3.3.6). Projections for other countries in Asia highlight the implications of expanding AC uptake. In India, overall energy demand is projected to rise by 15% to 2050 because of warming-related AC uptake, with daily summer demand peaks increasing by 20-30% (Colelli et al, 2023). Higher demand for cooling appliances will also extend to food and medicine supply chains, including for vaccines (see 3.2.6).

Targeted policy measures to improve cooling efficiency and building design can help manage warming-related increases in electricity demand (IEA, 2019). ASEAN countries have agreed minimum energy performance standards (MEPs) for ACs in an effort to manage cooling needs (IEA, 2019). Studies elsewhere indicate that improving AC energy efficiency could have a significant impact on demand. In India, for example, efficiency improvements could reduce the annual electricity consumption increase linked to rising temperatures by an estimated 40% (Colelli et al, 2013). Cambodia is the first country in the Southeast Asia region to launch a National Cooling Action Plan (Ministry of Environment, Kingdom of Cambodia, 2022). To cope with much higher cooling demands and peak loads, countries will need grid flexibility, storage capacity,[67] and the ability to install and maintain large amounts of expensive peak power generation capacity (IEA, 2018).

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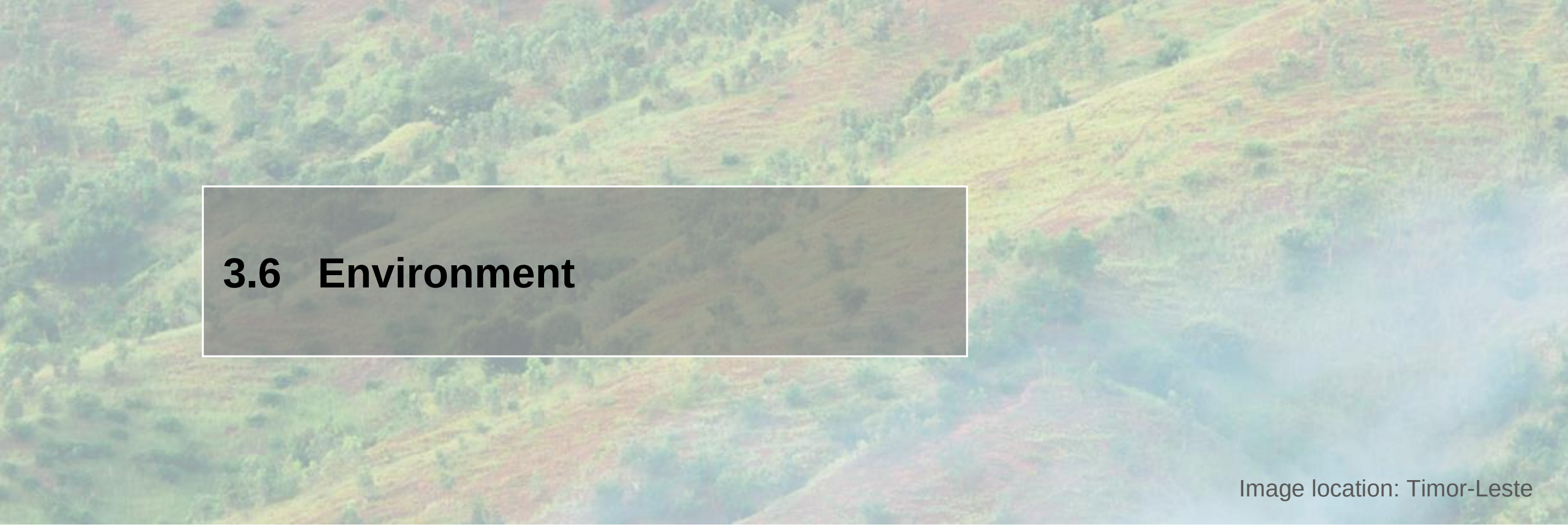
[65] The Future of Cooling in Southeast Asia (IEA, 2018).

[66] IEA (2019) suggest the number of AC units in 2040 could rise from 40 million in 2017 to 300 million in 2040, half of which will be in Indonesia.

[67] For example, the daily pattern of solar power supply will not meet demand for cooling in the evening when ambient air temperatures are often highest in hot-humid areas (IEA, 2018).



3.6 Environment

Image location: Timor-Leste

Summary of risks relevant to environment

- The region's four key biogeographical hotspots (Indo-Burma, Sundaland, Wallacea, and Philippines) are among the most biodiverse areas of the planet, but climate change will exacerbate habitat and species loss from agricultural and urban encroachment, undermining progress towards SDG15: *Halt and reverse land degradation and halt biodiversity loss.*
- A northward shift of biome boundaries and an upward shift in mountain treelines in Southeast Asia are expected due to rising temperatures. Upward shifts in the elevation of bioclimatic zones, decreases in the area of the highest elevation zones, and expansions of lower tropical and sub-tropical zones are projected for the 2050s.
- Ecosystems that are fragmented, either naturally or as a result of habitat destruction, are likely to be most at risk from climate-related species losses. This is because species unable to survive changes in climate may become regionally extinct if they are unable to disperse or migrate, for example by moving along elevational (temperature) gradients which allow them to track changes in temperature.
- The risks of drought-related forest dieback and forest fires will likely increase, amplifying pressures on more fragmented habitats. Southeast Asia's forest cover has declined by around 13% between 1990 and 2015 because of land clearance for agriculture and other uses. Southeast Asia is home to nearly 15% of the world's tropical forests, supporting globally significant tropical biodiversity and above-ground forest carbon stocks, but the region is also among the world's major deforestation and biodiversity loss hotspots.
- While many Southeast Asian countries are on track to achieve UN-Aichi targets for protected areas, boundaries may need to change to secure species habitats and facilitate species migration/dispersal as biomes shift northwards.
- The draining of tropical swamps and peatlands for agriculture (especially oil palm) has had major environmental impacts and increased the risks of peatland fires as temperatures rise. Indonesia accounts for 55% of the global peatland total, but fires from drained peatland generate seasonal cycles of transboundary haze and accounted for 8% of global fire carbon emissions between 1997 and 2016.
- There is growing interest in nature-based solutions to a range of climate mitigation and adaptation problems (e.g. in Viet Nam, Cambodia). However, monitoring the impacts of NbS over the long time periods needed to restore catchments and landscapes is costly, and differences between areas make it difficult to transfer empirical evidence from one location to another. The evidence base for impacts at scale and over time remains limited – a key evidence gap.

