Climate Resilience for Energy Security in Southeast Asia

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Abstract

The increasing impact of climate change is putting energy security at risk in Southeast Asia. Heatwaves, floods, droughts, tropical cyclones and rises in sea levels pose challenges to the energy system, affecting everything from fuel extraction to electricity distribution. High temperatures impair the functionality of solar PV and natural gas-fired power plants, while heavy rainfall and flooding disrupt coal and mineral mining operations. Increasingly intense tropical cyclones endanger energy infrastructure, especially in coastal and cyclone-prone areas. A climate-resilient energy system is needed to overcome these issues. This report provides a comprehensive overview of climate hazards and their impacts on the energy sector until the end of the 21st century. It also identifies effective measures to enhance climate resilience in Southeast Asia which can lead to a resilient and secure energy future for the region.

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The individuals and organisations that contributed to this report are not responsible for any opinions or judgements it contains. All errors and omissions are solely the responsibility of the IEA.

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Executive summary

Climate change's impacts have already become more apparent in Southeast Asia. The region has seen a significant rise in land surface temperatures by 0.8°C since the 1980s, accompanied by more frequent and intense heatwaves. Rising temperatures have altered precipitation patterns and increased flood risks beyond the world average. In addition, the region is experiencing intensified tropical cyclones, particularly affecting countries like Myanmar, the Philippines and Viet Nam.

Climate impacts are set to worsen in Southeast Asia. Erratic precipitation patterns are projected to increase, with more intense and frequent heavy rainfalls. The temporal concentration of precipitation may lead to higher risks of floods. Projections indicate that mean temperatures are likely to continue to rise, with extreme heat events potentially doubling under low-emissions scenarios and quadrupling under high-emissions scenarios by the end of the century. Projections also suggest that tropical cyclones continue to become more intense, posing risks to coastal and offshore energy infrastructure. Combined with more intense tropical cyclones, accelerated sea level rise could threaten coastal energy assets with an increasing number of storm surges and coastal flooding.

The impacts of these climate hazards are pervasive across the entire energy value chain, from fuel extraction and processing to electricity generation and distribution. Increasing climate risks pose challenges to an energy system already strained by rising electricity demand, heavy reliance on imported fuels and issues of energy affordability. Therefore, climate impacts have implications for the safe, reliable and affordable operation of the region's energy system.

Level of climate hazard and exposure by country in Southeast Asia

Country	Warming	River flood	Coastal flood	Drought	Tropical cyclone
Brunei Darussalam	🟩 0.023	🟨 4.9	🟨 3.3	🟩 1.6	🟩 0
Cambodia	🟩 0.017	🟥 8.7	🟨 3.8	🟨 3.9	🟩 1.8
Indonesia	🟨 0.029	🟥 8.3	🟥 8.1	🟩 2.2	🟩 1.5
Lao PDR	🟨 0.041	🟥 8.2	🟩 0	🟩 2.4	🟩 1.4
Malaysia	🟨 0.027	🟨 6.8	🟨 6.4	🟩 2.8	🟩 0
Myanmar	🟨 0.032	🟥 8.8	🟥 8	🟩 0.6	🟨 5.8
Philippines	🟨 0.026	🟨 6.7	🟥 8.9	🟨 3.3	🟥 9.2
Singapore	🟩 0.021	🟩 0	🟩 1.9	🟩 0	🟩 0
Thailand	🟨 0.026	🟥 9.8	🟨 5.5	🟨 5.2	🟩 1.6
Viet Nam	🟨 0.032	🟥 9.9	🟥 9.6	🟨 3.4	🟨 5.9
World average	0.037	4.5	3.5	2.9	1.6

Notes: 🟩 Low exposure 🟨 Medium exposure 🟥 High exposure. Lao PDR = Lao People's Democratic Republic. The level of climate hazard and exposure for warming is extracted from the Weather, Climate and Energy Tracker for the period 2000 2023. If the slope of a linear regression line of temperatures is higher than 0.048°C per year (+0.011°C from the world average) in a certain country, the climate hazard level of the country is "high". If the slope of a linear regression line of temperatures is lower than 0.026°C per year (-0.011°C from the world average) in a certain country, the climate hazard level of the country is "low". The world average was calculated based on the land temperature data from the NOAA National Centers for Environmental information, Climate at a Glance: Global Time Series, accessed on 16 May 2024. The levels of climate hazard and exposure for river flood, coastal flood, tropical cyclone and drought are assessed based on the indicators of the INFORM Risk Index for "River Flood", "Coastal Flood", "Tropical Cyclone" and "Drought". The minimum value is given 0 on the scale, while the maximum value is given 10. A detailed methodology of the indicator is described on the INFORM Risk Index page. In this report, the risk is defined as Low (0-2.99), Medium (3-6.99) and High (7-10).

Sources: IEA (2024), Weather, Climate and Energy Tracker; INFORM (2021), INFORM Risk Index 2024.

High temperatures and heatwaves have critical impacts on the power sector, notably on solar PV, gas-fired power plants and electricity networks. Higher temperatures may lead to less solar power generation by degrading generation efficiency and increasing the electrical resistance, while damaging cells and other materials. Similarly, natural gas-fired power plants can see a decrease in power generation due to a reduced air mass flow and increasing temperature of cooling water. Although the impacts of extreme heat are currently limited, solar PV and natural gas-fired power plants are projected to experience more frequent extreme heat events in the coming decades. Particularly in a high-emissions scenario, nearly 70% of solar PV and over 90% of natural gas-fired power plants would see more than 20 hot days above 35°C thresholds by 2100, presenting a notable increase from the current level.

Electricity grids are also under increasing stress due to increasing extreme heat events. Overhead power lines can heat up, expand and sag while underground power cables could experience short circuits due to stresses on cable and joint insulating materials. Critical components such as transformers, inverters and substations are also at higher risk of failure from overheating. Rapidly increasing electricity demand for cooling also adds strains to the grid.

Heavy rainfalls and flooding disrupt coal and critical mineral mining operations. Coal, nickel and copper mines in flood-prone areas of Southeast Asia have already experienced operational halts and supply chain interruptions due to inundation in mining pits and physical damage. If climate change is not mitigated on time, around 75% of coal mines, 75% of copper mines and 30% of nickel mines in the region could see a more than 10% increase in heavy rainfall in the middle of this century compared with the pre-industrial period.

The changes in precipitation patterns also require building climate resilience of hydropower. Hydropower, which is a crucial part of the energy mix in countries such as Laos PDR and Viet Nam, is sensitive to changes in precipitation patterns. Increased annual and seasonal variability in precipitation may lead to a decrease in hydropower generation capacity factor, 5% by 2100 compared with 1970-2010 in a low-emissions scenario or nearly 9% in a high-emissions scenario. Some Mekong River basin countries, which have already experienced electricity supply disruptions due to climate change, are projected to have the largest drop.

The intensification of tropical cyclones is another concern to energy security. Tropical cyclones can directly threaten the physical resilience of energy systems, inflicting damages to assets with severe winds, heavy rainfall, landslides and storm surges with the combination of sea level rise. In Southeast Asia, nearly half of the solar PV and hydropower installed capacities are situated in cyclone-prone areas, far exceeding the global level (15%). Over 40% of wind turbines and over 20% of electricity grids are also exposed to tropical cyclones. Some refineries located in coastal and cyclone-prone areas could face severe coastal floodings or storm surges as sea level rises and tropical cyclones intensify.

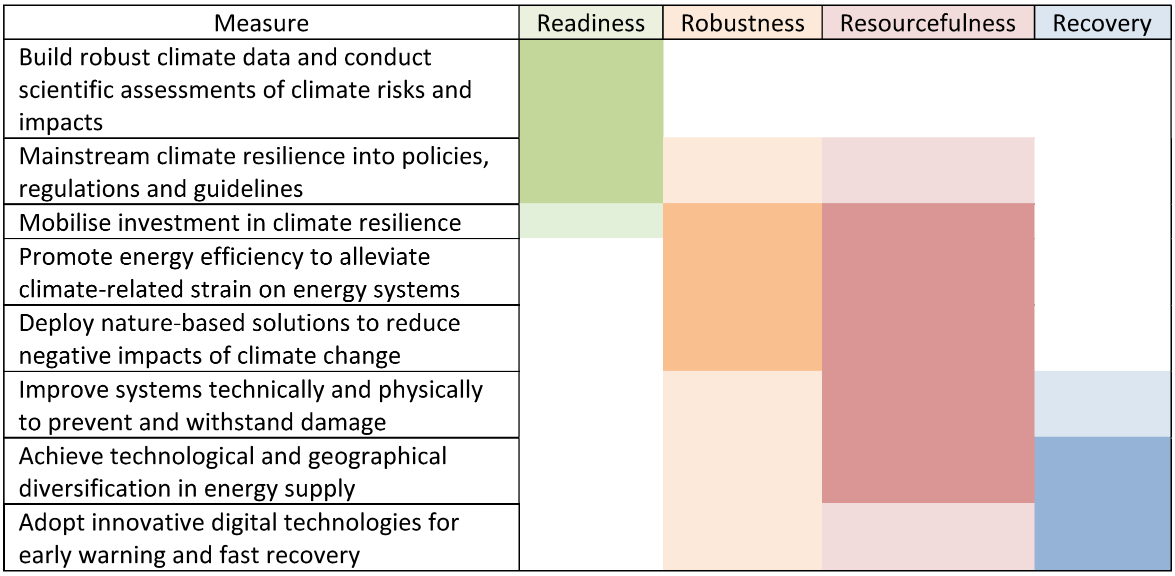
Shifting the way energy infrastructure is planned and developed can help mitigate climate impacts, while also supporting energy transition and security. A climate-resilient energy system that can prepare for climate changes (“readiness”), adapt to and withstand the slow-onset changes in climate patterns (“robustness”), continue to operate under the immediate shocks from extreme weather events using alternative sources (“resourcefulness”), and restore the system’s function after climate-driven disruptions (“recovery”) is essential to deliver energy and climate goals.

Actions for climate resilience could start with building a robust climate database, conducting scientific assessments and integrating climate resilience into energy policies. Despite notable progress in recent decades, the inadequate quality of observation data and climate projections in the region remains a major bottleneck for climate resilience, while the energy sector climate resilience is often neglected in climate change adaptation and resilience policies.

Mobilising private sector investment with public financing instruments, supportive policies and insurance is also required to support resilience measures to enhance robustness and resourcefulness. Deployment of energy-efficient technologies and nature-based solutions contribute to coping with both slow-onset and extreme weather events, while addressing fundamental issues with long-term time horizons. Technical and structural improvements of energy infrastructure, diversification of energy sources, and innovative digital solutions can help address immediate impacts from extreme weather events while enabling fast recovery.

Although adverse impacts of climate change are increasing in the region, they can be avoided or minimised by actions for climate resilience. Co-ordinated efforts from diverse stakeholders, including public and private sectors, regional organisations, and international partners, could lead to a more resilient and secure future for the energy sector in Southeast Asia.

Measures to build climate resilience for energy security in Southeast Asia



Measure	Readiness	Robustness	Resourcefulness	Recovery
Build robust climate data and conduct scientific assessments of climate risks and impacts	■			
Mainstream climate resilience into policies, regulations and guidelines	■	□	□	
Mobilise investment in climate resilience	□	■	■	
Promote energy efficiency to alleviate climate-related strain on energy systems		■	■	
Deploy nature-based solutions to reduce negative impacts of climate change		■	■	
Improve systems technically and physically to prevent and withstand damage		□	■	□
Achieve technological and geographical diversification in energy supply		□	■	■
Adopt innovative digital technologies for early warning and fast recovery		□	□	■

Introduction

Southeast Asia stands at the forefront of the climate crisis on energy security. Higher average temperatures and irregular precipitation patterns are making heatwaves, floods and droughts more frequent, while sea level rise and intensified tropical cyclones are becoming prevalent.

The increasing impacts of climate change are altering the landscape of energy system and have profound implications for energy security in Southeast Asia. Southeast Asia's energy system is already strained due to rapidly rising electricity demand, heavy reliance on imported fuels and energy affordability. More frequent heavy rainfalls and floods add challenges to coal and critical mineral mining, while the temporal concentration of precipitation requires hydropower resilience. Rising temperatures and extreme heatwaves put stress on the electricity generation assets and network, reducing their efficiency. Intensification of tropical cyclones combined with sea level rise also raises concerns about energy assets in coastal areas and offshore.

Building and strengthening climate resilience of energy systems is increasingly important due to the escalating climate change risks to energy security. Climate resilience is the ability to anticipate, absorb, accommodate and recover from the effects of a potentially hazardous event related to climate change. A climate-resilient energy system is one that can prepare for changes in climate, adapt to and withstand the slow-onset changes in climate patterns, continue to operate under the immediate shocks from extreme weather events, and restore the system's function after climate-driven disruptions.

This report, Climate Resilience for Energy Security in Southeast Asia, is designed to support building climate resilience and enhancing energy security in the region. This report provides a comprehensive analysis of climate trends, their impacts on energy systems and strategic measures for enhancing resilience in the following key chapters.

The first chapter provides an overview of historical trends and projections of four major climate hazards in the region focusing on four climate aspects: temperature, precipitation, wind and sea level rise. By comparing different greenhouse gas concentration trajectories, it aims to identify key climate hazards that would have strong impacts on the energy sector's resilience in Southeast Asia.

The second chapter comprehensively assesses climate change impacts on each segment of the energy value chain, from fuels and minerals to electricity grids and demand, comparing different climate scenarios. It highlights how various climate hazards would affect each segment of energy systems.

The third chapter outlines strategies and measures to enhance climate resilience of energy systems based on the conceptual framework of resilience. It identifies actions for each phase of climate resilience (readiness, robustness, resourcefulness and recovery), discussing the role of policy, investment and technologies in building climate resilience.

Trends and projections of climate change

Southeast Asia, with a tropical climate with high temperatures and humidity, is now grappling with heightened occurrences of extreme weather events due to climate change. Higher average temperatures and changing precipitation patterns are making heatwaves, floods and droughts more frequent, while an accelerated rise in sea levels and intensified tropical cyclones are becoming prevalent. These shifts are altering the landscape of energy demand and supply, posing a significant risk to the region's energy security.

This chapter focuses on four climate-driven hazards in the Southeast Asia region that affect energy supply and demand: temperature, precipitation, wind and sea level rise. Each hazard is thoroughly examined, delving into historical trends and projected changes. This chapter presents projected changes comparing different trajectories of GHG concentrations so that the analysis can provide a comprehensive overview of climate change trends. The chapter aims to identify and highlight key hazards which would have the greatest impacts on the energy sector's resilience in Southeast Asia.

Global trajectories of GHG concentrations

The direction and intensity of future climate change depend on the trajectory of GHG concentrations globally, largely determined by human activities. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report defines five Shared Socioeconomic Pathways (SSPs) that explore possible evolutions of human societies and their implications for the climate. They cover a wide range of future pathways, from a scenario in which GHG emissions decline drastically to net zero by 2050 and are negative in the second half of the century (SSP1-1.9) to a scenario in which emissions continue to rise sharply, doubling from today's levels by 2050 and more than tripling by 2100 (SSP5-8.5). SSP1-1.9, which is the most similar to the IEA's Net Zero Emissions by 2050 (NZE) Scenario, sets out a pathway of limiting global warming below 1.5°C in 2100 relative to pre-industrial levels with limited overshoot. SSP1-2.6, which is close to the IEA's Announced Pledges Scenario (APS), implies net zero emissions in the second half of the century and limits the temperature rise below 2°C. SSP2-4.5, which is aligned most closely with the IEA's Stated Policy Scenario (STEPS), limits global warming below 3°C.

The IPCC Sixth Assessment Report describes that it is likely to be more difficult to adapt to climate change when the global temperature increase gets close to or exceeds the 1.5°C threshold. Some adaptation measures will become less effective or ineffective above the 1.5°C threshold because of the severity of the projected changes in the climate system.

Emissions scenarios considered in the IPCC's Sixth Assessment Report

Scenario	Description	Global warming estimate for 2100
SSP1-1.9	A very low-emissions reference scenario; implies net zero emissions by mid-century*	Below 1.5°C
SSP1-2.6	A low-emissions reference scenario; implies net zero emissions in the second half of the century**	Below 2°C
SSP2-4.5	An intermediate scenario, in line with the upper end of aggregate nationally determined contribution (NDC) emissions levels by 2030***	Below 3°C
SSP3-7.0	A high reference scenario with no additional climate policy. Emissions almost double by 2100 compared with today's levels	Above 3°C
SSP5-8.5	An extremely high reference scenario with no additional climate policy. Emissions triple by 2100 compared with today's levels	Above 4°C

* In the IEA World Energy Outlook 2022, the assumption of net zero emissions by mid-century of SSP1-1.9 is reflected in the IEA NZE Scenario, a normative scenario that sets out a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. The NZE Scenario also meets key energy-related United Nations Sustainable Development Goals, in particular by achieving universal energy access by 2030 and major improvements in air quality.
** SSP1-2.6 is broadly in line with the IEA APS, another exploratory scenario that assumes that all climate commitments made by governments around the world, including NDCs and longer-term net zero targets, will be met in full and on time.
*** SSP2-4.5 is broadly in line with the IEA STEPS, an exploratory scenario that reflects current policy settings and provides a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy.
Source: Based on IPCC Sixth Assessment Report (2021).

Temperature

Extreme heat events would double in a low-emissions scenario and quadruple in a high-emissions scenario

Southeast Asia has become hotter, with a land surface temperature increase from 25.02°C in 1979-1988 to 25.76°C in 2013-2022. Together with the increase in mean temperature, most of Southeast Asia has seen an increase in the number of warm nights (especially during El Niño periods[1]) and the intensity and frequency

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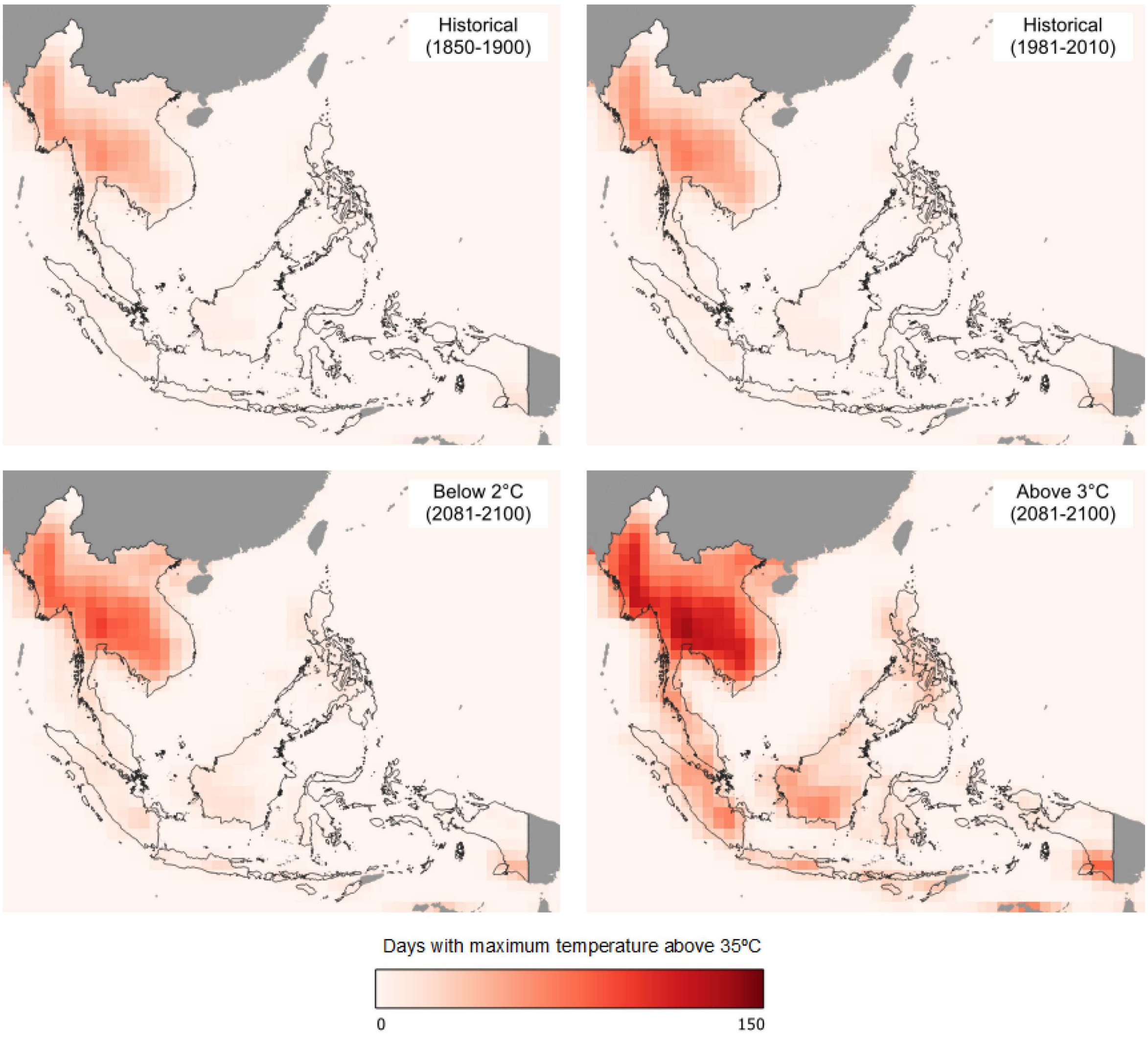
[1] Warm nights are defined by the IPCC as nights where the minimum temperature exceeds the 90th percentile, where the respective temperature distributions are generally defined with respect to the 1961-1990 reference period.

of heatwaves. In April and May 2023 (when a La Niña phase ended and transitioned to El Niño), the Lao People's Democratic Republic (Lao PDR), Thailand and Viet Nam experienced an unprecedented level of heatwaves, breaking the records of the hottest days in Thailand and Viet Nam. The heatwaves caused damage to energy infrastructure and electricity supply disruptions due to soaring electricity demand (e.g. 22.5% rise in average electricity consumption in Hanoi) and reduced water levels in hydropower dams. In Viet Nam, some cities had to cut power supply due to the failures in grids.

