EAST ASIA
PACIFIC

Thailand

World Bank Group

COUNTRY CLIMATE AND DEVELOPMENT REPORT

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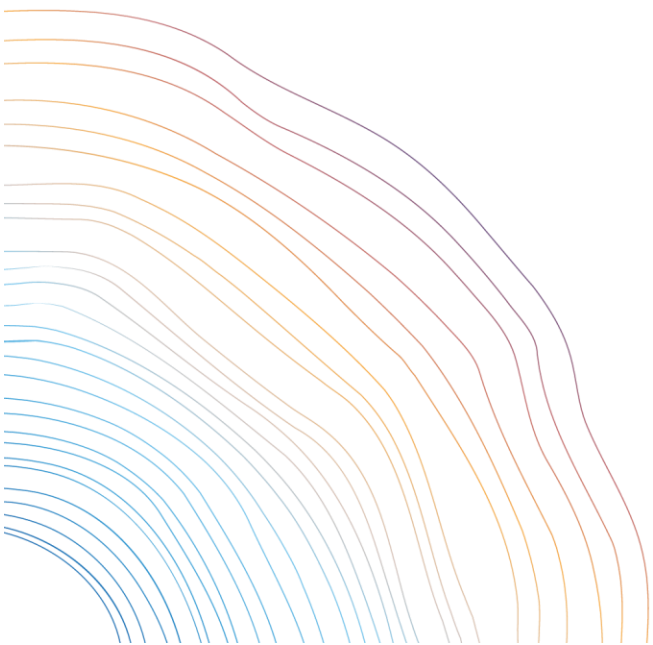

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1.
Introduction

1 Introduction

The Thailand Country Climate and Development Report (CCDR) identifies ways in which Thailand can achieve economic development that is greener and more climate resilient. Despite several decades of development success, Thailand's aspirations to become a high-income economy are facing headwinds: investment growth has slowed, structural transformation out of agriculture and into higher value-added activities has stalled, rising global protectionism poses threats to exports, and the population is aging rapidly. Incomes and wealth are concentrated in Bangkok, while other parts of the country struggle to develop. Climate change is reinforcing and exacerbating these challenges. Urban flooding risks are among the highest in the world and Bangkok – which hosts a concentration of Thailand's export-oriented industries – remains especially vulnerable. The relatively poor north and north-eastern parts of Thailand are vulnerable to drought, water shortages, and changing rainfall patterns, which will continue to impact agricultural production, exacerbating existing inequalities. Heat waves and prolonged heat exposure directly impact labor productivity and well-being, as well as increasing risks of illness.

Although Thailand is not a major emitter, substantial investments and reforms are needed to achieve the country's goals of reaching carbon neutrality by 2050 and net zero emissions by 2065. Reducing emissions will involve decarbonizing the electricity and transport sectors, investing in cleaner technologies, increasing energy efficiency, and adopting more sustainable climate-smart practices in agriculture. There are compelling co-benefits associated with such measures: lower costs, greater energy security (as fossil fuel dependence declines), improved air quality, and less congestion. At the same time, the global net-zero transition means that Thailand's future comparative advantage will hinge on its ability to lower the emission intensity of its economy, and shift production toward greener goods and services. Thailand is deeply integrated into global value chains and manufactured exports are a key driver of economic activity, equivalent to around half of GDP. Meeting international standards and requirements for greener production is therefore critical. The global transition toward sustainability is also generating new export opportunities for countries like Thailand, which has the potential to produce more complex green products and offer more sustainable tourism experiences.

Thailand must move swiftly to address both the physical and transition risks posed by climate change and to seize the opportunities that come with a global shift toward sustainability. Business as usual is no longer a viable path, and while the costs of required investments are substantial, the costs and risks of inaction are much higher. This Country Climate and Development Report (CCDR) offers a strategic playbook to support Thailand's climate ambitions, complementing existing national plans. It assesses critical risks to the economy, including the direct impacts of floods, droughts, heat stress, and other climate-related disasters, as well as the potential consequences for trade and investment if progress on emissions reduction and resilience-building falls short.

The report outlines concrete actions to help Thailand adapt to the impacts of climate change and reduce its greenhouse gas emissions. It also highlights the economic opportunities arising from global decarbonization efforts—particularly in sectors where Thailand holds comparative advantages, such as electric vehicle and component manufacturing, solar technologies, and energy-efficient air conditioning. Recognizing that public resources alone will not suffice, the CCDR underscores the vital role of private finance in scaling up investments in adaptation, mitigation, and innovation. As part of its analysis, the CCDR reviews current government plans, evaluating their alignment with national climate objectives, identifying implementation challenges, and pinpointing where additional efforts will be required.

This CCDR is organized in seven chapters. Chapter 2 describes the key inter-linkages between climate change and socio-economic development in Thailand, in the context of the country's current climate commitments and plans. Chapters 3 and 4 delve more deeply into the challenges Thailand faces in adapting to physical risks and reducing GHG emissions. Chapter 5 assesses green growth opportunities. Chapter 6 addresses the challenges of mobilizing financing to meet adaptation and mitigation investment needs, and the implications for Thailand's macro-fiscal sustainability. Chapter 7 concludes with a summary of policy recommendations.

2.
Climate change and development

2 Climate change and development

2.1 Motivation and context

Thailand is, in many respects, a development success story, having rapidly transitioned from an agriculture-based economy to one that is modern, industrialized, and export-driven. Between 1980 and 2019, the country achieved an average annual growth rate of 3.8 percent—surpassing Indonesia and Malaysia, though trailing Viet Nam. This progress was underpinned by a shift toward market-friendly macroeconomic policies and greater outward orientation in the 1980s and 1990s, coupled with strong investments in broad-based basic education. These reforms spurred significant structural transformation and income growth. Poverty fell sharply, with the share of the population living in poverty dropping from 77.2 percent in 1981 to just 13.5 percent in 2019. Over the same period, Thailand's "prosperity gap"—a measure of how far a population is from the prosperity threshold of $25 per day (2017 PPP)—narrowed significantly, indicating that rising living standards were broadly shared.[1]

But Thailand's recent growth and development experience has been less rosy. Progress toward high-income status has slowed. Investment growth has lagged, and structural transformation has stalled over the past decade, even though the share of low-productivity agricultural employment remains high relative to peers at about 30 percent. Inefficiencies in the regulatory framework, restrictions on services trade and foreign investment, and the presence of price controls are together deterring competition and limiting incentives to innovate. The decline in labor force participation associated with Thailand's rapidly aging population is also beginning to limit potential growth, while the Bangkok economy, which accounts for around a third of national GDP, is being constrained by increased congestion and emerging signs of diseconomies of scale.

At the same time, Thailand's economic development is exposed to the physical impacts of climate change because of the susceptibility of key industries to flooding, drought, heat stress, and other extreme weather events. Climate change is already affecting Thailand, which ranks as the 30th most affected country by extreme weather events in the last two decades, and its exposure to disasters and higher temperatures will continue to rise.[2] As laid out in reminder of this chapter, manufacturing, tourism, and agriculture will increasingly be disrupted by floods, coastal erosion, and water shortages. Additionally, while Thailand's carbon emissions are relatively small on a global scale, air pollution is worsening the health of Thai people. The cumulative impacts of these challenges will increasingly strain Thailand's human capital, labor productivity, and quality of life.

Moreover, climate change disproportionately impacts vulnerable populations in Thailand, a country where high inequality is a key constraint to sustainable and inclusive growth. With a Gini coefficient of income of 43.3 in 2021, Thailand ranked as the 13th most unequal out of 63 countries for which income-based Gini coefficients are available. Inequality is starker when considering concentration of wealth; over half of the country's wealth is held by the richest 10 percent of the population. Addressing this divide, which has a distinct spatial dimension, is critical to building a robust middle class that can propel Thailand into high-income country status. But climate change exacerbates the vulnerability of Thailand's poorest people to extreme weather events, disrupting their livelihoods, and increasing their exposure to health risks and economic insecurity.

The rapidly changing external environment is posing further challenges to the outlook. The net-zero transition is a global shift that will have particularly important implications for Thailand's trade and ability

[1] The prosperity gap is a recently introduced measure of shared prosperity. It refers to the amount by which incomes of everyone in a country needs to be multiplied by, on average, for the country to arrive at the prosperity standard of $25 a day (2017 PPP). Between 1981 and 2019, Thailand's prosperity gap declined from 8.0 to 2.2.

[2] Thailand is ranked 30th out of 174 countries on the 2025 Germanwatch Climate Risk Index for countries most affected by extreme weather events between 1993 and 2022 and ranked 51 out of 191 countries on the 2025 Inform Risk Index, with the fourth highest exposure to river flooding in the world, the 37th highest exposure to drought, and the 51st highest exposure to coastal flooding.

to attract foreign direct investment. Thailand is not a major contributor to global climate change, but its per capita emissions surpass those of several neighboring ASEAN countries. Shifting demand toward low-carbon goods and services means that Thailand's future comparative advantage will likely depend on its ability to lower the emissions intensity of production. Furthermore, the green transitions taking place within some of Thailand's major trade and investment partners are set to have ripple effects on the Thai economy. For instance, initiatives such as the EU's Carbon Border Adjustment Mechanism could have a larger impact if it is expanded to a wider set of products or services and/or if other countries implement similar measures. Failure to decarbonize could expose the country to rising costs, reduced access to global supply chains and foreign investment, and the possibility of stranded assets in some carbon-intensive industries.

Although Thailand is not a major global emitter, meeting the targets of carbon neutrality by 2050 and net zero emissions by 2065 will pose significant challenges. The country remains heavily reliant on fossil fuels, particularly for power generation, transport, and heavy industry, and transitioning to cleaner energy sources will require structural reforms in key sectors and substantial investment in renewable infrastructure, grid modernization, and energy efficiency. Introducing an effective carbon pricing mechanism will be an important part of this transition. A well-designed carbon price would prompt firms to internalize the environmental costs of emissions, shift investment and consumption patterns, and generate revenue to support green innovation and a just transition. However, a carbon price on its own will be insufficient on its own to lead to transformational change, in the absence of other reforms and investments as set out in Chapter 4.

Finally, Thailand's export-driven growth model faces mounting pressures and will likely falter unless the country takes decisive steps to mitigate emerging risks and seize new opportunities. Historically, Thailand's impressive growth and poverty reduction have been closely linked to its success in expanding manufactured goods and tourism exports. However, export growth has slowed in recent years, and the global trade landscape has become increasingly uncertain, marked by rising protectionism, fragmented trade rules, and the restructuring of global supply chains—all of which threaten Thailand's market access and competitiveness. Compounding these challenges, the post-pandemic acceleration of disruptive technologies—including green technologies—is reshaping global production and trade dynamics. Thailand's traditional export model, which has relied on low-cost labor and integration into established supply chains, is increasingly vulnerable in this shifting context. While these global shifts also present opportunities, particularly in high-value-added sectors such as electric vehicles, solar modules, and energy-efficient cooling technologies, Thailand faces several structural constraints which prevent it from fully capitalizing. These include persistent skills mismatches, restrictive regulations that inhibit innovation and market entry, and limited domestic competition that stifles productivity growth. Addressing these issues will be critical to ensuring that Thailand can adapt its export model and thrive in a more sustainability-focused and technologically advanced global economy.

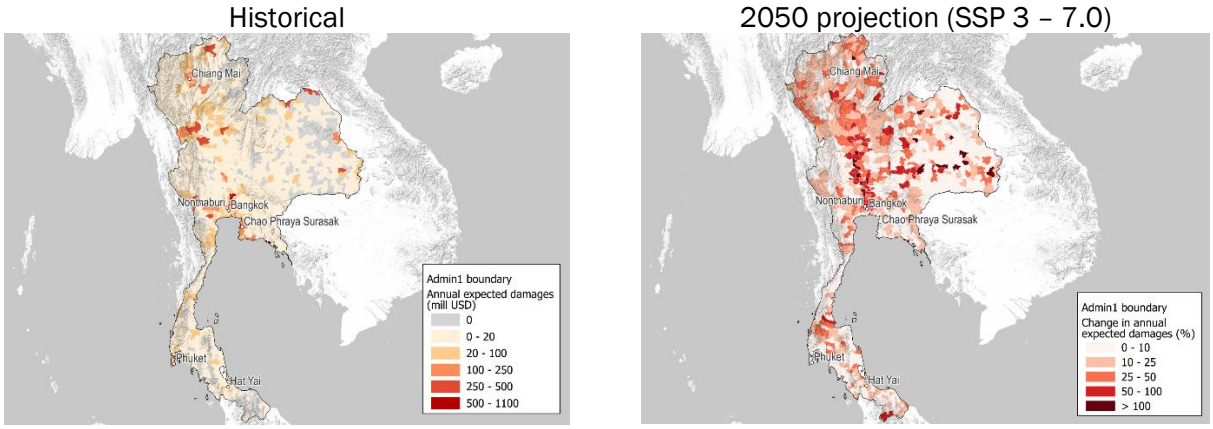
In the face of these challenges, Thailand aspires to become a resilient, green, and high-income economy—an ambition that lies at the heart of this report. The country aims to achieve high-income status by 2037, guided by the principles of security, prosperity, and sustainability outlined in its 20-year National Strategy. Attaining this goal will require sustained annual GDP growth of approximately 5 percent over the next 13 years—nearly double the average growth rate of 2.6 percent recorded since 2010. Supporting this ambition is Thailand's "4.0" vision, which emphasizes innovation and the transition to a Bio-Circular-Green (BCG) economic model. This approach focuses on producing higher value-added goods and services, reducing resource intensity, and safeguarding natural capital. In parallel, Thailand has committed to achieving carbon neutrality by 2050 and net zero greenhouse gas emissions by 2065, contributing to global climate goals while seeking to unlock new drivers of sustainable growth.[3]

[3] Achieving net-zero involves eliminating or offsetting all greenhouse gas emissions, both carbon (carbon dioxide) and non-carbon (including methane, nitrous oxide, and F gases).

2.2 The physical impacts of climate change on development

Floods are the greatest natural hazard facing Thailand in terms of economic and human impacts. Thailand is one of the ten most flood-prone countries in the world. Riverine floods occur nearly every year, during the latter part of the monsoon season (July to October), most prominently in the central floodplains along the Chao Phraya basin, which includes many agricultural and urban areas. As a particularly devastating example, in mid-2011 monsoon rains triggered by tropical storms caused flooding in the northern, north-eastern and central regions along the Mekong, Mun, Chi, and Chao Phraya basins, affecting 13.6 million people in 65 provinces, causing 815 deaths, and resulting in property damages worth an estimated 12.6 percent of GDP. Flooding incidence across Thailand is likely to increase because of climate change, with higher frequency of intense rainfall events contributing to riverbank overflow, flash floods in urban areas and landslides and flash floods in mountain areas (Figure 2.1). Compared to 2010, climate change has been projected to increase the number of people affected by floods by a factor of 2.5 for the period 2035 to 2044.[4] Previous estimates have suggested that under a high-emission scenario, the economic impact (as a share of GDP) of a 1-in-50-year flood in the early 2030s would be double that of the 2011 floods.

Figure 2.1: Change in annual expected damages from inland flooding



Source: Modeling conducted for this CCDR by Industrial Economics, Incorporated (IEc)

A combination of sea level rise and changing weather patterns could further accelerate coastal flooding and erosion. Current coastal flooding damages concentrate in the coastal urban areas around the Bay of Bangkok, as well as in Phuket, with limited damages elsewhere along Thailand's coastline. By 2050, most areas exposed to coastal flooding in the historical period will see increases in damages from future storm surges (Figure 2.2), although the effects of sea level rise (at around 0.2 meters) are expected to have only limited impacts over this period.[5] Coastal erosion also threatens Thai beaches. Although several flood and coastal erosion protection measures have since been implemented in Bangkok, they have often ended up diverting water to neighboring areas and increasing their vulnerability.

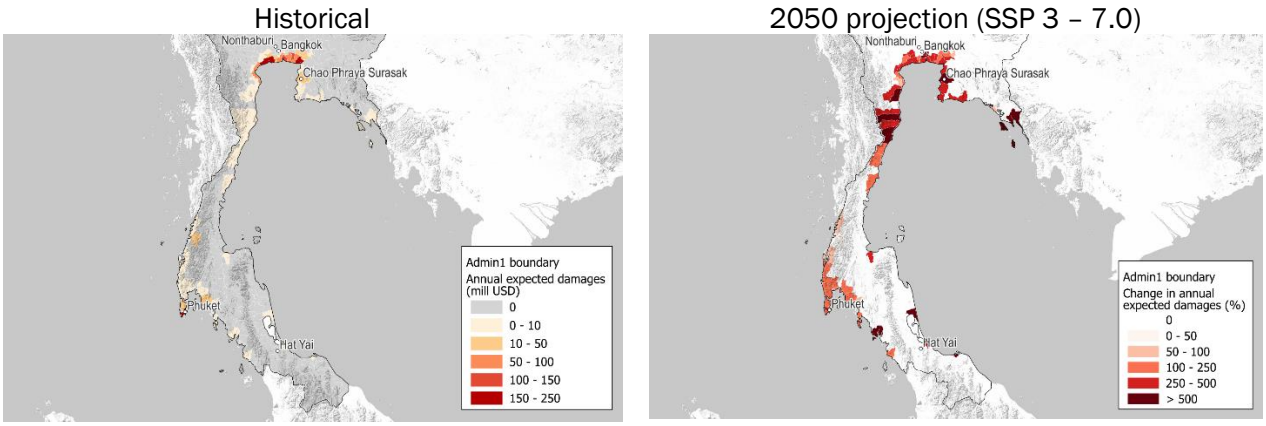
Bangkok and the Upper Gulf of Thailand, where population and economic activity are concentrated, remain especially vulnerable to flooding. Over 14 million people (about 22 percent of the total population) live within the Greater Bangkok area, which contributes close to half of Thailand's GDP. Bangkok is less than 2 meters above sea level and is sinking because of excessive underground water use and the weight of large-scale high-rise development. The combination of rising seas and sinking land means Bangkok is vulnerable to risks of flooding, storm surges, and permanent water incursion that are likely to worsen with climate change. Bangkok and the Upper Gulf of Thailand have already suffered six major flooding events

[4] The number of people affected by an extreme river flood could grow by over 2 million by 2035–2044, and coastal flooding could affect a further 2.4 million people by 2070–2100.

[5] More significant effects from sea-level rise are expected by the end of the century, with the median sea levels projected to increase by about 0.6 or 0.7 meters depending on the climate scenario.

since 1980, despite the introduction of flood control measures. A 2019 study indicated that parts of Bangkok could be unviable by 2050 with much of the area at risk of lying under water.

Figure 2.2: Change in annual expected damages from coastal flooding



Source: Modeling conducted for this CCDR by Industrial Economics, Incorporated (IEc)

Drought is another major hazard which will intensify further with climate change, exacerbating existing concerns about water security across large parts of Thailand. Changes in weather patterns are increasing the frequency of droughts and exacerbating water shortages in agricultural areas, including the north and north-eastern provinces. As one of the world's largest rice exporters, Thailand's agricultural sector demands vast amounts of water for irrigation. Traditional rice farming methods, which rely heavily on flooding fields, exacerbate this problem. This practice not only depletes local water resources but also leaves them susceptible to climate variability, such as prolonged dry seasons and unpredictable rainfall patterns. Industrial activity is also being affected by water supply constraints, including in the Eastern Economic Corridor. Competition for water between agricultural needs and other sectors — including urban and industrial use — is increasing.