3.6.1 Context

Southeast Asian biomes are dominated by tropical and subtropical broadleaf forests, deserts, and wetlands (see Figure 11). These include montane and lowland forests that support globally significant biodiversity, with four key biogeographical hotspots:[68] Indo-Burma; Sundaland; Wallecea; and Philippines. Each are among the most biodiverse regions of the planet (Hughes, 2017).

The Indo-Burma biodiversity hotspot extends from southern China into all non-maritime parts of Cambodia, Lao PDR, Myanmar, Thailand, and Viet Nam. The hotspot has over 470 mammal and 1,330 bird species, with many still being discovered (CEPF, 2020). With its high levels of plant and animal endemism, and limited remaining natural habitat, the area ranks among the top 10 biodiversity hotspots for irreplaceability and the top five for threat (CEPF, 2020). The area has low levels of forest biodiversity intactness, with many species including pygmy loris, Asian elephants, and pangolins on the IUCN most threatened list (CEPF, 2020). The Indo-Burma region is also home to more people than any other global hot spot, generating intense pressure on ecosystems and contributing to their loss and fragmentation (CEPF, 2020).

The Sundaland hotspot covers the western half of the Indonesian archipelago, a group of around 17,000 islands stretching 5,000km along the Equator between Asia and Australia. The area is dominated by the islands of Borneo and Sumatra, with a diverse topography that includes mountain ranges, volcanoes, alluvial plains, lakes, swamps, and shallow coastal waters. Indonesia alone is home to 10% of the world's known plant species, 12% of all mammals, 17% of all birds, 16% of all reptiles and amphibians, and 25% of all fish (CEPF, 2001a). Indonesia is among countries with most tree species in the world (FAO and UNEP, 2020) and also includes the rich marine habitats of the Coral Triangle (see Section 3.7).

The Wallecea biodiversity hotspot located to the east of Sundaland comprises the islands in the western half of the Indonesian archipelago between Borneo and Papua, supporting the highest levels of species endemism[69] found worldwide (CEPF, 2011). Natural vegetation is dominated by forests of different kinds (monsoon, tropical, montane, swamp), along with savannas and grasslands (CEPF, 2011). Much of the forested area has been cleared for agriculture, mining and human settlement, although more remote interior forests remain relatively intact (Struebig et al., 2021). The region also includes parts of the marine Coral Triangle (Section 3.7)

The Philippine hotspot islands feature diverse landscapes and climates, with each biogeographically distinct set of islands home to a unique community of plant and animal species (CEPF, 2001b), as well as rich marine resources (see Section 3.7). Larger islands hold more endemic species than most countries, but intense population pressure and conversion of natural habitats to agriculture (see below) is degrading and fragmenting habitats (CEPF, 2001b; Hughes, 2017).

[68] Biodiversity hotspots are regions that have at least 1,500 endemic plant species and which have lost at least 70% of their natural habitat.

[69] The condition of organisms or species which are native to a single defined geographic location such a mountain, lake, river, an island, country or other defined zone.

Data source: biomes data from Olson *et al.* (2001), and hotspots data from Conservation Synthesis – Center for Applied Biodiversity Science at Conservation International (2004) and R. A. Mittermeier *et al.* (2004).

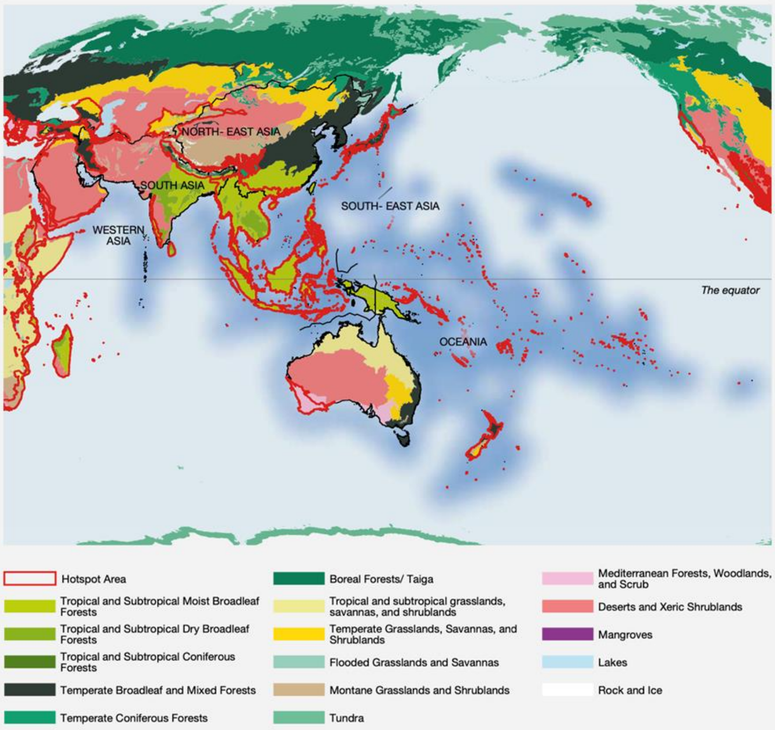


Figure 11: Major ecoregions and the five geographical subregions of the Asia-Pacific region as defined by IPBES.

Across the region biodiversity is threatened by habitat loss from agricultural expansion, urban encroachment, biofuel production, mining, and illegal wildlife trade (Hughes, 2017). Climate change, including rising temperatures and heat waves, creates additional pressures affecting the range and suitability of habitats for many animal and plant species. Collectively, these risks hamper progress towards SDG15: *Halt and reverse land degradation and halt biodiversity loss.*

Climate change could also generate indirect pressures on habitats through agricultural expansion and/or intensification. Cambodia, for example, has plans to expand the area of irrigated land by 50% over the next decade to increase crop productivity and reduce the impacts of rainfall variability on agriculture (World Bank, 2023 – see Section 3.1). To mitigate at least some of these impacts, changes in the range of protected areas and transboundary approaches to conservation may be needed.

Ecosystems across Southeast Asia provide valuable services that sustain local livelihoods and contribute to wider socio-economic support functions. Following the categorisation adopted for the Millenium Ecosystem Assessment (MEA, 2005), these services include *provisioning* – products obtained from ecosystems (e.g. food, fibre, fuel); *regulating* - benefits from the regulation of ecosystem processes (e.g. storm protection, erosion control, pollination); and cultural – the non-material benefits obtained by people (e.g. aesthetic, inspirational, spiritual) (Neugarten et al., 2018; CEPF, 2017). Threats to ecosystem services are discussed further below.