The IPCC projects that Southeast Asia is likely to experience an increase in temperature and extreme heat events. Southeast Asia is projected to see around a 1.6°C increase in mean surface temperature by the end of the century relative to pre-industrial levels under a low-emissions scenario (Below 2°C) and around 3.3°C increase in a high-emissions scenario (Above 3°C). Although the increase in mean temperature of Southeast Asia is likely to be less than the global average temperature increase in all scenarios, the region would be one of the most exposed to extreme heat events. Under a high-emissions scenario (Above 3°C), Southeast Asia is projected to face 48 days of maximum land temperature above 35°C, which is almost four times higher than the number of days of the pre-industrial period. Even under a low-emissions scenario (Below 2°C), the region is likely to see 25 days of maximum land temperature over the thresholds of 35°C, two times higher than that of the pre-industrial period. The increase in days with maximum temperature above 35°C is especially pronounced along the Mekong River basin spanning across Myanmar, Thailand, Lao PDR, Viet Nam and Cambodia.

Change in days with maximum temperature above 35°C, 1850-1900, 1981-2010 and 2081-2100



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Source: IEA analysis based on IPCC (2021), Working Group I Interactive Atlas.

El Niño Southern Oscillation

El Niño Southern Oscillation (ENSO) describes the climate phenomenon of periodic fluctuation in different phases of winds and sea surface temperatures over the tropical Pacific Ocean. ENSO is composed of three phases: a neutral phase, a warm phase (El Niño) and a cold phase (La Niña). El Niño, characterised by higher-than-average sea surface temperatures in the eastern tropical Pacific and a weakening of the trade winds, typically has a warming influence on global temperatures. La Niña, which is characterised by below-average sea surface temperatures in the central and eastern tropical Pacific and a strengthening of the trade winds, has the opposite effect. Although ENSO has widespread impacts around the world, the levels of impacts vary among countries and regions.

There are ongoing scientific debates on the extent to which climate change affects ENSO cycles. Although the strength and frequency of intense El Niño and La Niña events have increased relative to the pre-industrial period, the IPCC notes that the evidence attributing this increase to climate change is inconclusive. The latest studies using simulated models, however, suggest that ENSO variations have grown 10% more intense since 1960 due to anthropogenic climate change. The World Meteorological Organization also points out that climate change is likely to affect the impacts related to ENSO in terms of the intensity and frequency of extreme weather and climate events.

ENSO has a substantial impact on Southeast Asia, affecting both temperature and precipitation. In most of the region, El Niño episodes are associated with reduced rainfall and prolonged droughts, followed by an increasing number of warm nights and higher maximum temperatures. In fact, the eight hottest Aprils in Southeast Asia between 1980 and 2016 coincided with El Niño years. During the 2023 El Niño, Indonesia experienced record-setting droughts, leading to forest fires and water shortages. The Philippines also experienced below-average rainfall. On the contrary, La Niña has the opposite impact on rainfall and temperature, causing heavy rains over Southeast Asian countries such as Indonesia, Malaysia and the Philippines.

Precipitation

Intense rainfall has increased in Southeast Asia, raising flooding risks

Precipitation in Southeast Asia is largely determined by the region's monsoon systems, which are characterised by pronounced seasonal reversals of precipitation. The Southeast Asia monsoon starts in late May or early June and progresses towards the northeast, ending in late September or early October. The rainy monsoon season between June and September contributes to more than 75% of the annual rainfall over much of the region. Countries such as Cambodia, Lao PDR, Myanmar, the Philippines, Thailand and Viet Nam are under the area of influence of the region's monsoon systems.

Southeast Asia has witnessed an increase in heavy rainfall events[2] across the region since the 1950s, while the total number of rainy days has declined.[3] Those

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[2] Heavy rainfall is considered by the IPCC to be when the daily precipitation exceeds 100 mm, while moderate rainfall is when the daily precipitation is between 5 mm and 100 mm.

[3] Days with ≥1 mm of rain

effects have been particularly notable in Thailand, Malaysia, Viet Nam, and the southern Philippines. In Thailand, for instance, the average daily rainfall intensity increased by 0.24 mm to 0.73 mm per day per decade, while the average number of wet days decreased by 1.3 days to 5.9 days per decade from 1955 to 2014.

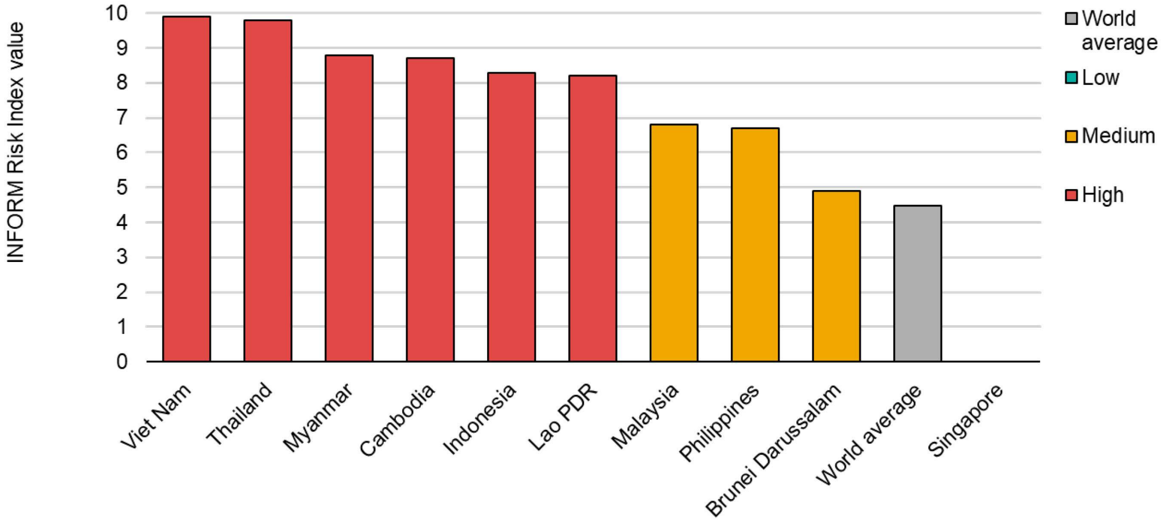
Climate change is considered a major reason for the increase in rainfall intensity in Southeast Asia. A warmer temperature increases evaporation, allows air to hold more moisture in it, and thus leads to more frequent and intense rainfalls. The latest IPCC report says that human-induced climate change contributed to the increase in the frequency and intensity of heavy precipitation events since 1950.

Intensification of tropical cyclones is also increasing heavy precipitation events. Indeed, in Southeast Asia, rainfall associated with tropical cyclones has increased since 1950. Tropical cyclone-induced floods accounted for 24.6% of the occurrence of all floods between 1985 and 2018 and brought bigger impacts than other types of floods in the Southeast Asian countries of Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam.

In addition, ENSO patterns contribute to heavy rainfalls in Southeast Asia. For instance, when Southeast Asia experienced a multi-year La Niña event from mid-2020 to early 2023, the amount of precipitation over Southeast Asia significantly increased, particularly during the winter season. In 2021 during the La Niña episode, Singapore reached its second-wettest year since 1980, and Malaysia and the Philippines also had rainfall well above their historical averages.

The increase in flooding risks with heavy rainfalls, intensification of tropical cyclones and ENSO effects has become a major concern in several parts of Southeast Asia. According to the INFORM Risk Index, a majority of Southeast Asian countries, including Viet Nam, Thailand, Myanmar, Cambodia, Indonesia, and Lao PDR are estimated to have a high flooding risk.

Level of river flood risk for Southeast Asian countries, 2024

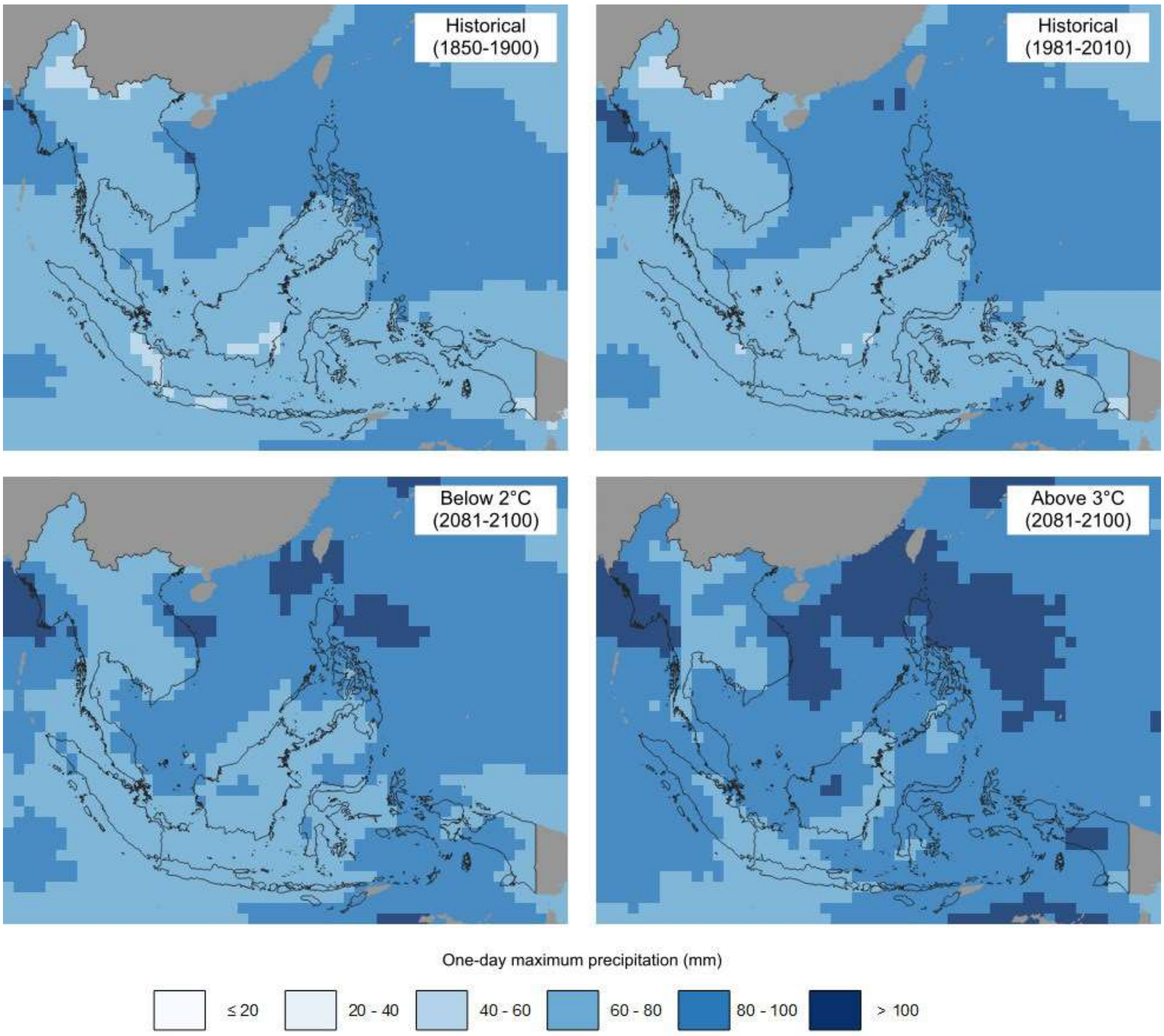


Notes: The level of climate hazard is assessed based on the indicator “River flood”. The minimum value is given 0 on the scale, while the maximum value is given 10. A detailed methodology of the indicator is described on the INFORM Risk Index page. In this report, the risk is defined as Low (0-2.99), Medium (3-6.99) and High (7-10).

Source: IEA analysis based on INFORM (2021), INFORM Risk Index 2024.

Climate projections show that Southeast Asia is likely to experience more intense and frequent heavy rainfalls including tropical cyclone-related rainfall. Climate projections show that more intense rainfalls, indicated by the one-day maximum precipitation, are especially notable in the coastal regions of Myanmar, the Philippines and Viet Nam. Especially when crossing the threshold of 2°C of warming, the region is likely to experience significantly different levels of changes in terms of heavy precipitation, run-off and flood risks. For instance, climate projections show that the increase in the frequency and intensity of heavy rainfalls would be more marked in higher-emissions scenarios, and the rate of tropical cyclone-related rainfall would increase more rapidly in a scenario over 4°C arming (28%) than in a scenario of 1.5°C warming (11%). Such increase in heavy rainfalls could lead to a notable increase of the total flood damage in river basins in Southeast Asia. Rapid urbanisation in the region could accelerate the increase of flood damage, given that the portion of urban land in a high-frequency flood zone is projected to expand to nearly 75% in Southeast Asia by 2030.

Change in maximum one-day precipitation, 1850-1900, 1981-2010 and 2081-2100



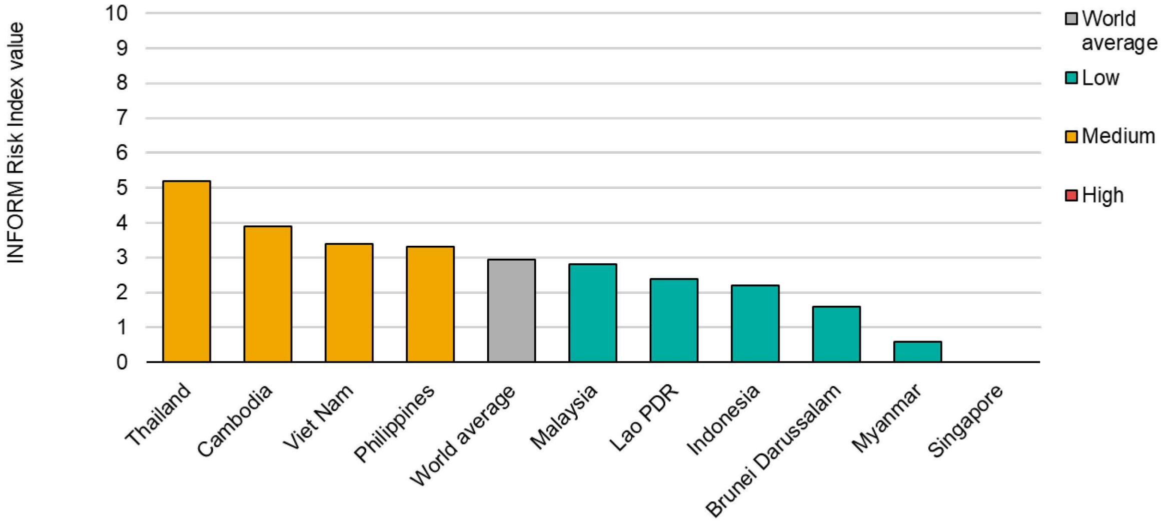
Source: IEA analysis based on IPCC (2021), Working Group I Interactive Atlas.

Temporal concentration of precipitation raises another issue – droughts

Since 1950, most Southeast Asian countries have experienced a reduction in the number of wet days while rainfall intensity has increased. It was a notable phenomenon given that global annual mean precipitation generally increased as global warming made air store more water. The dominant cause of the observed decrease in Southeast Asian monsoon precipitation was anthropogenic aerosol forcing, which weakened the land-ocean thermal contrast, and thus inhibited the development of monsoons. As rainfalls have become more temporally concentrated, some parts of Southeast Asia have suffered from a temporary increase in aridity. The number of mean consecutive dry days in Southeast Asia increased from 25.8 in the pre-industrial period to 27.6 in 1995-2014.

The increase in dry days and decrease in wet days resulting from the temporal concentration of rainfall events has caused temporary droughts in some parts of Southeast Asia. In the Philippines, for example, droughts increased during the dry season over the period between 1951 and 2010, despite the growth in precipitation during the wet season. According to the INFORM Risk Index, Thailand, Cambodia, Viet Nam and the Philippines have a higher level of drought risk than the world average. Similarly, the Association of Southeast Asian Nations (ASEAN) reported that more than 70% of the Southeast Asian land area was affected by droughts from 2015-2020.

Level of drought risk for Southeast Asian countries, 2024



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Notes: The level of climate hazard is assessed based on the indicator "Droughts". The minimum value is given 0 on the scale, while the maximum value is given 10. A detailed methodology of the indicator is described on the INFORM Risk Index page. In this report, the risk is defined as Low (0-2.99), Medium (3-6.99) and High (7-10).

Source: IEA analysis based on INFORM (2021), INFORM Risk Index 2024.

During the years of El Niño events, the risk of droughts increases further in Southeast Asia. In 2016, for instance, an El Niño episode contributed to a severe drought that resulted in the worst water crisis in 60 years in Indonesia, the Philippines and Thailand. When El Niño prevailed in 2018-2020, ASEAN reported that more than 200 million people were exposed to severe drought, representing around 30% of the region's population.

Climate models show a high level of uncertainty in drought projections for Southeast Asia due to the counteracting factors of projected increases in overall precipitation and temperature. In addition, human activities such as reservoir operation and water abstraction could add difficulties in assessing drought projections due to their profound effect on river flow and drought impacts in Southeast Asia.

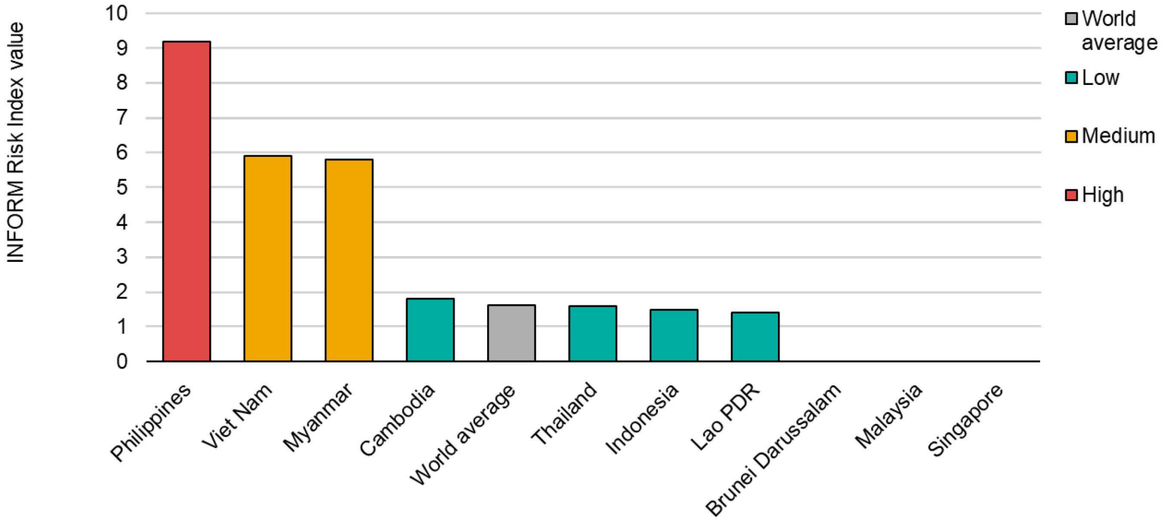
Wind

Surface wind speed remains stable but tropical cyclones are becoming more intense

In Southeast Asia, mean surface wind speeds have been stable while global mean wind speed has weakened over most land areas with good observational coverage. Historical observations show that surface wind speed in Southeast Asia did not change significantly from 4.1 m/s in the pre-industrial period (1850-1900) to 4.2 m/s between 1995 and 2014. Climate projections present that mean wind speed in the region would remain stable in all emissions scenarios, recording 4.1 m/s to 4.2 m/s average wind speeds across the century.

Although the mean surface wind speeds remain stable, Southeast Asia is highly exposed to high-speed winds such as tropical cyclones (which is also called typhoon in the region). Particularly, the Philippines, Viet Nam and Myanmar are considered to have the highest risks among Southeast Asian countries.

Level of tropical cyclone risk for Southeast Asian countries, 2024



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Notes: The level of climate hazard is assessed based on the indicator “Tropical cyclone”. The minimum value is given 0 on the scale, while the maximum value is given 10. A detailed methodology of the indicator is described on the INFORM Risk Index page. In this report, the risk is defined as Low (0-2.99), Medium (3-6.99) and High (7-10).