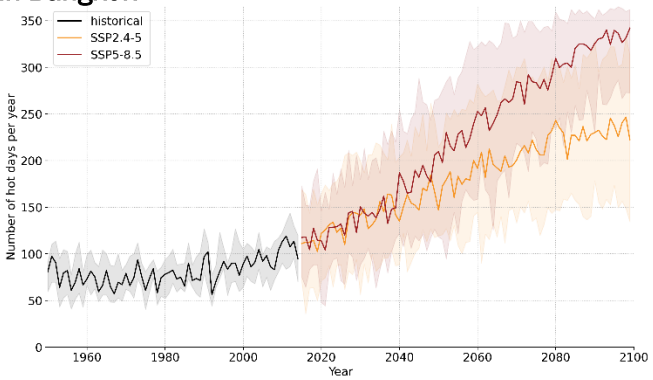
Heat stress resulting from climate change poses a significant threat to labor productivity in Thailand by increasing average workday temperatures and reducing the number of hours individuals can safely and effectively work. Among macroeconomic sectors, agriculture is projected to experience the most severe productivity losses due to elevated temperatures between 2041 and 2050, followed by industry and services. Across all sectors, informal workers will likely be particularly vulnerable. The impact will be most pronounced in the south-central provinces—including Bangkok, Pathum Thani, Samut Prakan, and Phra Nakhon Si Ayutthaya—where labor-intensive activities are concentrated and temperatures are expected to rise sharply. Beyond productivity, climate change will also have serious public health implications. By mid-century, the incidence of waterborne diseases is projected to increase by 7 to 15 percent, while the incidence and mortality rates from heat-related illnesses could more than double. More than two million people in Bangkok—and several hundred thousand more in other densely populated urban centers across the Chao Phraya basin—are already exposed annually to severe heat stress. These findings underscore the urgent need for adaptive measures to protect both livelihoods and public health in the face of escalating climate risks.[6]

Bangkok, already accustomed to a tropical climate, is now facing prolonged periods of extreme heat that put vulnerable populations—such as the elderly, children, and outdoor workers—at heightened risk. The Urban Heat Island (UHI) effect exacerbates this crisis, turning built-up areas into heat traps while straining infrastructure, energy demand, and economic productivity.[7] Due to the UHI effect, some Bangkok

[6] Mani, M. & Pollitt, H. (2024) "Towards a Green and Resilient Thailand" (September), World Bank, Washington, DC.
[7] The UHI effect is driven by replacing the natural landscape with man-made materials and structures – such as asphalt roads and steel buildings – that absorb and radiate heat. With less tree and vegetation cover, cooling from the evaporation of water held in the leaves of plants is also reduced. Abundant high-rise buildings in Bangkok also mean that heat from the built environment and from sources such as car engines, motors and air-conditioning units is often trapped between buildings.

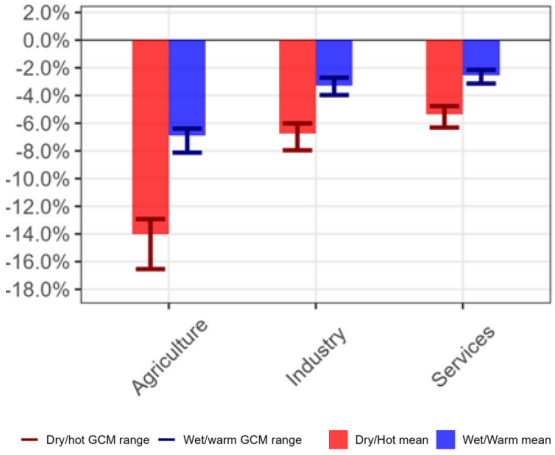
neighborhoods can be 2–3°C hotter on average than surrounding rural zones, with nighttime temperatures in certain spots surging to 6°C higher. Demographic data indicate that vulnerable groups—particularly the elderly, children, and those working outdoors—cluster in the hardest-hit areas. Economic estimates from the World Bank's Urban Heat report reveal that each additional degree Celsius could cost Bangkok between THB 85 billion to THB 123 billion—an equivalent to 1.6 and 2 percent of its GDP in 2019—in heat-related mortality, lost productivity, and higher energy consumption.[8]

Figure 2.3: Projected number of dangerously hot days in Bangkok



Source: World Bank analysis based on NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6, Trasher et al., 2022).

Figure 2.4: Projected labor productivity shocks by sector, 2041 – 2050



Source: Modeling conducted for this CCDR by Industrial Economics, Incorporated (IEc)

Taking a sectoral perspective of the economic effects of climate changes, projections suggest that Thailand's agriculture and fishing sectors could face significant impacts. Agriculture (which accounts for about 8 percent of GDP but around a third of all employment) is vulnerable to the labor productivity impacts of heat stress, and the impacts of droughts and water shortages, with highly water-intensive rice production especially susceptible as noted above. Rising temperatures, unpredictable rainfall patterns, and extreme weather events are already impacting other major agricultural commodities, including sugarcane, maize, livestock, and aquaculture. Water scarcity affects 58 percent of farmers, and only 26 percent have irrigation. Soil fertility is declining, and pesticide use is among the region's highest. Antimicrobial use in livestock is the world's highest, with central Thailand identified as a global hotspot. The rural poor in the North and Northeast, who rely on rainfed subsistence farming, face particular inequities in resource access, low labor productivity, and an aging population. Heat stress will also affect the oceans and losses from fishing are projected to be substantial in all climate scenarios, exceeding those from agriculture.

Manufacturing faces particular risks due to the concentration of industrial activity in areas which are exposed to flooding and urban heat effects. The manufacturing of goods for export is concentrated in and around Bangkok and is vulnerable to urban flooding; 70 per cent of the recorded damages and losses from the 2011 floods were attributed to the manufacturing sector, mainly from flooding in industrial estates in Ayutthaya and Pathum Thani. Even in indoor jobs, rising heat has been shown to increase workers' absenteeism and worsen their health and productivity, while the costs (and electricity needs) of cooling buildings across a range of economic sectors are likely to increase substantially.

Water supply constraints in manufacturing are also likely to worsen with climate change. Covering an area of ~13,000 km^2 in the provinces of Rayong, Chonburi, and Chachoengsao, the Eastern Economic Corridor

[8] See Rubinyi, Steven, Putu Sanjiwacika Wibisana, Jane Park, Nicholas K.W. Jones, Juan A. Acero, and Pichaya Moeller. 2025. *Shaping a Cooler Bangkok: Tackling Urban Heat for a More Livable City (English)*. Washington, DC. The World Bank.

(EEC) serves as a critical production base for advanced industries including petrochemicals, automotives, and smart electronics, accounting for approximately 15 percent of Thailand's GDP in 2022, and is already affected by water shortages. Current water infrastructure is inadequate to cope with peak demand during the dry season, leading to critical shortages that affect not only the industrial sector but also public utilities, tourism businesses and ecological systems. Currently only around half of water demand is being met, and in 2037 the deficit is projected to remain high at about 40 percent even with planned investments in water supply. Water security for the EEC cannot be achieved by supply augmentation alone. However, the international experience suggests that with investments in circularity and measures to increase the efficiency of water use, it is possible to reduce the supply gap and effectively decouple water demand from economic growth in the EEC.

Tourism is a vital pillar of Thailand's economy, contributing nearly one-fifth of GDP prior to the COVID-19 pandemic. While the pandemic dealt a severe blow to the sector, international arrivals have since recovered. However, the sector faces mounting longer-term risks from climate change, particularly given the concentration of tourism clusters along Thailand's coastlines. Tourism operators are increasingly vulnerable to coastal erosion, flooding, and other climate-related hazards (including air pollution) that can damage critical infrastructure, cultural heritage sites, and tourism assets, disrupt transport access, and compromise visitor health and safety.

Recent inland flooding in northern tourist provinces such as Chiang Mai has also negatively impacted visitor arrivals and revenue, highlighting that the risks extend beyond the coast. Left unaddressed, these climate impacts may erode Thailand's reputation as a safe and attractive tourist destination, with potential long-term consequences for the sector. While zoning regulations have been introduced in some locations to restrict the construction of new tourism infrastructure in high-risk areas, enforcement has often been inconsistent or weak. Moreover, rising temperatures could diminish visitor comfort, shift peak tourism seasons, and reduce overall competitiveness, while increasing reliance on air conditioning will drive up operational costs for tourism businesses. To safeguard this critical sector, Thailand will need to strengthen climate resilience planning, improve enforcement of risk-informed zoning policies, and support sustainable tourism practices.

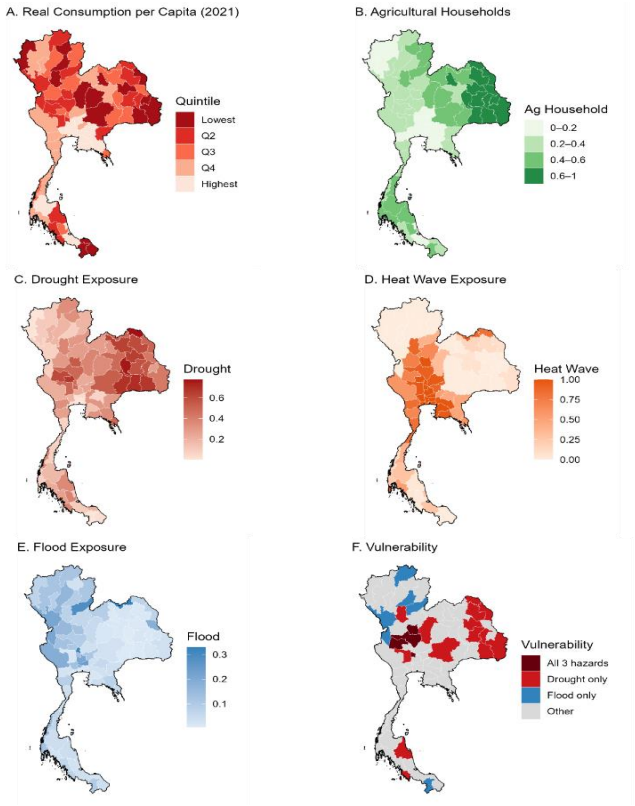
Moreover, warmer water temperatures and acidification are already affecting coral reefs and marine ecosystems. As one example, after finding that 50-70 percent of the coral had experienced bleaching caused by rising sea temperatures, Thailand's Department of National Parks, Wildlife, and Plant Conservation closed 12 marine national parks to allow coral reefs to recover to their usual condition. Increased water temperatures can therefore have major economic implications for those destinations that depend on marine ecosystems and marine tourism.

Thailand's low-income populations are particularly exposed to the physical risks of climate change. Provinces such as Nakhon Ratchasima, Nakhon Sawan, and Khon Kaen face a combination of high vulnerability to both floods and drought, and high physical risk (Figure 2.5). Together with Bangkok, Nakhon Ratchasima also faces very high heat risks. Samut Sakhon stands out in terms of its exposure to risks from coastal erosion, along with Samut Prakan and Chachoengsao. These regions are not only facing immediate risks to their coastlines but also potential long-term impacts on local economies reliant on coastal and marine resources. Populations in these areas are characterized by lower income and employment levels, high dependency ratios, and weaker community response systems, as well as a lack of infrastructure, education, and healthcare which compounds these challenges. A relatively high proportion of individuals engage in agriculture and fishery sectors, which are particularly sensitive to heat and drought conditions.

The heightened impacts of natural disasters on the most vulnerable were illustrated in the aftermath of the 2011 floods. Households across income distribution were affected, but the impacts were relatively larger for poorer households. Richer households primarily faced losses in business incomes and were able to build back more quickly in subsequent years. Poorer households were most affected due to losses in agricultural incomes and were slower rebuilding their homes and livelihoods. Government

compensation was not only inadequate to cover the full extent of these losses but also ended up benefiting relatively richer households rather than the poor (Noy, Nguyen and Patel 2019).[9]

Figure 2.5: Climate hazard exposure and vulnerability across Thailand



Source: Doan et al (2024)

Note: Hazard exposure is measured as the share of population likely to be affected by 20-year return period event, with separate estimates for drought, heatwave and flood risks as described in Doan et al (2024).[10] A province is classified as vulnerable if it is in the bottom 40 percent of the average per capita consumption distribution and top 40 percent in terms of exposure to a given hazard.

Inequalities in household welfare are also linked to security of water access. Historically, higher rainfall is positively associated with the average level of welfare, as measured by household consumption expenditures, and negatively associated with poverty and a variety of measures of inequality in the country. More frequent and more intense shortages of rainfall will decrease welfare and increase inequality at the national level and in both urban and rural areas. While social assistance can ameliorate some of these effects, at present there is considerable variation in the extent to which access to social benefit and credit programs mitigate the negative impacts of rainfall shortages on welfare.

2.3 The development challenge of emissions reduction

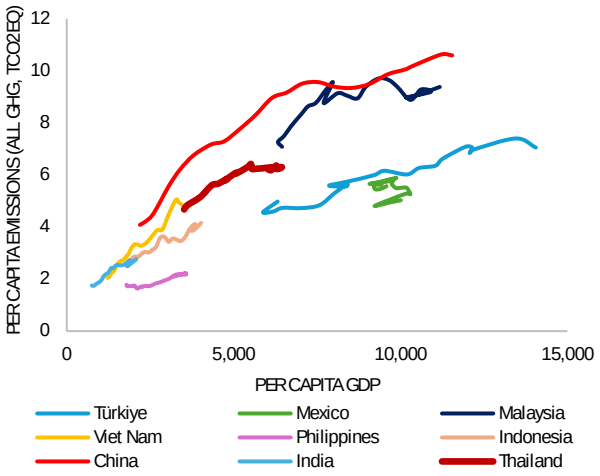
Thailand is not a large emitter of greenhouse gas emissions in global terms. In 2022, Thailand accounted for 0.88 percent of global greenhouse gas (GHG) emissions, ranking as the world's 20th largest emitter. Emissions per capita are well below the global average but are higher than those in several other ASEAN

[9] Noy, Ilan; Nguyen, Cuong; Patel, Pooja (2019), "Floods and spillovers: households after the 2011 great flood in Thailand", CESifo Working Paper, No. 7644, Center for Economic Studies and ifo Institute (CESifo), Munich.

[10] Doan, Miki Khanh; Hill, Ruth; Hallegatte, Stephane; Corral Rodas, Paul Andres; Brunckhorst, Ben James; Nguyen, Minh; Freije-Rodriguez, Samuel; Naikal, Esther G. (2024). "Counting People Exposed to, Vulnerable to, or at High Risk From Climate Shocks — A Methodology". Policy Research Working Paper; no. WPS 10619 Washington, D.C: World Bank.

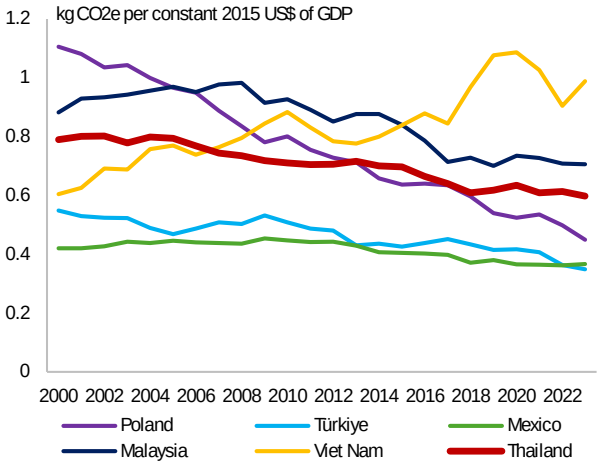
countries (Figure 2.6). Conversely, Thailand's GHG intensity of production (i.e. emissions per unit of GDP) is below ASEAN competitors but above the global average (Figure 2.7).

Figure 2.6: Per Capita GDP (constant 2015 US$) vs. Per capita Emissions (2000-2022)



Source: EDGAR and World Development Indicators

Figure 2.7: Carbon intensity of GDP (kg CO2e per constant 2015 US$ of GDP)



Source: World Development Indicators

There have been some signs that GDP growth is decoupling from GHG emissions, but achieving carbon neutrality and net zero will require substantial investments and policy effort. Between 2010 and 2022, real GDP per capita increased by 1.8 percent per year on average, while GHG emissions from all sources were flat and GHG emissions from energy increased by an average of 0.7 percent (Figure 2.8). But substantial work remains to be done to achieve carbon neutrality and net zero objectives, with emissions not yet declining as they have in many high-income countries. These international commitments to reduce emissions will not be met in the absence of further policy reforms and investments.

Table 2.1: Measures of Thailand's carbon footprint

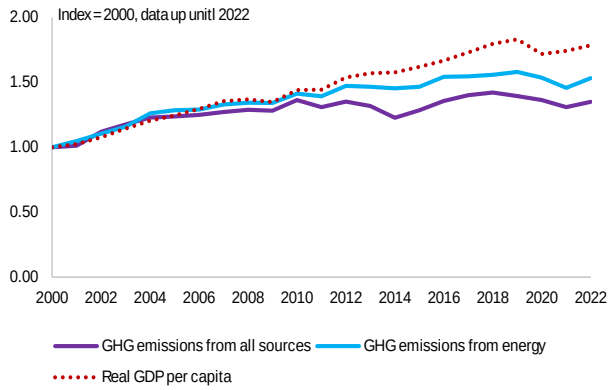
Country	GHG EMISSIONS PER CAPITA (tCO2e per capita)	CARBON INTENSITY (tCO2e per USD million of GDP)	TOTAL GHG EMISSIONS (MtCO2e)	ANNUAL GHG EMISSIONS GROWTH RATE (% between 2011 and 2021)
China	9.1	718	12792	2.22
Viet Nam	4.6	1247	457	6.45
Cambodia	4.5	2091	77	-2.73
Indonesia	5.4	1251	1485	-1.03
Philippines	2.1	603	238	3.91
Thailand	6.3	888	450	2.12
USA	16.8	235	5565	-0.44

Sources: ClimateWatch, WDI, World Bank analysis.

Industry, power, transport, and agriculture account for most of Thailand's GHG emissions. In 2022, the energy sector was responsible for approximately two-thirds of Thailand's total greenhouse gas emissions, with most of these emissions stemming from electricity generation, transport, and manufacturing activities (see Figures 1.8 and 1.9). Energy emissions grew gradually between 2000 and the mid-2010s, before stabilizing. Agriculture accounted for 18 percent of emissions, while industrial processes contributed around 10 percent: both these shares have remained broadly stable over time. Within the power sector, carbon dioxide (CO_2) represents the predominant greenhouse gas emitted, whereas agricultural emissions are primarily composed of methane (CH_4) and nitrous oxide (N_2O). Industrial

emissions include a rising share of fluorinated gases (F-gases), which are potent greenhouse gases with significant warming potential.

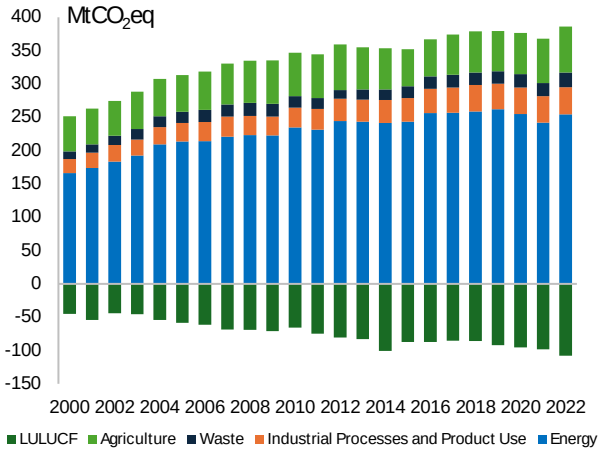
Figure 2.8: GHG emissions and GDP per capita



Source: Thailand. 2024 Biennial Transparency Report (BTR) and World Development Indicators

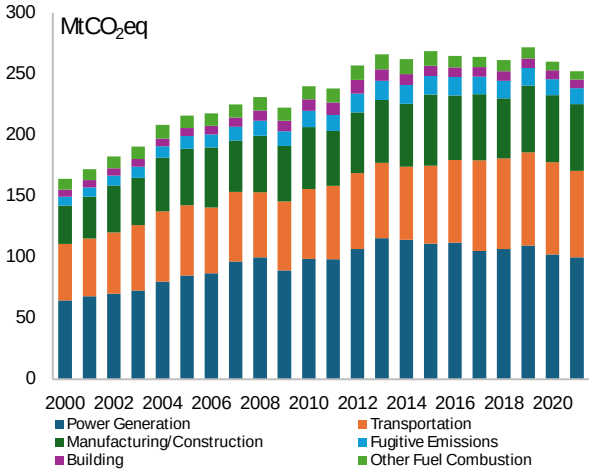
Thailand's energy consumption and supply relies heavily on petroleum products, driven mainly by the industrial and transportation sectors. The largest user of energy is the transport sector (28 percent), followed by the industrial sector (22 percent), largely manufacturing. Oil is the major energy source (42 percent of total), with transportation and industry as main consumers. Other non-renewable sources of energy consist of natural gas and coal, specifically for electricity production. Renewable energy sources accounted for 18 percent of total energy supply, with biofuels and waste representing by far the largest share, accounting for about 95 percent of renewable energy sources. Biofuel and solar PV have increased their share of electricity production in Thailand in recent years, but starting from very low levels.