3.6.2 Biomes

Across Asia, and under a range of climate projections, rising temperatures are expected to contribute to a northward shift of biome boundaries and an upward shift in mountain treelines (Shaw et al, 2022; Parmesan et al, 2022). Upward shifts in the elevation of bioclimatic zones, decreases in area of the highest elevation zones, and expansions of lower tropical and sub-tropical zones (Figure 11) are projected for the 2050s (Shaw et al, 2022).

Projections are based largely on predictive modelling, with few long-term data to document or verify biotic responses in Southeast Asia (Parmesan et al, 2022). Under both RCP 4.5 and 8.5 scenarios, the suitable habitat for dipterocarp tree species in Philippines, a keystone group of tropical lowland rainforest trees used for tracking tropical rainforest ecosystem health, will likely shrink and shift to higher elevations (Pang et al., 2021). Higher temperatures may also affect the flowering of some dipterocarp species (a modest 1.2 °C rise in temperature under the RCP2.6 scenario will reduce flowering by 50%) (Numata et al., 2022). Pine species, important in watershed areas and for reforestation, could have varying responses: *P. kesiya* growing at higher elevations in Myanmar, Thailand and elsewhere are expected to be less affected, while *P. merkusii* (Sumatran Pine) is vulnerable at lower elevations where temperatures exceed 36°C (van Zonneveld et al., 2009).

Both the length of wildfire seasons, and the areas that are susceptible to them, may increase as a result of higher temperatures and heat extremes (FAO and UNEP, 2020 – see also Section 2). Natural fires help maintain forest productivity, but they can spread and become unmanageable (FAO, 2022). In Indonesia, higher summer temperatures could create drier soil conditions through evapotranspiration, particularly during El Niño years, increasing fire risk – see below (Ometto et al., 2022). In Borneo, fire risks are intensified when meteorological droughts interact with hydrological droughts and land use changes (Ometto et al., 2022). Smoke from forest and peatland fires can also spread across countries (see below) with risks to health (see Section 3.3). More intense droughts could also lead to forest dieback. The impact of drought on forest conditions remains poorly understood but is known to alter leaf chemistry and increase mortality rates in trees, and is likely to alter forest composition (Hughes, 2017; Parmesan, 2022).

Regional forest cover has declined by around 13% between 1990 and 2015 because of land clearance for agriculture and other uses, although rates of loss vary significantly between countries (IPBES, 2018; Shaw et al, 2022). Southeast Asia is home to nearly 15% of the world's tropical forests, supporting rich tropical biodiversity and above ground forest carbon stocks (Estoque et al, 2019). However, the region is also among the world's major deforestation hotspots, driven mainly by agricultural expansion, mining, urban encroachment, and clearance for tree plantations. Data probably underestimate losses to natural forest because it is difficult to distinguish between natural forest and tree plantations for rubber, palm oil, wood pulp and fruit, often grown in monocultures (Hughes, 2017). In Philippines, a biodiversity hotspot, deforestation has already removed over 90% of original forest cover (Hughes, 2017). Lao PDR, Cambodia, Indonesia, and Malaysia all recorded losses of between 5% and 15% between 1970 and 2009; more recently Lao PDR lost almost 2% of primary forest in 2023 alone, driven largely by agricultural investment from China (Global Forest Watch, 2014). Continued deforestation could disproportionately impact forest biodiversity as remaining areas become more fragmented and the risk of climate-driven species loss increases - see below (FAO and UNEP, 2020). The tropical forests of the Mekong region are among the most fragmented with cascading impacts on biodiversity losses (FAO and UNEP, 2020).

Wetlands provide vital provisioning and regulating services, including carbon storage, but are being degraded or lost, largely because of agricultural expansion but are under further threat from sea level rise. The region's wetlands (Figure 12) are under pressure from agricultural expansion and, to a lesser extent, urban encroachment. Once degraded or lost, they are difficult to restore or replace. Future climate suitability for wetland species remains a research gap in Southeast Asia. Yet sea level rise is known to cause permanent inundation and subsequent loss of mangroves in coastal areas, and results in permanent saltwater inundation areas which are not suitable for the survival and development of *Melaleuca cajuputi* (inland wetland forest) species (Dang et al. 2021). One study by Dang et al. (2021) suggests that projected wetland habitat suitability could reduce by up to 30% by 2070 in the Mekong Delta (Vietnam) (under the worst-case scenario RCP 8.5) due to the combined effects of sea level rise, rising temperatures, and shifts in seasonal rainfall (Dang et al., 2021).

Indonesia accounts for approximately 55% of the global peatland total with around 60,000 km^2 of wetlands, containing the majority of southeast Asia's peatlands, coexisting with swamp forests (Liu et al., 2022). Its peatlands are a major carbon sink storing around 57 Gigatonnes of carbon (Kiely et al., 2021). Agriculture is the main driver of tropical swamp forest deforestation and drainage of the underlying peat (see below). Slash and burn practices to clear land leave peat exposed, drying quickly and burning deep underground, especially during hot and dry El Niño events. Fires have generated seasonal cycles of haze across much of the region with impacts on air quality and health (Kiely et al., 2021 – see also Section 3.3). The cross-sectoral economic costs of Indonesia's peatland fires in 2015 and 2019 were estimated at around USD16 billion and USD5 billion, respectively, and drained peatlands also contributed to the country's carbon emissions, with peatland fires alone accounting for roughly 8% of global fire carbon emissions between 1997 and 2016 (Kiely et al., 2021). Indonesia's Peatland Restoration Agency, founded in 2016, aims to restore almost 2.5 million hectares of degraded lands through peat re-wetting, restrictions on clearing, and a zero-fire policy (World Bank Group, 2023).