Source: IEA analysis based on INFORM (2021), INFORM Risk Index 2024.

Climate models show that tropical cyclones in Southeast Asia would decrease in frequency but increase in intensity. The proportion of intense tropical cyclones (Categories 3-5) and cyclone-related heavy precipitation have increased over the past four decades. Global warming is considered as the source of the intensification of tropical cyclones as warmer ocean temperatures fuel the intensification of tropical cyclones with more moisture in the air. If global warming continues, the proportion of intense tropical cyclones (Category 4-5) is likely to increase. The latest IPCC report projects that the proportion of intense cyclones is likely to increase by 10% in a scenario of 1.5°C warming and by 30 % in a scenario over 4°C warming, and Southeast Asia would not be an exception.

Sea level rise

The rate of sea level rise has accelerated, threatening the coastlines of Southeast Asia

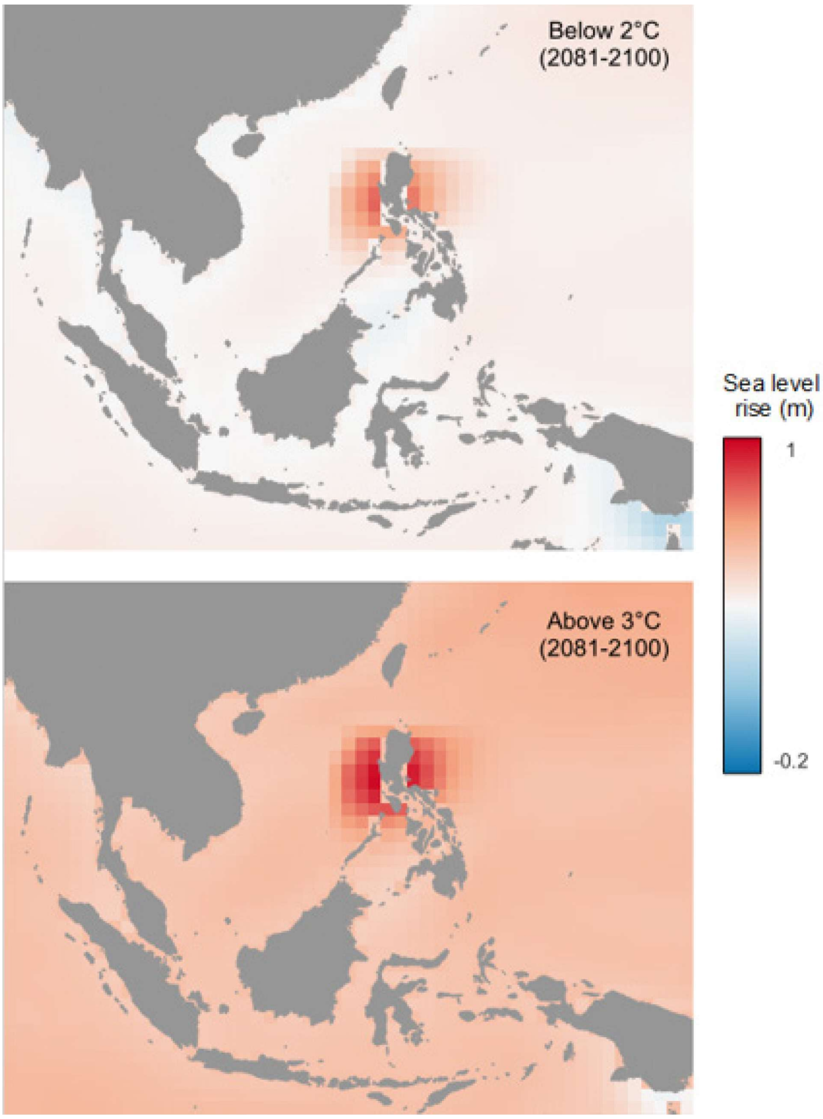
The increase in global temperatures has contributed to a rise in the global mean sea level. Since 1901, the global mean sea level has risen by 0.2 m. The rate of sea level rise accelerated from 1.3 mm per year on average from 1901-1971 to 1.9 mm from 1971-2006, and to 3.7 mm from 2006-2018. Glacial melt was the largest factor contributing to sea level rise, accounting for 40% of the rise between 1901 and 2018, and thermal expansion of ocean is the second-largest factor, accounting for 38% of the annual global mean sea level rise. In 2023, global mean sea level reached a record high with a current annual rate of rise of 4.4 mm per year.

Southeast Asia, which has a long coastline, could be affected by sea level rise and associated events (e.g. storm surges, coastal erosion and saltwater intrusion). Currently, 77% of the region's population lives along the coastline and 60% of GDP comes from the region. The IPCC projects that sea level rise in the oceans around Southeast Asia could be higher by 0.4 m to 0.7 m in 2081-2100 relative to the 1995-2014 period. If global warming and sea level rise are not mitigated on time, almost 90% of Viet Nam's population, 54% of Thailand's population, 24% of the Philippines' population, and 21% of Indonesia's population could be severely affected by sea level rise. At regional level, 229 million people and 39% of the population living in coastal areas are assessed to be vulnerable because they fall below the high tide line.

Several Southeast Asian countries are taking action to prepare for significant sea level rise. In Viet Nam, Ho Chi Minh city developed a plan to erect extensive tidal defence against the rising level of tides. In Singapore, the government claims that the country needs to spend at least USD 72 billion to construct coastal defences and build other adaptation measures to sea level rise.

Around the northern Philippines, sea level rise is more marked than in other areas. In the Manila Bay area in the Philippines, sea levels increased by 14.4 mm per year from 1965 to 2022, roughly four times the yearly global average rate of 3.4 mm per year. The impacts of climate-induced sea level rise in Manila Bay are amplified by land subsidence through intensive groundwater pumping causing these rapid but highly localised developments. To reduce coastal hazards, the Philippines are mainly using grey and green infrastructure. The Philippines' Department of Public Works and Highways has built and restored sea walls for protection, such as a 937 m long sea wall in Manila Bay. The Department of Environment and Natural Resources additionally targets the rehabilitation and conservation of mangroves for coastal protection.

Sea level rise by climate scenario, 2081-2100 relative to 1995-2014



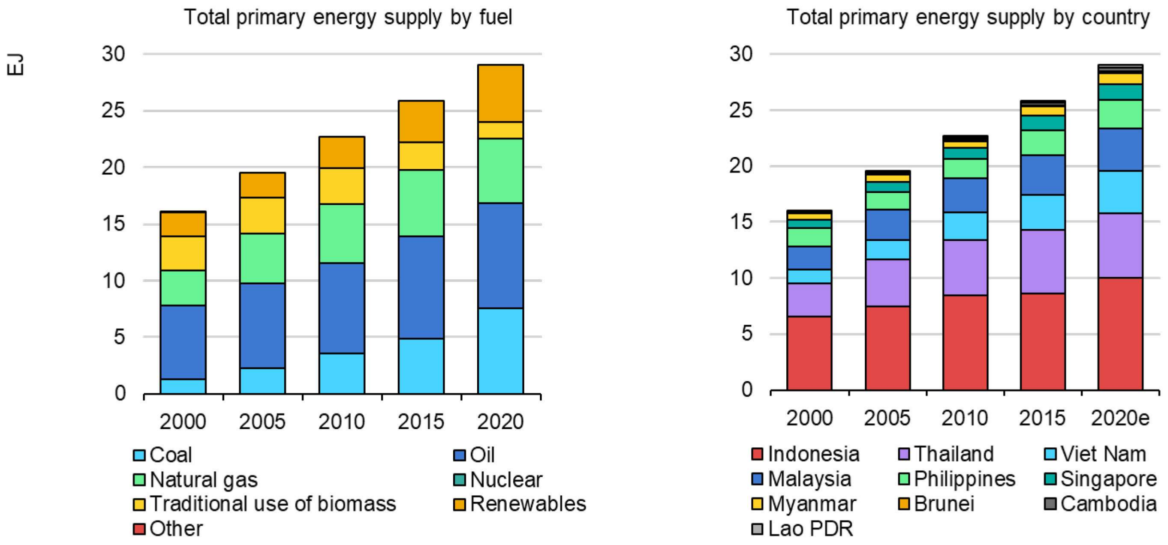
Note: Sea level rise (in metres) for 2081-2100 relative to 1995-2014 for scenarios Below 2°C (top) and Above 3°C (bottom).
Sources: IEA analysis based on IPCC (2021), Working Group I Interactive Atlas.

Climate change impacts on energy supply

The energy supply in Southeast Asia has substantially increased, supporting the expansion of the region's economic development and population growth. Between 2000 and 2020, Southeast Asia's overall energy supply increased by about 80%. The growth in energy supply is largely driven by fossil fuels, which more than doubled during the period. Renewable energy also recorded a notable growth of almost 2.5 times.

In parallel with the energy supply growth, climate change impacts have also increased. Southeast Asia is one of the regions most affected by climate change, experiencing more frequent heatwaves, intense rainfalls, droughts, tropical cyclones and sea level rise. Such climate impacts are adding pressure on energy systems that are already straining to meet the demands of economic growth, energy security and social welfare. Fossil fuels, which are currently serving a dominating role in Southeast Asia, could be disrupted by floods, sea level rise and tropical cyclones. Heavy precipitation and associated floods can interrupt the mining of critical minerals, which are key elements for clean energy technology deployment.

Total primary energy supply by fuel and by country in Southeast Asia, 2000-2020



Notes: EJ = exajoule; 2020e= estimated values for 2020.
Source: IEA (2022), Southeast Asia Energy Outlook 2022.

Fossil fuels

With economic development, urbanisation and population growth, fossil fuel demand is increasing in Southeast Asia. Coal recorded the largest growth in terms of its share in total energy supply between 2000 and 2020 from 8% to 26%. Demand for oil in Southeast Asia surged by more than 40% between 2000 and 2020 despite a reduction in its portion of the total energy supply from 40% to 32%. Natural gas consumption also increased by more than 80% between 2000 and 2020 and reached 162 bcm in 2021, although it maintained a 20% proportion of the overall energy mix. The use of natural gas in the economy is mostly driven by the electrical and industrial sectors.

By 2030, fossil fuel demand is projected to increase in the region, driven by a growing population, rising standards of living and rapid urbanisation. If today's policy setting remains, coal, oil and gas demand is set to increase by more than 30% by 2030. With policies and measures to ensure sustainable development, coal demand is projected to decrease by 17%, while oil and gas demand would increase by 22% and 38% respectively, driven by the expansion of car fleets, use of oil use in petrochemical feedstock and increasing gas demand for power generation.

Heavy rainfalls and flood risks add challenges to coal production

Coal provided a quarter of total primary energy supply in Southeast Asia in 2020. Nearly 90% of Southeast Asia's coal production comes from Indonesia, the third-largest coal producer in the world. About half of the coal produced in Southeast Asia is consumed within the region, with the rest being exported mainly to the People's Republic of China (hereafter "China") and India. Policy efforts to reduce greenhouse gas emissions from coal production have been made in Indonesia, with the international financing support of Just Energy Transition Partnerships.

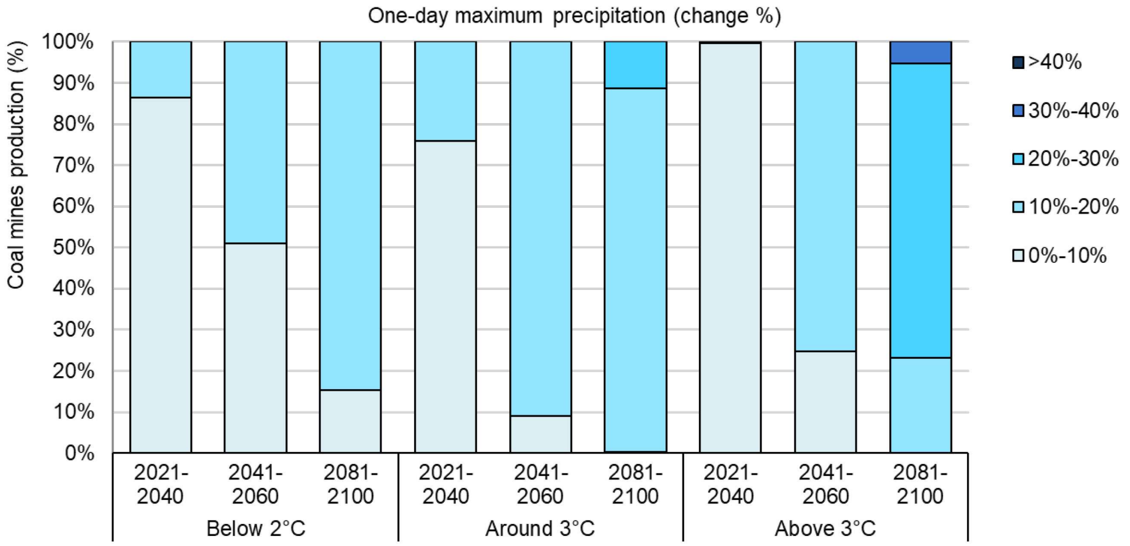
Coal production areas in Southeast Asia are projected to face notable challenges from climate change, such as more frequent heavy rainfalls. Nearly half of coal mines are projected to see over 10% increases in one-day maximum precipitation in 2041-2060 under a low-emissions scenario (Below 2°C). If climate change is not mitigated, over 75% of coal mines are projected to see more than 10% increases in 2041-2060 (Around 3°C and Above 3°C).

The projected increase in exposure of coal mines to intense rainfalls can add concerns to coal production. If coal is soaked at mines or stockyards by excessive precipitation or floods, its quality declines. Heavy rainfall and floods can also suspend production, force operation at reduced capacity or cause physical damage to mines. For instance, a week of heavy rain in 2015 in northern Viet Nam, where most of the coal output of the country is produced, caused water run-off from 16 open-pit coal mines. Thousands of tonnes of coal were swept away in the floods and two mines were completely submerged, according to the Viet Nam National Coal and Mineral Industries Corporation. The floods also led to an ecological disaster from the potentially hazardous toxic slurry from coal mines. In Indonesia, heavy rains hit a major coal production site, Kalimantan, and caused flooding at several mines, raising the coal price in 2021. Some illegal coal mines were accused of aggravating flood risks by exacerbating deforestation.

In order to reduce the flooding risk in coal production areas, some coal mining production sites are introducing resilience measures. In Viet Nam, for instance, restoration of trees and construction of dykes and dams have been implemented to prevent soil and rock from being swept away during the floods. In addition, hundreds of households in Quang Ninh province were migrated to ensure their safety as the risk of floods and landslides in coal mining areas increased.

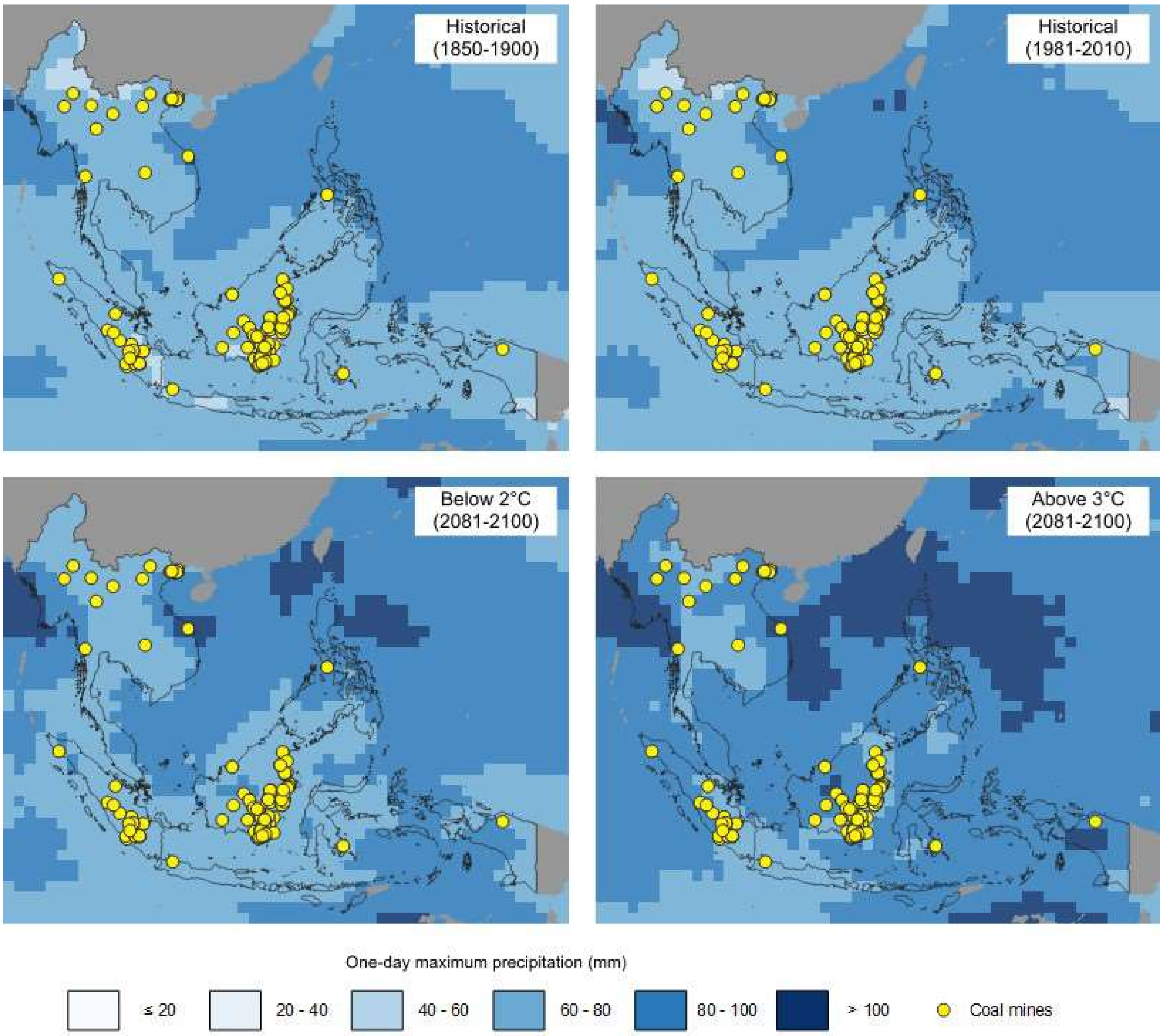
Given that higher greenhouse gas emissions would lead to more intense precipitation, a transition towards low-emissions sources is an effective and fundamental solution. In the pathway towards sustainable energy development with clean energy technologies and universal energy access, Southeast Asia's coal demand is expected to drop to 79 mtce in 2050 from 257 mtce in 2020. The reduced reliance on coal and diversification of energy sources would contribute to building a more resilient energy supply system by avoiding a further increase in emissions which can add flood risks to coal mines.

Share of coal mines exposed to more intense precipitation, 2021-2100



Note: The graphs show the share of coal mine production capacities exposed to the increase in intense precipitation, using the projected changes in one-day maximum precipitation, compared with the level of the pre-industrial period (1850-1900).
Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Coal mines exposed to more intense precipitation, 1850-1900, 1981-2010 and 2081-2100



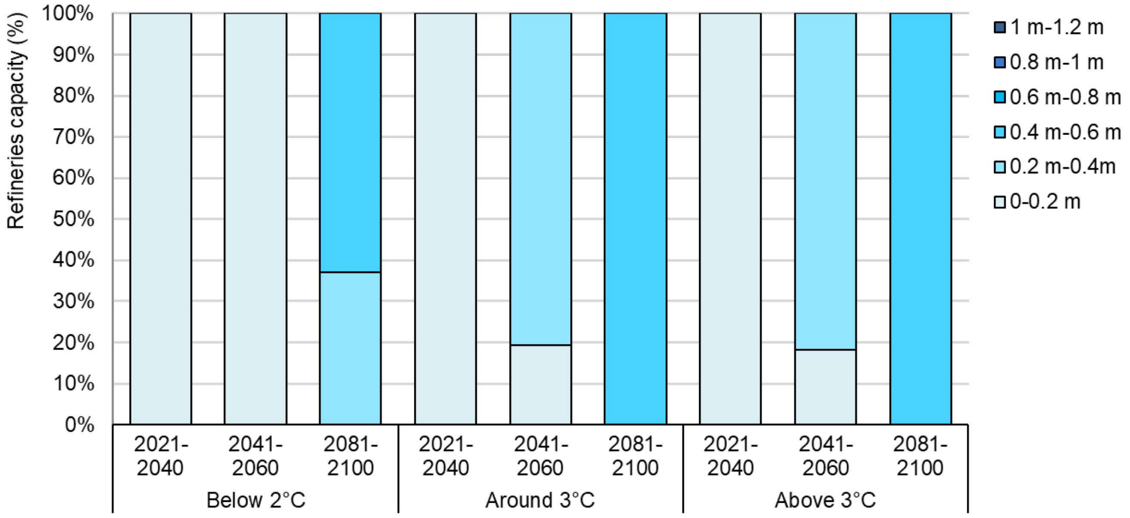
Sources: IEA analysis based on S&P Global (2021), [Market Intelligence Platform (database)]() and IPCC (2021), [Working Group I Interactive Atlas]().