Figure 2.9: Trend of national GHG emissions/removals by sector



Source: Thailand 2024 BTR

Figure 2.10: Energy emissions by sector



Source: Climate Watch

The manufacturing sector is more emissions intensive than other sectors in Thailand but less emission intensive than the manufacturing sector of most of Thailand's peers. That said, the manufacturing sector in Thailand remains 26.5 percent more emission intensive than the manufacturing sector in the EU, despite being 7.5 percent less energy intensive. As Chapter 4 shows, there are large differences in emission intensity across manufacturing subsectors in Thailand, and among manufacturing firms even within the same subsector. Moreover, emissions are highly concentrated among a relatively small number of firms, with the top 1 percent of firms responsible for more than three quarters of emissions from the sector.

Agriculture is a large source of GHG emissions in Thailand, with rice farming and livestock contributing significantly. Around half of agricultural emissions are contributed by rice farming and another quarter by the livestock sector. Rice fields are a significant source of methane emissions, primarily due to the anaerobic decomposition of organic matter in flooded paddies. Swine and poultry farms generate methane emissions from manure decomposition and carbon emissions from energy use, while ruminants (cattle, sheep, and goats) produce significant methane and nitrous oxide emissions through enteric fermentation and manure management. The burning of agriculture residues is a major contributor to carbon dioxide and black carbon emissions, impacting air quality and climate. It is estimated that biomass burning contributes to 25 percent of atmospheric particulate matter ($PM_{2.5}$) in the Bangkok Metropolitan Region, which rises to 35 percent in dry season. Accounting for the entire agrifood supply chain, from on-farm production to processing and sale, Thailand is the second largest agrifood emitter in Southeast Asia, after Indonesia.

Deforestation and land conversion, especially for agricultural expansion, are the primary drivers of emissions in the Land Use, Land Use Change, and Forestry (LULUCF) sector. Forested areas are often cleared to make way for rubber plantations and other commercial crops, releasing carbon stored in trees and soil. Additionally, degradation from illegal logging, forest fires, and infrastructure development exacerbates carbon release. Poor land management practices, including insufficient reforestation efforts, hinder the natural carbon sequestration potential of forests. At sea, mangrove forests have been cleared for shrimp farming, with the pollution from these farms causing further damage. Thailand's LT-LEDS aims to increase annual net emission removals from the sector from 90 to 120 mtCO2e/year by 2050, which would offset more than 25 percent of current GHG emissions and would be a key factor in bringing emissions towards net-zero in the second half of the century.

To meet the LT-LEDS target, around 40 percent of Thailand's land mass would need to be covered by forest. But the overall share of forested land in Thailand is decreasing. In 2020, forests covered 31.6 percent of Thailand's land mass, down from a corresponding share of 33.4 percent in 2008. Despite efforts by several agencies in Thailand to promote reforestation, satellite images show that the level of forest coverage is decreasing by around 0.3 percent per year. Some forests have been degraded because of natural forest fires. However, the main reasons for deforestation are human encroachment and illegal logging.

Beyond their primary goal of reducing greenhouse gas emissions, climate mitigation measures offer a range of important co-benefits that can enhance economic, social, and environmental outcomes. For instance, improving energy efficiency and accelerating the transition to renewable energy sources will not only curb emissions but can also significantly lower energy costs over the medium to long term. This shift reduces Thailand's reliance on imported fossil fuels, thereby enhancing national energy security and buffering the economy against volatile global energy markets and price shocks. While the upfront capital investment required to deploy renewable technologies and upgrade infrastructure can be substantial, the rapidly declining costs of renewables—combined with the inclusion of environmental externalities such as air pollution and carbon emissions—are making clean energy increasingly cost-competitive compared to conventional fossil fuels. This evolving economics creates a compelling case for accelerated deployment, particularly as renewables also tend to have lower operating and maintenance costs.

Reducing emissions will also be important to secure Thailand's position in greener global value chains (GVCs). In pursuit of their own climate goals, surveys suggest that a majority of multinational corporations (MNCs) plan to exclude high-carbon producers from their supply chains (see Chapter 4). Carbon pricing and other decarbonization measures could help to shield Thailand's economy from the associated risks to trade. They could also help Thailand adapt to international trade policy measures such as the EU's CBAM, and reduce risks associated with the potential implementation of similar measures by other countries. As discussed in Chapter 4, the impacts on Thailand of the CBAM in its current form are likely to be limited outside the carbon-intensive plastics sector. Nevertheless, an expansion of CBAM to encompass other products or the adoption of CBAM-like mechanisms by other countries would have more significant impacts on Thailand in the absence of measures to decarbonize.

2.4 Climate commitments and plans

Thailand has made a range of climate commitments, captured in various plans and policy statements, which demonstrate its recognition of the need to act on climate change given the risks outlined above. The Climate Change Master Plan 2015-2050 provides a long-term national framework for climate change adaptation and the promotion of low carbon growth in line with sustainable development principles. In line with the global commitments made by countries under the Paris Agreement, Thailand submitted a Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) to the UNFCCC in 2021, which was subsequently updated in 2022 – together with a second updated Nationally Determined Contribution (NDC) – to target a reduction in GHG emissions of 30 to 40 percent from business-as-usual levels by 2030.[11] This is an intermediate step towards meeting Thailand's overall objectives of carbon neutrality by 2050 and net zero greenhouse gas emissions by 2065.

A range of plans for the power and transport sectors are linked with Thailand's net-zero emissions goal. These include the National Energy Plan (which supports these targets and outlines pathways for decarbonizing the energy sector), Power Development Plan, Alternative Energy Development Plan, and Energy Efficiency Plan. These plans set specific targets for renewable power generation (50 percent of total generation by 2050, with the recently updated draft PDP 2024 targeting 90 percent) and energy intensity (30 percent reduction from 2010 levels by 2037). Thailand has also set ambitious targets for the sale and production of electric passenger cars and light commercial vehicles.

The National Committee on Climate Change Policy (NCCC), chaired by the Prime Minister, was set up in 2007 to coordinate climate change efforts across various ministries to meet UNFCCC commitments. The NCCC is responsible for defining national climate policies and devising implementation mechanisms. The NCCC includes members from both the public and private sectors, as well as experts from relevant agencies, and comprises nine subcommittees. Among the NCCC's key decisions was the approval of the updated Nationally Determined Contribution (NDC) in 2022. More recently, the NCCC approved the principles of the draft Climate Change Act in December 2024 and instructed the Ministry of Natural Resources and Environment to expedite the submission of the draft bill to the Cabinet.

The Ministry of Natural Resources and Environment (MONRE) oversees climate change initiatives in Thailand. Within MONRE, the Office of Natural Resources and Environmental Policy and Planning (ONEP) has been the National Focal Point (NFP) for the UNFCCC since 1995, coordinating Thailand's climate change efforts. In August 2023, the Government created a new Department of Climate Change and Environment (DCCE) as the central coordination body for Thailand under the United Nations Framework Convention on Climate Change (UNFCCC). As a relatively new agency within MONRE, DCCE is in the process of building up its technical capacity, supported by an expanding budget allocation. DCCE's current remit is largely confined to policy recommendations and coordination with other institutional stakeholders. It lacks legal power to mandate actions (especially information sharing and reporting) by public sector agencies as well as regulated private sector entities. This is expected to change once the Climate Change Act is enacted and assigns additional roles and powers to DCCE.[12]

The Climate Change Act will provide an overarching legal framework for carbon pricing and Thailand's emissions reduction efforts (Box 2.1). The draft bill is under review and is expected to be approved by 2026.

[11] The higher target (40 percent) is contingent upon enhanced access to technology development and transfer, financial resources, and capacity-building support. Thailand's NDC 3.0 will shift to an absolute emissions reduction target for 2035.
[12] DCCE will have to operationalize the new climate mitigation instruments, offer technical support to sub-national government entities as well as sectoral ministries/departments on both climate mitigation and adaptation fronts, and supervise and regulate the domestic carbon markets, among other new responsibilities.

Box 2.1: Thailand's Climate Change Act

The draft bill has been assessed against the World Bank's key legislative criteria for effective climate governance.[13] The assessment covers 12 critical elements, highlighting strengths and gaps in Thailand's framework for mitigating and adapting to climate change. Overall, Thailand's current draft CCA provides a strong foundation for climate governance, with clear targets, policy tools, and institutional structures. The framework aligns with international standards but could benefit from stronger accountability and subnational support. Gaps remain in parliamentary oversight, independent review mechanisms, and explicit 2030 targets.

Targets: The bill requires the country's climate change goals to be integrated into the missions of government agencies, as well as sector-specific targets, action plans and measures that align with the national objectives. The bill mandates the production of a national climate change master plan, to be updated every 5 years (or sooner, if necessary), that includes greenhouse gas emission scenarios, greenhouse gas reduction targets, and adaptation measures, including implementation guidelines and monitoring.

Instruments: The bill proposes several policy instruments to support GHG reduction. These include:

- A carbon tax
- An emission trading system (ETS), to be applied to industries based on their carbon intensity.
- A regulatory framework for carbon credits, which inter alia sets out licensing requirements for carbon credit businesses, certification services, and trading centers.
- A Carbon Border Adjustment Mechanism (CBAM)
- A Climate Change Fund to finance activities related to GHG reduction, climate change adaptation, and climate research and development, and funded with revenues from the ETS, CBAM, and other sources including government subsidies.
- The bill also mandates GHG reporting and establishes a national GHG database to track the quantity of GHG emissions from human activities, sequestration, and reduction efforts.

While a hybrid ETS/carbon tax system is envisaged, it remains unclear which sectors will be subject to which system and how the interactions between the ETS and the carbon tax will be managed.

Institutions: The bill mandates a high-level committee (essentially the existing National Climate Change Policy Committee) to oversee and coordinate the government's climate actions. It tasks DCCE to operationalize the new climate mitigation policy tools listed above by, inter alia, establishing necessary databases (e.g., GHG inventory) and registries (e.g., CBAM, ETS, carbon credits), monitoring and reporting on implementation progress (e.g., National Climate Change Master Plan, National Climate Adaptation Plan); and supervising/regulating carbon trading markets, adjudicating any appeal from regulated entities, and resolving any inconsistency between the Master Plan, the GHG Reduction Plan, etc., and sectoral plans/actions.

Through public consultations, some segments of the private sector, especially small and medium enterprises, have raised concerns about the cost of GHG reductions and the associated investments to make their operations less carbon intensive.[14]

Critical Elements	Assessment
1. Long-Term Targets	• The CCA identifies targets of carbon neutrality by 2050 and net-zero GHG emissions by 2065, as well as high-level adaptation objectives.
2. Intermediate & Sectoral Targets	• No explicit 2030 target in the CCA, but Thailand's NDC commits to 30–40 percent emissions reduction (BAU) by 2030. • Requires sectoral action plans, budgets, and alignment with national goals. • Given the proliferation of plans and strategies, the bill could play a role in streamlining the "policy ecosystem", specifying the minimum necessary plans and strategies within a clear hierarchy and relationships among them.

[13] The draft bill is as of November 2024, Public Hearing Version. See also World Bank (2023), Reference Guide to Climate Change Framework Legislation.

[14] See https://enviliance.com/regions/southeast-asia/th/th-climate-change-act-draft.

Box 2.1: Thailand's Climate Change Act	
3. Risk & Vulnerability Assessments	• Mandates periodic climate risk assessments (water, agriculture, health, etc.) and public dissemination.
4. Climate Strategies & Plans	• Requires a National Climate Change Master Plan (updated every 5 years) and sectoral GHG reduction plans and adaptation plans.
5. Policy Instruments	• Comprehensive tools: ETS, carbon tax, carbon credits, CBAM. Few details on the sectoral coverage of the ETS and carbon tax or the management of interactions between these instruments.
6. Independent Expert Advice	• A National Climate Change Policy Committee (with private sector and civil society reps) provides expertise, but no formal requirement for government response to advice. • The bill could be strengthened by mandating an independent advisory body (as opposed to minority representation of non-governmental actors in an otherwise government-led committee as proposed) to institutionalize use of scientific advice in climate policy-making and implementation.
7. Coordination Mechanism	• The Department of Climate Change and Environment (DCCE) leads implementation, with oversight from a Prime Minister-chaired Committee. • Subnational governments must develop Provincial Action Plans.
8. Stakeholder Engagement	• Mandates public consultations for climate plans and includes private sector/civil society in policymaking.
9. Subnational Governance	• Requires local adaptation plans and allows provinces to request support for climate action.
10 Financing Implementation	• Establishes a Climate Fund (from carbon pricing, donations, etc.) but lacks direct integration of climate risks into national budgeting.
11. Measurement & Reporting	• DCCE collects and publishes GHG and climate risk data, with mandatory reporting for key sectors.
12. Oversight	• Cabinet oversight (not Parliament) of climate plans; no independent progress assessments.

Thailand's National Adaptation Plan (NAP) was updated in 2023. This plan addresses climate impacts and enhanced resilience across six sectors: water resources management, agriculture and food security, tourism, public health, natural resources management, and human settlements and security. It specifies institutional responsibilities for implementation, as well as the monitoring and evaluation framework including targets and indicators. In addition, measures are being implemented to manage natural disasters, including the development of early warning systems and strategies for managing contingent liabilities. Under the NCCC, the Subcommittee on Climate Change Policy and Planning Integration provides expert guidance on integrating mitigation and adaptation into national strategies, recommends legal and financial measures, and advocates for coordinated budget allocation.

Institutional fragmentation poses challenges for climate adaptation in Thailand. Several sectoral ministries and agencies which need to incorporate climate adaptation into their policies and operations suffer from technical capacity deficits and struggle to manage climate adaptation against other competing priorities. Some actions are constrained by legal, financial, or knowledge constraints. Progress has been made to improve policy coordination and oversight – e.g. in the water sector; see Box 2.2 – but more needs to be done to clearly define roles and responsibilities across ministries and agencies and ensure that climate actions are appropriately prioritized.

Box 2.2: Strengthening coordination and oversight of water resource management

With the adoption of the Water Resources Act in 2018 and the creation of ONWR in 2017, the Government of Thailand implemented long-standing policy recommendations aimed at increasing coordination among ministries and departments responsible for water resources management. More than 30 ministries and departments are responsible for water resources management, leading to a scattered institutional landscape, unclear mandates and overlapping responsibilities. Prior to the establishment of ONWR, Thailand lacked an effective policy coordination and oversight body to guide water resources management. This often resulted in a series of sector plans or fragmented strategies without effective coordination (ADB, 2015). ONWR was created with the mandates of formulating water management policies, developing strategic plans and master plans, integrating information and projects, scrutinizing projects and budgets, and monitoring and evaluating water resource management. ONWR also has an important role as the Secretariat of the Thai National Mekong Committee, which serves as Thailand's main coordinating body for transboundary water cooperation.

The institutional reform process that started with the establishment of ONWR now needs to be further advanced. For example, the current protocols for inter-agency co-ordination during flood emergencies are inadequate and should be improved, including through development of Standard Operating Procedures. Building upon the coordinating role of ONWR, more clearly defined roles and responsibilities among the related agencies regarding operation of infrastructure, data integration, communication, planning and response are critical.

Key issues that are yet to be addressed include (i) strengthening of early warning communication with the public and affected communities, (ii) enhancing coordination among government departments in the context of preparedness and response, (iii) strengthening land management and flood zoning, (iv) preparing comprehensive risk reduction and contingency planning tools, (v) strengthening hydraulic modelling, data management, and data integration, (vi) dissemination of risk information, and (vii) enabling community driven disaster prevention. While Thailand has robust hydrometeorological services, the communication with stakeholders and affected communities when a flood event is expected could be improved.

As many climate adaptation needs are location specific, sub-national governments play an important role, but in Thailand their mandate and ability to plan and implement adaptation solutions is limited. In many countries, sub-national governments are assigned specific sectoral functions, such as water resource management, environmental conservation and urban development, that are relevant for climate change. In Thailand, the actual roles of the elected provincial and local governments are constrained due to their limited legal mandates, fiscal resources, and technical capacity. The situation is further complicated by the co-existence of deconcentrated national government agencies that operate in parallel with elected provincial and local authorities in the same geographic spaces. For example, Provincial Offices of Natural Resources and Environment under MONRE are responsible for implementing MONRE directives. On the other hand, MONRE has no legal power to oblige elected provincial and local administrative organizations to follow its directives, unless specifically authorized to do so by legislation. Provincial governors appointed by the Ministry of Interior coordinate national government actions at the provincial level but do not control their budgets. The provincial offices of national ministries and departments retain primary reporting lines to their ministry/department headquarters in Bangkok. Governors do have the authority to review and approve budget proposals from elected sub-national administrations but play no role in implementation.

To meet its ambitious climate goals, Thailand will need to modernize its policies, regulations, and institutional frameworks. This includes strengthening the coherence and enforcement of climate-related regulations across sectors, enhancing transparency and data systems for better 'climate screening' of public investments and better monitoring and reporting of emissions, and fostering more agile and integrated governance structures capable of coordinating climate action at national and subnational levels. Accelerating the passage of the Climate Change Act will be important to set the framework for carbon pricing and other proposed climate policy instruments, provide DCCE with the mandate to lead and implement climate actions and regulations, and reduce private sector uncertainty. Institutional mechanisms should be developed to strengthen the linkages between sectoral climate plans and ensure that these plans are also linked with annual budgets.

3.

Adapting to the physical impacts of climate change

3 Adapting to the physical impacts of climate change

This chapter explores how the economic and social impacts of climate change on Thailand (as set out in Section 2.2) might be reduced by climate adaptation actions. To start with, the potential economic impacts of climate change over the next 25 years are estimated under a "business-as-usual" (BAU) scenario, which assumes no additional adaptation measures are implemented. An "adaptation" scenario is then used to assess how targeted adaptation policies and investments could reduce climate-related damages and influence broader economic outcomes. This "adaptation" scenario incorporates investments in flood mitigation, water security, coastal protection, and other measures designed to enhance Thailand's capacity to limit and adapt to the physical impacts of climate change (Annex 1 provides details on the modelling approach).

The modelling conducted for this CCDR shows that climate change could have substantial impacts on the Thai economy over the next 25 years, making it much more difficult to achieve high-income targets. The magnitudes of impact vary across the two macro-economic models used in this CCDR owing to differences in modeling assumptions, and also vary from previously published estimates.[15] But both models are consistent in showing that climate change could substantially lower aggregate output in the business-as-usual scenario (relative to a baseline scenario without climate change) by mid-century. The size of the 2050 GDP impact in the pessimistic (dry/hot) scenario is centered around -7 percent for MFMod and -14 percent in E3-Thailand. This implies that in the coming two to three decades climate change could reduce annual average growth rates by half a percentage point or more, making it much more difficult to achieve already ambitious high income targets. Despite uncertainties, both models are consistent on the compounding effect of climate change, i.e., the cost of inaction under the business-as-usual scenario grows larger with passing time. Both models are also consistent in picking up heat related labor productivity loss as the strongest mechanism of impact, impacting workers across all sectors and in all parts of the country.

The annual average impacts set out in Figure 3.1 may understate the physical threats of climate change in Thailand. First, the results only estimate the marginal impacts from additional climate change over the next 25 years, not the impacts of climate change already realized. For instance, the additional impacts from flooding attributable to future changes in climate do not capture the total estimated impacts of flooding on the Thai economy, which are estimated to average around USD 18 billion or about 3 percent of GDP per year (providing a key rationale for flood mitigation investments). Second, while the impacts of flooding are relatively modest in annual average terms, flooding shocks could have a much larger impact in years in which tail risk events (such as the 2011 floods) materialize (Box 3.1). Climate change will also increase the risk of extreme events and scenarios that, for example, could have implications for the viability of some urban areas in and around Bangkok, triggering substantial costs which are not accounted for in the modelling.