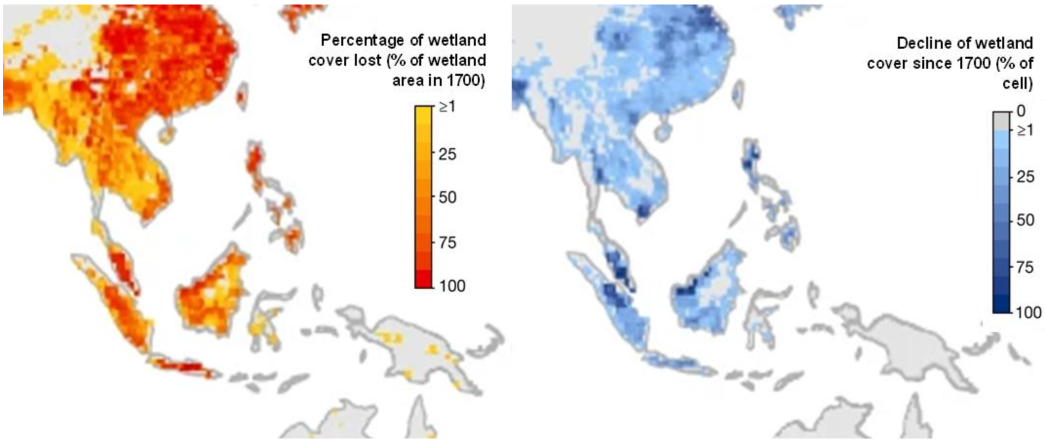


Figure 12: left) percentage of wetland cover lost (% of wetland area in 1700), and right) decline of wetland cover since 1700 (% of cell). Source Fluet-Chouinard, et a., 2023.

Wetlands could be impacted by higher temperatures, heat extremes and more variable rainfall, though evidence on climate sensitivities and impacts is limited. There are very few studies of climate-wetland interactions in Southeast Asia. One of the few focusses on the Stung Sen Ramsar Site on the Tonle Sap floodplain in Cambodia, already under pressure from human encroachment and the construction of upstream hydropower (Muñoz and Vong, 2022). Here, open water, flooded forests and grassland habitats are vulnerable to higher temperatures, droughts and rainfall variability, increasing evaporation and heat stress. Impacts vary across seasons, with higher maximum temperatures and more variable rainfall during wet seasons negatively impacting flooded habitats (Muñoz and Vong, 2022). In the dry season (December to April), higher temperatures may lead to more forest fires in surrounding areas, reducing water quality feeding the wetland, lowering inflows and water levels, and reducing fish stocks (Muñoz and Vong, 2022). Open water habitats were also found to be most at risk at the Boueng Prek Lapouv Protected Landscape in Cambodia, already under pressure from agricultural land conversion (Sophanna et al., 2019).

Wetlands play a key role in storing carbon and reducing greenhouse emissions. Wetland greenhouse gas budgets are highly sensitive to changes in wetland area, and wetland restoration – specifically rewetting – can be a very effective Nature-based Solution (NbS) for reducing GHGs. A global study by Zou et al (2022) indicates a volume equivalent to 10% of anthropogenic CO_2 emissions could be reduced through wetland restoration. This is higher than potential GHG reductions from the rehabilitation of other types of ecosystem, for example forest re-growth or afforestation (Zou et al, 2022). While some Nationally Determined Contributions (NDCs) in the region note the role wetlands can play in providing provisioning and regulating services, references to specific targets and actions remain limited. Indonesia (see above) is an important exception (Convention on Wetlands, 2021).

3.6.3 Biodiversity and species loss

The main drivers of biodiversity and species loss are land conversion, habitat fragmentation, and, for some species, wildlife trade. Fragmented ecosystems are particularly vulnerable to climate change (Hughes, 2017; IPBES, 2018). Agricultural and urban expansion, including the growth or plantation monocultures, plus mining for critical minerals (essential to the production of solar panels, electric vehicles and other ‘green’ manufacturing) will increase pressure on key biodiversity areas. Further habitat fragmentation is a key risk because it prevents species movement in response to rising temperatures – see below (Hughes, 2017; Sonter et al., 2020). By 2000, over 50% of Southeast Asia’s rapidly expanding urban areas had already fallen within the region’s biodiversity hotspots (Hughes, 2017). Southeast Asia is a source, transit point and destination for illegal wildlife trade with cascading impacts on biodiversity and ecosystem services such as eco-tourism. Transboundary cooperation in tackling the issue remains limited (OECD, 2019). Pangolins, African elephant ivory and rhino horns are trafficked through the region, but native animals, including endemic species such as pig-nosed turtles from Indonesia’s Papua province are also poached in the tens of thousands (Krishnasamy and Zavagli, 2020).

Ecosystems that are fragmented, either naturally or as a result of habitat destruction, are likely to be most at risk from climate-related losses. This is because species unable to survive changes in climate may become regionally extict if they are unable to disperse or migrate, for example by moving along elevational (temperature) gradients which allow them to ‘track climate change’ (Hughes, 2017; Shaw, 2022). This is a key reason for prioritising south-north altitude corridors and, if necessary, moving the boundaries of protected areas to facilitate species movement.

Species range, dispersal, ecological interactions, and behaviour patterns will likely be affected by higher temperatures and higher rainfall variability (IPBES, 2018; Shaw et al, 2022). The open water habitats of flagship bird and fish species including painted stork, cranes pelicans and Kontor in Cambodia's Boeung Prek Lapouv Protected Landscape have moderate to high baseline conservation status and were found to be most at risk in a changing climate, particularly the impacts of higher temperatures and droughts in dry seasons (Sophanna et al., 2019). In Thailand's protected areas, where the habitat of many species is restricted by hunting and other human pressures, modelling for almost 900 animal and 600 plant species shows that by 2070 over half will be threatened and 11 extinct under RCP 8.5, including plant, bird and animal species distributed across northern and southern Thailand (Pomoim et al., 2022). However, climate impacts across species will be uneven with potential declines for birds, mammals and plants and increases for amphibians and reptiles (Pomoim et al, 2022).

While many Southeast Asian countries were on track to achieve UN-Aichi targets for protected areas, securing species habitats in the future will need to account for climate impacts on species distribution as biome boundaries shift (IPBES, 2018). UN targets on global biodiversity (Aichi targets) include Strategic Goal C: *Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity targets for protected areas* (IPBES, 2018). Poorer countries such as Myanmar can struggle to find the resources for conservation monitoring and enforcement (Xu et al., 2019). Conversely in Thailand, which has exceeded Aichi targets of 17% protected area coverage, rising temperatures will likely alter species range and require increasing north-south altitude corridors and potentially assisted migration. Integrating transboundary approaches and regional cooperation is critical in transboundary biodiversity hotspots across Asia, where 82% of global border hotspots are located (Xu et al., 2019; Farhadinia et al., 2022).