Refineries in coastal areas are exposed to increasing risks of coastal flooding and storm surges with sea level rise and intensification of tropical cyclones

Over 90% of the refining capacity of Southeast Asia is located in coastal areas exposed to coastal flooding and storm surges. Around 42% of the total refining capacity is located in low-elevation areas of below 10 m over the sea surface which storm surge may reach. The share of low-elevated refineries in Southeast Asia is notably higher than that of the world, 34%. Thus, Southeast Asian refineries are considered more exposed to the effects of sea level rise and intensification of tropical cyclones than others.

Sea level rise can raise a concern for coastal flooding and storm surges for refineries in low-lying areas. Sea level rise is one of the important drivers of coastal floods and higher storm surges, which can cause physical damage to refineries and lead to temporary shutdowns. Although the sea level rise could be limited in a low-emissions scenario, in a high-emissions scenario over 80% of low-elevation refineries are projected to face a sea level rise of 0.2 m to 0.4 m in 2041-2060 and 0.4 m to 0.6 m in 2081-2100.

Low-elevation refineries capacity exposed to sea level rise, 2021-2100



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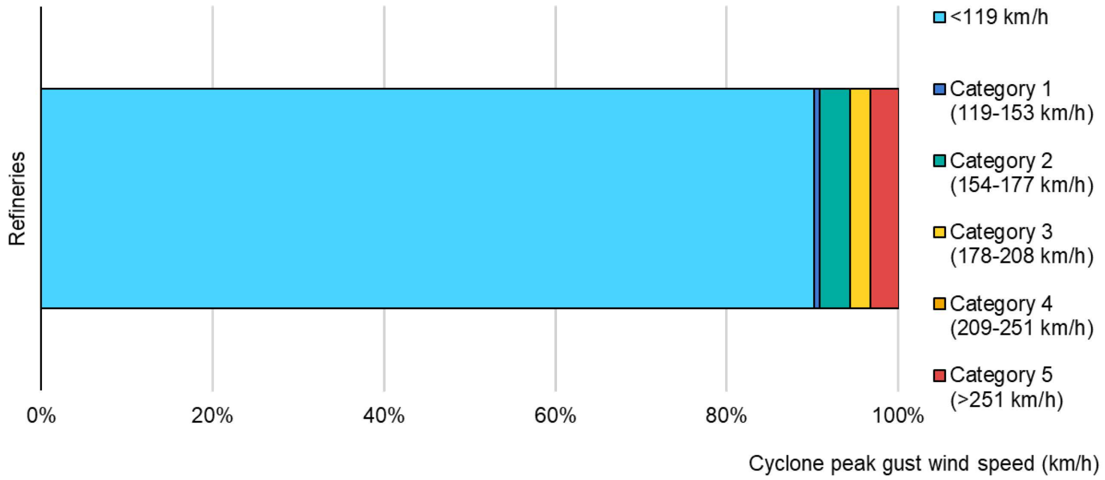
Note: The graph shows the exposure to sea level rise of refineries located in low-elevation areas (i.e. located at a level below 10 m), representing 42% of the total refining capacity, which is equivalent to 2 318 mb/d. The sea level rise is calculated relative to 1995-2014.

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Tropical cyclones, which are projected to intensify due to climate change, may add the risk of physical damage to refineries in coastal and offshore areas. Tropical cyclones are considered the main driver of coastal floods and storm surges together with sea level rise, and around 10% of refineries in Southeast Asia are located in tropical cyclone-prone areas. In 2019, for instance, tropical storm Pabuk led to a temporary shutdown of oil and gas production in the Gulf of Thailand, although the storm was comparatively weaker than normal tropical cyclones. Given that Thailand's refinery capacities are concentrated in the Gulf of Thailand, where tropical cyclones and storms occasionally pass, the intensification of tropical cyclones may require more resilience measures for refineries.

To cope with the adverse impacts of tropical cyclones, some countries have already assessed tropical cyclones' impacts on oil production and transportation. For instance, the Petroleum Authority of Thailand assessed the potential reduction of oil supply due to natural disasters, including tropical cyclones, and Malaysia developed a multi-hazard early warning system.

Share of refinery capacity exposed to tropical cyclones



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Note: The wind speed categories are divided according to the Saffir-Simpson Hurricane Wind Scale, a 1 to 5 rating based on a hurricane's maximum sustained wind speed. To be classified as a hurricane, a tropical cyclone must have a wind speed of at least 119 km/h, after which it falls into Category 1. Hurricanes rated Category 3 and higher (>177 km/h) are known as major hurricanes.

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and UNDRR (2015), Global Assessment Report on Disaster Risk Reduction.

Climate change impacts on shipping

Shipping and ports of Southeast Asia serve an important role in global and regional trade and transportation, including fossil fuels. The region has more than 500 international seaports, and more than one-third of global shipping passes through Southeast Asian waters. They also play an important role in international travel, transferring 5.3 million international sea passengers per year (as of 2018).

However, shipping is exposed to climate change impacts. Rising sea levels are likely to require more protection and management for ports, channels and coastal infrastructure against higher water levels, tides and storm surges. Moreover, intensified tropical cyclones and heavy rainfalls could disrupt shipping and port operation. In December 2021, for instance, heavy rainfall and flooding severely damaged Klang seaport, the second-largest port in Southeast Asia, and delayed port and logistics operations. In Viet Nam, due to tropical cyclone Noru, the Dung Quat oil refinery, which was in Noru's path, temporarily suspended crude oil imports and fuel exports in 2022.

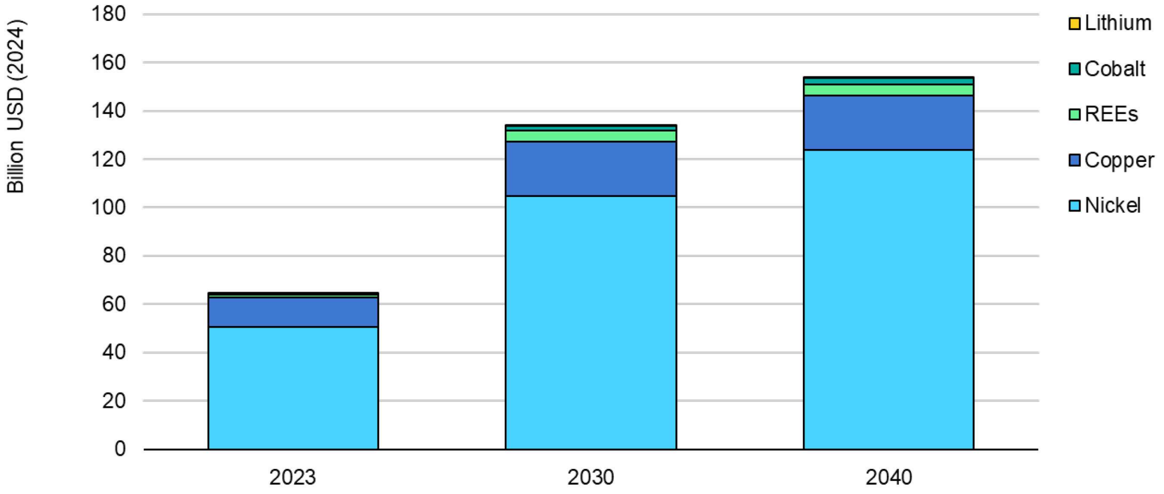
Such climate-driven disruptions to shipping and port operation may lead to higher energy consumption. Climate impacts can cause port congestion, shipping with alternative routes or substitution to more energy-intensive transport (such as aircraft and road transport) and consequently reduce energy efficiency for shipping. In 2021, container ships heading to China had to take alternative routes because Typhoon Kompasu scattered ships out of Hong Kong and Shenzhen. Vessel congestion rates in Southeast Asian ports jumped by 22% above normal in Singapore, and by 30% in Malaysia's Tanjung Pelepas, resulting in energy and economic losses.

Critical minerals

Critical minerals are fundamental to clean energy transitions and energy security. Global demand for critical minerals linked to clean energy technologies is set to rise sharply, spurred by growth in renewables, EVs, battery storage and electricity networks. Under current policy settings, the IEA Stated Policies Scenario (STEPS), mineral demand for clean energy technologies doubles by 2030. In the IEA Announced Pledges Scenario (APS), global demand for critical minerals is even higher, and it almost triples in the IEA Net Zero Emissions by 2050 (NZE) Scenario by 2030.

Southeast Asia plays a significant role in supply for nickel, tin, rare earth, copper and other critical minerals. Indonesia and the Philippines are the two largest nickel ore producers in the world. Indonesia and Myanmar are the second- and third-largest tin producers. Myanmar accounts for around 10% of global rare earth elements production. The mining sector has historically been an important contributor to the economy in Southeast Asia, although investment in mineral exploration has declined in recent years. If the region can develop domestic value chains for multiple industries, the market size from mining and refining production of nickel, copper, rare earth elements (REEs), cobalt and lithium in Southeast Asia could more than double to nearly USD 154 billion by 2040.

Market size of mining and refining production in Southeast Asia, 2023-2040



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Note: The market value is calculated by multiplying Southeast Asia's production volume in the base case in each year with today's market price for final products. The base case includes production from existing assets and those under construction, along with projects that have a high chance of moving ahead as they have obtained all necessary permits, secured financing, and/or established offtake contracts.

Source: IEA (2024), Global Critical Minerals Outlook 2024.

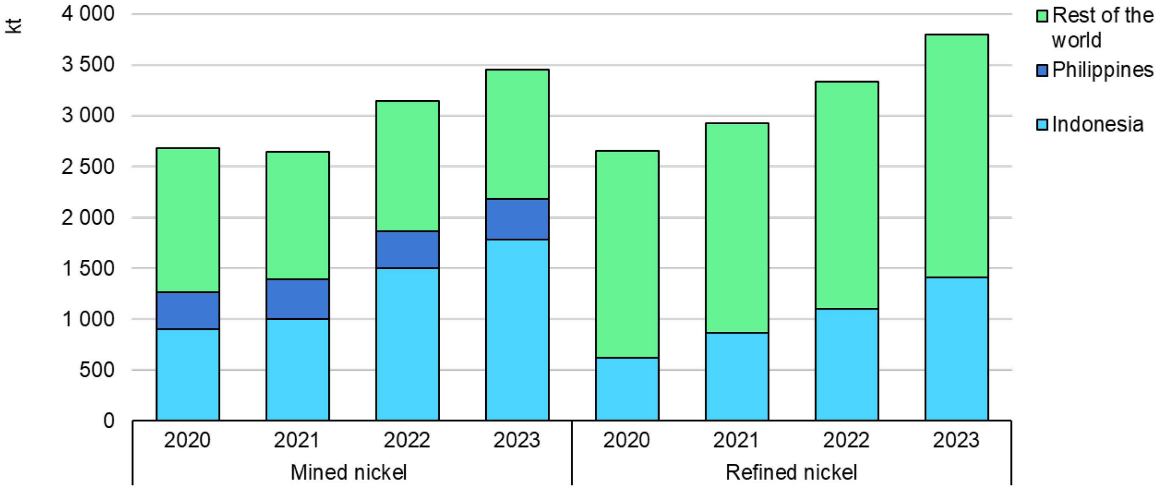
However, increasing climate risks, particularly related to water-related hazards, are becoming a concern to critical minerals mining. Critical minerals extraction and processing are generally water-intensive. Although Southeast Asia is likely to see an overall increase in total precipitation, the geographical and temporal concentration of precipitation may halt mining operations and damage mining facilities.

Increasing floods and heavy rainfalls in the region could become a concern to the global nickel supply in the long term

Nickel is a vital raw material in the production of stainless steel and batteries that are widely used in renewable energy deployment. The expansion of clean energy technologies drove the rapid growth in global demand for nickel by 30% between 2018 and 2023, and doubled the nickel market size. In the NZE Scenario, the demand for nickel is projected to double from the 2023 level.

Southeast Asia is delivering a dominant role in nickel supply today. Indonesia and the Philippines represent nearly two-thirds of the global output of mined nickel, which has significantly increased from around 40% in 2018. Indonesia alone accounts for around 40% of global output of refined nickel, which jumped from around 13% in 2018. Southeast Asian share in nickel production is expected to continue increasing in the coming years. By 2040, Indonesia could account for nearly 75% of mined nickel production and 60% of refined nickel production.

Production trends for mined and refined nickel, 2020-2023



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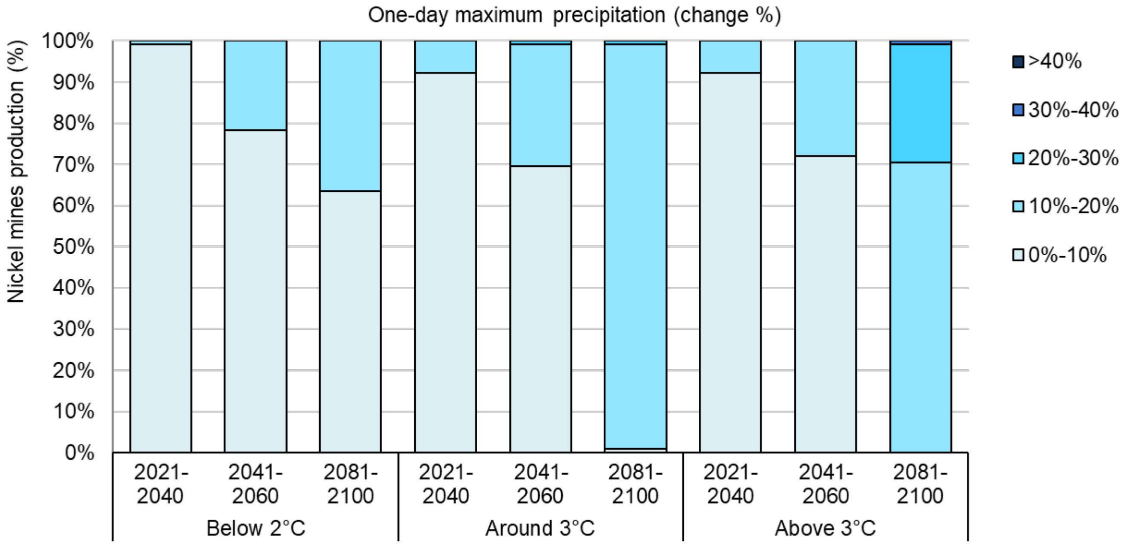
Note: Refining includes final refined products and sulphate production.
Source: IEA (2024), Global Critical Minerals Outlook 2024.

Climate change could become an emerging threat to nickel production in Southeast Asia by increasing the risk of flooding if resilience measures are not in place. Most of the nickel mines in Southeast Asia are projected to see more frequent heavy rainfall events and a wetter climate. Although the level of exposure of nickel mines is projected to be comparatively low until 2041-2060, changes in precipitation are likely to become more visible around the end of the 21st century. One-third of nickel mines in Southeast Asia are likely to see a more than 10% increase in one-day maximum precipitation by 2100 compared with the pre-industrial period in a low-emissions scenario. If climate change is not mitigated on time, almost all nickel mines in the region would see over 10% increases or more (in Around 3°C scenario and Above 3°C scenario).

The escalating risks of pluvial floods due to heavy rainfalls could be a long-term threat to reliable supply of nickel, which is already occasionally experiencing disruptions associated with extreme weather events. Indeed, heavy rainfall in 2019 led to floods on the Indonesian island of Sulawesi, a major hub for nickel mining, and caused several mines to shut down for weeks. Nickel prices worldwide jumped to two-week highs on fears of further supply disruptions. In August 2020 and in September 2023 heavy rain caused flooding that briefly shut down the Weda Bay smelter complex, one of the main nickel processing hubs in Indonesia. Moreover, the increasing intensity and frequency of heavy rainfalls are raising concerns about the run-off of toxic waste and pollution from nickel mines, as well as siltation of streams.

Share of nickel production exposed to more intense precipitation, 2021-2100

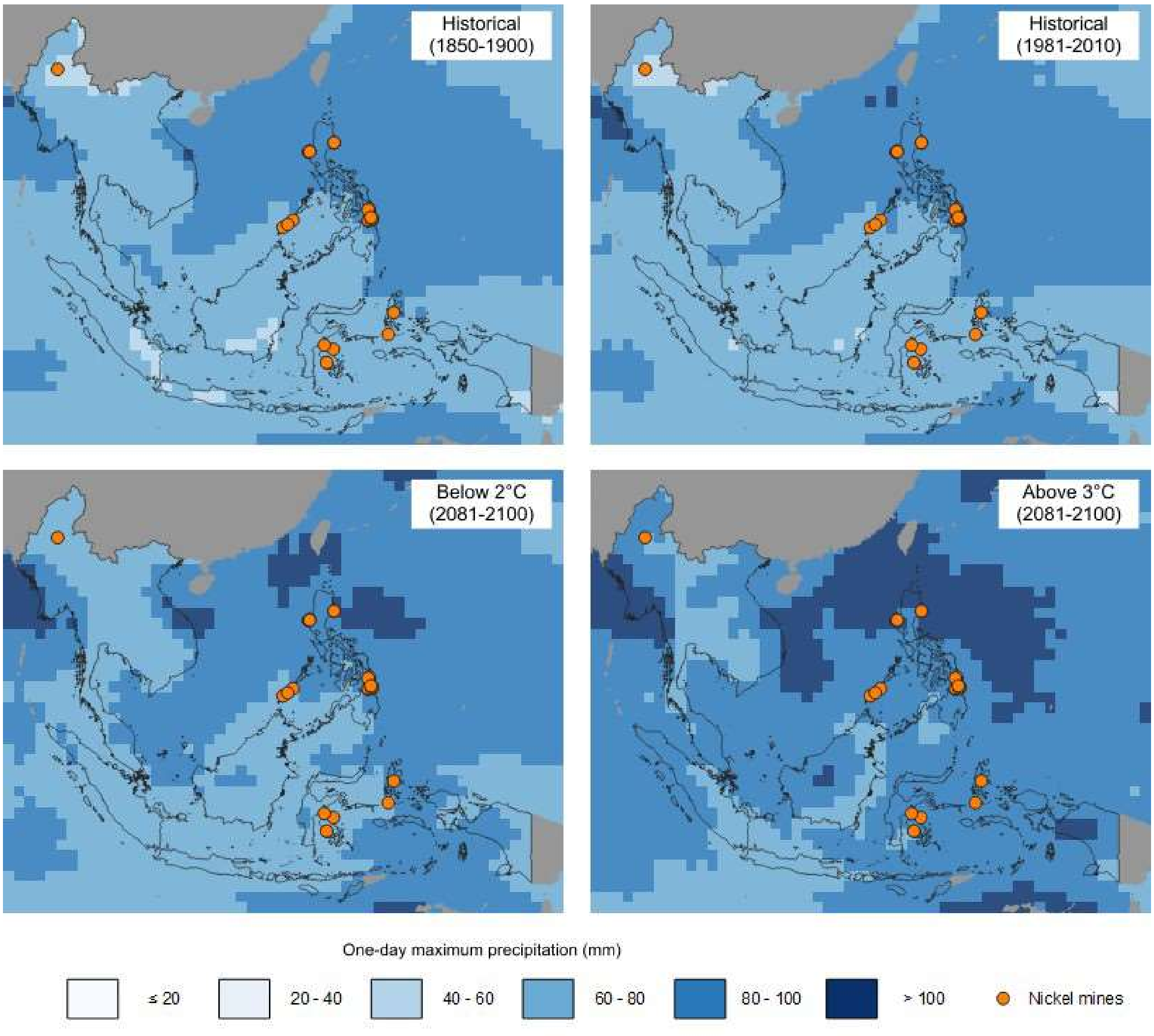


IEA. CC BY 4.0.

Note: The graphs show the share of nickel mine production capacities exposed to the increase in intense precipitation, using the projected changes in one-day maximum precipitation, compared with the level of the pre-industrial period (1850-1900).

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Nickel production exposed to more intense precipitation, 1850-1900, 1981-2010 and 2081-2100



IEA. CC BY 4.0.