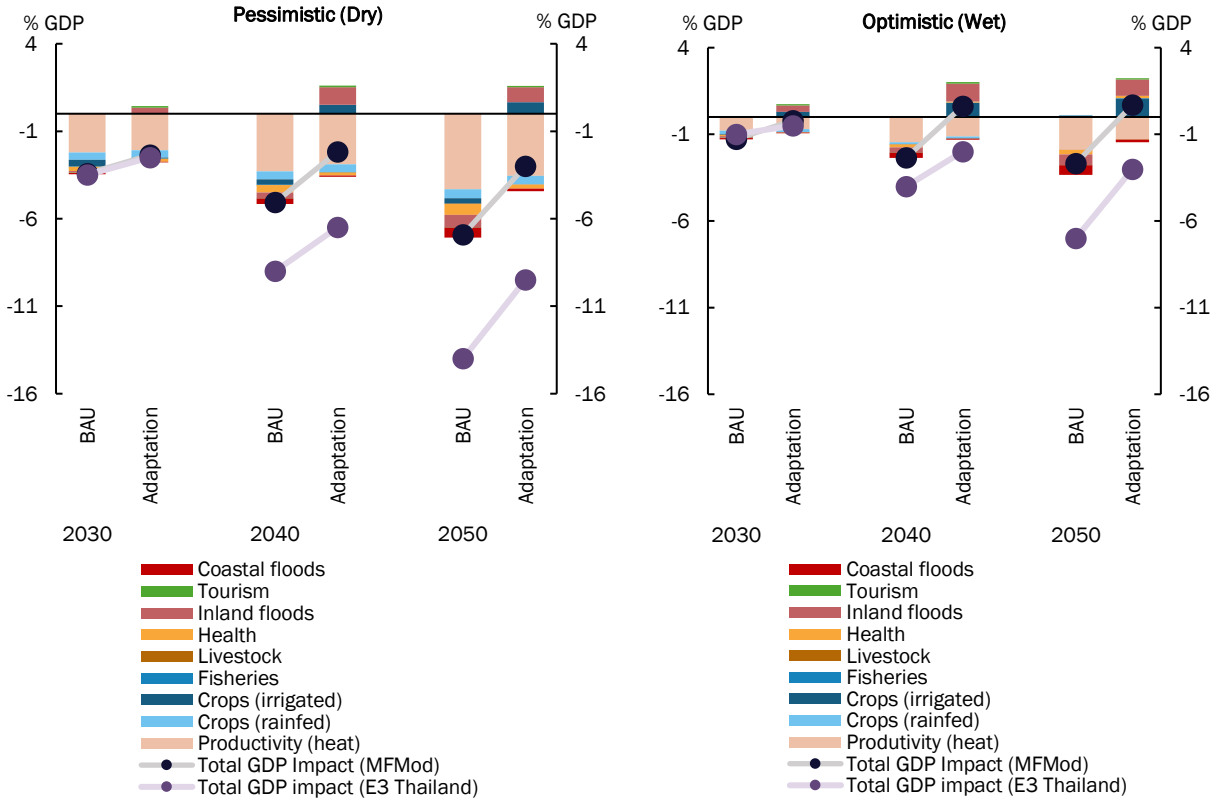
Average economy-wide effects also conceal sizeable impacts on certain demographic, social and economic sub-groups. Households with more concentrated income sources and lower savings and other forms of assets are more vulnerable to climate-induced hazards such as floods and droughts. Empirical analysis of socio-economic and geo-physical data over the 2007-2021 period shows that precipitation shortfalls have had a significant negative impact on aggregate household welfare,

[15] Two macroeconomic models are used to estimate economy-wide impacts in this CCDR. The first is the World Bank's Macro-Fiscal Model (MFMod) which is a comprehensive macro-structural econometric tool that simulates the flow of funds throughout the entire economy. The second is E3-Thailand, another macro-econometric model that was built specifically to look at climate-economy interactions in Thailand. Previous estimates have suggested that the cost of climate change on the Thai economy could be around 10 to 20 percent of GDP by mid-century, with noticeable impacts possible even this decade (World Bank. 2023. Thailand Public Revenue and Spending Assessment: Promoting an Inclusive and Sustainable Future. World Bank, Bangkok). Another more recent estimate suggests more muted average impacts on GDP of around 2.5 percent of GDP by 2050 (Mani, M. & Pollitt, H. (2024) "Towards a Green and Resilient Thailand" (September), World Bank, Washington, DC.).

increasing poverty and inequality rates. The impact on welfare is particularly acute in rural, rice-growing parts of the country that have less irrigation infrastructure. The same work also shows that households with a more diversified income portfolio, those benefiting from existing social protection programs and those with stronger access to finance, are more resilient to these shocks (Tiwari et al 2025).[16] Similarly, households with elderly, children, pregnant and lactating mothers are typically more vulnerable. For example, there is evidence that displacement during 2011 floods adversely impacted birth outcomes among pregnant women. Climate vulnerabilities in Thailand are also compounded for specific communities such as indigenous groups in the northern province of Chiang Rai who have lost control over ethnic lands because of forest conservation and reclamation efforts while also remaining ineligible for government assistance on account of their lack of Thai ID.[17]

Figure 3.1: Physical impacts of climate change on GDP

("Business as usual (BAU)" and "Adaptation" scenarios are relative to a baseline scenario with no additional climate change from 2025-50)



Note: Climate scenarios are obtained from the World Bank's Climate Change Knowledge Portal for 30 General Circulation Models (GCMs) from the Coupled Model Intercomparison Project 6 (CMIP6) suite of model outputs. We select climate scenarios in such a way as to capture the broadest range of climate change effects across GCMs. Further, we consider climate projections for SSP2-4.5 and SSP3-7.0 as the two most likely scenarios. SSP2-4.5 represents a global mitigation scenario consistent with current climate commitments and SSP3-7.0 a scenario in which warming reaches 4°C by 2100 due to lax climate policies or a reduction in ecosystems and oceans' ability to capture carbon. Wet/warm and dry/hot scenarios are constructed by taking the 10th and 90th percentiles of mean temperature and precipitation changes across SSP2-4.5 and SSP3-7.0 GCMs.

[16] Tiwari, Sailesh, Emmanuel Skoufias & Varun Kshirsagar (2025). "Welfare Impacts of Climate Change in Thailand" CCDR background paper.

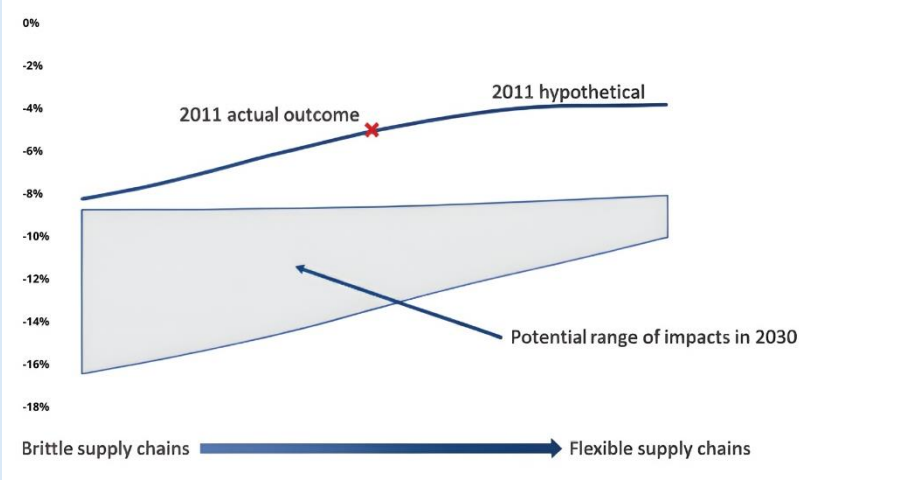
[17] While recent policy efforts have been geared towards making it easier for indigenous communities to obtain Thai ID cards, many elders still lack them, limiting their access to a variety of government services. See Tansanguanwong, Pamornrat; Geithner, Sarah; Vichitrananda, Sutthana (2025). Building Climate Resilience of Vulnerable Populations and Communities in Thailand: Synthesis Report (English). Washington, D.C: World Bank Group.

Box 3.1: The need to protect against extreme risks

Thailand faces substantial tail risks from climate change, including the risks of a severe flood or drought. From a risk mitigation perspective, adaptation responses should also account for the possibility of these tail events occurring rather than being calibrated solely on estimates of annual average impacts, which smooth over the impact of rare but severe events.

One example is the 2011 floods—classified as a 1-in-50-year event—which caused damages equivalent to 12.6 percent of GDP (THB 1.43 trillion or USD 46.5 billion) and cut production by around 5 percent of GDP.[18] Due to climate change, the intensity of similar events could increase, and there is now an estimated 50 percent chance that such a flood could occur again by 2050.[19] An equivalent flood in 2030 could reduce Thailand's GDP by nearly 10 percent in that year alone, with losses rising to 15 percent if recovery is slow or future floods hit before reconstruction is complete (Figure Box 3.1). Impacts will vary by location and adaptive capacity—but risks to GDP are magnified when supply chains are disrupted or businesses unaffected by flooding are forced to shut down.

Figure Box 3.1: Potential loss of GDP from future floods (%)



Source: World Bank Group. 2023. Thailand Economic Monitor: Coping with Droughts and Floods; Building a Sustainable Future. World Bank, Bangkok.
Notes: Supply chain flexibility is measured as length of time companies can keep production uninterrupted in the event of disruption. The range on the chart's x-axis is zero to six weeks.

Another tail risk is a sharp increase in susceptibility to flooding due to land subsidence in and around Bangkok, the impacts of which would be amplified by climate-induced sea level rise and the increased intensity of storm surges. While groundwater pumping restrictions have mitigated some of these risks, there remains substantial uncertainty around future outcomes.[20] Under some scenarios the coastal provinces in particular would become much more flood-prone than they are today, which in the absence of remedial action could have implications for their longer-term viability. While not accounted for in the modelling, the realization of this tail risk could have substantial economic impacts: one in four Thais could be directly affected while the capital region accounts for half of national GDP. [21]

Adaptation investments can significantly reduce but not entirely offset the adverse macroeconomic impact of climate shocks, with the costs of inaction significantly greater than the costs of action. The

[18] Thai Flood 2011: rapid assessment for resilient recovery and reconstruction planning (Vol. 2 of 2): Final report (English). Washington, DC: World Bank.
[19] World Bank Group. 2023. Thailand Public Revenue and Spending Assessment: Promoting an Inclusive and Sustainable Future. World Bank, Bangkok.
[20] See UNESCO, 2024. Catalogue of Hydrologic Analysis for Asia and the Pacific, Volume 3, Groundwater.
[21] World Bank Group. 2023. Thailand Economic Monitor: Coping with Droughts and Floods; Building a Sustainable Future. World Bank, Bangkok.

modelling indicates that investments in flood mitigation, coastal protection, water security, and cooling could raise annual GDP by 2-3 percent by 2040 and 4-5 percent by 2050 relative to a business-as-usual scenario, at an annualized cost of a little over 1 percent of GDP (see Chapter 6). These net benefits would likely be even larger to the extent that concerted action to mitigate climate risks helps to boost the attractiveness of Thailand as a destination for foreign investment. The modeled climate resilient pathway incorporates the costs and benefits of recommended adaptation investments, as well as the impacts of other policy reforms and interventions such as early warning systems and better land use planning. These include investments to protect against flooding, particularly in the Chao Phraya basin and Greater Bangkok area; to promote water security, particularly in the EEC and in the drought-affected north and north-east regions; and to protect against coastal erosion, particularly in heavily touristed areas on the Gulf of Thailand. We include the capital costs of these investments in this scenario and, given their public goods characteristics, assume that they are funded largely by the public sector, with implications for public finances and debt. The estimated benefits associated with these investments (avoided climate damage and economic losses, alongside macroeconomic gains from the investments themselves) are also incorporated.

The efficacy of adaptation investments varies across the different climate scenarios. The results suggest that adaptation investments can significantly limit the losses and damages from flooding but have a proportionally smaller impact on heat stress and associated declines in labor productivity. This reflects less scope for additional heat adaptation due to the high prevalence of air conditioning especially in urban areas, and also highlights the challenges of mitigating heat impacts on outdoor workers.[22]

The remainder of the chapter assesses key investments and actions needed to reduce the damage and losses associated with climate change and adapt to its impacts. It sets out more details on the recommended investments in adaptation and the supporting policies and reforms that would be needed to boost climate resilience.

3.1 Mitigating flood risks

Thailand's vulnerability to flooding is largely concentrated in the Chao Phraya basin. The Chao Phraya basin is the largest in Thailand, home to 40 percent of the population, 78 percent of its workforce, and 66 percent of its GDP, but suffers from an increasing intensity and frequency of floods. While the flood risk in this area stems from multiple factors in addition to rainfall and runoff (such as land use changes, subsidence, river morphology, and tidal effects), climate change is leading to a very significant increase in the flood hazard (see Table 3.1 below). For example, by the 2040s and 2050s, the current 120-year flood is expected to return every 19 years (in RCP 4.5 scenario) or every 6 years (RCP 8.5 scenario).

Table 3.1: Projected Flood Return Periods in the Chao Phraya Basin

Flood Event (Year)	Observed Chao Phraya discharge	Return Period	Return Period under RCP 4.5 scenario		Return Period under RCP 8.5 scenario	
	(m^3/s)	Present	2040- 2059	2080-2099	2040- 2059	2080-2099
2006	5,457	120	18.4	11.6	5.4	7.0
1995	4,820	43	7.1	5.1	2.8	3.5
2002	3,997	19	3.8	2.9	1.9	2.2
2010	2,826	6	1.9	1.4	1.2	1.4

Source: Singharak, P., (2015). Final Report on the Work of the National Climate Change Expert - Training for Royal Irrigation Department on Project and Budget Analysis under Climate Change. Prepared for UNDP and Chulalongkorn University.

[22] Identifying the exact mechanisms of impact of heat stress on worker productivity is a knowledge gap that future analytical work could address.

A range of interventions have been and are being considered to protect against floods in the Chao Phraya basin. The Chao Phraya River Basin Flood Mitigation Master Plan, developed by the Office of the National Water Resources (ONWR) and Royal Irrigation Department (RID) in response to the 2011 floods remains a key strategy for flood management in the Chao Phraya basin. The Master Plan is designed to achieve flood protection for a 1 in 50-year flood event and comprises of nine projects ("Nine Plans") with a combined cost of USD 12.3 billion. The Plans include provisions for new upstream water retention, the Ayutthaya bypass, Bangkok outer ring road diversion, new Pasak-Gulf of Thailand bypass canal excavation, raising of dikes, upgrade of irrigation structures and river improvement works, among others.

Full implementation of the Chao Phraya "Nine Plans" could significantly curtail future damages and losses due to floods. Given the large scale of investments and extended timeline of the program, different implementation scenarios have been simulated to assess the differential benefits of incremental investments in Chao Phraya floods management. In a "No Action" baseline scenario, the Chao Phraya River Basin is projected to incur substantial and recurring climate-related damages—estimated at USD 811 million annually in direct physical losses, alongside economic disruptions amounting to USD 488 million per year. This results in a combined annual impact of approximately USD 1.3 billion. However, comprehensively scaling up investment in flood management infrastructure and planning demonstrates clear economic benefits. Full implementation of all nine planned flood management interventions could almost entirely mitigate the damages and losses in most years, lowering the costs associated with flood-proofing individual buildings and structures.

While Thailand's focus on flood management infrastructure is well placed, global experience shows that complementary efforts are needed to provide more comprehensive protection. Investments geared towards, for example, technical and institutional improvements in hydrometeorological services, flood forecasting and early warning systems are not only critical for reducing casualties but also provide the highest rates of return across a range of investments.[23] Better land management, zoning, and management of construction in flood-prone areas are also important components of effective flood mitigation strategies.

Measures to conserve and enhance the forest areas in the upper basin can help to attenuate runoff and forestall flash floods, while providing substantial carbon reduction benefits. Forests' role as a carbon sink is a key component of Thailand's overall decarbonization pathway (see Chapter 4). At the same time, forests provide critical ecosystem services. By regulating water flows, forests help mitigate flash floods in upstream/mountainous regions, while absorbing excess water and reducing downstream flood risks. Forests can also protect water quality by reducing soil erosion and landslides, preventing sediment from entering rivers and reservoirs.

Recommendations

Given the significant projected impacts and risks associated with flooding, particularly in the Chao Phraya basin, Thailand should prioritize the implementation of comprehensive flood management strategies which reduce the vulnerability of communities and infrastructure to flooding events. Community engagement is critical to address local risks. This CCDR recommends:

- **Prioritize implementation of critical flood management plans.** Chao Phraya basin is the central focus of Thailand's flood management efforts with the Nine Plans representing the main

[23] Recent amendment to the scope of "Plan 1" attempt to address some of these issues. Specifically a new component has been added to the plan that includes efforts to: (i) upgrade hydromet networks (including communication systems) which still include many manual or non-functional stations at important locations; (ii) improve communication and coordination between the four independent flood forecast and Early Warning systems operated by different agencies in Thailand; (iii) upgrade the current flood forecasting models (from 1D to 2D or combined 1D2D models which are required to produce reliable forecasts of flood flows and water levels), and; (iv) streamline the multi-institution process for decision-making which is currently too slow for emergency scenarios.

strategy. Two of these plans (Plans 6 and 9) have been completed and Plan 7 is in an advanced construction stage. However, implementation of the most critical plans has not yet started. The government could use scenario-based planning to sequence the roll-out of remaining plans, accounting for risk exposure and the cost-effectiveness of each intervention. For example, a two-phased implementation of Plan 2 (with a first phase starting in conjunction with Plan 1) could bring very significant flood protection benefits in a relatively short period of time. Global experience on capturing land value enhancements that result from flood risk reduction could also be explored as a complementary source of finance, especially in urban areas.

- **Promote sustainable upland and watershed management** through reforestation, wetland restoration, sustainable farming and soil stabilization which would not only help reduce flash floods, erosion and landslides in upstream/mountainous regions but also absorb excess water and reduce downstream flood risks.
- **Enforce climate-smart land use planning and floodplain zoning** to steer new development away from high-risk areas and reduce downstream flood impacts would help build greater resilience.
- **Expand and modernize early warning systems and hydrometeorological services**. Enhanced forecasting and real-time alerts will allow vulnerable communities and key sectors to prepare for flood events, reducing loss of life, economic disruption, and the burden on emergency services.

3.2 Protecting against coastal erosion

Over the past three decades, up to 30 percent of the Thai coastline has suffered from coastal erosion, resulting in total land loss of around 12000 hectares, a land value loss of more than USD 1.3 billion exclusive of other economic losses and damages. Natural defenses along the Gulf of Thailand coastline, including mangroves and beaches, have been degraded due to unsustainable land use and urban development. Modelling conducted for this CCDR indicates that annual tourism revenue losses along this coastline (due to additional land loss) could reach around USD 1 billion (in constant 2025 prices) by the mid-2040s in a no-adaptation scenario. Thailand's National Adaptation Plan and Climate Change Master Plan (2015–2050) identify coastal flooding as a major risk, with coastal zone management prioritized as an adaptation strategy.

Several measures have already been adopted to protect against coastal erosion, but the efforts have largely been *ad hoc* and fragmented in nature, tending to over-emphasize hard engineering-based solutions. Recent investments—such as seawalls, revetments, breakwaters, and flood barriers around urban centers like Bangkok—offer temporary protection. However, these hard infrastructure solutions are costly to maintain, inflexible to worsening climate conditions (e.g., rising seas, stronger storms), and can have unintended consequences. In particular, poorly coordinated measures may shift flood risk to neighboring areas, while seawalls can disrupt sediment flows, exacerbating erosion elsewhere.

Lessons learnt from experience in other countries and incipient efforts within Thailand suggest that nature-based solutions could provide a more effective and sustainable alternative to coastal protection. Adaptation measures should prioritize structural designs that mimic natural processes—such as planting mangrove pioneer species—to reduce wave energy, curb coastal erosion, and promote sediment accumulation. The optimal approach combines minimal structural intervention with effective water flow and wave dissipation. Beyond enhancing resilience to extreme events like storm surges and sea-level rise, these nature-based solutions support local livelihoods by revitalizing ecosystems that underpin tourism, recreation, and fisheries. Mangroves also offer significant climate co-benefits, playing a vital role in carbon sequestration. Private operators are also turning to nature-based solutions, in addition to flood-resistant designs (Box 3.2).

Modelling conducted for this CCDR indicates that the economic benefits of investments in such nature-based solutions would outweigh costs by an order of magnitude. Five areas in the Upper Gulf of Thailand—Bangkok, Samut Prakan, Samut Songkhram, Samut Sakhon, and Chachoengsao—have been identified as priority zones for coastal mud beach protection. The total investment required for designing and installing nature-based protective structures, including mangrove restoration and maintenance across three phases, is estimated at USD 1.5 billion over a 20-year period (USD 1.1 billion in NPV terms). In parallel, 35 beaches along both the Gulf of Thailand and the Andaman Sea have been identified as needing urgent investment in sustainable sand beach nourishment. The total cost for these interventions, implemented over nine phases within 20 years, is projected at USD 1.4 billion (USD 0.9 billion in NPV terms). On the other hand, the net economic gains – purely in the form of additional tourism revenues associated with avoided losses from lost land, and additional gains from reclaimed land – could reach USD 14 billion in NPV terms, or upwards of USD 2 billion per year by the mid-2040s.