3.6.4 Ecosystem services

The services provided by ecosystems can be monetised. Their future value will likely increase. Across the Asia-Pacific region the value of services provided by terrestrial ecosystems is estimated at USD14 trillion, with USD1.7 trillion in Indonesia alone and around USD 0.6 trillion in Cambodia, Viet Nam, Lao PDR and Thailand (Kubiszewski et al., 2016). In Myanmar, the value provided by forests has been estimated at around USD7 billion (Xu et al., 2019; Emerton and Aung, 2013). Valuation studies can help gain political traction for ecosystem protection and restoration, although capturing and quantifying the services ecosystems provide, particularly their regulatory functions and contributions to adaptation and mitigation efforts, is difficult. Even without monetisation, however, there is growing recognition of service types and contributions, reflected in NbS programmes and initiatives.

Nature-based solutions offer potential to tackle both climate mitigation and adaptation challenges, although the evidence base for impact at scale remains limited. Cambodia is among the countries in the region to have recognised the value of ecosystems in societal adaptation. Its NDC acknowledges the role environmental conservation can play in addressing both climate adaptation and mitigation (The General Secretariat of the National Council for Sustainable Development and Ministry of Environment of Cambodia, 2020). Viet Nam has similar plans for "carrying out sustainable management of forest resources associated with biodiversity protection and the enhancement of ecosystem services”. Across the ASEAN region, however, financial and political obstacles act as a break on implementation (ASEAN Secretariat, 2023). In addition, the empirical evidence linking NbS with flood mitigation and other benefits remains limited. Monitoring the impacts of NbS over the long time periods needed to restore catchments and landscapes is costly, and differences between areas makes it difficult to transfer empirical evidence from one location to another (Seddon et al, 2020 – see also Section 3.2, Focus Box 4).

Roughly 58% of Southeast Asia’s forests threatened by loss could be protected as financially viable carbon projects (Sarira et al, 2022). Nature-based interventions and the uptake of nature-based carbon credits could potentially save 835 $MtCO_2e$ of emissions annually, protect 25 million hectares of key biodiversity areas, and support forest-dependent livelihoods (Sarira et al., 2022). Forests in the Indonesian provinces of Riau and West Kalimantan have the greatest climate mitigation potential in Southeast Asia (Sarira et al, 2022).

3.7 Blue economy and the marine environment

Image location: Thailand

Summary of risks relevant to the blue economy and the marine environment

- ASEAN countries account for 15% of global fish production, 33% of seagrass beds, 34% of coral reef cover, and 35% of mangrove forests, but key services are at risk from rising sea temperatures, sea-level rise, more intense cyclones, and ocean acidification. Across the 10 ASEAN member states roughly 625 million depend on the marine environment for their livelihoods, significantly more than most other global regions.
- Reef survival in the Coral Triangle off the coasts of Philippines, Malaysia and Indonesia is threatened by rising sea surface temperatures, marine heatwaves, and more intense cyclones. The Coral Triangle is a globally significant biodiversity hotspot supporting the livelihoods of over 100 million people, with reefs throughout the region providing coastal protection benefits estimated at USD19 billion/year.
- Mangrove forests and seagrass meadows are threatened by rising sea levels, more intense cyclones, and storm surges. Southeast Asia has the world's most extensive area of mangrove forests, protecting coasts from erosion and flooding and providing nursery habitats for fish. Roughly one-third has been cleared to provide land for aquaculture and coastal development.
- Marine fisheries, including marine aquaculture, will be negatively affected by higher sea temperatures and ocean acidification, amplifying existing pressures from overfishing, pollution, and habitat destruction. Indonesia, Viet Nam and Philippines are among the world's ten largest marine fisheries producers, but fishery potential in Indonesia where fish account for over 60% of all dietary animal protein could decrease 13-29% by the 2050s.
- Artisanal fishers and the coastal communities they support likely face the biggest risks from climate hazards as well as coastal habitat destruction, the loss of fish nurseries, and the intensifying 'squeeze' on coastal space. Fish unable to adapt to higher ocean temperatures will likely migrate to higher latitudes and different fishing grounds. While commercial fleets have the means to track migrating stocks, poorer artisanal fishers operating near-coast vessels do not, potentially undermining their access to traditional target species and the diets and incomes they support.
- Risks to coastal and marine habitats could potentially affect the tourism industry which generated around 12% of the region's GDP pre-Covid-19. Scuba-diving alone is worth around USD4.5 billion/year in Thailand, Indonesia and Malaysia.
- Climate pressures related to ocean warming and marine heatwaves could further undermine progress in Southeast Asia towards SDG14: *Conserve and sustainably use the oceans, seas and marine resources for sustainable development.*
- Climate risks to marine species and fisheries remain poorly understood, climate sensitivities and impact pathways are complex, and projections for fish productivity and distribution are uncertain – a key evidence gap given the importance of fish to regional economies, livelihoods and food security.

3.7.1 Context

All Southeast Asia countries, except for landlocked Lao PDR, are maritime nations. The region hosts one of the world's most extensive and diverse marine ecoregions and is considered a global hotspot for both its marine biodiversity and the potential of its blue economy to power economic growth (ADB, 2021).

ASEAN[70] countries have two million kilometers of coastline and over 25,000 islands, home to more than 50% of the population, with territorial waters covering three times the size of constituent members' aggregate landmass (Gopal and Anbumozhi, 2019; ADB, 2021). Within the ASEAN region, roughly 625 million depend on the ocean for their livelihoods, significantly more than most other global regions. The region also accounts for roughly 15% of global fish production, 33% of seagrass beds, 34% of coral reef cover, and 35% of mangrove forests (ADB, 2021). Fish also account for over 35% of animal protein intake in Malaysia, Myanmar, Thailand and Indonesia (Gopal and Anbumozhi, 2019; FAO, 2021).

The compound effect of multiple climate hazards (sea-level rise, extreme weather events, marine heatwaves, and ocean acidification – see Section 2.1) and the impacts of pollution, coastal habitat destruction and overfishing are putting the coastal economies of the region under growing pressures, impacting the livelihoods of the poorest communities (ADB, 2021). Risks to the blue economy in Southeast Asia vary depending on location, ecosystem and reliance on ecosystem services for coastline activities and livelihoods.

Rising sea levels combined with more intense typhoons are likely to further increase the vulnerability of the poorest populations living in coastal zones as coastal communities, infrastructure, marine environment and blue economy become more exposed to impacts from extreme weather events (see Section 2.1.2 and Section 3.4). Over the period 1993-2018, ASEAN countries incurred direct economic losses of USD124 billion due to weather-related events (Beirne et al., 2021). Thailand experienced the highest economic losses (USD574 million) while Philippines experienced the highest number of climate-related natural disasters - 273 for this specific period (Beirne et al., 2021).