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

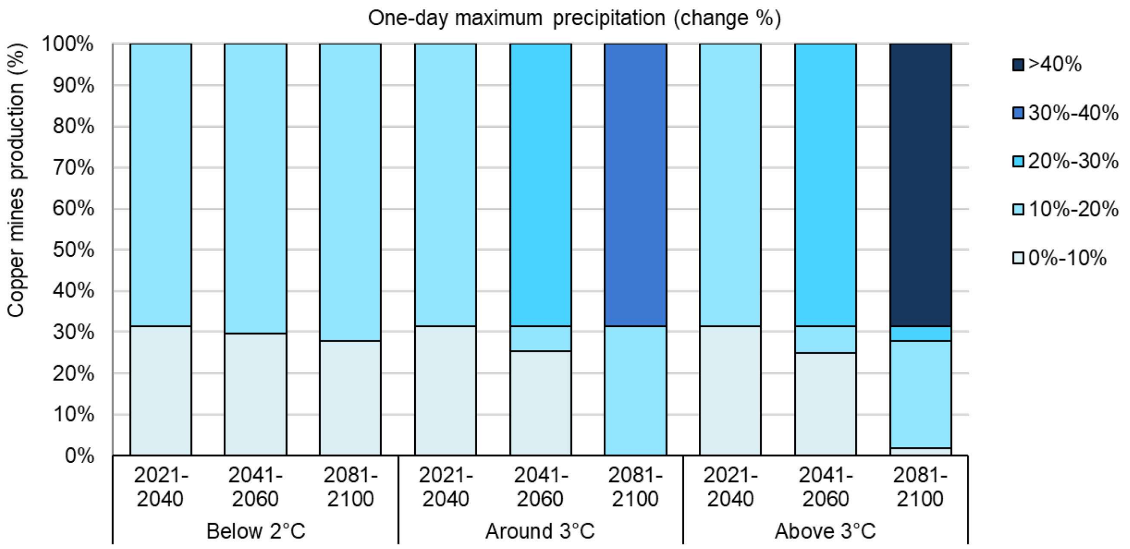
Copper mines in Southeast Asia are exposed to more frequent intense precipitation

Copper is used extensively in electricity networks, and it is an essential component for low-emissions power generation technologies such as solar PV modules, wind turbines and batteries. Global copper production is projected to see the largest increase of any critical mineral in terms of absolute volume by 2030. As copper production increases, the role of Southeast Asia becomes more important. Currently, Indonesia, Myanmar and the Philippines collectively account for around 5% of global production.

However, climate change poses an increasing risk to copper production, causing a majority of the copper mines in Southeast Asia to be more exposed to intense rainfalls and associated disasters such as floods and landslides. Operations at Grasberg mine, the biggest copper mine in Indonesia and second-largest in the world, for instance, were suspended for more than two weeks after heavy rainfalls and landslides in February 2023.

Although almost all components of the energy supply chain are projected to see more adverse impacts of climate change with high emissions, the difference between low- and high-emissions pathways is especially notable for copper production. While changes in one-day maximum precipitation are likely to be less than 20% in a low-emissions scenario (Below 2°C) until the end of the century, almost 70% of copper mines in the region could experience more than a 40% increase in a high-emissions scenario (Above 3°C).

Share of copper production exposed to more intense precipitation, 2021-2100

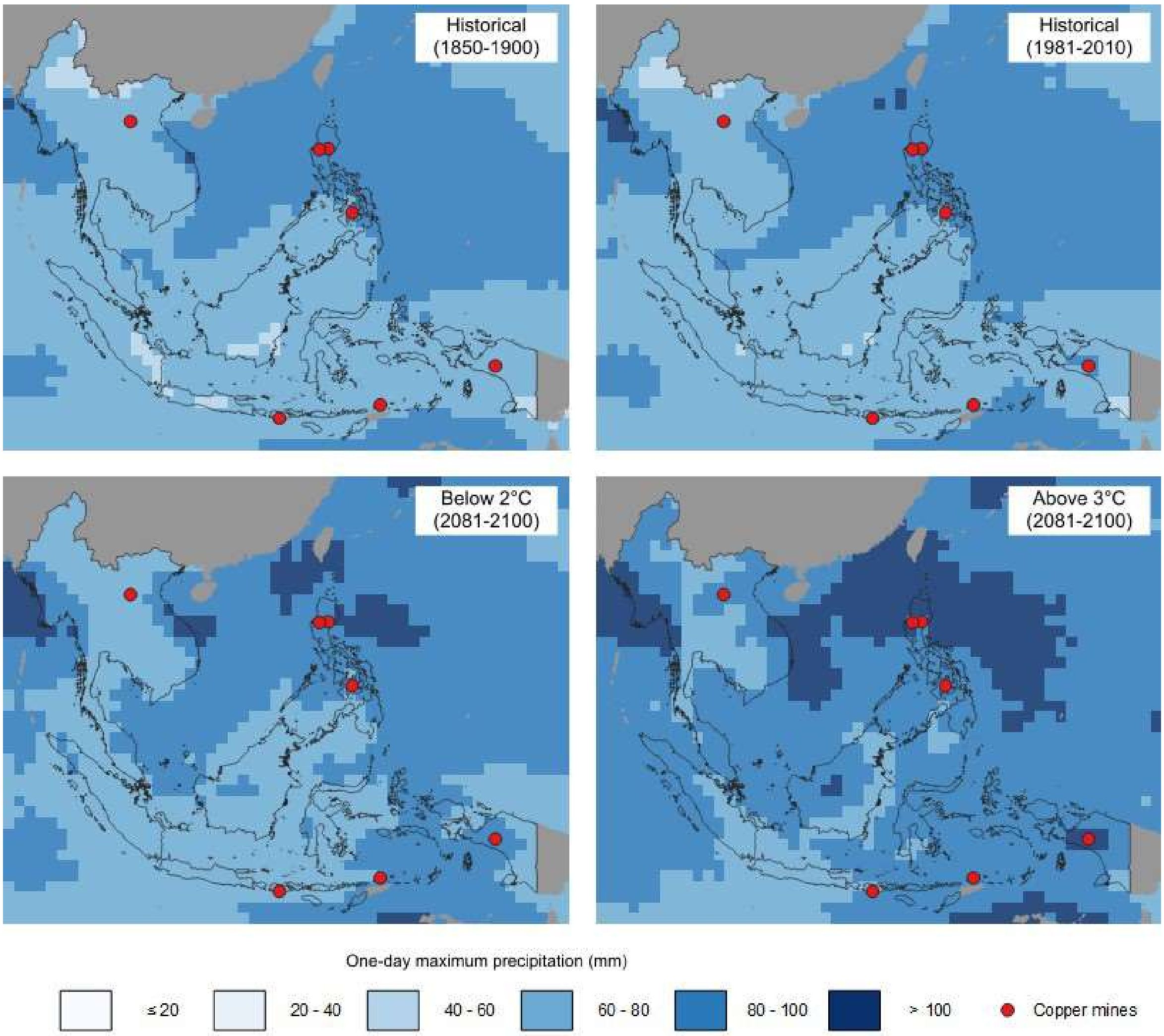


IEA. CC BY 4.0.

Note: The graphs show the share of copper mine production capacities exposed to the increase in intense precipitation, using the projected changes in one-day maximum precipitation, compared with the level of the pre-industrial period (1850-1900).

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Copper production exposed to more intense precipitation, 1850-1900, 1981-2010 and 2081-2100



Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Climate change impacts on bioenergy

Modern bioenergy* increased its share in the energy mix of Southeast Asia, as a key part of energy transitions. While the share of traditional use of biomass** in Southeast Asia's primary energy supply in 2020 was halved from what it was in 2010 to about 5% (1.5 EJ), modern bioenergy recorded a more than 50% increase accounting for over 7% (about 2.3 EJ). The share of modern bioenergy is expected to grow further until 2050 to near 5 EJ by 2050*** to meet climate and sustainable development goals, replacing fossil fuels in transport, industry, clean cooking and power generation. In this path, modern bioenergy would provide 15% of total final energy consumption by 2050, with power generation using solid modern bioenergy growing from 40 TWh in 2020 to 200 TWh by 2050, and advanced biofuel use reaching about 800 PJ by 2050.

Several countries in the region are already playing a leading role in global bioenergy production with robust industries and policies. Indonesia produces 8.1 billion litres of biodiesel each year, making it the third-largest biofuel producer in the world, while Malaysia produces 1.5 billion litres of biodiesel, exporting together 500 million litres annually.

Climate change which alters the precipitation patterns may affect the production of biomass in the region, although its net effects would vary by country, by crop and by adaptation measures taken by producers. Experts estimate that increased levels of CO_2 in the atmosphere would lead to improved vegetation growth and productivity, but increasing heat and changing precipitation patterns may constrain the production of biomass in at least some countries in Southeast Asia. For instance, palm oil production in Indonesia and Malaysia is likely to suffer from the projected increase in droughts, floods, wildfires and sea levels, despite the overall increase in total precipitation. Among others, prolonged droughts are already posing challenges to palm oil production by lowering palm yields and raising prices, as seen in the cases of Indonesia and Malaysia in 2015, 2019 and 2023. Other Southeast Asian countries including Cambodia, Thailand, the Philippines and Viet Nam are also facing issues related to droughts, which threaten consistently high crop yields, reduce photosynthesis and change the chemical composition of crops. In 2016, for example, a drought in Viet Nam's Central Highland region led to a 60% decline in crop production.

* Modern bioenergy comprises solid bioenergy mostly derived from organic waste sources, such as forestry residues or municipal solid waste, liquid biofuels, and biogas and biomethane.
** Traditional use of biomass refers to the use of solid biomass with basic technologies, such as a three-stone fire or basic improved cookstoves, often with no or poorly operating chimneys.
*** Includes all solid bioenergy products, except the traditional use of biomass.

Power sector

Over the past two decades, power generation has almost tripled in Southeast Asia. Urbanisation has been one of the key drivers of the increase in electricity consumption, with the buildings sector seeing the largest increase, notably due to air conditioning and ownership of appliances such as refrigerators. This growth was mainly supported by coal-fired power generation, which was multiplied by six, accounting for 43% of power generation in 2022. Natural gas and renewables provided the rest of the electricity generation, with natural gas covering 29% and renewables 27%.

Electricity generation and consumption in Southeast Asia is likely to grow rapidly in all scenarios, while growing climate change impacts put strains on the power system. Rising temperatures, changing precipitation patterns, sea level rise and shifting wind speeds are raising new questions about the intersection between climate change impacts and the power system. They are likely to affect every aspect of the power system from the potential, efficiency and reliability of power generation to the physical resilience of energy infrastructure. Given that extreme weather events (e.g. floods, droughts, heatwaves, tropical cyclones) are projected to become more frequent and intense as climate change continues, a comprehensive understanding of climate impacts is crucial to ensure electricity security.

Rising temperatures and heatwaves affect solar PV and gas power plants, and reducing emissions is key

Climate change leads to increased global mean surface temperature,[4] which impacts precipitation, winds, sea level rise, and extreme weather events. Average temperatures in Southeast Asia have risen every decade since 1960. The average land surface temperature in the region increased from 25.02°C in 1979-1988 to 25.76°C in 2013-2022. The Intergovernmental Panel on Climate Change (IPCC) projects that Southeast Asia are likely to continue experiencing an increase in annual mean surface temperature by around 1.6°C until the end of the century relative to pre-industrial levels under the Below 2°C scenario and by around 3.3°C in the Above 3°C scenario. The changes in ambient temperatures could directly affect energy systems, notably through changing seasonal lengths and the increasing frequency and intensity of extreme heatwaves.

Power generation from solar PV is subject to weather and climate conditions. Solar PV relies on irradiance and is affected by heat. Although potential changes in solar radiation due to climate change could be minor, the negative impacts of extreme heat are growing. Higher temperatures lead to a lower voltage and less solar power generation, as most solar PV works best in cool, sunny weather around 25°C. Moreover, solar power generation efficiency degrades as the surface temperature of solar PV panels increases generally from -0.3% to -0.5% per degree above 25°C. Extreme heat can also increase the electrical resistance of the circuits and damage cells and other materials, while adding heat stress to inverters.

In Southeast Asia, solar PV is rapidly growing. In 2022, solar PV generated 45 TWh, which accounts for 4% of total installed capacity in the Association for Southeast Asian Nations (ASEAN). Viet Nam, Thailand and Malaysia have the largest installed solar PV capacity in 2022 and the future growth is likely to be led by Thailand and

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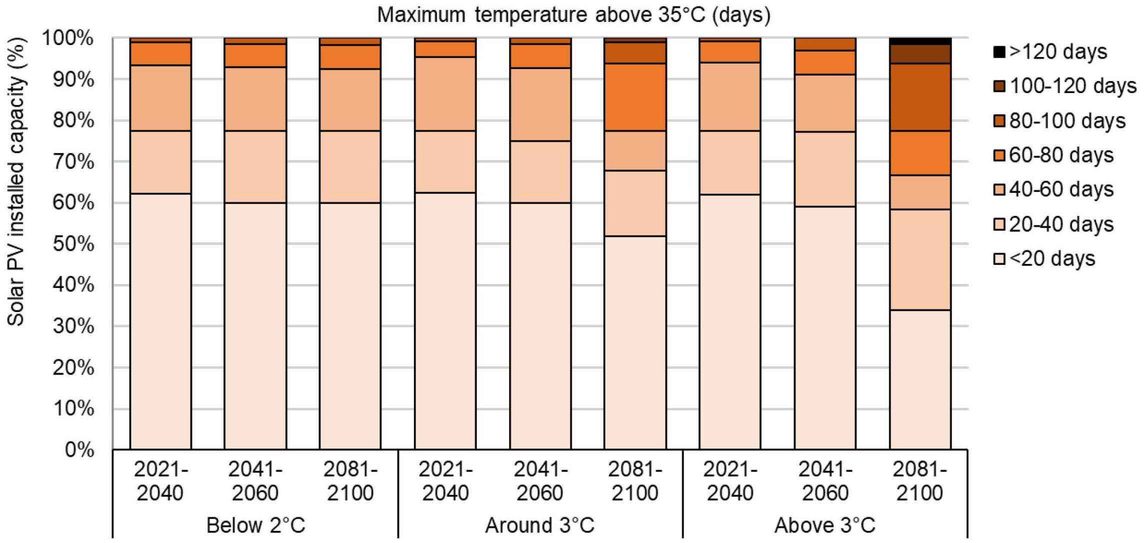
[4] Average temperature at the surface of land and ocean areas.

Myanmar. The IEA's Sustainable Development Scenario (SDS)[5] estimates the power generation of solar PV in the region would reach 163 TWh by 2030 and 732 TWh by 2050.

However, rising temperatures due to climate change are likely to challenge electricity generation using solar PV in the region. Although most installed solar PV capacity in Southeast Asia is located in places with annual mean temperatures of 25°C-30°C – suitable for solar PV generation – they are projected to experience more frequent extreme heat events in the coming decades. Particularly in a high-emissions scenario, around two-thirds of solar PV would see more than 20 days of maximum temperature above 35°C in 2081-2100, presenting a notable increase from the current level. Moreover, climate models show that around 20% of solar PV might see over 80 days of 35°C thresholds by 2100 in the same scenario.

Share of solar PV exposed to heatwaves, 2021-2100



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Note: The graphs show the share of solar PV installed capacities for each level of temperature rise and extreme heat using the number of days with maximum temperature above 35°C.
Sources: IEA analysis based on Global Energy Monitor (2022), Global Solar Power Tracker and IPCC (2021), Working Group I Interactive Atlas.

Increasing temperatures could also decrease electricity generation from natural gas power plants. According to the Southeast Asia Energy Outlook 2022, natural gas consumption surged by over 80% between 2000 and 2020, consistently holding a 20% share of the energy mix. Natural gas power plants are generally affected by changes in ambient temperatures since their performance depends on the air mass flow entering the gas turbine compressor. The air mass flow is determined by the density of the air, which decreases when ambient temperature

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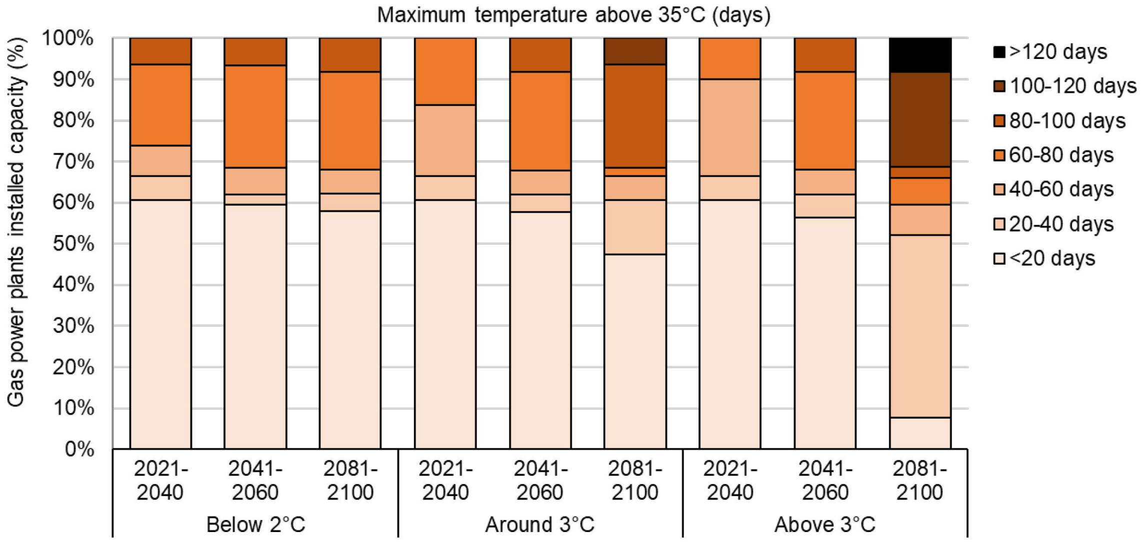
[5] The SDS delivers on the Paris Agreement goal to limit the temperature to "well below 2°C", alongside the goals on energy access and air pollution. This scenario is consistent with Southeast Asia's current announced climate aspirations.

increases. Thus, high ambient temperature negatively affects the performance of natural gas power plants by 0.3-1.0% per degree increase. For instance, Muara Karang natural gas power plants in Indonesia reported a 0.6% decrease in the power output of the open-cycle gas turbine plant with every 1°C rise in ambient air temperature above 16°C.

Rising temperature of cooling water also has negative impacts on generation efficiency, although the impact is marginal compared with the impact of a warmer ambient temperature. A study on the Muara Tawar combined-cycle power plant in Indonesia discovered that power output could decrease by around 0.17% for each 1°C increase in the temperature of the cooling water drawn from nearby seawater.

Climate models project that annual mean temperatures are likely to continue increasing with more frequent extreme heat events. In all scenarios, over 30% of gas power plants are projected to experience more than 40 days of maximum temperature above 35°C in 2021-2040. In 2081-2100, the number could jump notably to over 80 days in the Around 3°C scenario and over 100 days in Above 3°C, while there would be minor changes in Below 2°C.

Share of gas power plants exposed to heatwaves, 2021-2100



IEA. CC BY 4.0.

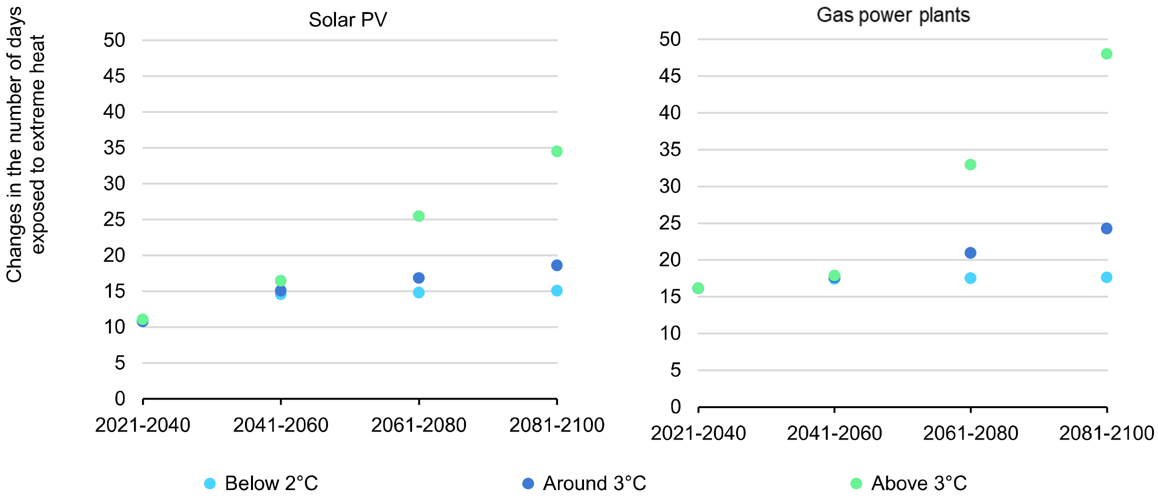
Note: The graphs show the share of gas power plants installed capacities for each level of temperature rise and extreme heat using the number of days with maximum temperature above 35°C.

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

The analysis shows that limiting the global temperature increase is critically important for the resilient operation of solar PV and natural gas power plants. Climate models warn that both power technologies would be more exposed to extreme heat if climate change is not mitigated, and the negative climate impacts would be significant given that they are sensitive to extreme heat. Solar PV is projected to experience 15 days more above 35°C thresholds in a low-emissions scenario (Below 2°C) by the end of this century compared with the pre-industrial period, and the number could jump to 35 days in a high-emissions scenario (Above 3°C). The difference is even more marked with natural gas power plants. They are projected to face 18 extreme heat days more in a low-emissions scenario (Below 2°C), and 48 days in a high-emissions scenario (Above 3°C).