Box 3.2: How the private sector is leading efforts toward sustainable tourism

Thailand's private sector has been playing a vital role in enhancing climate resilience in tourism. Developments like IconSiam in Bangkok, with elevated structures and flood barriers, demonstrate how flood-resistant designs can protect operations in urban areas. In heritage-rich locations like Ayutthaya, portable flood barriers—similar to those used in Venice—offer practical protection for cultural assets. Resorts such as Keemala in Phuket have adopted elevated villas and water diversion systems to reduce flood impacts.

Private operators are turning to nature-based solutions. Coastal resorts in Phuket and Pattaya are funding or co-financing mangrove restoration, which helps prevent erosion and storm surges while supporting eco-tourism through guided tours and education programs. Marine tourism providers are engaging in coral reef restoration; for instance, The Sarojin in Khao Lak and Banyan Tree Hotels have established coral nurseries and artificial reefs to protect biodiversity and attract divers.

Community partnerships offer further promise. In Krabi, the Nai Nang Apiculture Group, supported by Marriott Hotels, links mangrove restoration with beekeeping, creating local livelihoods and sustaining conservation. Products like Nai Nang honey are now sold in Marriott gift shops and used in restaurants, aligning community benefit with corporate sustainability goals.

The private sector is also acting to reduce tourism sector emissions, partly in response to a shift in consumer preferences towards environmentally conscious travel. A 2024 survey by Booking.com revealed that 75 percent of global travellers aim to embrace more sustainable travel practices in the coming year, and the trend is particularly strong in the Asia-Pacific region. Thailand is no exception to this global trend. Agoda's Eco Deals Survey from 2024 found that 84 percent of Thai consumers are ready to adopt greener travel options, with financial incentives like discounts being a major motivator. Emissions-reduction initiatives in Thailand include the CF-Hotels platform, launched by the Tourism Authority of Thailand (TAT), which allows participating hotels to track and reduce emissions across energy, water, waste, and carbon metrics. While over 695 hotels (as at August 2025) have joined the platform, only 160 hotels self-reported their emissions reduction efforts in 2024. The overall adoption and use of the platform still remains limited due to resource and capacity constraints.

Scaling sustainability across the sector will require more than a few flagship initiatives, and broader challenges to additional private sector investment will have to be addressed. There is a business case for investing in sustainable tourism which can lead to higher revenues and cost savings, particularly via energy and water usage efficiencies. However, the significant initial investment is a deterrent. Financial incentives can help address this gap and improve the attractiveness of investment in nature-based solutions in particular, which tend to have wider public benefits that are not fully captured by the private investor. Tailored financial tools such as concessional loans, results-based subsidies, or co-financing tied to climate resilience remain limited (see Chapter 6). Biodiversity and catastrophe bonds, and climate insurance are also viable financing instruments which need to be scaled up in Thailand. Broader uptake of sustainable and adaptive practices will also require clearer policy signals. Publicly provided financial incentives and regulations—such as tax breaks for resilient infrastructure or stricter zoning laws to avoid risky construction—can be used as a way of scaling efforts. Limited awareness and understanding of sustainability principles, and lack of

standardized sustainability benchmarks, further hinders progress, particularly among smaller players. Government support will be particularly important to help SMEs access capital and technical expertise, enabling them to respond to evolving climate risks and consumer expectations alike.

Moreover, while Thailand's tourism strategies reference sustainability, they often lack concrete action plans and enforcement mechanisms, leaving implementation inconsistent across regions. For instance, while the National Tourism Development Plan (2023-2027) sets an emissions reduction target of 2 percent per year, it lacks clear mechanisms, incentives, or compliance measures to help hotels contribute to this goal.

Underpinning all of the above is the need for stronger inter-agency coordination and a robust public-private sector dialogue. For instance, in Thailand, agencies such as the Ministry of Tourism and Sports, the Ministry of Natural Resources and Environment, and the Energy Regulatory Commission have overlapping mandates but lack a cohesive strategy for sustainable tourism, leading to policy inconsistencies and gaps in enforcement. On the private sector side, tourism businesses, particularly SMEs, have limited representation in policymaking discussions.

Recommendations

A scaled-up and better coordinated approach to coastal protection is vital to avoid land loss to erosion, protect against storm surges and coastal flooding, revitalize ecosystems that underpin recreation and fisheries, and support the tourism industry which is concentrated on Thailand's coasts.

- **Nature-based solutions and ecosystem-based adaptation should be scaled up and positioned as the first line of defense against coastal erosion**, including by pursuing investments in mud beach protection in priority zones of the Upper Gulf of Thailand, and in sand beach protection and nourishment at the 35 identified beaches along the Gulf of Thailand and the Andaman Sea. This would entail rebalancing the current infrastructure-heavy approach, e.g. by blending green and grey infrastructure through a combination of mangrove buffers and low-impact barriers.
- **A more integrated approach to coastal protection could be pursued, by aligning coastal policies with land-use plans, urban planning and watershed management efforts**. Greater use of spatial planning tools and Integrated Coastal Zone Management (ICZM) would help coordinate actions across government. A more coordinated approach could also be used to discourage hard infrastructure in those cases where nature-based alternatives may be more viable.
- **Engagement of local communities in the planning and monitoring of these efforts and facilitating investments from the private sector** – including through financial incentives where possible – would foster greater ownership, acceptance and sustainability of these efforts.

3.3 Addressing water scarcity

Thailand's baseline water security challenges are being exacerbated by climate change, prompting interventions to protect farmers, industry, and households. In agricultural areas in the north and northeastern parts of the country, the development of irrigation systems and measures to climate-proof and increase the capacity of water storage infrastructure have the potential to have significant impacts on agricultural yields and farmer incomes. In the Eastern Economic Corridor (EEC), a regional hub being promoted by the government to drive innovation and growth, the challenge is to climate-proof water supply to ensure that it can adequately meet the growing demand for industrial uses.

Several adaptation solutions are available, but implementation is hampered by challenges related to financing, capacity and institutional support. Key adaptation measures to address water security in the northern provinces include increasing small-scale retention ponds, enhancing retention capacities in canals and small river networks and improving groundwater and reservoir strategies. However, the implementation of these measures remains challenging due to bureaucratic budgeting scrutiny, limited authority to administer water management tasks, lack of an integrated and evidence-based

provincial master plan, and in some cases, lack of capacity within local governments. A qualitative exploration of these issues in Khon Kaen Province (see Annex 1), drawing on in-depth interviews of several key stakeholders including the Governor and the provincial administrative team, revealed technical capacity to conduct integrated provincial water planning and mobilizing financing for small-scale retention ponds as two main challenges that need to be overcome.

The government is aware that the planned growth of the EEC cannot be realized without a secure water supply. The EEC is being championed as a transformative hub for investments, technology, and transportation. Covering an area of approximately 13,000 sq.km in the provinces of Rayong, Chonburi, and Chachoengsao, the EEC is already a major contributor to national economic output, accounting for approximately 15 percent of GDP in 2022. It serves as a critical production base for advanced industries including petrochemicals, smart electronics, and electric vehicles. Additionally, the region is a source of high-value agricultural exports such as durian, mangosteen, and premium seafood products, and it is also emerging as a prominent destination for tourism, particularly in Chonburi. As a part of Thailand 4.0 strategy, the EEC's goal is to become a world-class smart city and an investment destination for a range of critical sectors, including digital technology, health, smart logistics, and decarbonization. The growth plan envisions the creation of over 200 thousand jobs by 2032.

Addressing the imbalance between increasing water demand and limited available supply is a key challenge to realizing this vision for the EEC. The current water infrastructure is inadequate to cope with peak demand during the dry season, leading to critical shortages that affect not only the industrial sector but also agriculture and public utilities. Given the current situation, EEC's future development is not feasible without addressing water scarcity. Table 3.2 below presents the demand-supply gap for the three provinces comprising the EEC, for 2024, 2027 and 2037. Assuming average water supplies are similar to average actual hydrological conditions in the decade leading up to 2023, it is projected that in 2037 the EEC will face a supply shortfall of almost 40 percent. The situation in dry years will be even more precarious, with the shortfall increasing to 72 percent. These projections already account for the 32 infrastructure investments that have been planned to improve water supply in the EEC.

However, measures to promote more efficiency and circularity in water use can potentially address these constraints. Supply augmentation needs to be complemented by investments in water demand management and circularity (for example via the treatment and reuse of wastewater, only 37 percent of which is currently treated in the EEC) in order to address the water security challenge. In this context, it is instructive to look at the water management paradigm of California, with which the EEC shares many similarities in terms of geo-climatic location, hydrological conditions, and multi-sectoral asset base. California has achieved a path-breaking decoupling of water use and economic growth: over the 50 years to 2017, its Gross State Product increased by ~500 percent while water use increased by only ~10 percent. The EEC can aspire toward a similar decoupling.

Table 3.2: Projected water balance in the EEC provinces (in million cubic meters, MCM)

Area	2024		2027		2037	
	Demand	Deficit	Demand	Deficit	Demand	Deficit
Chachoengsao	1237	-897	1171	-811	1115	-379
Chonburi	794	-412	894	-464	1228	-729
Rayong	924	-170	1047	-139	1272	-292
EEC Total	2955	-1479	3112	-1414	3615	-1400

Source: Water Balance Report for the Eastern Economic Corridor, Office of the Eastern Economic Corridor, August 2024.
Note: Demand and deficit values are based on average water supply scenarios as opposed to dry or wet years and the average scenario assumes water supplies similar to the average actual hydrological situation for the period 2013-2023.

Recommendations

Thailand's development ambitions and its water-security challenges converge sharply in the EEC, an industrial area that is also vulnerable to other climate risks. At the same time, water availability remains a pressing issue for agricultural livelihoods in the drought-prone north and north-eastern provinces. This CCDR recommends:

- **Additional measures to boost water supply in the EEC, including the pursuit of water conveyance projects.** The Government can expedite the approval and implementation of key water conveyance projects like Prasae-Nongkhor-Bangphra and Phanthong-Bangphra to boost supply in the EEC.
- **Better harnessing latent sources of "new water", including by scaling wastewater treatment and doing better demand management.** More than 60 percent of EEC's wastewater currently goes untreated, and it is the single largest untapped source of new water supplies for the region, especially for industrial users. The initiatives being taken by the Wastewater Management Authority and the Industrial Estates Authority of Thailand for treatment and reuse of municipal wastewater need to be supported and scaled. Reducing demand is another important latent source of "new" water supplies, and this has significant potential given that water productivity in Thailand remains low compared with global and regional benchmarks.[24]
- **Identify, pilot and scale smart, innovative approaches to water management.**[25] Negotiation instruments to facilitate inter-sectoral water transfers (especially in emergencies), multi-stakeholder water platform to bring together public and private actors, smart metering and tariffs, dynamic and long-range water planning, PPPs for the enhancement of investment efficiency in water infrastructure projects, and promoting net-zero water use in key industrial sectors are some innovative approaches that could be adopted at a larger scale.
- **In drought-prone agricultural areas in the north and north-east, integrate provincial water planning and mobilize financing for retention ponds, reservoirs, canals, and small-river networks.**

3.4 Adapting to extreme temperatures and heat stress

Extreme temperatures have significant adverse impacts on the Thai economy and society. Heat stress can affect the productivity of workers, 61.5 percent of whom work outdoors. These impacts are likely to be felt most severely in the agricultural sector due to greater exposure to outdoor work and the higher proportion of workers performing strenuous physical activities. High temperatures also compound water scarcity issues faced by agriculture and industry. Tourism will be affected by more frequent and intense heatwaves, hurting Thailand's attractiveness as a year-round tourist destination. Coastal provinces such as Phuket, Pattaya, and Krabi, which rely heavily on beach tourism, are particularly vulnerable. Higher temperatures could reduce the appeal of outdoor activities, shorten peak travel seasons, and result in a shift in visitor preferences toward cooler destinations.

Rising heat can affect society in other less quantifiable ways. Overheated classrooms can make it difficult for children to concentrate and learn, affecting educational attainments and long run human capital. Infants and young children, elderly, and people with pre-existing health conditions such as cardiovascular disease or diabetes are also particularly vulnerable to extreme heat as their bodies are

[24] See also Chokchai S. and Koontanakulvong, S. (2019), Evaluation of water productivity of Thailand and improvement measure proposals.
[25] See also Koontanakulvong, S. (2024), Policy recommendations for water management through science, technology and innovation (STI).

not as efficient in regulating body temperature. Consequences include heat stroke, a life-threatening condition. Chronic heat can also strain infrastructure systems and erode overall urban livability.

Populous places such as the Bangkok Metropolitan Area (BMA) have already started putting in place variety of measures to adapt to extreme heat. These measures consist of policies, institutions and investments ranging from early warning systems to green infrastructure projects such as cooling centers, hydration initiatives and a variety of building regulations conducive to urban cooling (Box 3.3)

Box 3.3: Urban heat island adaptations[26]

In 2024, the BMA developed the Urban Heat Management Framework to address rising temperatures in the Bagkok. The framework consists of two main components. The Year-Round Intervention Framework includes measures that are implemented continuously, regardless of the season. The Hot Season Intervention Framework consists of targeted interventions activated specifically during the hot season, with priority actions determined based on four specific heat index levels: the monitoring phase (27°C – 32.9°C), the warning phase (33°C – 41.9°C), the critical phase (42°C – 51.9°C) and the extreme critical phase (beyond 52°C).

The Year-Round Intervention Framework focuses on two key areas: strengthening healthcare capacity and mitigating urban heat impacts. Efforts to enhance healthcare preparedness include training medical personnel on heat-related risks, and integrating heat risk management into public health protocols. To mitigate urban heat impacts, the BMA is implementing long-term strategies such as expanding green spaces through initiatives like planting two million trees and establishing 15-minute parks to enhance urban cooling. Additionally, climate-sensitive urban planning measures are being introduced, including promoting open façades in high-rise buildings to improve ventilation, increasing blue spaces such as water bodies to moderate temperatures, and encouraging the use of heat-reflective materials in newly constructed buildings. Efforts to cool the physical environment place emphasis on green infrastructure and surface improvements. Projects like planting more trees and expanding green spaces seek to enhance shade and reduce ambient temperatures, while cool pavements and permeable surfaces aim to reflect more sunlight and improve water infiltration, thereby lowering surrounding heat levels. Similarly, integrating design features like urban ventilation corridors and water-based elements—such as fountains—into open areas contributes to localized cooling. These strategies are at various stages of implementation across Bangkok.

Complementary measures highlight the importance of consistent hydration and workplace adjustments. For hydration, the city has introduced initiatives such as installing additional water refill stations and fountains, aiming to make clean drinking water more readily accessible in public spaces. These efforts also include educational outreach to underscore the significance of adequate fluid intake in hot weather. Additionally, the BMA has encouraged modifying work schedules, especially for outdoor laborers, to reduce exposure during the hottest times of day.

More can be done to systematically scale similar efforts across the country. Several solutions being piloted by BMA have the potential to be replicated at provincial and local levels. The gaps and shortcomings in BMA experience also provide important lessons for broader nationwide efforts. For example, a recent review identifies several opportunities to do better on protecting vulnerable populations, targeting high-risk areas, and aligning citywide efforts. The review finds that several green infrastructure efforts currently underway are not always spatially targeted with many high risk "heat hotspots" remaining underserved due to limited integration of micro-climate data and urban heat mapping into the planning process. Relatedly, the needs of vulnerable groups – including the elderly, children, outdoor workers, and low-income communities – could be better integrated into the design and implementation of these solutions.

[26] Based on Rubinyi, Steven, Putu Sanjiwacika Wibisana, Jane Park, Nicholas K.W. Jones, Juan A. Acero, and Pichaya Moeller. 2025. *Shaping a Cooler Bangkok: Tackling Urban Heat for a More Livable City.* Washington, DC: The World Bank.

Recommendations

Labor productivity loss due to heat stress is one of the main channels by which climate change could impact the economy; heat also has a range of impacts on health and education. The following recommended actions could help Thailand better adapt to high temperatures:

- **Support policies and investments to cool indoor public and residential spaces.** Availability and use of air conditioning has been growing in Thailand but only around 40 percent of the population has AC units at home. AC ownership is substantially higher among richer households. Financing instruments to help qualifying lower-income households afford the up-front capital investments needed to procure low cost but energy-efficient air conditioning units (e.g., window-fitted) could help boost access among the most vulnerable. To avoid exacerbating emissions from excessive air conditioning use, incentives could be provided to promote smart cooling technologies and zonal temperature controls. In the medium to long term, heat resilience considerations could be embedded in building codes and planning, mandating green roofs, reflective surfaces, minimum green cover and design that enhances natural ventilation.
- **Expand cooling centres by repurposing public facilities**. Schools are particularly well suited to double as cooling centres because of their widespread presence in communities. In addition to serving as accessible refuges for the local population during heatwaves, they can provide a relief to students for a longer period, potentially helping contain heat-related learning loss.[27]
- **Implement targeted outreach programs to identify and protect the most vulnerable.** Tailored programs and specialized outreach could be used to ensure that those without air conditioning or safe cooling options receive targeted support. For outdoor labourers, this could include heat safety measures such as mandated rest breaks, shaded workspaces, and adjusted schedules. Priority interventions could also include home visits for elderly residents, school-based heat safety education, and mobile cooling units—to protect vulnerable populations without access to safe cooling in high risks areas. Collaboration with community leaders and health agencies could be used identify at-risk populations and provide them with practical guidance.

3.5 Making agriculture more climate resilient

Thailand's agriculture and food sector is already being affected by climate change and other environmental concerns. Thailand is a major agri-business hub in the region, with agriculture employing about a third of the country's labor force and accounting for 15-20 percent of Thailand's exports and around 8 percent of GDP. Yet, most farm households in Thailand are smallholders, with around half owning less than 10 rai (1.6 ha) of land. Declining farm productivity has significantly stalled living standards improvements in recent years.[28] Rising temperatures, unpredictable rainfall patterns, and extreme weather events such as droughts and floods are compounding these challenges. By 2040, climate change is projected to reduce national rainfed crop production by up to 12.4 percent under Dry/Hot scenarios, primarily due to heat stress and reduced water availability. While wetter conditions in the Wet/Warm scenario may slightly benefit rice and vegetables, most other rainfed crops will still face production declines. Irrigated crops are also expected to suffer, with production losses reaching 7.0 percent under Dry/Hot conditions, though sugarcane may be an exception due to its lower sensitivity to water stress.

[27] Park, R.J et al (2020) show that without air conditioning, a 1-degree F hotter school year reduces that year's learning by 1 percent among secondary students in the United States. See Park, R. Jisung, Joshua Goodman, Michael Hurwitz, and Jonathan Smith. 2020. "Heat and Learning." *American Economic Journal*: Economic Policy 12 (2): 306–39.
[28] World Bank Group. 2022. *Thailand Rural Income Diagnostic: Challenges and opportunities for rural farmers.* World Bank, Bangkok.

Several climate-smart agricultural practices have begun to emerge as farmers adapt to climate change. Farmers have been adjusting crop calendars with delayed sowing of short duration crops, diversifying crops to heat, flood and disease resistant seed varieties and adopting mixed farming practices. One approach that has some policy support involves crop rotation, particularly the practice of growing maize on residual soil moisture or with limited irrigation following wet-season rice harvests. Additionally, farmers are diversifying their production by introducing alternative crops such as mung beans and sun hemp. In highland areas, agricultural adaptation has taken different forms, with some farmers shifting towards vegetable cultivation or incorporating tourism activities alongside their farming operations. In animal husbandry and livestock, farmers have invested in sophisticated housing infrastructure, incorporating modern design elements and evaporative cooling technology to combat heat stress.

Location specific solutions are also being deployed to address water security challenges. Small-scale farmers in Phetchabun's flat plains have implemented drip irrigation systems on their modest maize holdings of 2-4 rai, leveraging available groundwater resources to improve crop yields. This adoption mirrors a broader trend where farmers in drought-susceptible areas are turning to drip irrigation technology. While the initial investment is considerable, some evidence suggests that the benefits of improved water efficiency and increased crop production make drip irrigation a worthwhile adaptation strategy.[29] Similarly, livestock farms have begun installing rainwater harvesting systems to enhance water security. These installations enable farms to capture and store precipitation, providing a reliable water source during periods of drought.