The following section discusses climate change risks to the blue economy and marine environment arising from rising sea levels, typhoons, marine heatwaves and ocean acidification, and their interaction with non-climate pressures. The blue economy can be described as the '*sustainable use of ocean resources to improve livelihoods and employment as well as support economic growth*' (World Bank, 2017).

3.7.2 Biodiversity and ecosystem services

Coral reefs

Reef systems in the Coral Triangle, a global biodiversity hotspot, are threatened by rising sea temperatures, marine heatwaves and ocean acidification, as well as pollution, coral mining and destructive fishing practices (Lam et al., 2019; Fordyce et al., 2019). The Coral Triangle is a one million square kilometer area between Philippines, Malaysia

[70] The Association of Southeast Asian Nations (ASEAN), established in 1967, currently includes 10 member states: Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei Darussalam, Viet Nam, Lao PDR, Myanmar and Cambodia.

and Indonesia and a global hotspot for coral reef habitats and biodiversity. Some 76% of all coral species are found in the area, along with six species of sea turtle and roughly 2,000 species of fish (Burke et al., 2012). Reef systems are particularly sensitive to rising sea surface temperatures and marine heatwaves,[71] with reefs in Indonesia, Brunei Darussalam, Malaysia, and Singapore already close to their thermal tolerance limits. Warmer seas and marine heatwaves can stunt reef growth, cause coral bleaching, and lead to coral death (van Woesik et al., 2022). Ocean acidification poses further risks because acidification affects marine invertebrates with calcium carbonate skeletons, including zooplankton, shellfish and corals (Focus Box 8). Climate-related risks act as an additional stressor on reef systems already under threat from destructive fishing practices, coral mining and pollution (White et al, 2014). For example, pollution from terrestrial watersheds has been identified as a key issue affecting the health of reef systems around the Maluka islands of Indonesia (Januar et al, 2023).

Marine heatwaves pose the biggest climate-related threat to coral systems, with heatwaves of just 1-2^{o}C above average conditions for the location able to cause coral bleaching in both the Coral Triangle and Gulf of Thailand (Yeemin et al, 2013; McManus et al, 2019; Obura et al, 2021). Bleached corals can recover, but are more susceptible to disease in a bleached state (van Woesik et al., 2022). For the Coral Triangle as a whole, projections suggest that reef survival probability and mean (percent) coral cover over time are determined largely by the presence or absence of interannual sea surface temperature extremes as well as absolute temperature increase, both driving long-term coral decline (McManus et al, 2019). Major coral bleaching has been reported in Philippine reefs during severe El Niño events (Raitzer et al, 2015), as well as in reef systems outside the Coral Triangle in the Gulf of Thailand (Yeemin et al, 2013). The most extreme marine heatwaves are projected for tropical Central and West Pacific and Indian Oceans by the end of the century (Cheng et al., 2023) – see also Section 2.1.

Coral reefs help protect coastlines, drive tourism, provide nurseries for fish and support shallow water artisanal fishers, so the health of coral ecosystems is important. Coral reefs help dissipate wave energy, especially during storms, protecting coastlines from erosion and flooding (Ferrario et al, 2014; Burke and Spalding, 2022). Reefs also provide important nurseries and habitats for fish, important to near-coast artisanal fishers and coastal tourism (see below). McManus et al (2019) suggest that Coral Triangle reefs serve as direct providers of livelihoods for over 100 million people living in coastal communities in the region. Estimates by Ramadhan et al. (2017) show that the total economic value of protected coral reef areas in the Tropical Coral Triangle region amounts to USD10 million per hectare per year. Lam et al (2019) estimate[72] that coral reefs in Southeast Asia provide coastal protection benefits of around USD19 billion annually.

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[71] A marine heatwave is a period of abnormally high ocean temperatures relative to the average seasonal temperature in a particular marine region (Hobday et al., 2016).

[72] Drawing on 2017 data from the International Coral Reef Initiative (ICRI) forum: https://icriforum.org/

Focus Box 8: Ocean acidification

Oceans are becoming more acidic (lower pH) as they absorb excess amounts of atmospheric CO_2 released from human activities. Ocean acidification interacts with pre-existing stressors such as pollution, sedimentation, overfishing, warming and habitat destruction (Lam et al., 2019). The consequences of less alkaline conditions on marine life are the subject of intense research efforts. Reported effects include changes in cellular biology, physiology, population dynamics, and ecosystem function (Hansson and Gattuso, 2011). There is still considerable uncertainty over the likely impacts on many ecosystems, organisms and species, and their ability to tolerate and/or adapt to less alkaline conditions (Doney et al., 2020). For example, emerging evidence suggests the physiology of some fish species can adapt to a lower pH in their blood, while marine invertebrates with calcium carbonate skeletons - such as corals, zooplankton, and shellfish - are likely to grow more slowly (Esbaugh, 2017; Lam et al., 2019). Further uncertainty remains over how these effects will interact in complex ecosystem dynamics, for example in pelagic or coral reef food webs where the nutrition of commercially important fish relies on the productivity of zooplankton or corals (Doney et al., 2020). However, it is clear that ocean acidification adds further pressure to marine ecosystems under stress.

Mangroves

Mangroves provide important provisioning and regulating services but face multiple threats. Southeast Asia has the most extensive area of mangroves of any global region, covering an estimated 48,000 km^2 in 2020, roughly 35% of the global total (see Section 3.6.2, Figure 12, Sakti et al., 2020; ADB, 2021). Mangroves provide a range of services, helping to protect coasts through wave attenuation, shoreline stabilistion and shelter from high winds (see Section 3.6.2, Figure 12). They also provide an important source of timber, livestock forage and food, sequester and store significant amounts of carbon,[73] and provide important habitats for fish and invertebrates (Giri et al, 2015; Rahman et al, 2021). However, roughly one third of mangroves in Southeast Asia were deforested between 1980 and 2020 (see also Figure 12, Section 3.6.2), mainly for aquaculture and agricultural expansion, while a significant proportion of mangroves continue to suffer from degradation, the causes of which are difficult to unravel but include sea level rise, pollution, and reductions in sediment delivery to coastal areas (see Section 3.6.2, Sakti et al. 2020).