To cope with the increasing heat stress, innovative technologies are increasingly adopted to curtail the adverse impacts on solar PV and natural gas power plants. For solar PV, active cooling technologies are increasingly applied, shifting from traditional passive cooling systems based on natural convection. More solar PV projects are considering using cooling methods based on water, enhanced phase change materials, heat pipes and sink cooling. Some natural gas plants use inlet air cooling technologies to reduce ambient air temperature before air enters.

Solar PV and natural gas plants exposed to extreme heat compared with the pre-industrial period by climate scenario



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Note: The graphs show changes in the number of days with maximum temperature above 35°C by 2100 compared with the pre-industrial period (1850-1900).

Sources: IEA analysis based on Global Energy Monitor (2022), Global Solar Power Tracker, S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Extreme heat puts stress on the electricity network, increasing the need for more investment in power grid enhancement

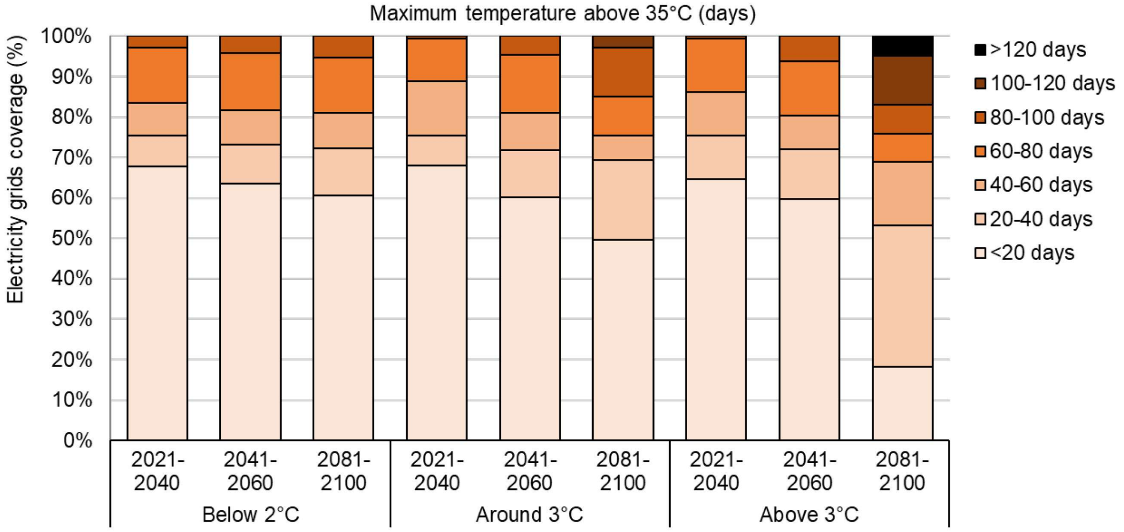
Higher ambient temperatures reduce not only power generation efficiency but also transmission and distribution efficiency. Overhead power lines can heat up, expand and sag. Underground power cables could experience short circuits due to the combination of extreme heat and droughts, as persistent high temperatures stress cable and joint insulating materials. Critical components such as transformers, inverters and substations are also at higher risk of failure from overheating.

Furthermore, a warmer temperature combined with increasing aridity could augment wildfire risks to electricity grids. For instance, forest fires triggered by sweltering temperatures in central Viet Nam in June 2019 put at risk a power transmission line and prompted a power cut. The state-run Viet Nam Electricity Group reported power shortages in the northern and central parts of the country due to the forest fires while electrical loads rapidly increased with heat.

Climate models show that electricity networks are likely to face more heat-related stress in the long term. In the near term (2021-2040), around one-third of the electricity network would be subject to over 20 days of above 35°C maximum temperature in all scenarios. If climate change is not mitigated, the share would jump significantly to over 80% by 2100 in a high-emissions scenario (Above 3°C). A quarter of the global electricity network is projected to see over 80 days of extreme heat over the 35°C threshold.

The increasing heat stress requires more investment for power grid enhancement. Upgrades, modernisation and maintenance of electricity networks can limit losses. Smart and advanced digital technologies provide options to reduce the stress and risks to electricity grids, enabling network operators to manage potential disruptions remotely and on time. Furthermore, connections to distributed energy sources and batteries can provide backup power when electricity network disruption occurs due to extreme heat. Regional integration requires the scaling up of investment in electricity grids, including in interconnections between countries. Grid investment may need to rise from around USD 10 billion in 2022 to USD 20 billion to USD 40 billion in 2050.

Share of electricity grids exposed to heatwaves, 2021-2100



Note: The graphs show the share of electricity grids installed capacities for each level of temperature rise and extreme heat using the number of days with maximum temperature above 35°C.
Sources: IEA analysis based on OpenStreetMap and IPCC (2021), Working Group I Interactive Atlas.

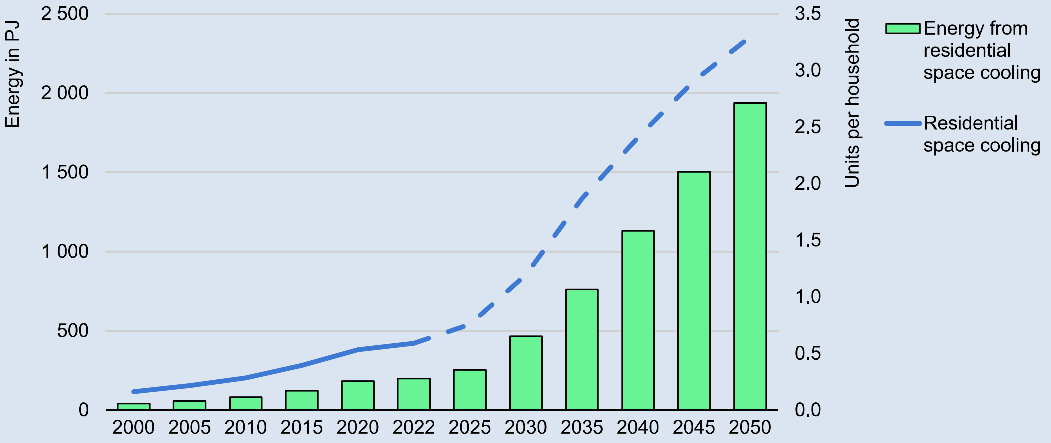
Climate change impacts on electricity demand for cooling

Electricity demand in Southeast Asia is increasing rapidly. Electricity demand in the ASEAN countries is among the fastest-increasing globally, rising by more than 6% per year on average over the last 20 years. The increase is mainly driven by population and economic growth. Southeast Asia is home to nearly 9% of the world's population and accounts for 6% of global GDP. Collective GDP of Southeast Asian countries has nearly tripled since 2000.

Climate change may increase electricity demand further on top of the projected rise in Southeast Asia. Rising global temperatures can increase electricity usage during peak hours in summer months due to increased cooling needs in buildings. Since the 1980s, the regional mean temperature increased with a higher frequency of warm nights and heatwaves. The number of cooling degree days, which indicates the sum of the excess temperatures above a threshold for cooling, increased from around 1 200 in 1850-1900 to around 1 350 in 1981-2010.

The combination of escalating temperatures and economic growth in Southeast Asia has led to a large increase in air conditioner and appliance use in the region, making space cooling one of the fastest-growing electricity-consuming end uses in Southeast Asia. Its energy consumption is expected to more than triple by 2040. Consequently, in the past two decades, the buildings sector has seen the largest increase in electricity consumption among all sectors and as of 2022, accounted directly and indirectly for 22% of final energy consumed and for 54% of electricity consumption in Southeast Asia.

Residential space cooling units per household and energy use in Southeast Asia in the Stated Policies Scenario, 2000-2050



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Note: Projections starting in 2023.

With rising temperatures, the electricity demand for cooling will continue to increase. The regional average cooling degree days is projected to reach around 2 100 in 2080-2100 under a low-emissions scenario (Below 2°C) and nearly 3 000 in a high-emissions scenario (Above 3°C). Climate models warn that the number of days above a maximum temperature of 35°C may increase by two to five times in Southeast Asia compared with the pre-industrial period.

Although only 18% of households in Southeast Asia had air conditioning in 2019, around 60% of households in Southeast Asia are projected to have access to space cooling by 2040 in the IEA STEPS. By then, the average household could own almost two air conditioning units. This increase may lead to a large growth in electricity demand and can pose risks to the electricity system. Some Southeast Asian countries are projected to experience more strains than others. Countries with low air conditioning ownership rates (less than 10% as of 2017), such as Cambodia, Indonesia, Lao People's Democratic Republic (PDR), Myanmar, the Philippines and Viet Nam, are projected to see a greater increase in air conditioner use in coming decades.

The rapidly growing air conditioner use further escalates peak electricity demand in countries where electricity demand is already reaching its peak during the hottest months of summer. Increasing peak electricity demand can pose a serious risk of disruption to the electricity system. In Viet Nam, for instance, soaring peak electricity demand combined with severe heatwaves led to power cuts in May 2023. In northern Viet Nam, where more than 32% of national GDP comes from, soaring demand combined with decreased hydropower output caused frequent power outages which lasted as long as 26 hours.

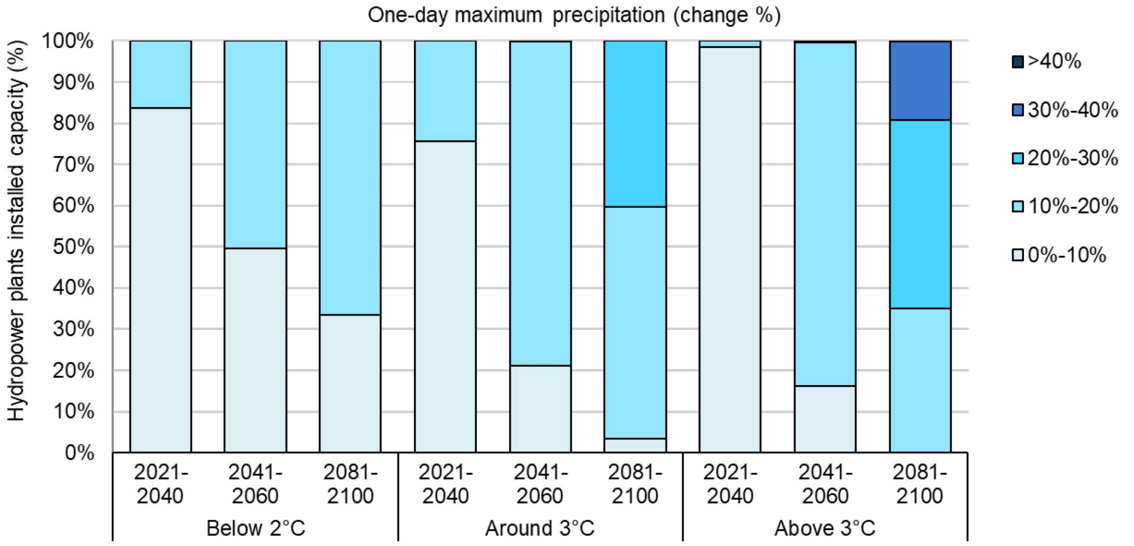
Increasing annual and seasonal variability in precipitation requires building climate resilience for hydropower

Hydropower plays a pivotal role as the largest renewable energy source for electricity in Southeast Asia. It accounts for nearly 15% of total electricity generation. The installed hydropower capacity is expected to grow in order to meet the region's growing electricity demand and electricity export opportunities. Hydropower is likely to provide the most seasonal flexibility in the coming decades, supporting the integration of variable renewable energies. Under the IEA's SDS, hydropower generation is projected to be more than quadrupled in 2050 compared with today's level in Southeast Asia, although its share may decrease.

While hydropower's role expands, the impacts of climate change are also growing. Although hydropower dams can help mitigate extreme weather impacts, hydropower's dependence on hydrological conditions implies its vulnerability to climate change. Changes in rainfall patterns and prolonged droughts directly affect water availability for hydropower generation, although the magnitude of their impacts may vary depending on types of hydropower plants. Generally, run-of-river and impoundment hydropower plants tend to be more sensitive to changes in precipitation patterns, while pumped storage hydropower plants tend to be less dependent on precipitation thanks to their closed-loop operation between two reservoirs. More frequent floods resulting from heavy rainfalls, glacier melt and tropical cyclones may interrupt hydropower operation, and physically damage plants with landslides, sediments and debris.

Climate change is projected to affect hydropower generation in Southeast Asia, increasing annual and seasonal variabilities in precipitation and run-off. In all climate scenarios (Below 2°C, Around 3°C and Above 3°C), over half of hydropower installed capacity in Southeast Asia is projected to see a more than 10% increase in one-day maximum precipitation in 2041-2060 compared with the pre-industrial period. If climate change is not mitigated (Around 3°C and Above 3°C), 40-65% of hydropower installed capacity may experience a 20-40% increase in one-day maximum precipitation in 2081-2100.

Share of hydropower plants exposed to more intense precipitation, 2021-2100



IEA. CC BY 4.0.

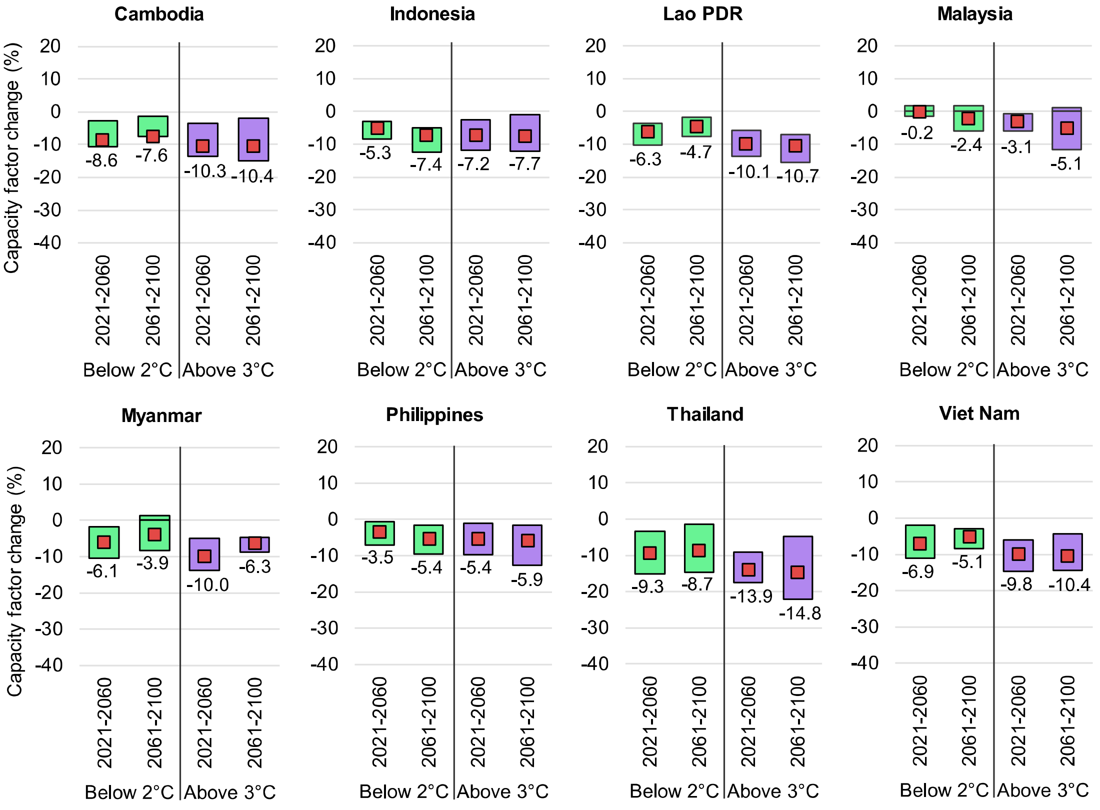
Note: The graphs show the share of hydropower installed capacities exposed to the increase in intense precipitation, using the projected changes in one-day maximum precipitation, compared with the level of the pre-industrial period (1850-1900).

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database) and IPCC (2021), Working Group I Interactive Atlas.

Temporal concentration of precipitation, with more frequent intense rainfalls, raises a concern about hydropower generation. Generally, hydropower generation output can be maximised with consistent water flow year-round aligned with design capacity. However, the temporally concentrated rainfalls with fewer wet days may lead to a decrease in hydropower capacity factor. According to IEA analysis based on the IPCC climate models and hydrological models, the hydropower capacity factor in Southeast Asia is projected to fall by around 5% in a low-emissions scenario (Below 2°C) by 2100 compared with 1970-2010. In a high-emissions scenario (Above 3°C), the hydropower capacity factor may decline by nearly 9%. The decrease could be more marked in Mekong River basin (e.g. Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam) than other Southeast Asian countries.

Some Mekong River basin countries have already experienced electricity supply disruptions due to negative climate impacts on water availability for hydropower generation. In June 2023, reduced water levels in hydropower dams combined with a sharp rise in electricity demand due to extreme heat resulted in power cuts for 26 hours in Viet Nam. Similarly, Cambodia faced a nationwide power shortage in 2019 that was largely attributed to low reservoir levels caused by a prolonged drought.

Changes in hydropower capacity factor in Southeast Asia by country, 2021-2100 relative to 1970-2010



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Note: The assessment is based on 12 different combinations of general circulation and global hydrological models. Green and purple boxes indicate the range of 67% of modelling results and red dots indicate the average of all modelling results.

Governments have several policy options available to minimise the impacts of climate change on hydropower generation. Governments can build climate resilience by mainstreaming climate change consideration into their decision-making process: mandating assessments of climate change impacts on potential plant sites, incorporating resilience standards into construction codes and establishing emergency response plans. Hydropower operators can enhance climate resilience by identifying climate risks of hydropower projects, modernising vulnerable hydropower plants and adopting more flexible operating regimes in response to variabilities. Infrastructure enhancements such as incorporating smart technologies, increasing reservoir and spillway capacity, and introducing landslide protection also contribute to greater resilience.

Furthermore, international co-operation can play a key role in enhancing climate resilience. Global and regional collaboration is essential for accurate climate projections and data collection. In Southeast Asia, interconnected power networks across different river basins are being explored as a solution to address variabilities in water availability. Cross-border co-operation in water resource management further supports the development of climate resilience. Through proactive measures and co-operative efforts, hydropower can become more resilient in the face of climate change.

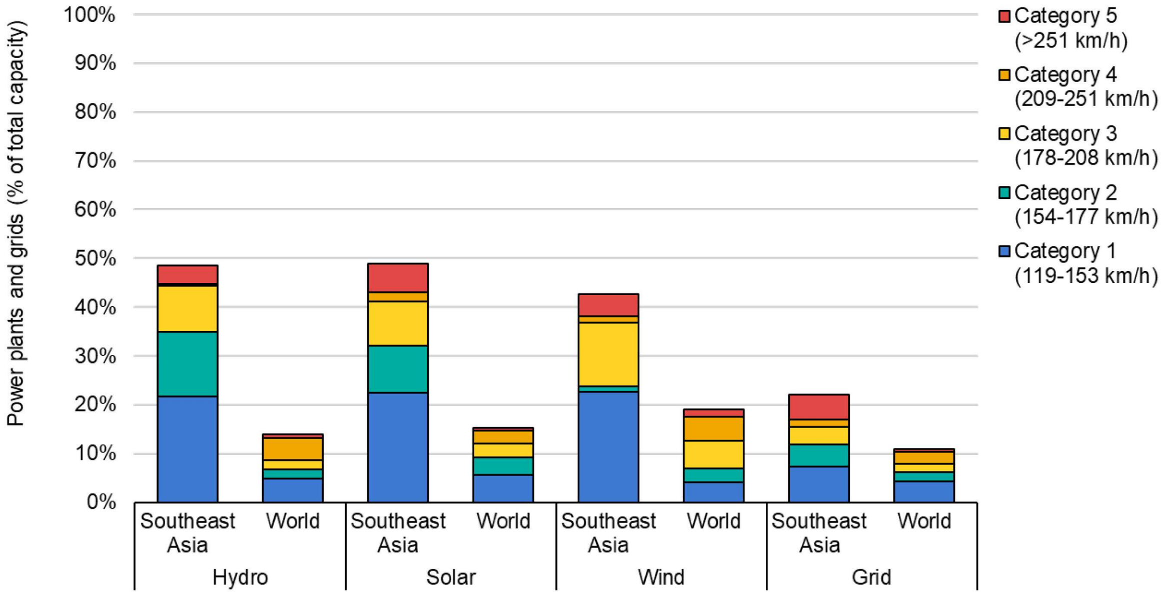
Intensification of tropical cyclones necessitates meticulous planning for renewable power plants and grids

Climate models and studies project that tropical cyclones in Southeast Asia could become more destructive with higher wind speed, longer duration and farther travel distances. Over the past four decades, Southeast Asia experienced the intensification of tropical cyclones, resulting in significant damage. Projections suggest a 10-20% rise in the proportion of intense cyclones over the 21st century, and the increase would be the most notable in Cambodia, Viet Nam and the Philippines. These projections underscore the urgency for bolstering resilience against tropical cyclones.