Several scientifically proven solutions are available for adoption at larger scale and some of these solutions can deliver dual benefits of reduced emissions and greater climate resilience. In coastal areas affected by salinization and sea level rise, current rice systems are becoming untenable. Transitioning from rice to shrimp farming—which already accounts for more than half of Thailand's total production—could improve farm incomes and climate resilience. However, the transition must be carefully managed and regulated to have a low impact. Fluctuations in water temperature leading to reduced oxygen levels, salinity changes and declining water quality, can increase the risk of disease and early mortality for shrimp and prawns. Recirculating Aquaculture Systems (RAS), which filter and reuse water, can enhance biosecurity while simultaneously reducing emissions and water demand. Smart water quality monitoring systems—integrating AI, IoT sensors, and real-time analytics—allow for early detection of disease risks and enable farmers to proactively adjust water conditions. Additionally, incorporating mangrove forests into shrimp farms not only improves yields but also provides natural protection against storm surges and coastal erosion, while leveraging the carbon sequestration benefits of mangroves to offset emissions.

At the farm level, key barriers to adopting climate-smart agriculture (CSA) in Thailand stem from financial, operational, and behavioral constraints. The financial challenge is primarily one of scale: many CSA technologies require significant upfront investment that is not viable for smallholders operating on limited land and income. While credit is generally accessible through institutions like the Bank of Agriculture and Agricultural Cooperatives (BAAC), the high marginal costs relative to farm size often deter investment. Collective action through cooperatives could offer a pathway to shared investment and risk reduction. Agribusinesses with links to farmers could also play a key role in providing services and enforcing standards that encourage farm-level adoption. Additionally, widespread knowledge gaps and entrenched behavioral biases also hinder uptake. Tailored, region-specific interventions that combine technical support, infrastructure, and behavior change strategies are therefore essential to enable widespread CSA adoption.

[29] Chuchird, R.; Sasaki, N.; Abe, I. 2017, Influencing Factors of the Adoption of Agricultural Irrigation Technologies and the Economic Returns: A Case Study in Chaiyaphum Province, Thailand. *Sustainability*, 9, 1524.

Farmers also face several structural barriers to using weather index-based insurance instruments. In collaboration with the BAAC and through public-private partnerships, Thailand has implemented several insurance programs, including beef cattle farming, fisheries, in-season rice farming, animal-feed maize, and longan insurance. Structural challenges associated with inaccurate damage assessment, lack of partial compensation, and slow payouts have hindered greater adoption and use of weather index-based insurance in Thailand. Traditional indices, such as regional rainfall data, often fail to reflect localized impacts, creating basis risk. In 2019, more than 45 percent of claims were denied because official thresholds were unmet despite visible crop damage.

Recommendations

There are several actions that could help encourage the adoption of CSA practices by farmers, increasing their resilience to climate shocks:

- **Repurpose agricultural public expenditure away from distortionary price support schemes toward long-term productivity and resilience.** Thailand could significantly increase investment in public agricultural R&D and extension services to drive innovation in climate-resilient crops, sustainable practices, and farm management. Providing financial support for science- and information-based technologies—such as digital advisory tools, satellite data, and precision agriculture—will empower smallholders with real-time decision-making capabilities. Public funds should prioritize infrastructure upgrades—including irrigation systems that improve water-use efficiency and drought resilience, alongside rural roads, storage, and local market hubs—to reduce post-harvest losses and improve input-output efficiency. Finally, financial support for farmers should shift to non-distortionary instruments like targeted, decoupled cash transfers, crop insurance, and smart subsidies, delivered through an expanded and digitized farmer registry.
- **Help scale CSA practices by embedding economic incentives for collective actions and linking with the private sector.** Farmer aggregation is a critical first step in the value chain approach to climate adaptation, as it empowers smallholder farmers in Thailand to overcome diseconomies of scale, limited market access, and labor shortages through collective action and enabling access to climate-smart technologies, finance, and private sector markets. Clear legal recognition, support for land block aggregation, improved water governance, and targeted policies for input services and extension delivery can enhance productivity and resilience. Formalizing and professionalizing cooperatives will unlock investment in adaptation and mitigation strategies while fostering equitable, climate-resilient growth.
- **Overhaul land and regulatory systems to incentivize innovation and sustainability.** Outdated regulations, insecure land tenure, and fragmented coordination among public, private, academic, and farmer institutions hinder the flow of innovation from lab to farm. Without legal land rights, especially in highland areas, farmers lack incentives to adopt long-term sustainable practices. Cumbersome laws on plant variety registration block access to improved germplasm. A policy reset is needed to remove such regulatory and legal distortions and allow climate-smart solutions that work on the ground.
- **Address structural challenges that inhibit greater use of weather index-based insurance instruments by farmers.** Solutions include deploying AI-enhanced satellite assessments, adopting tiered payout structures, and investing in hyperlocal weather infrastructure to improve index precision. Compensation delays can be reduced through digital claims automation and regulatory streamlining. Most critically, the government should externalize systemic weather risks by accessing international reinsurance or catastrophe bond markets, as done in countries like Mexico and the Philippines, allowing the state to transfer extreme event risks and stabilize domestic insurance schemes.

3.6 Protecting people

Even with the best efforts to adapt, protecting people from the adverse impacts of extreme climatic events will require a greater role for social protection. Empirical work conducted for the CCDR shows that while social assistance beneficiary households are better able to protect themselves from climate shocks, the protection is only partial. Existing schemes such as the State Welfare Card (SWC) and the Old Age Allowance provide broad coverage across the population but the benefits provided are low; for instance, the SWC covers around 14 million people (including those most exposed and vulnerable to climate impacts), but the spending allowance for essential goods is only around 300 baht per month (USD 9), though other allowances and discounts are also included. The strong and robust association between climate shocks and a buildup of household debt points to the possibility of there being significant uninsured risk that the social protection system could help manage (Tiwari et al 2025).

Assistance provided in the aftermath of climate-related disasters has tended to skew towards floods and fallen short of fully addressing the needs of those affected. The "contingency fund for the emergency assistance to disaster victims" is a designated budget line that is intended to ensure that victims of disasters receive timely assistance. It is intended to cover urgent and localized needs arising from sudden onset disasters and is activated when it is determined that existing budget allocations within agencies cannot be mobilized with requisite speed. This fund has disbursed an average of 4.7 billion baht per year over the last decade with a significant share of it being allocated to flood-related disasters with very little going to slower onset disasters like drought, whose impacts are less visible but accumulate over a longer time. Estimates suggest that even for floods, assistance provided often falls short of needs. For example, assistance provided in the aftermath of the 2023 floods, on average, covered only about 20 percent of the estimated loss to lives and livelihoods.[30] Noy, Nguyen and Patel (2019) report that government compensation in the aftermath of the 2011 floods was not only inadequate to cover the full extent of the losses but also regressive.

Fragmentation of social programs limits effectiveness and hinders a transition toward adaptive social protection. Social assistance programs in Thailand are numerous, fragmented and operate in silos with separate processes for outreach, intake, eligibility and payment. This limits their overall effectiveness in boosting ex ante resilience. The lack of a common unified social registry also makes it difficult to identify newly vulnerable households, which is crucial for increasing coverage of existing programs or establishing new ones.

Thailand's response to the pandemic provides an illustrative example of the strengths and weaknesses of the system as the country makes its overall program more adaptive to climate change. Thailand leveraged its digital ID, interoperable platforms, and administrative databases to rapidly scale cash transfers and create an instant social registry, reaching over 30 million people. The response included new emergency support for informal workers and farmers, plus expanded aid for vulnerable groups through the State Welfare Card program. However, given high workforce informality and limited social security coverage among informal workers, many of the intended beneficiaries remained unidentified by the instant social registry. Challenges with temporarily linking databases showed the need for permanent, dynamic data integration. Coordination costs and concerns about data privacy and security caused delays in accessing and linking various beneficiary databases, highlighting the importance of interoperable data platforms and robust data protection legislation. The Personal Data Protection Law became effective in 2022 but many of the other challenges around data integration

[30] 400,000 households were provided housing assistance of around 9000 baht per month with total outlay of 3.5 billion THB. An additional 0.5 billion THB was provided in the form of increased welfare. The total assistance provided (4 billion THB) however was only a fifth of the estimated 20 billion in forgone income losses from the death, job dislocations and loss of agricultural production. See Building Climate Resilience of Vulnerable Populations and Communities in Thailand: Synthesis Report (English). World Bank Group.

that Thailand experienced during COVID will need to be addressed to establish a social protection system that is adaptive to climate related disasters.

Recommendations

Thailand's social protection system has an important role in protecting the country's poorest and the most vulnerable from climate shocks, which will continue to have substantial impacts on lives and livelihoods despite the other adaptation measures outlined above. This CCDR recommends:

- **Increase the regular and post-disaster benefits provided to State Welfare Card (SWC) holders who are exposed to climate risks.** Additional annual spending of around 0.6 percent of GDP on social protection would allow a significant increase in SWC payments, as well as increased payments to affected individuals in the aftermath of disasters, thereby building both *ex ante* and *ex post* resilience to climate shocks. This additional spending would effectively double the average annual level of assistance provided to the 14.5 million holders of the SWC.[31] With other sectoral efficiencies likely to be achieved with improvements in targeting and greater use of integrated social registries, increased benefits for the most vulnerable could be achieved at a lower cost.
- **Improve targeting via hybrid proxy means tests (PMT) and integrate programs through unified social registries.** Developing integrated social registries will streamline beneficiary identification, reduce duplication, and improve the efficiency and effectiveness of social protection delivery, potentially lowering overall costs.[32] Well-functioning social registries with enhanced interoperability as well as robust targeting instruments such as hybrid PMTs that integrate administrative data will also facilitate the onboarding of newly vulnerable households or the introduction of new programs.
- **Strengthen the data underpinnings of the delivery system.** Thailand could establish a social protection data governance cluster made up of the relevant ministries and agencies that administer SP programs to establish data sharing protocols and systematize data collection and sharing when dealing with natural disasters and other shocks.[33] Geo-coding social protection beneficiary households would facilitate rapid response in the case of floods or other natural disasters that affect specific geographic regions.
- **Develop a high-level social protection strategy that incorporates responses to climate related events.** There are several agencies that are currently tasked with the delivery of assistance in the aftermath of disasters. Thailand's Disaster Risk Management (DRM) plan sets out the roles of the Ministry of Social Development and Human Services (MSDHS) and the Ministry of Labor (MOL) to provide assistance to disaster-affected people and workers, as well as contingency funds for disaster response. An inter-agency coordination entity tasked with developing and executing a framework for such a high-level social protection strategy would enhance effectiveness.

[31] World Bank estimates based on 2021 SES survey data.
[32] A hybrid PMT to identify vulnerable households could retain the exclusion filters currently used for SWC eligibility while introducing additional eligibility criteria. These criteria would be based on other observed household characteristics that predict welfare, helping to reduce inclusion errors. Additionally combining the proxy means test with community-based targeting methods and ensuring there is a robust outreach and grievance redressal system in place can help minimize exclusion errors.
[33] See "Thailand: Data Analytics Strategy for Social Protection Sector to Enhance Service Delivery and Policymaking", World Bank 2025.

4.
Managing the net-zero transition

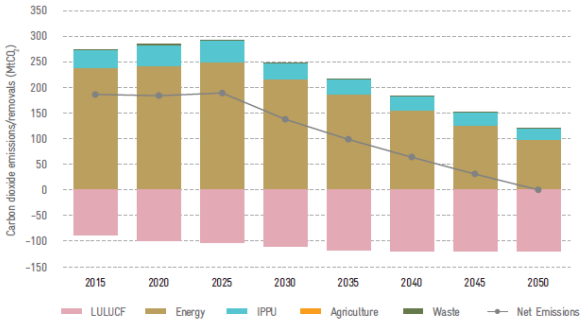
4 Managing the net-zero transition

This chapter assesses the challenge of meeting Thailand's commitments to achieve carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. It focuses on the required investments and policy reforms in the power, manufacturing, transport, agriculture, and land use/forestry sectors that are needed to meet these targets. Together, these sectors are responsible for almost all Thailand's GHG emissions.[34] As laid out in Chapter 1, although GHG emissions have been broadly flat in per capita terms over the past decade, net GHG emissions increased by 35 percent between 2000 and 2022, despite a significant expansion in carbon removal efforts through LULUCF. This underscores the significant challenge associated with putting net emissions on a downward trajectory.

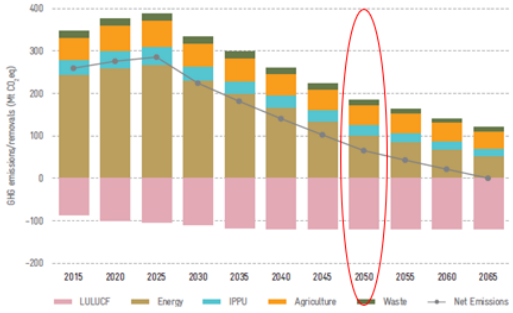
Thailand's revised Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS), submitted to the UNFCCC in November 2022, sets out a trajectory of decarbonization across all sectors which is consistent with Thailand's long-term objectives (Figure 4.1). The LT-LEDS focuses on energy and transport which are the largest contributors to overall emissions. Key measures include scaling renewable energy adoption, enhancing energy efficiency, accelerating electric vehicle (EV) deployment, and deploying carbon capture and storage (CCS) technologies in high-emission industries. Thailand aims to ensure at least 50 percent of new power generation comes from renewables by 2050. The land use, land-use change, and forestry (LULUCF) sector is projected to sequester 120 $MtCO_2$ annually by 2037, with plans to expand forest cover to 55 percent of Thailand's land area over the same period to enhance carbon sinks, supported by REDD+ programs. A carbon tax, an Emissions Trading Scheme (ETS) (operating as part of an envisaged hybrid system), and a framework for trade in carbon credits are each intended to incentivize industries to transition toward low-carbon practices.[35]

Figure 4.1: Thailand's carbon neutrality and net-zero targets

2050 Carbon Neutrality pathway



2065 Net-zero GHG Emission Pathway



Source: Thailand Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS) (Revised Version)

While Thailand's 2030 NDC commitments can be viewed as an intermediate objective, substantial additional action will be required to meet longer term objectives in 2050 and 2065. As part of its NDC commitments, Thailand pledged to reduce its greenhouse gas (GHG) emissions by 30 percent from the projected business-as-usual (BAU) level of 555 $MtCO_2eq$ by 2030, with the potential to increase this target to 40 percent contingent on enhanced access to technology, financial resources, and capacity-building support.[36] Even assuming the more ambitious 40 percent reduction is met by 2030,

[34] While not covered in detail in this report, action on waste management (particularly at the community level), as set out in the NDC Action Plan on Mitigation 2021-2030, will also make a material contribution to Thailand's overall emissions reduction efforts.

[35] Options for the design of these different carbon pricing instruments are analyzed in detail in the *Thailand Carbon Pricing Impacts Assessment Final Report*, World Bank Partnership for Market Implementation, May 2025, and the *Thailand Carbon Pricing Design Options Final Report*, World Bank Partnership for Market Implementation, May 2025.

[36] Thailand's NDC 3.0 will shift to an absolute emissions reduction target for 2035.

Thailand will need to reduce its gross GHG emissions by a further two thirds by 2065 to meet its net-zero target.

Moreover, newly emerging industries like data centers are not fully accounted for in these decarbonization trajectories, posing additional challenges. Data centers will be important in providing the digital infrastructure needed for Thailand to achieve its Industry 4.0 agenda. There has been a sharp rise in investment in recent years, and some projections suggest that data center investments in Thailand are set to exceed USD 7.8 billion by 2027 (equivalent to more than 1 percent of GDP).[37] Key drivers of growth include Thailand's favorable location in the region, growing digital demand, its mature digital market, strong supporting infrastructure and government policies. However, data centers also have major sustainability challenges. They are extremely energy-intensive, contributing approximately 1-3 percent of global energy-related GHG emissions, consume lots of water and have embodied carbon through the value chain. Given these concerns, global players have committed to making data centers sustainable with aggressive targets on use of water and energy. This will require efforts to secure the availability of renewable energy directly to firms.

This chapter examines three scenarios which are used to assess the feasibility of meeting these targets and the impacts of recommended policy reforms and investments. These scenarios incorporate the costs and benefits of recommended investments to reduce emissions, as well as the impacts of other policy reforms and interventions to promote decarbonization.

- A **Baseline** scenario, which assumes no additional climate mitigation policies or investments beyond those already in place;
- A **Current Policy (CP)** scenario, which assesses the impacts of climate mitigation policies currently planned for implementation by 2030;
- An **Accelerated Decarbonization (AD)** scenario, which examines the effect of accelerated action to reduce (net) emissions in the power, manufacturing, transport, agriculture and LULUCF sectors.

Current policies and investment trajectories are consistent with only modest reductions in emissions. In the BAU case, there is limited scope for renewable energy because of current power market structures, and policies to induce change in other sectors are absent (Table 4.1). Under the CP scenario, a carbon price is introduced by 2030, starting at $25-$27/tCO2e and increasing at an annual growth rate of 2.25 percent. Although the carbon price supports some efficiency improvements and the adoption of cleaner technologies in the industrial sector, it does not on its own lead to transformational change. As per the draft Power Development Plan, there are gradual changes in the generation mix with renewables being integrated at a moderate pace (largely driven by regulatory considerations rather than price signals) but continued reliance on natural gas. Subsidies and tax reductions for electric vehicles remain in place until 2027, and adoption of EVs continues to increase thereafter as the relative price continues to decline relative to ICE vehicles.

On the other hand, a concerted effort to accelerate decarbonization could see Thailand meeting its carbon neutrality and net zero targets. The "accelerated decarbonization" scenario involves strengthened investment in renewable energy and the faster roll-out of low-carbon and energy efficient technologies, supported by robust policy incentives. Energy CO2 emissions fall to just a third of business-as-usual levels by 2050 (Figure 4.2). Improvements in land use and afforestation offset the remaining carbon emissions from energy and non-energy sectors. This outcome is consistent with the carbon neutrality target, with the economy on course to achieve its 2065 net-zero GHG emissions goal. Additional policy interventions could bring the net-zero target forward to 2050, in line with the Paris Agreement.

[37] The Nation (November 2024), Thailand a favourite pick for data centre investors.

A suite of investments and reforms beyond carbon pricing will be needed to achieve Thailand's decarbonization objectives. These include reforms to allow more market-based competition in the power sector, which incentivizes the inclusion of lower-cost renewable generation, particularly solar. Higher carbon prices become much more effective in such a system. Investments in battery storage, regional grid interconnections, and demand-side management all help to offset renewable variability. Energy efficiency mandates and subsidies lead manufacturers to improve efficiency by 0.75 percent per annum over the projection period, over and above the impact from carbon pricing. Transport policy – promoting the electrification of light vehicles through investment in charging infrastructure and mandates/incentives shifting heavy vehicles to biofuels – reduces road transport emissions substantially. Low-carbon farming technologies are adopted on a large scale, and investment in reforestation scales up significantly, alongside strengthened land management practices and legal frameworks.

These recommended measures would allow Thailand to meet its carbon neutrality target without undue reliance on carbon capture, utilization, and storage (CCUS). CCUS has been seen as an important strategy to reduce emissions in sectors like cement and petrochemicals. The country has begun exploring pilot projects and assessing offshore storage potential in the Gulf of Thailand, signaling its interest in developing CCUS capabilities. However, scaling CCUS faces significant challenges such as high costs, limited infrastructure, and regulatory gaps (Box 4.1).

Box 4.1: Thailand's CCUS ambitions: challenges and opportunities

Thailand has identified carbon capture, utilization, and storage (CCUS) as a critical lever to achieve its 2050 net-zero target, particularly for hard-to-abate sectors like cement and petrochemicals. The government's Long-Term Low Emissions Development Strategy (LT-LEDS) and collaborations with international partners signal growing interest in CCUS technologies. Pilot projects, such as those led by industrial giant SCG, aim to capture CO_2 from cement kilns and petrochemical plants, while offshore geological storage potential in the Gulf of Thailand offers opportunities for permanent sequestration. However, scaling CCUS faces significant hurdles, including high costs (estimated at $50–100 per tonne of CO_2 in Southeast Asia), underdeveloped infrastructure for CO_2 transport and storage, and regulatory gaps in licensing and liability frameworks. Public skepticism about safety and competing priorities for green investment further complicates progress.

The financial viability of CCUS remains a challenge. Unlike renewable energy, CCUS lacks a clear revenue model beyond compliance markets or carbon credits, which are still nascent in the region. Building pipelines to transport captured CO_2 to storage sites—potentially offshore—requires massive capital, while uncertainties around geological storage capacity and leakage risks deter private investors. Domestically, fragmented policies and overlapping jurisdiction between energy and environment ministries slow regulatory clarity. Public awareness campaigns are also needed to address concerns about the safety of CO_2 storage, particularly in coastal communities near proposed sites.