Country-level data highlight the scale of mangrove loss, although national governments now recognise the importance of mangrove protection and restoration for coastal resilience. Indonesia accounts for roughly 23% of the world's mangrove forests and supports the greatest variety of mangrove species globally, but 40% of forests have been lost to aquaculture over the last three decades (Kazi et al, 2022). In Philippines, over 50% of the country's mangroves were cleared for aquaculture between 1980 and 2020 (Fallin et al., 2021). In Indonesia, halting mangrove loss for aquaculture development (concentrated in Kalimantan and Sulawesi) and for oil palm (concentrated in Sumatra) is expected to protect coastlines and support local communities. The government has committed to restore 600,000 hectares of mangroves by 2024 – the largest such effort in the world (World Bank Group, 2023).

[73] Tropical mangrove forests have a higher carbon density than tropical rainforest and sequester carbon faster than any other terrestrial ecosystem (Donato et al, 2011).

Mangroves are potentially vulnerable to rising sea levels and more intense cyclones and storm surges, but risks are likely to be site-specific (Ward et al., 2016; Woodroffe et al., 2016; Kazi et al, 2022). Rising sea levels can increase the frequency, depth, and duration of inundation experienced by mangroves, for example during storm surges, making them vulnerable to drowning or coastal squeeze – the loss of inter-tidal habitat (Woodroffe et al., 2016). Some studies conclude that mangrove sediment accretion can keep pace with sea level rise as long as sufficient sediments continue flowing to coastal areas (Woodroffe et al., 2016). However, Lovelock et al (2015) suggest that mangrove forests at sites with low tidal range and low sediment supply could be submerged as early as 2070. The World Bank (ADB and World Bank Group, 2021d) highlight research suggesting that all of Malaysia's mangroves could be at risk from rising sea levels and storm surges by 2040.

Seagrasses

Seagrasses provide important ecosystem services but are threatened by a combination of climate and non-climate hazards (Fortes et al, 2018). Sea grass occurs in the waters of all non-landlocked countries of Southeast Asia (Fortes et al., 2018). Sea grasses provide nurseries and breeding grounds for other organisms including commercially important fish, help stabilise sediments and prevent erosion, improve the habitability for coral reefs by trapping heavy metals and nutrients, provide a source of forage and food for marine turtles and dugongs, and capture and store carbon (Patro et al., 2017; Unsworth et al, 2019). In Philippines and Indonesia, for example, seagrass meadows provide habitats that support both artisanal fishers and larger commercial operators (Fortes et al, 2018; Unsworth et al, 2019; Supriyadi et al, 2023 – see also Section 3.7.3 below). Southeast Asia has 21 seagrass species, with the highest diversity (and area coverage) in Philippines (Fortes et al., 2018). Some 33% of the world's seagrass beds are found in the territorial waters of East Asian seas (ADB, 2021).

Rising sea levels can prevent seagrass meadow growth, and warmer seas can lead to seagrass mortality. However, most damage is likely caused by pollution, dredging, and excess sedimentation linked to inland deforestation. Despite their importance, regional research on sea grass status and trends, and responses to different pressures, is scarce: we can point to trends and likely impacts in broad terms, not to evidenced climate-related impacts in the region (Fortes et al, 2018). When seagrass is lost, however, there is strong evidence globally that fisheries and their stocks often become compromised with negative economic consequences (Gillanders, 2006).

3.7.3 Marine fisheries

Marine fisheries are significant contributors to livelihoods and economies in the region, so climate-related impacts on fish stocks, productivity and distribution could have far-reaching consequences. The fisheries sector, including ocean fishing and marine aquaculture, is a key source of employment, revenue and food security (ADB, 2021). ASEAN's 10 member states account for almost 20% of global fisheries production, with export earnings valued at around USD1.95 billion in 2018 (Gopal and Anbumozhi, 2019; ADB, 2021). Indonesia, Viet Nam, and Philippines are among the world's 10 largest marine fisheries producers (FAO, 2021), and while the fisheries sector of Timor-Leste is small and under-developed it is a key source of livelihoods and has potential for growth (ADB and World Bank Group, 2021e). However, statistics do not disaggregate the socioeconomic contributions of marine fisheries from those of inland (freshwater) fisheries. Fisheries employ almost two million fishers in Philippines, and 2.8 million fishers and 4.2 fish farmers in Indonesia; it is reasonable to assume that most of these fishers and a minority of these fish farmers are employed in marine production (FAO, 2021). In Viet Nam, where the sector is more mixed between inland and marine fisheries, 2.6 million are employed directly as fishers or fish farmers, and a further 254 thousand people are engaged in fish processing (FAO, 2021). In 2021, fish and crustacean exports generated over USD 9 billion for Viet Nam, USD 5.3 billion for Thailand, USD 5.2 billion for Indonesia and USD 919,000 for Philippines (FAO, 2023a,b), implying that most of the large catches of these two nations are consumed domestically. Fish is also a significant contributor to food security in the region (Gopal and Anbumozhi, 2019; ADB, 2021; FAO, 2021). This is particularly so in Indonesia, where fish accounts for over 60% of all dietary animal protein, but also in Malaysia, Myanmar, and Thailand where fish contribute over 35% of animal protein (FAO, 2021) – see also Section 3.1.

Marine species are likely to experience average and maximum temperatures above, and pH and oxygen below, the levels to which they are adapted, with negative impacts on fish production. Evidence remains limited, but the fisheries potential of Indonesian waters could decrease by 13-29% by the 2050s (Barange et al, 2018). Southeast Asian seas are projected to warm by 1.2 °C by the 2050s and by around 3°C by the end of the century (Gutiérrez et al., 2021 - CMIP6; Kay et al., 2023), reducing fish productivity. Indirect climate effects may also include the loss of nursery habitats for fish such as mangroves and coral reefs due to sea-level rise and increasing temperatures (see above). These trends will likely exacerbate existing pressures on fish stocks from overfishing, pollution and habitat destruction (Gopal and Anbumozhi, 2019; ADB, 2021). Data for the region are sparse, but fisheries catch potential in Indonesian waters could potentially decline by 13-29% to the 2050s, depending on the emissions scenario, rising to 18-63% by the end of the century, though with some gains possible off the south coast of Java (Barange et al, 2018). Uncertainty intervals are large reflecting difficulties in identifying and quantifying fish sensitivities to compound hazards, but marine species generally are likely to experience sea temperatures, pH and dissolved oxygen levels beyond their adapted range (Barange et al, 2018). Risks to port infrastructure and maritime trade are discussed in Section 3.4.