The intensification of tropical cyclones directly threatens physical resilience of power systems, inflicting damages to assets with severe winds, heavy rainfall, landslides and storm surges. While all energy technologies face risks from tropical cyclones, certain clean energy technologies, including hydropower, solar PV, wind power and electricity grids, are particularly vulnerable. Hydropower plants may experience interruptions due to increased sediment, floating debris and torrential streamflow, which impair equipment, threaten dam security and cut generation output. Similarly, inadequately attached solar panels could be dislocated by severe winds, while flying objects pose a threat of damage to panels and equipment. Wind power plants, typically programmed to shut down beyond specific wind speed thresholds (around 20 m/s to 25 m/s), experience significant reductions in power output during cyclones. Moreover, severe wind can damage transmission and distribution lines, poles, and transformers, mainly by toppling trees and branches.

In Southeast Asia, the intensification of tropical cyclones has a direct impact on the physical resilience of the electricity system due to its high level of exposure. Nearly half of the hydropower and solar PV installed capacities are situated in cyclone-prone areas, far exceeding the global average, 15%. Furthermore, 14% of the hydropower and 17% of the solar PV are installed in the areas where intense tropical cyclones (above Category 3) traversed before. Similarly, 43% of wind turbines are located in tropical cyclone-prone areas, while 19% of them are exposed to the risk of intense tropical cyclones. 22% of electricity grids in Southeast Asia are facing a threat of tropical cyclones, while only 11% of the world's electricity networks are exposed to tropical cyclones.

Share of power plants and electricity grids exposed to tropical cyclones



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Note: A tropical cyclone is a strong, cyclonic-scale disturbance that has one-minute average surface winds beyond 32 m/s. It is called a hurricane, typhoon or cyclone, depending on geographic location. In this graph, tropical cyclones were categorised according to the Saffir-Simpson Hurricane Wind Scale, a 1 to 5 rating based on a hurricane's maximum sustained wind speed. In general, tropical cyclones at Category 3 and higher (>177 km/h) are known as intense tropical cyclones.

Sources: IEA analysis based on S&P Global (2021), Market Intelligence Platform (database), Global Energy Monitor (2022), Global Solar Power Tracker and Global Wind Power Tracker, UNDRR (2015), Global Assessment Report on Disaster Risk Reduction and OpenStreetMap.

Tropical cyclones have already caused substantial physical damage to power generation assets and grids in Southeast Asia. The 420 MW Xe Pian Xe Namnoy Dam in Lao PDR collapsed when it was 90% complete due to the passage of tropical cyclone Son-Tinh and the summer monsoon in July 2018. Typhoon Odette in 2021 led to an extensive outage at the Visayas and Mindanao islands of the Philippines, leaving over 3 million people without electricity for days by toppling poles and transmission towers. Typhoon Damrey in 2017 caused an electricity cut in Viet Nam, with the collapse of electricity poles due to heavy rainfall and strong winds. Typhoon Haiyan in 2013 made landfall in the Philippines, destroying stations, transmission towers and distribution substations and cutting electricity to millions of people.

Given the projected increase in intense tropical cyclones, meticulous planning for renewable power plants and grids is imperative. Mapping cyclone-prone areas can guide the siting of new renewable energy projects to avoid high levels of exposure and bolster resilience against potential cyclone impacts. Strengthening construction codes to ensure climate resilience of power plants will enhance preparedness against cyclone-related damages. For instance, the Philippines and Viet Nam already established their building codes to address severe wind loads on buildings.

Furthermore, enhancing the resilience of power plants and grids through resilient designs is crucial. Hydropower plants can enhance their resilience against tropical cyclones by increasing dam height, enhancing reservoir capacity, modifying canals or tunnels, building upstream sediment control facilities, increasing flood fences to protect power stations, strengthening banks, and modifying the spillway capacities to flush silted reservoirs. Solar power plants could become more resilient with better attachments and advanced sensors to minimise physical damage from tropical cyclones. Wind power plants can enhance their resilience with stronger towers, customised rotor sizes and reinforced foundations which can help to cope with the intensification of tropical cyclones. There are also attempts to develop cyclone-proof wind turbines using vertical axis wind turbines with a pilot project in the Philippines. Electricity grids can be also fortified with underground lines, replacing concrete and wooden poles with galvanised steel poles, installing battery storage solutions, and upgrading towers as well as insulators. In some places, designing strongly meshed networks, which include redundant lines as backups in case of failure in the main line, helps avoid loss of load and enhance resilience to tropical cyclones.

Measures to build climate resilience for energy security

Enhancing climate resilience requires actions from all stakeholders. Energy suppliers, consumers and authorities are key actors, while science communities, international organisations, civil society and businesses in other sectors are all involved. This chapter provides a non-exhaustive overview of measures that can improve the overall resilience of the energy system to climate impacts, looking at supply, demand and cross-cutting actions from energy authorities. These measures can be applicable to various stages of climate resilience: readiness, robustness, resourcefulness and recovery (see Figure and Table below).

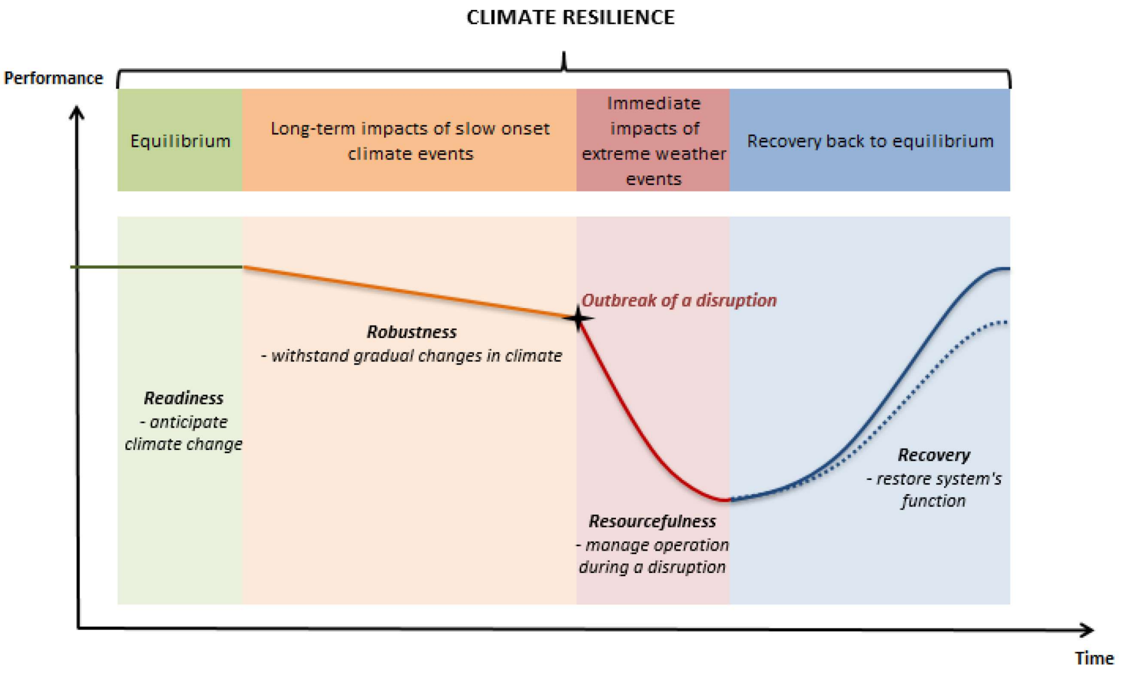
Readiness is the ability to assess, anticipate and prepare for changes in climate in advance.

Robustness is the ability of an energy system to withstand the gradual, long-term changes in climate patterns and continue operation.

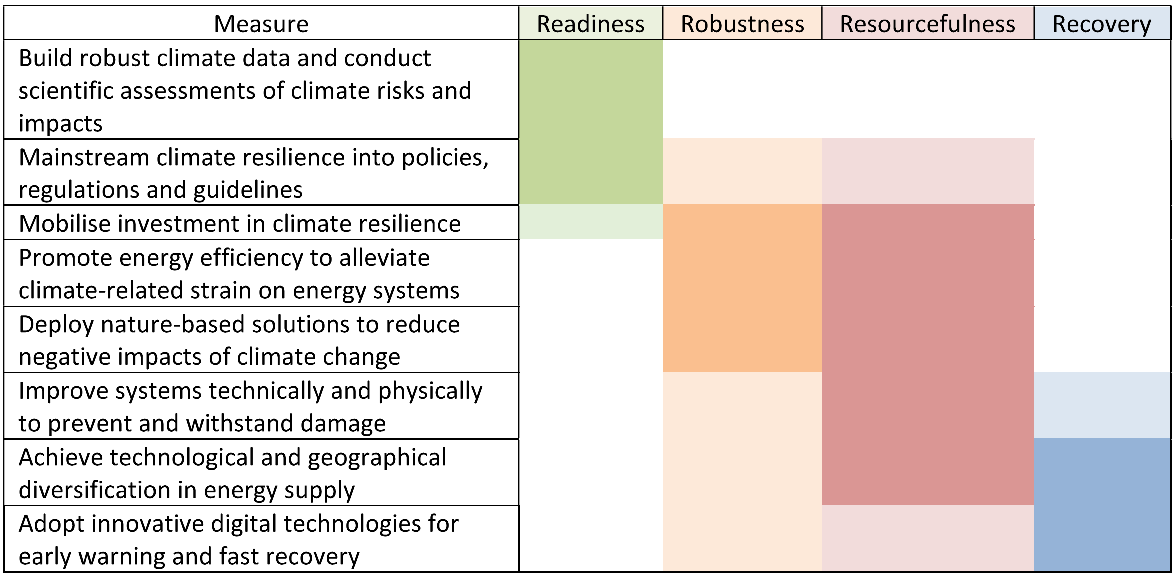
Resourcefulness is the ability to continue operation during immediate shocks, such as extreme weather events, using alternative resources.

Recovery is the ability to restore the system's function after an interruption resulting from climate hazards.

Conceptual framework of energy sector climate resilience



Measures to build climate resilience for energy security in Southeast Asia



Measure	Readiness	Robustness	Resourcefulness	Recovery
Build robust climate data and conduct scientific assessments of climate risks and impacts	■			
Mainstream climate resilience into policies, regulations and guidelines	■	▨	▨	
Mobilise investment in climate resilience	▨	■	■	
Promote energy efficiency to alleviate climate-related strain on energy systems		■	■	
Deploy nature-based solutions to reduce negative impacts of climate change		■	■	
Improve systems technically and physically to prevent and withstand damage		▨	■	▨
Achieve technological and geographical diversification in energy supply		▨	■	■
Adopt innovative digital technologies for early warning and fast recovery		▨	▨	■

Climate resilience requires robust climate data and scientific assessments

Although climate risk and impact assessments are crucial to building resilient energy systems, the assessments for the energy sector are largely lacking in the region. Robust and comprehensive data are prerequisites for scientific climate risk and impact assessments. According to the State of Climate Change Report, by the Association of Southeast Asian Nations (ASEAN), the inadequate quality of observation data and climate projections in the region is a major bottleneck for conducting climate risk and impact assessments. Energy authorities and governments can additionally support such activities by providing high-quality observation data and projections. For instance, Singapore's Centre for Climate Research produced detailed climate projections, building upon Intergovernmental Panel on Climate Change (IPCC) data and using dynamical downscaling. It includes downscaled information on observed and future changes in climate variables, at precision levels up to 2 km for Singapore and 8 km for all Southeast Asia. It aims to form the basis of climate adaptation planning in Singapore for key sectors, including energy, enabling precise and downscaled assessments. Similarly, Malaysia developed the Malaysian Adaptation Index (MAIN), which summarises the level of climate risks and readiness of each Malaysian state facing climate change impacts. It provides local-level analyses of future climate risks. The aim is to help stakeholders make smart decisions regarding future climate-related disruptions.

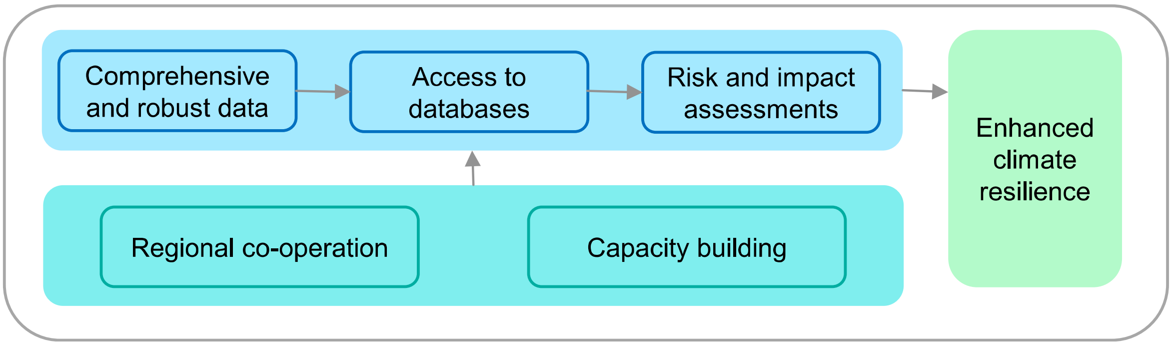
After building robust data, accessibility to the data is essential for its application. All stakeholders such as energy suppliers and authorities need access to climate data so that they can conduct climate risk and impact assessments for their specific project sites. In order to support accessibility to climate data, the IEA is providing climate and weather information which are relevant to energy supply and demand through its online platform, Weather, Climate and Energy Tracker. All users of this platform can access open data sources for yearly, monthly and daily observation of climate. The Copernicus Interactive Climate Atlas provides global and regional in-depth assessment of past, current and future trends for key climate variables (e.g. temperature, wind and precipitation). Similarly, the World Meteorological Organization's Energy and Meteorological Portal provides assessments of climate change risks on renewable energy systems. Governments are also improving data accessibility. Singapore is sharing downscaled data over Southeast Asia with international organisations including the Food and Agriculture Organization and the scientific community.

Building upon the scientific and accessible data, customising climate risk and impact assessments considering the characteristics of the energy sector is needed. In order to conduct climate risk and impact assessments for the energy sector, general climate information should be translated and analysed in a specific context. Some initiatives have started to support the energy sector's assessments of climate impacts. For instance, the Lao People's Democratic Republic (PDR) worked in collaboration with the United States Agency for International Development to assess the vulnerability of its power sector in the face of climate- and non-climate-related natural hazards as well as human and technological hazards. The report then lists 17 vulnerabilities associated with climate hazards, such as the lack of compliance with design codes, proposing short-, medium- and long-term steps the power sector can follow to implement resilience in its activities.

Regional co-operation could enhance climate data collection and assessments. It can help better understand complex regional meteorological mechanisms such as the monsoon, providing a full picture of climate mechanisms. The ASEAN State of Climate Change Report underlines the need for cross-border studies in order to address climate risks as a whole and to cover gaps in national strategies. The Mekong River Commission, which brings together several Southeast Asian countries, is one of the pioneering entities in this area. It established the regional strategy for the Basin development for the period 2021-2030, highlighting urgent need for further regional co-operation in the collection of data and joint management of water in the Mekong River basin, which has direct impacts on hydropower generation in the region.

In addition, capacity-building programmes could improve the quality of climate data and assessments. The United Nations' Office for Disaster Risk Reduction underlines the need for greater capacity-building efforts to understand disaster risk and improve the resilience of energy infrastructures. In this context, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) published a user guidebook for its Risk and Resilience Portal and Decision Support Systems in 2024 to assist local experts' training. It provides step-by-step guidelines to explore and navigate the tools for risk assessments and resilience enhancement, so that policy makers and development planners can make risk-informed decisions.

Process to build robust climate data and scientific assessments



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Resilience needs to be mainstreamed into policies, regulations and guidelines

To build climate resilience, policies and regulations have a critical role to play. Mainstreaming climate resilience in energy systems through national energy and climate policies can encourage the energy sector to consider climate risks and impacts from the initial stage of energy projects and incorporate resilience measures into operation and maintenance. Furthermore, such policy development can help identify synergies and trade-offs with other policy objectives and avoid maladaptation.

Although there has been notable progress in incorporating climate resilience in national energy and climate plans, there are still some places where resilience consideration is missing. By 2021, only six out of ten ASEAN countries had identified energy as a key sector for climate change adaptation and resilience, while all countries established concrete adaptation plans for other sectors (e.g. food and agriculture, water, health, forestry and biodiversity). Still in some countries, the energy sector is being discussed only from the mitigation angle despite the increasing impacts of climate change.

There are already ongoing efforts to support mainstreaming climate risk consideration into decision-making activities. For instance, the IEA developed country reports to provide a tailored overview of climate hazards of each country and to check the current level of policy preparedness against such climate hazards. UNESCAP launched a Decision Support System to enable disaster risk data to support evidence-based decision-making in Asia Pacific countries including Myanmar.

In addition to national policies and plans, technical codes, standards and guidelines can support building climate resilience. For instance, Malaysia, the Philippines, Singapore and Viet Nam set construction standards for buildings to resist strong winds based on historical records. Although the construction codes may require updates in anticipation of stronger wind in the future, the attempt to set building codes based on best practices helps address increasing wind loads.

Mobilising investment is key to fostering climate resilience

Investment in building climate resilience in the energy sector brings more benefits than costs. Climate resilience investment can help ensure energy security, support clean energy transitions, reduce maintenance costs, extend asset lifetime and generate socio-economic benefits across the energy value chain. The World Bank explored possible socio-economic and climate trends for low- and middle-income countries, and found that in 96% of them, investing in resilient infrastructure was beneficial. The report estimated that every dollar invested in climate-resilient infrastructure in low- and medium-income countries yields about four dollars of benefits. IEA analysis affirms the finding, showing that the benefit-cost ratio (i.e. the ratio between the present value of the benefits to the cost) of resilience measures against floods in Asia would reach nearly four in a low-emissions scenario (Below 2°C).

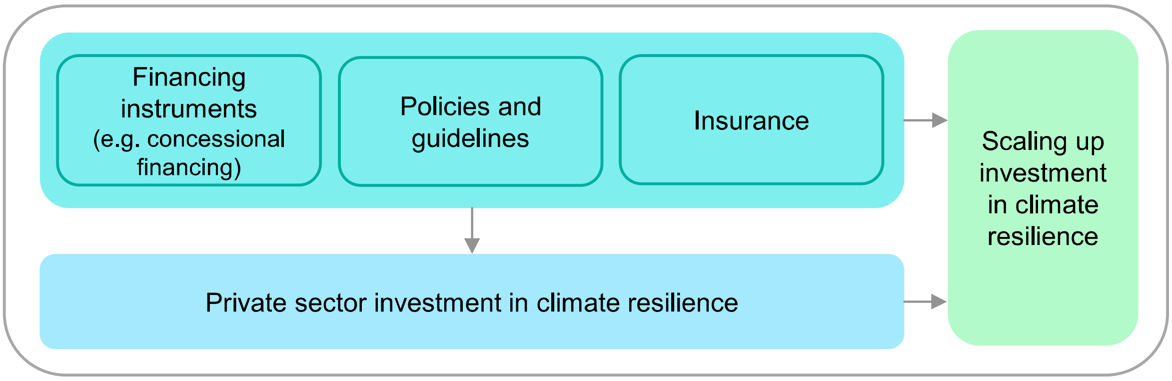
Although climate resilience investment is likely to bring more benefits than its cost, there is a wide financial gap due to some barriers. One of the major barriers that block investment in resilience is the limited awareness of climate impacts. In many countries, the true costs of forgoing climate resilience measures are not accurately captured by stakeholders. When a climate-driven disruption occurs, the significant socio-economic costs of interrupted energy supply spread across society, while energy providers bear only a fraction of the entire cost. Furthermore, high upfront costs of resilience measures, comparatively long return periods of resilience investment and monopolistic market conditions may hinder energy providers from investing more in resilience measures.

Therefore, the public sector has a critical role to play in mobilising climate resilience investment. Concessional financing provided by international development banks and public institutions can scale up climate resilience investment, enabling low-interest loans and grants to projects. This type of financing helps lower the overall cost of capital, making it feasible to implement essential resilience measures in vulnerable countries and sectors. Already, some international development banks and governments have initiated programmes to fill the existing financing gap. For instance, the Asian Development Bank (ADB) and Japan created the Asia Pacific Disaster Response Fund in 2009, which issues grants after major natural disasters in developing member countries.

In addition to concessional financing, the public sector supports climate resilience investment through insurance. Insurance coverage against climate risk in the private sector of Southeast Asia is still insufficient, with just 14% of losses from natural disasters insured in Asia Pacific in 2023. The difference between total and insured losses is especially high in Indonesia and the Philippines. To address this issue, regional public insurance pools, often supported by international development assistance, are offering opportunities to cover the excess risk that is not covered by the private sector. The Southeast Asia Disaster Risk Insurance Facility (SEADRIF), established in 2019, supports climate resilience by facilitating liquidity financing for immediate help in affected countries. Similarly, a public-private partnership project between the United Nations Development Programme (UNDP) and a global insurance company, Generali, supports climate risk insurance of micro, small and medium-sized enterprises in Malaysia and Thailand.