Thailand's industrial clusters, such as the Eastern Economic Corridor (EEC), provide an opportunity to integrate CCUS into existing supply chains. Captured CO_2 could be utilized in enhanced oil recovery (EOR) to boost declining hydrocarbon reserves or converted into materials like synthetic fuels, chemicals, or low-carbon concrete. International partnerships are key: Japan's Joint Crediting Mechanism (JCM) and ASEAN collaborations offer funding and technical expertise, while Thailand's participation in global carbon markets could unlock financing via carbon credits. Additionally, aligning CCUS with the Bio-Circular-Green (BCG) economy model could spur innovation—for instance, coupling bioenergy with carbon capture (BECCS) using agricultural waste feedstocks.

To realize its CCUS ambitions, Thailand must prioritize policy frameworks that incentivize early movers, such as tax breaks for pilot projects or carbon contracts for difference (CCfD) to guarantee CO_2 prices.[38] Public-private partnerships can de-risk infrastructure investments, while regional cooperation with neighbors like

[38] Under a carbon contract for difference, the government provides a fixed price for emissions reductions, insuring projects against fluctuations in market carbon prices.

Box 4.1: Thailand's CCUS ambitions: challenges and opportunities
Malaysia or Viet Nam could pool storage resources and reduce costs. Workforce training and R&D hubs focused on carbon utilization technologies will also be essential. If these steps are taken, CCUS could not only help Thailand meet its climate goals but also position it as a regional hub for carbon management.

Table 4.1: Assumptions underpinning transition scenarios

	Baseline	Current Policy	Accelerated Decarbonization
Carbon price	USD 6/tCO2e (on fuel)	Carbon price is phased in by 2030, starting at USD 25/tCO2e and increasing at an annual growth rate of 2.25 percent	Carbon price is phased in by 2030, starting at USD 38/tCO2e and increasing at an annual growth rate of 2.25 percent
Power	Ongoing reliance on fossil fuel-based generation	Shift toward renewables but restrictions in third party access continue to limit transition	Market reform to liberalize grid access. Investment in grid modernization and regional grid integration to maintain system stability with a higher renewable share.
Industry	No fuel switching or energy efficiency measures	Moderate increase in energy efficiency spurred by carbon price/ETS	Impact of carbon price supported by energy efficiency mandates and public subsidies for low-emissions machinery and appliances.
Transport	No further support for EV adoption	Subsidies and tax reductions for EVs between 2025-27	Substantial additional investment in EV charging infrastructure and public EV fleet, promotion of biofuel use for heavy vehicles.
Agriculture	No change	Limited adoption of low-carbon technology	Subsidies and education promote scale-up of low-carbon farming technologies
LULUCF	No change	No change	Significant investment in reforestation

Accelerated efforts on emissions reduction have the potential to raise economic activity. Thailand's GDP in 2050 is projected to be up to 2.5 percent higher under the accelerated decarbonization scenario compared to the baseline (Figure 4.2). In the short term, GDP growth is mainly driven by increased investment spending, particularly in renewable energy projects.[39] Over the longer term, most GDP gains stem from higher household consumption, supported by more affordable renewable energy, as well as reduced fuel imports, as consumers and businesses shift more of their spending toward domestic production.[40] Notably, a larger share of transport service expenditures supports Thailand's domestic supply chains when vehicles no longer rely on imported oil—even if batteries remain imported. Power sector reforms enable electricity generators to reduce dependence on imported gas. For most of the projection period, revenues from carbon taxes are sufficient to cover the public costs of other decarbonization measures, such as investments in energy efficiency and electric vehicle charging infrastructure. However, by 2050, as CO2 emissions approach minimal levels, the public sector faces a net cost.

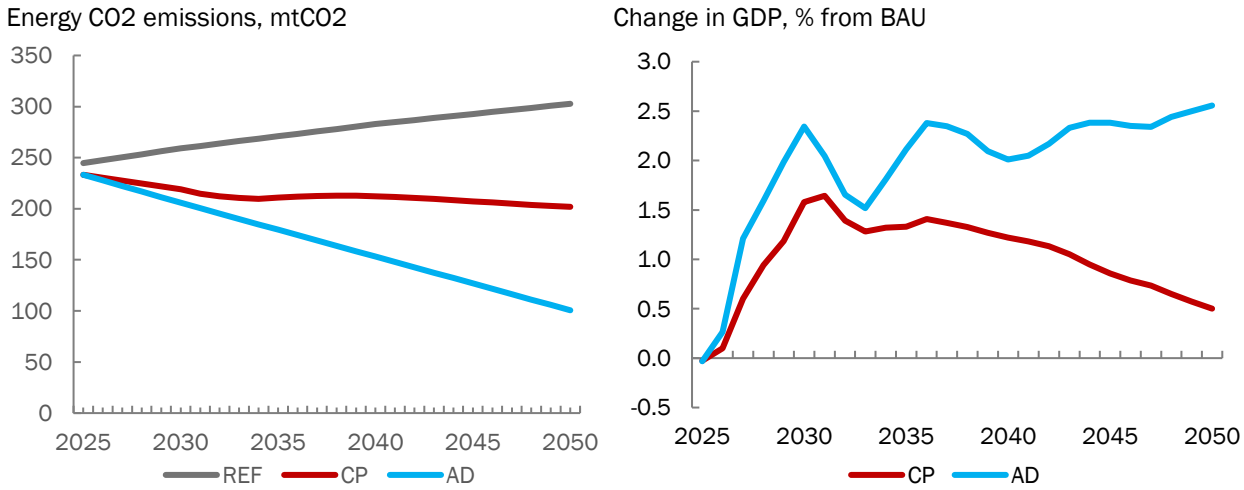
Emissions reduction will also help to insulate Thai exporters from increased risks to production associated with trading partners implementing stricter climate policies over time, and as the private sector steps up its efforts to make value chains greener. International decarbonization efforts—whether led by the public or private sector—could negatively affect exporters of Thai goods and services

[39] This investment is financed by borrowing, which is assumed to not crowd out investment in other sectors, meaning it results in a stimulus effect.

[40] Compared with E3 Thailand, in MFMod macroeconomic adjustments (e.g. exchange rate appreciation) work more automatically to close positive trade balances: this means that the magnitude of the economic gains in the AD scenario are smaller compared with BAU, at around 1.2 percent in 2040 and 0.7 percent in 2050 (compared with 2 and 2.5 percent respectively in E3 Thailand), and largely driven by rising household consumption due to lower energy prices.

if Thailand's emission reduction efforts lag behind. For instance, while the EU's Carbon Border Adjustment Mechanism (CBAM) in its current form is expected to have only modest impacts given the composition of Thailand's exports (see Box 4.2), these risks could grow if CBAM's scope expands or if other countries implement similar measures. Furthermore, an estimated 78 percent of multinational companies plan to exclude high-carbon producers from their supply chains starting in 2025. Without proactive carbon reduction measures, Thai companies risk losing access to these supply chains.[41]

Figure 4.2: Changes in energy emissions and GDP under mitigation scenarios



Note: REF = baseline; CP = 'current policies' scenario; AD = 'accelerated decarbonization' scenario. Results from E3-Thailand. Year-to-year variation in the impacts on GDP largely reflects the profile of recommended mitigation investments over the next 25 years.

Box 4.2: Thailand's exposure to global transition risks from CBAM and the greening of value chains

The EU's Carbon Border Adjustment Mechanism introduces carbon adjusting tariffs on certain goods imported into the EU with a carbon footprint that is not priced at a level comparable to that paid by EU producers under the EU ETS carbon pricing mechanism. These border adjustments – which are to be collected by the EU – can be reduced or offset completely if the exporters have been taxed locally via a carbon tax or emission trading scheme.[42]

CBAM in its current form is likely to have limited aggregate impacts on Thailand's manufacturing sector, but impacts can be important for exporters of iron and steel industry and aluminum. Based on the current guidelines on CBAM implementation only Thailand's iron and steel and aluminum sectors are likely to be affected by the new carbon adjustment instrument. According to the World Bank CBAM Exposure Tool, out of the six sectors currently included in the CBAM (starting in 2026), Thailand actively exports to the EU in only two of them – iron and steel and aluminum. Based on World Bank assessments, the most exposed sector is iron and steel, where the emission intensity of Thailand's exports is higher than that of most European economies, putting this sector at a competitive disadvantage once carbon prices are explicitly accounted for through CBAM. Thailand's aluminum exports on the other hand tend to be less emission intensive than aluminum production in most EU countries. Overall, the impact for the Thai economy is likely to be relatively small, as exports to the EU in the iron and steel and aluminum sector account for only 5.2 percent and 4.4 percent of the sectors' total exports, respectively, and less than 0.03 percent of GDP.

[41] Steenbergen, Victor; Saurav, Abhishek. 2023. The Effect of Multinational Enterprises on Climate Change: Supply Chain Emissions, Green Technology Transfers, and Corporate Commitments. World Bank.
[42] As of September 2025 the sectors included in the CBAM are cement, iron and steel, aluminum, fertilizers, electricity and hydrogen. Other sectors could be added at later stages (see related European Commission page).

Box 4.2: Thailand's exposure to global transition risks from CBAM and the greening of value chains

Nonetheless, the expansion of CBAM to other sectors and the adoption of similar policies by other countries or by large corporations could raise competitiveness challenges for Thailand, and/or lead to foregone revenue if a domestic carbon price is not imposed. While CBAM currently covers only six sectors, the EU is planning to assess and potentially expand its coverage to all sectors currently under the EU ETS. Other countries are either working to introduce (UK) or considering the option of introducing (Canada) a similar mechanism. These potential developments could increase the cost to Thai exporters of failing to decarbonize. Moreover, not implementing a carbon pricing scheme on exporters subject to CBAM would thus results in an implicit transfer from the government of Thailand – which would forego potential carbon pricing revenue – to the EU – which would collect an equivalent carbon tax on its imports.

At the same time, large MNEs are increasingly adopting green supply chain policies, which can result in the exclusion of suppliers that are uncapable or unwilling to invest in greener technologies and practices. As these companies play a central role in global value chains and global emissions – with the top 157 MNEs accounting for 60 percent of global emissions through their value chains (Steenbergen and Saurav, 2023) – their policies can have substantial repercussions for the competitiveness of Thailand's manufacturing sector. The sector's access to these important buyers – and their associated value chains – is thus increasingly dependent on its ability to green its production process.

Results from an indicative "transition risk" scenario suggest that a gradual loss of access to value chains and reduced tourism expenditure could reduce GDP by nearly 7 percent by 2050 (with similarly sized impacts on employment, particularly in manufacturing). Exports would fall by 20 percent compared to a business as usual baseline. In this scenario, Thailand continues its current domestic practices without significant changes, while facing increasing transition risks from abroad as trading partners implement stricter climate policies over time and the global market shifts its preference towards low-carbon activities. Tourism and basic manufacturing are most vulnerable to these risks.

Under the accelerated decarbonization scenario, Thailand stands to gain substantial air quality and public health benefits alongside its climate objectives. The rapid transition to renewable energy, widespread adoption of electric vehicles, and deployment of energy-efficient technologies together result in a sharp decline in harmful air pollutants such as PM2.5, NO_x, and SO_2, particularly from fossil fuel combustion in the power and transport sectors. Drawing on regional empirical estimates and Thailand's baseline of approximately 32,000 annual air pollution-related deaths, such an ambitious mitigation pathway could reduce exposure to PM2.5 by around 80 percent—potentially avoiding over 15,000 premature deaths annually by 2050. This translates into major health gains for the population, including fewer cases of respiratory and cardiovascular illness, lower public health expenditures, and improved labor productivity. These air pollution co-benefits significantly strengthen the case for accelerated climate action.

The remainder of this chapter looks in more detail at the reforms and investments needed to decarbonize each of the main emitting sectors: power, manufacturing, transport, agriculture, and land use and forestry.

4.1 Shifting to renewables for power generation

As of 2024, fossil fuels dominate Thailand's power generation, contributing more than two thirds of total output—59 percent from natural gas and 10 percent from coal (this includes imports of coal-powered electricity from Lao PDR).[43] Biomass, hydropower, solar, and wind are the main renewable

[43] Thailand is the largest purchaser of electricity produced in Laos, buying approximately 80 percent of the total. As Lao PDR has two export-oriented coal-fired power plants within its territory, the emissions from these plants are included in Lao PDR's total, even though the electricity is almost entirely exported and consumed in neighboring countries like Thailand (GHG

energy (RE) sources. Thailand's power sector is characterized as an "Enhanced Single Buyer Model" with generation assets owned by the Electricity Generating Authority of Thailand (EGAT) and private power producers, and transmission assets owned entirely by EGAT. Distribution is managed by the Metropolitan Electricity Authority (MEA) (Bangkok, Nonthaburi, and Samut Prakan) and the Provincial Electricity Authority (PEA).

Thailand faces a challenge of meeting rising power demand with lower emissions generation. Power demand is projected to rise from 37 GW in 2024 to over 120 GW by 2050, driven by urbanization, industrial growth, and electrification of transport. The key question is how this increase in demand can be met while reducing GHG emissions, containing costs, and maintaining system stability.

Thailand is revising its Power Development Plan (PDP) to diversify the energy mix, strengthen grid infrastructure, and meet its Nationally Determined Contribution (NDC) targets. This includes accelerating the deployment of variable renewables like solar and wind, and expanding power imports—particularly from Lao PDR—while deepening regional grid integration through the ASEAN Power Grid, a long-term vision to connect all ten ASEAN nations by 2045. These revisions are accounted for in the Current Policy scenario.

However, for Thailand to meet its overall emissions reduction targets, a more pronounced shift in the generation mix will be needed, as per the Accelerated Decarbonization scenario. The three scenarios considered imply substantial differences in the energy mix and in emissions from the power sector (Figure 4.3). In the baseline coal and natural gas continue to underpin generation capacity. In the Current Policy scenario, renewable capacity increase, spurred by lower costs, though fossil fuels remain a significant share of the energy mix. In the Accelerated Decarbonization (AD) scenario, market liberalization spurs further integration of solar, wind, and storage systems. These renewable sources are becoming increasingly cost competitive and adoption is further incentivized by carbon pricing.

A faster transition to renewables will also incur lower costs. The Levelized Cost of Electricity (LCOE) analysis underscores the financial advantages of transitioning to the AD scenario. The 20 percent reduction in LCOE under this scenario (relative to baseline) stems from three interrelated drivers. First, a decisive shift in the generation mix from fossil fuels to low-cost renewables—notably solar and wind—reduces reliance on volatile fuel markets and harnesses technologies with near-zero marginal operating costs. Second, declining capital expenditures for renewable installations, driven by technological advancements and economies of scale, lower upfront costs: solar PV and onshore wind capital costs are projected to fall by 20–30 percent by mid-century. Third, the AD pathway avoids substantial fuel import expenses and internalizes environmental externalities, such as carbon damages and public health impacts, which traditional cost calculations often overlook. Together, these factors enable annual savings of USD 3–5 billion in avoided fuel and externality costs, offsetting initial investments in renewables and grid modernization.[44]

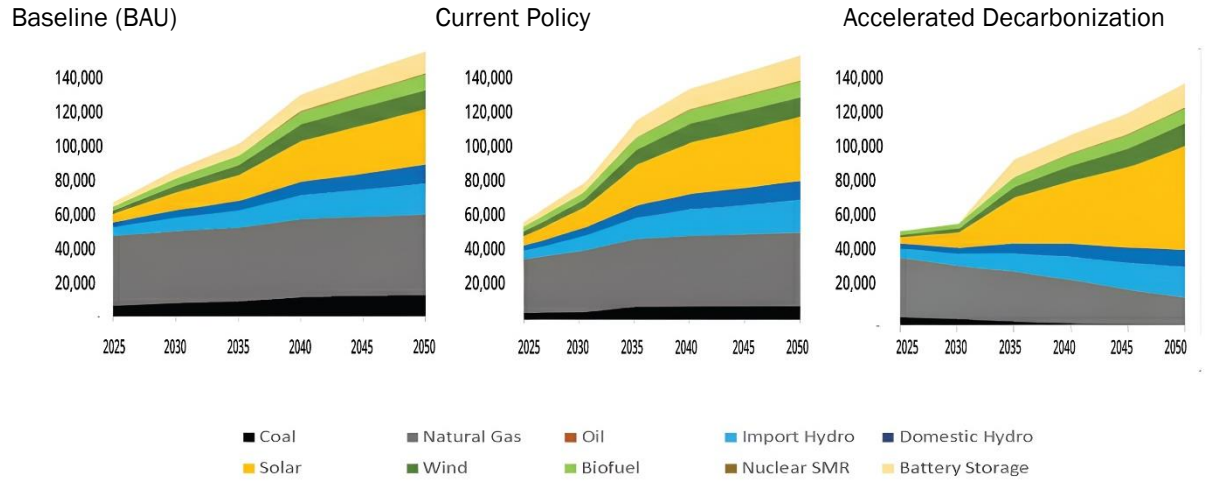
On the other hand, maintaining system stability as the share of intermittent sources grows will require the integration of sufficient reserve margins, storage, and demand-side management. Under the baseline, a system dominated by conventional fossil fuel generation typically has stability and predictable dispatchability. However, reliance on aging fossil fleets may eventually lead to inflexibility or decreased resilience to market shocks. The CP scenario preserves much of the stability provided by conventional plants while gradually introducing renewables. This scenario is less challenging than AD in terms of transitions but still requires deliberate grid modernization. With a high penetration of renewables, the AD scenario faces greater challenges from intermittency and variability. Maintaining

emissions reported are accounted for on a territorial or production basis, in line with UNFCCC standards). As such emissions emanate from Lao PDR's power plants, they do not affect Thailand GHG emissions inventory. However, EGAT does not plan to renew the PPA with coal-fired power producers in Lao PDR.

[44] Note that in the absence of market reform, regulated tariffs under Thailand's Enhanced Single Buyer Model and legacy fossil fuel contracts may keep actual electricity prices higher than the report's estimated LCOE.

system stability requires significant investments in storage systems, enhanced grid flexibility and regional interconnections, and advanced forecasting and demand-side management.

Figure 4.3: Power generation capacity (MW)



Source: World Bank analysis

Table 4.2: Power sector outcomes under various transition scenarios
(all costs are for 2025-50, calculated as present values at 6 percent)

	Baseline (BAU)	Current Policy	Accelerated Decarbonization
CO2 Emissions (2050)	+45 percent from 2024 levels	-30 percent from 2024 levels	-73 percent from 2024 levels
Capital investment costs	USD 74 bn	USD 82 bn	USD 98 bn
Fuel costs	USD 176 bn	USD 140 bn	USD 124 bn
O&M costs	USD 78 bn	USD 81 bn	USD 81 bn
Levelized Cost of Electricity (c/kWh)	7.0 c/kWh	5.9 c/kWh	5.6c/kWh

Source: World Bank analysis

Recommendations

Thailand stands at a critical juncture in its energy transition. The country's current "Enhanced Single Buyer" model, which once spurred rapid economic growth by favoring incumbent utilities, now inhibits competition and innovation. Third Party Access regulations heavily favor the incumbents (i.e. PTT and EGAT) and are not conducive to new market entrants. Embedded interests in the gas and power sector have led to legacy contracts that provided security in the past, but has now become barriers to innovation, efficiency, and flexibility. Achieving the necessary transformation will require an estimated $260 billion in infrastructure investment by 2040, along with regulatory frameworks that can attract and sustain private sector participation. Key recommendations are:

- **Market structure reform to promote competition in the power sector and accelerate the adoption of renewable energy (RE).** Achieving the AD scenario hinges on reforming the Enhanced Single Buyer Model to incentivize private RE investments, expanding grid access for decentralized renewables, and aligning regulatory frameworks with decarbonization goals. This includes liberalizing grid access by removing preferential treatment for fossil fuel generators and streamlining interconnection processes for both utility-scale and distributed RE projects. Such reforms will also ensure that the price signals generated by a carbon price have an impact on renewable investments. Competitive procurement mechanisms—such as

auctions or capacity markets backed by long-term power purchase agreements—would offer investor certainty and ensure cost-effective deployment. Introducing PPAs for direct access to renewable energy sources would be an important step to facilitate private sector use. Regulatory incentives can further align market participation with decarbonization goals by rewarding low-emission projects and penalizing high-carbon assets. At the same time, a transparent tariff structure that reflects the declining cost of renewables while equitably allocating the residual costs of dispatchable power will be crucial for market efficiency and fairness.