Existing pressures on fish stocks, particularly from overfishing and habitat destruction, exacerbate climate-related risks. FAO assessments report roughly 21% of western Pacific and 35% of eastern Indian Ocean fish stocks as overfished and exploited beyond their sustainable limits (FAO, 2019; 2022). Part of this overfishing effort comes from East Asian vessels moving beyond their own waters, where 45% of stocks are overfished (FAO, 2022). Illegal, unreported, and unregulated activities also contribute to overfishing (FAO, 2018). Other pressures on fish stocks include marine pollution, the loss of nursery habitats to aquaculture and agriculture, and destructive fishing methods. This baseline of environmental degradation exacerbates vulnerability to climate impacts. Small-scale fisheries and coastal communities in Southeast Asia must negotiate deepening commodification, worsening environmental degradation, loss of access to fishing grounds, degradation of fish nurseries (see above) and an intensifying ‘squeeze’ on coastal space (Fabinyi et al., 2022).

Southeast Asia’s fisheries sector is transforming, and this will affect the distribution of risks between different fishing sectors and groups of people. Inland aquaculture production in the region increased by 460% between 2000 and 2015 (FAO, 2023b). However, most nations still derive the majority of their fish production from marine areas (OECD and FAO, 2017). For example, Indonesia is the world’s third largest fish producer and in 2021, 53% of the 13 million tonnes it produced came from marine capture fisheries, 15% from marine aquaculture, and 33% from inland waters (FAO, 2023a,b). Similar patterns hold in Malaysia, Philippines, Thailand, and Viet Nam, which respectively produce 93%, 82%, 77%, and 66% of their fish from marine waters (FAO, 2023a,b). Marine aquaculture is also a large and growing sector in many of these nations. Marine aquaculture generates 25% of Viet Nam's 8.3 million tonnes of annual fisheries production and includes over one million tonnes of crustacea each year, primarily commercially valuable shrimp, and a further 300,000 tonnes of marine snails (FAO, 2023b). Indonesia's marine aquaculture produces almost one million tonnes of crustacea but also over nine million tonnes of seaweed, primarily for industrial applications. Marine aquaculture represents a significant and growing use of sea space in Southeast Asia and has contributed significantly to the loss of mangrove ecosystems – see above (McSherry et al., 2023).

As fish unable to adapt to higher sea temperatures migrate to higher latitudes, target species accessible to poorer, artisanal fishers operating smaller, near-coast vessels may change. Over the last two decades Southeast Asia's marine fisheries have evolved from small-scale production for domestic consumption to a mixture of small- and larger-scale export-oriented production (OECD and Food and Agriculture Organization of the United Nations, 2017). As part of this transformation, in most countries the number of traditional unpowered fishing vessels has declined while the number and average size of powered vessels has increased. For example, between 2000 and 2019 the number of unpowered vessels in Indonesia decreased from 252,515 to 165,050 while the number of powered vessels grew from 352,332 to 460,657 (FAO, 2021). Over the same period, the average tonnage of Indonesian tuna longliners grew from 67 to 75 tons, purse seiners from between 30-120 tons to 147 tons, and pole-and-line vessels from 10-50 tons to 80 tons (FAO, 2020). This development of the fishing sector to supply global food chains is therefore likely to have reduced some aspects of climate vulnerability, with commercial fleets able to access finance, invest in new gear and track target species. However, small, unpowered artisanal vessels continue to provide livelihoods for some of the poorest and most climate-vulnerable members of society, particularly in Indonesia and Philippines (292,182 vessels), and pockets remain in countries such as Myanmar (5,122 vessels) and Malaysia (3,155 vessels) (FAO, 2021). For these fishers and the communities, they support, changes in species composition and accessibility could have negative impacts on diets and incomes. This is a tentative conclusion as data are sparse, however, and the main risks they face will likely come from habitat destruction in coastal areas – see above (Fabinyi et al, 2022).

Intensifying typhoons are likely to disproportionately affect artisanal fishers because of their smaller boats and limited coastal protection compared to larger fishing fleets with access to port infrastructure. When not at sea industrial fleets are more likely to be protected against typhoons in port facilities, although those facilities may need upgrading to cope with sea-level rise and more intense storms (see Section 3.4). In contrast, artisanal fishers in smaller (often unpowered) vessels are more exposed: less able to travel to more distant fishing grounds, and less able to access shelter from intense storms.

Marine aquaculture production is also vulnerable to climate hazards. Marine aquaculture made up 25% of Viet Nam's and 15% of Indonesia's fishery production in 2021 (authors' calculation from FAO, 2023a,b) and will be negatively affected by higher water temperatures, particularly in shallow systems. Aquaculture production will also be unable to move production towards more tolerable conditions as sea temperatures rise. With coastal flooding also comes higher risk of saline intrusion, damaging freshwater capture fisheries and decreasing freshwater availability for aquaculture (FAO, 2011 – see also Section 3.1). In addition, crustacea and mollusk species are likely to be particularly vulnerable to ocean acidification (Focus Box 8), impacting commercially important species.

3.7.4 Coastal and Marine Tourism

Climate risks to coastal and marine habitats could also affect the tourism industry. Travel and tourism generated around 12% of Southeast Asia's GDP pre-Covid (OECD, 2023), with the scuba-diving industry alone estimated at around USD4.5 billion/year in the early 2000s in Thailand, Indonesia, and Malaysia (Pascoe et al., 2014).

Over three million people are employed by roughly 8000 businesses depending directly or indirectly on coral reefs in Southeast Asia (Lam et al., 2019).[74] There are around 3.4 million coral reef fishers in Southeast Asia. Although revenues from coral reef fisheries represent a small share of agricultural GDP, the benefits mainly accrue to small-scale artisanal fishers and poorer communities dependent on shallower, near-coast waters (Lam et al., 2019). Countries with a predominantly rural economy are more directly dependent on ecosystem services and biodiversity, including Myanmar, Lao PDR, Cambodia, and Viet Nam (Renaud et al., 2021).

Proactive policies to restore the health of the Coral Triangle could generate substantial economic returns. According to a quantitative model looking at interactions between coral reefs, tourism, coastal development and fisheries, policies to deliver a healthy coral reef could deliver additional economic benefits amounting to USD36.7 billion by 2030, although coral reefs themselves may (UN environment et al., 2018).

[74] Drawing on 2017 data from the International Coral Reef Initiative forum: https://icriforum.org/

Met Office Hadley Centre ODI UKaid from the British people

Image location: Thailand

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Image location: Bohey Dulang island, Malaysia