Policies and guidelines can also support integrating climate resilience consideration into investment decisions. Requiring climate risk assessments in the investment decision-making process has become increasingly adopted by many public financing institutions. For instance, the ADB requires climate risk screening (in terms of temperature increase, precipitation change, wind speed change, sea level rise, solar radiation change, water availability, flooding, tropical storms, wildfire, snow loading and landslides) for all investments and a more detailed risk and adaptation assessment for projects that are assessed to be at medium or high risk. The World Bank also screens its lending for exposure to climate and disaster risks and developed a set of tools to support that process. At a national level, the Malaysian stock exchange, Bursa Malaysia, announced in 2022 that it would introduce a framework with new climate change reporting by 2025 to include climate change-related disclosures aligned with the Recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD) addressing both mitigation and adaptation measures. To support investors in incorporating climate resilience consideration in their investment decisions, the UN Office for Disaster Risk Reduction and the Adaptation & Resilience Investors Collaborative (ARIC) developed climate-resilient investment frameworks as well.

Building climate resilience by unlocking private sector investment



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Promoting energy efficiency alleviates climate-related strain on energy systems

Managing energy consumption through energy efficiency measures could alleviate adverse impacts of climate change. With the projected increase in temperatures and heatwaves, energy demand for cooling is projected to jump and account for up to 40% of peak load in Southeast Asia in 2040. Without major efficiency improvements to cooling equipment, Southeast Asian countries may need to add an additional 200 GW of capacity by 2040 to meet growing air conditioning demand. The augmenting cooling demand may add strains to energy systems, particularly during heatwaves, when they are already stretched out due to rapid demand growth with population and economic growth.

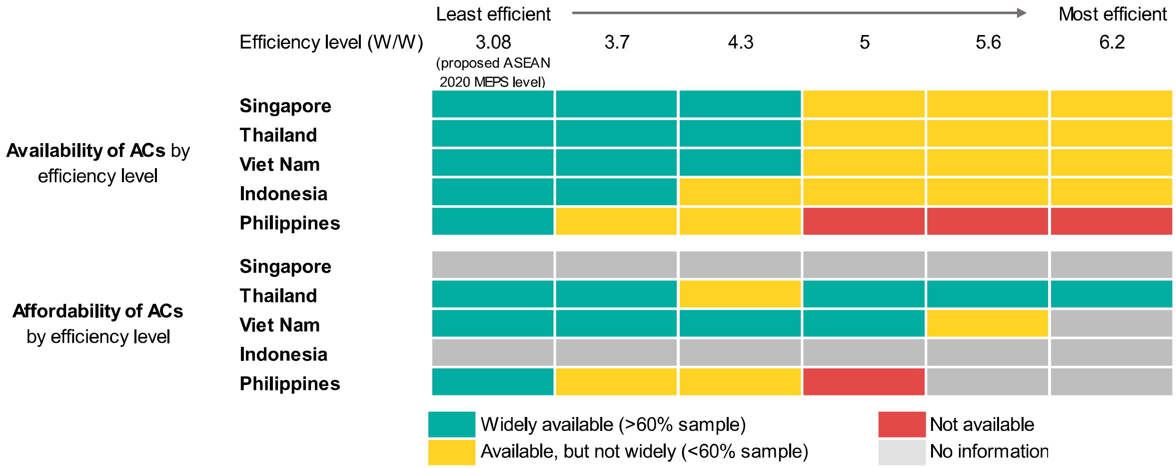
Deployment of energy-efficient technologies can curtail the energy demand escalation and reduce the climate-driven strains to energy systems. For instance, passive cooling measures, such as building materials with better insulation and low heat transfer, can lower energy demand for cooling. Cool roofs, which have high solar reflectance and high thermal emittance, can decrease the need for air conditioning, lowering the net annual energy use associated with cooling by 10-20%. According to a study in Malaysia, an innovative roofing system can reduce indoor air temperature by 2.1°C compared with a conventional roof. Based on the scientific outcomes, some international organisations and countries in Southeast Asia have already made efforts to increase the application of cool roofs, including the Indonesia Cool Roof project in 15 cities.

Some countries in Southeast Asia have district cooling initiatives. Within urban centres of the region, the implementation of district cooling solutions can reduce energy consumption by 30% or more, which may ease strains on electricity systems during peak periods. In the Philippines, for example, the Northgate district in Alabang reduced electricity consumption by 39% per year by using a district cooling system. Similarly in Malaysia, district cooling services in Cyberjaya improved energy efficiency by 5% and reduced energy consumption in 2017.

In addition to the building-level approaches, behavioural changes at the individual level can improve energy efficiency. For instance, by choosing more efficient air conditioners (ACs), energy consumers can contribute to limiting the peak load hike in heatwaves. Currently, energy consumers in Southeast Asia tend to purchase cheap ACs that are significantly less efficient than what is available, although in many countries they could buy more efficient AC equipment than the average without a price increase. Due to the wide deployment of less-efficient ACs, the best available AC technologies are already more than twice as efficient as the market average. By shifting to efficient ACs, energy consumers can help power systems withstand increasing temperatures and heatwaves.

Moreover, energy consumers can reduce the strains on power systems during heatwaves by adjusting the set temperature of ACs closer to outside temperatures. In Singapore, the National Environment Agency promotes further behavioural changes to citizens, such as setting the temperature of ACs to 25°C and regularly examining and cleaning the AC air filter to reduce energy consumption.

Air conditioning efficiency analysis in selected Southeast Asian countries



		Least efficient →					Most efficient
	Efficiency level (W/W)	3.08 (proposed ASEAN 2020 MEPS level)	3.7	4.3	5	5.6	6.2
Availability of ACs by efficiency level	**Singapore**	🟩	🟩	🟩	🟨	🟨	🟨
	Thailand	🟩	🟩	🟩	🟨	🟨	🟨
	Viet Nam	🟩	🟩	🟩	🟨	🟨	🟨
	Indonesia	🟩	🟩	🟨	🟨	🟨	🟨
	Philippines	🟩	🟨	🟨	🟥	🟥	🟥
Affordability of ACs by efficiency level	**Singapore**	⬜	⬜	⬜	⬜	⬜	⬜
	Thailand	🟩	🟩	🟨	🟩	🟩	🟩
	Viet Nam	🟩	🟩	🟩	🟩	🟨	⬜
	Indonesia	⬜	⬜	⬜	⬜	⬜	⬜
	Philippines	🟩	🟨	🟨	🟥	⬜	⬜

🟩 Widely available (>60% sample)
🟨 Available, but not widely (<60% sample)
🟥 Not available
⬜ No information

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Notes: MEPS = minimum energy performance standards. Results shown for models with cooling capacity <15 000 BTU/h. Efficiency level defined in terms of seasonal energy efficiency ratio (SEER) where higher values equal greater efficiency. “Widely available” means that at least 40% of models in the sample are of equal efficiency or higher than the efficiency level shown. Availability of ACs means that models exist on the market which have an efficiency greater than the efficiency tested; Affordability of ACs means that models with efficiency greater than the efficiency tested are available at a price that is lower than the average price of models in that category. Price has been normalised by capacity.

Source: IEA (2019), Southeast Asia Energy Outlook.

Policies and regulations can support energy efficiency improvements and reduce climate-related strains on energy systems. Several Southeast Asian countries have implemented building energy codes for certain building types to drive energy efficiency improvements and to curtail a projected energy demand increase for cooling. The Indonesian government, for example, regulates the efficiency of buildings with a minimum of 5 000 m^2 gross floor area and sets criteria for energy efficiency evaluation, such as building envelope, ventilation systems, air conditioning and lighting. In addition, governments can reduce the impacts of rising temperatures by improving the energy efficiency of cooling devices by setting legally binding minimum efficiency requirements for products sold on the market, known as minimum energy performance standards (MEPS). Indeed, In Southeast Asia, all countries now have some form of MEPS and labelling policies for ACs either in force or under development. Under current policies in Indonesia, the combined impact of MEPS and improvements in building envelopes leads to a decrease in the average annual electricity consumption per air conditioner from 3 000 kWh to 1 500 kWh by 2060. The IEA projects that robust appliance efficiency standards, energy pricing reforms and building energy codes and standards in Indonesia alone can help to avoid 225 TWh of electricity demand growth until 2050.

Nature-based solutions can reduce the negative impacts of climate change on energy assets

Nature-based solutions have gained momentum in recent years to address climate change impacts and have significant potential to enhance climate resilience of infrastructure in cost-effective and flexible ways while harnessing environmental and social co-benefits. Nature-based solutions can provide multiple benefits: minimising disaster risk; protecting coasts against erosion, floods and tropical cyclones; reducing flood impacts; mitigating extreme heat; and improving water availability and quality.

Multiple benefits of nature-based solutions

Examples of nature-based solutions	Associated ecosystem services		
	Coastal protection	Reduction in flood impacts	Heat mitigation
Protecting/restoring coastal habitats (e.g. mangroves, salt marshes, coral and oyster reefs)	O		
Protecting/restoring upland forests		O	O
Creating parks and open green space		O	O

Note: The list of examples and services is not exhaustive. It depends on the selected nature-based solutions intervention, its location and the scale of implementation.

Source: OECD (2020), Nature-based solutions for adapting to water-related climate risks.

Preservation and restoration of coastal areas can reduce the risk of flood and tropical cyclone to energy infrastructure in coastal areas. In Southeast Asia, 77% of population and 60% of GDP come from coastal areas where climate change is projected to exacerbate coastal floods, coastal erosion and storm surges. Coastal ecosystems in Southeast Asia, such as coastal wetlands of over 120 000 km^2, natural coastal habitats (e.g. coral reefs, salt marshes, seagrass, mangroves), sandy beaches and dunes play a major role in mitigating destructive climate impacts. For instance, mangroves in the Mekong Delta in Viet Nam have supported reducing coastal erosion and mitigating the impacts of tropical cyclones by stabilising soil and functioning as a protective wall against strong winds and storm surges. Mangroves and coral reefs in the Philippines also helped address the impacts of tropical cyclones. When tropical cyclone Haiyan hit the Philippines in 2013, coastal villages with substantial mangrove cover received less damage from tropical cyclones compared with coastal villages with reduced mangrove cover.

Acknowledging the importance of coastal ecosystems, many countries in Southeast Asia, including Indonesia, the Philippines, Thailand and Viet Nam, are working on preservation and restoration activities in collaboration with international organisations and civil society organisations. For example, Indonesia power company PLN developed mangrove forests around the power plant on the coast of Denpasar, Bali, to prevent the coastline from erosion while protecting community benefits.

River catchment management can also play a crucial role in preventing floods in Southeast Asia. Wetlands and floodplains absorb excess rainfall and slow down water flow, while forests in catchments stabilise soil and reduce surface run-off. The ADB's case study on flood risk management in the Philippines highlights the importance of restoring wetlands, preserving the river flow path and reforestation upstream to reduce flood risks.

Technical and structural improvement contributes to climate resilience

Physical system improvement can help energy systems withstand the impacts of extreme weather events, such as floods and tropical cyclones. It can significantly reduce the probability of damage from floods, which are expected to become more frequent in the majority of Southeast Asian countries. For instance, improving the flood walls and dykes of generation assets and relocating substations to higher ground can help power plants prevent flood damage. Particularly for hydropower generation, which is directly affected by floods, hardening and redesigning infrastructure can be useful for dam security. Measures can include enhancing reservoir capacity, increasing dam height, increasing flood fences around power stations, relocating power stations to higher ground, modifying canals or tunnels, building upstream sediment control facilities, and modifying spillway capacities.

Technical and structural improvements of power generation assets and electricity networks can also enhance resilience against tropical cyclones. In Southeast Asia, tropical cyclones are projected to become less frequent but more intense. The projected intensification of tropical cyclones may have negative impacts on wind power generation and electricity networks, which already suffer from these climate hazards. Improving electricity networks with underground lines, replacing concrete and wooden poles with galvanised steel poles, installing battery storage solutions, and upgrading towers and insulators can reduce damage to transmission and distribution networks by improving their physical strength and reducing their vulnerability. In some places, designing strongly meshed networks, which include redundant lines as backups in case of failure in the main line, may help avoid loss of load and enhance resilience to tropical cyclones.

Physical system hardening can also enhance the resilience of energy systems against sea level rise and coastal flooding. Many oil and natural gas facilities, as well as thermal power plants, are located along coasts since they rely on imported fuels or seawater for cooling. Electricity networks are also heavily concentrated along coastlines because a high number of cities are located on the coasts.

Energy systems situated on coasts can be vulnerable to sea level rise and its associated events, such as storm surges, erosion and flooding. In order to build resilience against sea level rise and associated events, energy suppliers establish coastal barriers using green infrastructure (e.g. plants, reefs and sand) or grey infrastructure (e.g. seawalls and dykes). Additionally, they can consider relocating vulnerable facilities out of flood-prone areas. For instance, the Central Mekong Delta Connectivity Project in Viet Nam changed its design after a study assessing the vulnerability of the project to sea level rise. It raised the design height of the road embankment by 0.3 m to make it less vulnerable, and the cost of adaptation represents only 0.5% of the total project cost.

Technological and geographical diversification in energy supply contributes to climate resilience

Diversifying the energy mix is a long-term solution for climate resilience and energy security. Although all energy technologies in Southeast Asia are subject to increases in heatwaves, heavy rainfalls, floods, droughts, intense tropical cyclones and sea level rise, the magnitudes of their impacts could vary substantially among technologies. For instance, wind power plants can be more resilient to heavy rainfalls than hydropower plants, but they tend to be more vulnerable to tropical cyclones. Similarly, solar power plants are likely to be less affected by droughts than thermal power plants with wet cooling systems, while their operation might be more dependent on heat and clouds. Given that climate change is likely to increase the level of exposure to multiple climate hazards, building a diverse energy mix is recommended to ensure various backup options.

Some Southeast Asian countries are already looking into diversification of energy sources pursuing climate resilience and energy transitions. Indonesia and Viet Nam, where coal covers a notable share of the total energy supply (30% in Indonesia and 49% in Viet Nam), have experienced coal supply disruptions in recent years due to floods. In 2021, for instance, severe floods on the islands of Kalimantan and Java, Indonesia, damaged several coal mines. The disrupted coal supply led to low coal reserves in coal-fired power plants and raised the prices of coal. Similarly, Viet Nam coal mines in the northern Quang Ninh province were halted for several days in 2015 due to heavy rainfalls and floods. The supply disruption led to a fuel shortage in coal-fired power plants which covered over one-third of power generation of Viet Nam at that time. To cut their reliance on coal, both countries initiated the Just Energy Transition Partnership in 2023.

In addition, geographical diversification of production sites also contributes to energy security, enabling continued energy supply despite shocks to one production site. More distributed energy systems, batteries and interconnections enable reliable power supply even if a part of the electricity supply chain is interrupted by extreme weather events. Microgrids with distributed energy resources (e.g. solar PV, wind turbines, diesel generators, small natural gas turbines) can be used for backup generation, functioning independently from the main grid in the event of outages. For instance, during the Malaysia Sabah floods in 2021, microgrids with distributed energy sources provided electricity for emergency services amid widespread power outages.

Enhancing climate resilience through regional interconnection

More interconnections to link diverse energy sources (e.g. regional power pools) and redundancies can be a solution for improving reliability. Interconnected networks can provide alternative electricity supply options if they have the flexibility and redundancy to switch loads at speed and bypass the fault. However, if a transboundary network relies heavily on a single or limited number of energy sources, a failure in a single part of the electricity network could transmit impacts across borders, and the cascaded impacts may escalate.

With aims to foster greater grid resilience, the ASEAN Power Grid (APG) initiative was established to integrate the Southeast Asia power grid system. More interconnections among the countries linking diverse energy sources (e.g. regional power pools) and redundancies can be one solution for improving reliability. The APG initiative, which constructed 7 720 MW of interconnectors between 1997 and 2022, is expected to promote energy sector resilience and security while promoting regional co-operation. By linking national grids across the region and planning to add up to 22 369 MW of interconnectors in the future, the APG is creating a more robust and flexible electricity network in Southeast Asia capable of better withstanding potential risks from climate hazards.

Innovative digital technologies can enhance early warning and fast recovery

Innovative technologies provide new opportunities and tools to monitor, mitigate and respond to climate hazards that affect energy systems. Technologies such as artificial intelligence (AI), the internet of things (IoT), advanced computing and drones can transform the way we collect, process and analyse information along the energy value chain. This enhances decision-making and enables early warning as well as fast response. The United Nations Early Warnings for All initiative recognises that digital technologies, such as AI, can improve data quality, access and sharing while enhancing forecasting capabilities for significant weather-associated risks. Additionally, digital solutions can enable utilities to locate and fix faults on the electricity grid more effectively and provide quicker restoration times, lowering the cost and disruption caused by extreme weather events. The adoption of new technologies can rapidly improve climate resilience in energy systems.

Real-time climate monitoring devices are increasingly adopted for energy sector resilience in Southeast Asia. Improved monitoring options include unmanned aerial vehicles or drones, AI software in combination with cameras and IoT solutions supported by satellite imagery. In Thailand, for instance, state-owned oil and gas company PTT Public Company Limited made a contract to monitor over 2 500 km of pipelines by using remote sensing via satellite and AI technologies. In Indonesia, a tool called Haze Gazer was developed to provide real-time insights on the location of fire and haze based on multiple data sources: open data, including satellite fire hotspot information and population density; citizen-generated data; and real-time big data from social media channels. The tool enhances the existing functionalities of the Indonesia disaster management information system, providing insights on hotspot locations.

The resilience of the electricity infrastructure can be further improved by deploying smart grid technologies. These provide system operators with increased visibility into real-time operation, predictive maintenance, and predictive capacity as to when equipment or other assets may fail, and can help minimise damage from climate hazards. For instance, in cases of outages, smart grid technologies can automatically alert energy suppliers and help resolve issues. Smart grid technologies can also enable energy suppliers to reroute power around the detected problem, preventing a potential disruption of electricity supply.

Smart grids and smart metering can contribute to minimising the impacts of extreme weather events. Smart grids and metering are becoming more commonly applied in Southeast Asia, enabling the communication of energy usage across the distribution network in close to real-time. The main utilities in Indonesia and Thailand are at the beginning of smart metering implementation plans. In Viet Nam, the national utility has rolled out basic remote metering technologies to transition to more advanced technologies. Distribution system operators benefit from extensive visibility into operations, improving decision-making and allowing them to apply the most effective solutions to cope with the impact of stress on the network including the identification of outage events. For example, when the electricity system is impaired by an extreme weather event, energy suppliers can use smart meters to implement targeted load shedding while limiting the likelihood of large-scale outages.

New technologies can also allow operators to control energy use remotely or automatically. Controllable switches can limit the impact of lost grid capacity due to climate-induced incidents in small areas and allow for prioritised service to critical clients. Automation and remote control, in the form of smart appliances and smart homes, allow energy end users to adapt consumption in real-time, alleviating stress on energy systems during extreme weather events. For example, smart, responsive AC appliances and thermostats can help reduce peak electricity demand during heatwaves, reducing the risk of disruptions to electricity supply. Further, alarm systems, remote fault indicators or control centres can disconnect electrical equipment as a preventive measure during floods, hindering extensive damage, reducing fire risk and avoiding system-wide blackouts by isolating at-risk components.

Running digital simulations, or so-called “digital twins”, can support better decision-making against potential climate hazards. Connected to real data sources, digital twins can update in real-time and optimise simulation, scenario planning and decision-making. Alongside the potential to reduce disruptions in extreme weather, digital twins also demonstrate how operators can benefit from prevention of future damage. The Climate Resilience Demonstrator (CReDo) is a United Kingdom-based pioneering project that uses digital twin technology to enhance climate adaptation and resilience for critical infrastructure systems. It specifically focuses on the impacts of flooding on energy, water and telecommunication networks, demonstrating how digital twin technology can improve the co-ordination and resilience of networks against extreme weather events.

Abbreviations and acronyms

AC	air conditioner
ADB	Asian Development Bank
AI	artificial intelligence
APG	ASEAN Power Grid
APS	Announced Pledges Scenario
ARIC	Adaptation & Resilience Investors Collaborative
ASEAN	Association of Southeast Asian Nations
CO_2	carbon dioxide
CReDo	Climate Resilience Demonstrator
ENSO	El Niño Southern Oscillation
GDP	gross domestic product
GHG	greenhouse gas
IoT	internet of things
IPCC	Intergovernmental Panel on Climate Change
Lao PDR	Lao People's Democratic Republic
MAIN	Malaysian Adaptation Index
MEPS	minimum energy performance standards
NZE	Net Zero Emissions by 2050
OECD	Organisation for Economic Co-operation and Development
REEs	rare earth elements
SDS	Sustainable Development Scenario
SEADRIF	Southeast Asia Disaster Risk Insurance Facility
SSPs	Shared Socioeconomic Pathways
STEPS	Stated Policy Scenario
TCFD	Task Force on Climate-Related Financial Disclosures
UNDP	United Nations Development Programme
UNDRR	United Nations' Office for Disaster Risk Reduction
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific

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