- **Investment in grid modernization and regional integration to enhance energy security and enabling a renewables-led transition**. Thailand must deploy advanced grid management technologies, demand response, and storage solutions. This ensures that the growing share of intermittent RE can be effectively integrated while maintaining system stability. In addition, it must invest in high-voltage direct current (HVDC) system and cross-border transmission infrastructure to facilitate energy trading and manage intermittent renewable supply. Harmonizing grid codes, market rules, and third-party access frameworks across ASEAN countries will be vital for seamless regional operations. The establishment of regional power exchanges can allow trading of surplus renewable energy, improving system balance, lowering costs, and reducing curtailment. As part of this effort, Thailand can play a leadership role in advancing the ASEAN Power Grid, which aligns with its own national energy and climate goals.

4.2 Reducing manufacturers' emissions intensity

Manufacturing accounts for almost a quarter of Thailand's energy emissions, only part of which is attributable to electricity use; fuel switching, energy efficiency and other measures are therefore needed to decarbonize the sector.[45] As of 2021, electricity accounted for only 31.2 percent of the total energy (in equivalent energy units) consumed by the Thai manufacturing sector, while fossil fuels accounted for a combined 56.8 percent. While necessary, decarbonizing the generation of electricity is not enough to achieve a substantial reduction of emissions in the manufacturing sector. Improving the energy efficiency of manufacturing firms, promoting switching to cleaner fuels, and taking action on 'hard-to-abate' sectors such as concrete and petrochemicals is necessary to achieve Thailand's emission reductions goals. While manufacturing is less emission intensive in Thailand than in most of Thailand's peers, there remain margins to further reduce emissions.

Emissions in Thailand's manufacturing sector are concentrated among a small subset of firms, presenting an opportunity for targeted climate actions. 5 percent of manufacturing firms account for 94 percent of the sector's direct (Scope 1 and 2) emissions. Concentration intensifies at the top: the top 1 percent of emitters are responsible for 77 percent of total emissions while producing 60 percent of manufacturing value added and employing just 41 percent of workers.

There are substantial differences in energy emission intensity among Thai manufacturing firms, with sectors such as cement and paper requiring specific attention. Four IEA sectors have substantially higher emission intensities than the aggregate manufacturing sector: non-metallic mineral products, paper and paper products, non-ferrous metals products, and wood products. Of these, non-metallic mineral products and paper each account for about 5 percent of manufacturing value-added, but close to 10 percent of energy emissions. Both differences in energy intensity and in the emission intensity of energy play an important role in explaining differences in overall emission intensity across sectors (Figure 4.4). Firm-level data from Thailand's 2022 Business and Industrial Census also show a

[45] The analysis in section 4.2 largely focuses on energy-related emissions from the manufacturing sector, rather than emissions from Industrial Processes and Product Use (IPPU). According to the Ministry of Natural Resources and Environment (2024), in 2016 emissions from IPPU were equal to 31.5 MtCO2-equivalent, equivalent to 12.9 percent of total emissions from fuel combustion in the same year (from IEA data), and 37.1 percent of manufacturing emissions from fuel combustion.

substantial heterogeneity in the level of emission intensity of manufacturing firms within narrowly defined (3-digit ISIC) sectors.

Thailand's manufacturing industry includes several 'hard to abate' activities – including cement, steel, and chemicals and petrochemicals – for which reducing emissions is particularly challenging due to the nature of their processes or reliance on fossil fuels. Box 4.3 assesses opportunities to decarbonize in the cement and concrete industry, and in petrochemicals, which together account for 30-40 percent of total emissions from Thailand's manufacturing sector.

Figure 4.4: Manufacturing sector emissions and energy intensities

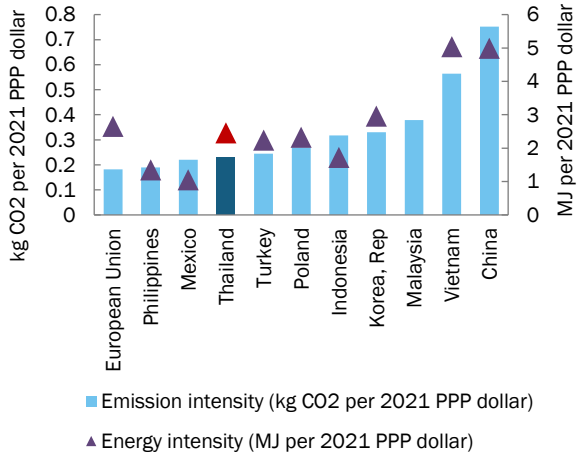
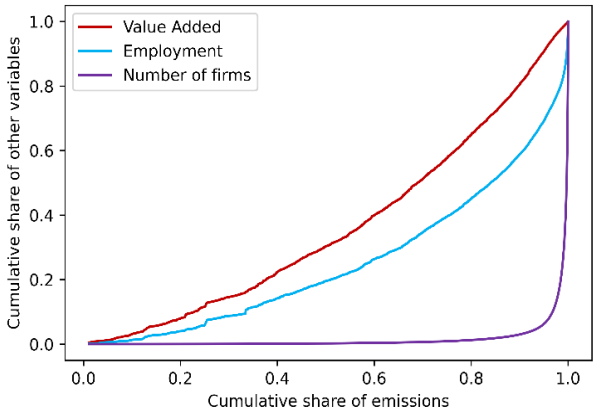


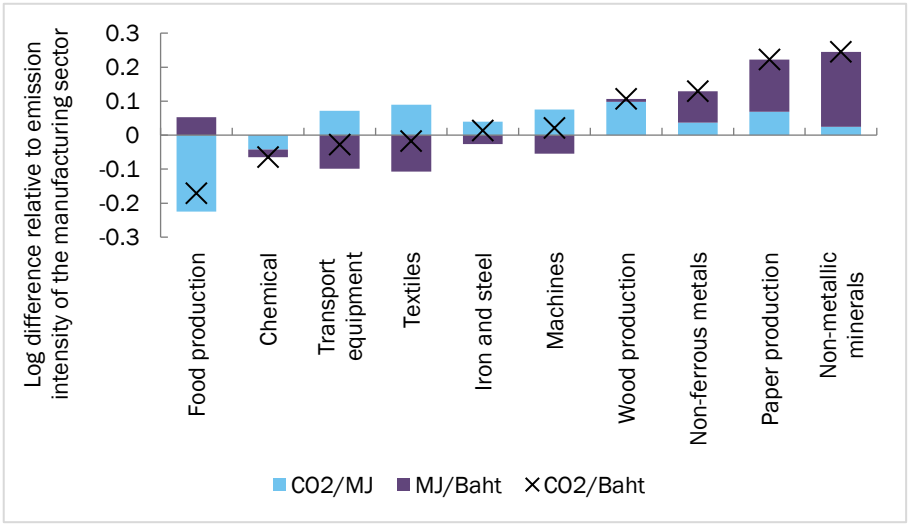
Figure 4.5: Concentration of emissions, value added, and employment across Thai manufacturing firms



Source: Authors' calculations based on IEA and 2022 Business and Industrial Census and IEA data.

Figure 4.6: Differences in energy intensity play an important role in explaining differences in emission intensity across sectors.

(log deviation relative to the emission intensity of the manufacturing sector)



Source: Authors' calculations based on 2022 Business and Industrial Census and IEA data.
Notes: MJ (megajoules) is a measure of energy usage. X marks are equivalent to the log deviation of sectoral emission intensities relative to the emission intensity of the manufacturing sectors. Green and orange stacked bars show the contribution of sectoral emission intensity of energy and sectoral energy intensity to this difference. Percentage figures in red denote the share of total manufacturing value added.

Box 4.3: Decarbonizing cement and petrochemicals

Thailand's cement industry faces steep challenges in aligning with the nation's 2050 net-zero target. Clinker production—contributing over 90 percent of sectoral emissions—drives its carbon intensity, exacerbated by Thailand's high clinker-to-cement ratio (80 percent) and reliance on fossil fuels for kilns. While global solutions like blended cement, waste heat recovery, and carbon capture exist, adoption remains limited due to regulatory gaps, fragmented value chains, and financing barriers. Smaller firms struggle with costs, while policy shortfalls—e.g. on carbon pricing, green procurement mandates, and performance-based building codes—stifle demand for low-carbon alternatives. To accelerate decarbonization, Thailand must enforce standards for low-carbon cement, mandate Environmental Product Declarations (EPDs), and incentivize clinker substitution. Investment in alternative binders and co-processing frameworks for alternative fuels is critical. Carbon capture, utilization, and storage (CCUS) may be needed. Public-private partnerships and financial tools like carbon contracts for difference can de-risk innovation and scale solutions.

Similarly, Thailand's plastics sector, vital to its export economy, is a major emissions source due to fossil fuel-derived feedstocks (e.g., naphtha) and energy-intensive processes like steam cracking. Packaging dominates plastic use (42 percent), but recycling rates lag at 17.6 percent, with 2.88 million tonnes discarded annually, causing environmental harm and USD 3.6–4 billion in material losses. Transitioning to bio-based plastics is hindered by high costs (1.1–2.3x conventional) and an energy grid still reliant on fossil fuels. Policy gaps, such as unenforced Extended Producer Responsibility (EPR) schemes and voluntary recycling targets, undermine circularity. Land-use conflicts with agriculture further complicate bio-based feedstock scaling. Key solutions include mandating recycled content (e.g., 30 percent in packaging), taxing virgin plastics, and investing in chemical recycling infrastructure.

Both sectors require systemic reforms. Financial innovation—blended finance, transition bonds, and green credit lines—can mobilize capital for high-risk projects like CCUS or electrified manufacturing. Carbon markets (e.g., Thailand's T-VER) and plastic credits offer revenue streams for emissions reductions and waste recovery. Regulatory coherence is essential: Thailand's green taxonomy must clarify criteria for industrial decarbonization, while land-use zoning and sustainability certifications can mitigate bioeconomy risks. Strengthening cross-sector collaboration through platforms for SMEs, R&D hubs, and mandatory green procurement will drive demand for low-carbon products.

Thailand's industrial decarbonization hinges on aligning policy, finance, and innovation. For cement, scaling clinker alternatives and CCUS are priorities. For plastics, circular infrastructure and bio-based feedstocks are key. By embedding sustainability into regulations, redirecting capital, and fostering workforce readiness, Thailand can transform these sectors into climate-resilient pillars of growth.

Carbon pricing (in the form of an emissions trading scheme) could help the manufacturing sector meet its NDC targets. Previous simulations suggested that a broad carbon price of approximately US$25 per ton (2023 equivalent values) would induce a 30 percent reduction in aggregate energy and process emissions in Thailand's manufacturing sector.[46] The direct cost of this carbon price would be relatively low for most Thai manufacturing firms, as the country is not a major producer or exporter of carbon-intensive products. However, compliance costs could be burdensome for smaller emitters. Without any response from affected firms or compensatory government measures, a US$25 carbon price would increase the average Thai manufacturing firm's total operating costs (including wages) by about 2.1 percent, equivalent to 3.4 percent of value added. Most firms (62 percent) would face smaller direct costs, with the median firm seeing total costs rise by 1.5 percent. Larger firms would experience substantially lower relative costs. Moreover, the carbon price would incentivize firms to adopt greener practices, potentially lowering overall costs despite investments in cleaner machinery and equipment. Early adoption of carbon pricing could also position Thailand as a regional leader in sustainable manufacturing, attracting green investment and fostering innovation.

[46] See World Bank. 2023. Thailand Public Revenue and Spending Assessment: Promoting an Inclusive and Sustainable Future. World Bank, Bangkok.

These low costs imply less potential for harmful competitiveness effects from introducing an ETS or other form of carbon pricing instrument: costs and disruption could be further reduced by imposing a higher carbon price covering only top emitters.[47] As emissions are highly concentrated among a few large emitters, targeting a small number of top emitting firms can be a pragmatic and effective strategy to reduce emissions, while reducing the implementation costs of a carbon pricing instrument (especially if the instrument of choice is an emission trading scheme) and limiting the potential negative effect of fixed compliance/administrative costs for small emitters. For example, the same 819 baht per ton carbon price imposed only on firms emitting more than 5,000 tons of CO2 per year[48], coupled with a 5,000 tons emission allowance, would apply to 0.5 percent of firms while covering 46.3 percent of manufacturing emissions and still achieving a 14.6 percent reduction in total manufacturing emissions. A 30 percent reduction in line with Thailand unconditional 2030 NDC could then be achieved by increasing the carbon price to 1562 baht (in 2023 values). This alternative design would tend to target users of underpriced, carbon-intensive energy sources, and minimizes economic disruption by exempting SMEs, which dominate employment but contribute marginally to emissions (Box 4.4)

Box 4.4: Pros and cons of eligibility thresholds in carbon pricing design

Designing a carbon pricing scheme with eligibility thresholds involves important trade-offs. Thresholds are commonly used in midstream or downstream carbon pricing—such as emissions trading systems applied to power generators or large industrial emitters—but are rare when carbon taxes are applied upstream (e.g., embedded in fuel taxes at the distribution level). For instance, the EU Emissions Trading System includes a 25,000-ton opt-out threshold.

Thresholds can be effective when emissions are concentrated among a few large entities, as in Thailand's case, and the fixed costs of compliance are high. They also help reduce administrative burdens, especially in countries with limited institutional capacity, by simplifying verification and enforcement. However, thresholds can distort market dynamics. They impose a heavier burden on large firms relative to smaller ones and may discourage firms just below the threshold from growing—or even prompt large firms to split operations to avoid compliance. These unintended effects can weaken the scheme's fairness and efficiency.

Setting an appropriate threshold requires balancing the benefits of administrative simplicity and cost-effectiveness with the risks of economic distortion. It should be carefully calibrated to target major emitters while minimizing perverse incentives.

Other complementary policies can help to achieve Thailand's emissions reduction goals and strengthen the effectiveness of carbon pricing (Blanchard et al. 2023). Box 4.5 provides an overview of complementary green policies to promote the adoption of green technologies and practices – including those that promote energy efficiency – based on recent work done by the World Bank (Cirera and Grinsted, 2025)[49]. By tailoring and targeting these policies at high-emission sub-sectors and firms, Thailand could achieve emissions reductions with less economic disruption.

Energy efficiency measures represent one of the most cost-effective strategies for reducing demand growth and emissions. Thailand can unlock major energy and cost savings by strengthening energy efficiency standards across buildings, appliances, and industrial equipment. Targeted financial incentives—such as subsidies and low-interest loans—can support households and businesses in adopting energy-efficient technologies, retrofitting existing systems, and conducting energy audits.

[47] This scenario is simulated using an elasticity of emissions to carbon pricing that is homogeneous across sectors and focusing only on emissions from energy consumption. Results can vary if elasticities are heterogenous across sectors, as top emitters are not homogeneously distributed across sectors. If the carbon pricing scheme is to cover also emissions from IPPU, the size of the allowance would need to be adjusted accordingly to achieve the targeted level of reduction in energy and IPPU related emissions.

[48] This is equivalent to one fifth of the EU ETS opt-out threshold.

[49] Xavier Cirera and Philip Grinsted (2025) "Fostering Green Technology Adoption. A Toolkit for Policymakers" World Bank.

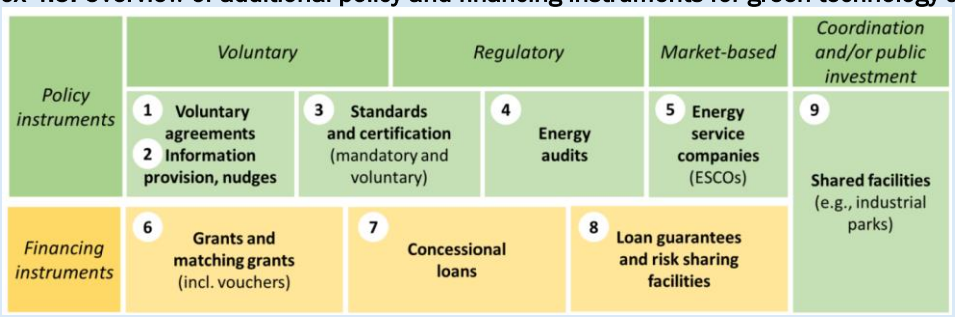
Public awareness campaigns can further drive behavioral change across residential, commercial, and industrial sectors. Embedding clear efficiency targets into national energy strategies will not only curb emissions but also delay the need for new power generation and lower long-term system costs. This CCDR estimates that an average of US$2 billion in additional annual investment—equivalent to around 0.2 percent of GDP—will be needed over the next 25 years to scale up energy efficiency beyond what carbon pricing alone would achieve. These investments could deliver energy savings of approximately 18 percent, playing a vital role in reaching carbon neutrality targets in the industrial sector.[50] A portion of the required investment would be in the form of public subsidies to accelerate adoption. Most of the projected energy savings come from improvements that are already cost-effective but remain untapped due to information gaps or a lack of prioritization by firms. Firm-level analysis confirms that achieving this level of savings is realistic — particularly if efforts are targeted at the lowest-performing firms, where the efficiency gains are greatest.

Box 4.5: Complementary policies for the adoption of green technologies and practices

Policies need to address the factors that prevent firms from adopting greener and more energy efficient technologies and practices. First, the returns of investments on these technologies for individual firms might not be high enough to justify their adoption. This may be because firms do not fully internalize the social benefits of greener technologies and thus, in the absence of public policies, will tend to underinvest in them. Second, firms might be unaware of or lack the capacity to adopt greener technologies or practices. This can be due to several factors, including a lack of awareness, behavioral biases, and lack of specific skills among managers and workers. Third, even when green investments are profitable and firms are willing to adopt, firms might be unable to obtain adequate and affordable financing to cover the initial fixed costs of these investments.

Public policies can act on all these factors to promote decarbonization, complementing carbon pricing, while there is also scope to deploy public financial support more effectively. Cirera and Grinsted (2025) list nine policy instruments that can be used to strengthen a country's decarbonization strategy (Figure Box 4.5). With respect to financing, a recent World Bank analysis of Thailand's public expenditures on sciences, technology, and innovation (STI), shows that while public support on STI in Thailand has a strong focus on green innovation, it tends to be skewed towards upstream research in research centers and universities. Support for adoption of greener technologies and practices in the private sector could be expanded.

Figure Box 4.5: Overview of additional policy and financing instruments for green technology adoption



Source: Xavier Cirera and Philip Grinsted (2025) "Fostering Green Technology Adoption. A Toolkit for Policymakers" World Bank.

Finally, broader business environment policies that support productivity and competitiveness can play an important role in reducing carbon emissions. For instance, increasing competitive pressures on market incumbents can raise firms' incentives to become more efficient, reduce unnecessary costs,

[50] The costs are estimated by combining two IEA reports – the latest World Energy Outlook (WEO) and the 2024 report on energy efficiency. The WEO provides an estimate of the size of total global energy savings needed for a net-zero scenario, and the energy efficiency report provides estimates on costs. A unit cost for energy savings is estimated from these two sources, which is then used to calculate the cost of achieving energy savings in Thailand of 0.75 percent each year, or 18 percent by 2050.

adopt better managerial practices, and invest in innovation – a dynamic that can have a positive spillover effect on energy efficiency. Indeed, firm level analysis shows that more productive firms in Thailand tend to be more emission efficient than less productive firms performing similar activities, pointing to a potential complementarity between productive efficiency and emission efficiency.

Recommendations

A range of policies will be required to decarbonize Thailand's manufacturing industry and insulate it from global transition risks. These policies should account for the fact that manufacturing emissions in Thailand are concentrated among only a few sectors and firms. Hard-to-abate sectors pose particular challenges. This CCDR recommends:

- **Consider the implementation of an ETS that targets top emitters only**. Since emissions are concentrated among a few large firms, applying an ETS only to major emitters can deliver substantial reductions while lowering administrative and compliance costs for SMEs, which dominate employment but contribute much less to total emissions.
- **Strengthen energy efficiency standards across buildings, appliances, and industrial equipment, and provide targeted financial incentives—such as subsidies and low-interest loans—to support households and businesses in adopting energy-efficient technologies**, retrofitting existing systems, and conducting energy audits. This CCDR estimates that an average of US$2 billion in additional annual investment—equivalent to around 0.2 percent of GDP—will be needed over the next 25 years to scale up energy efficiency and deliver additional energy savings of around 18 percent (beyond what carbon pricing alone would achieve).
- **Enforce standards for low-carbon cement, mandate Environmental Product Declarations (EPDs), and incentivize clinker substitution**. Investment in alternative binders and co-processing frameworks for alternative fuels is critical. Carbon capture, utilization, and storage (CCUS) may be needed in cases where it is technically and financially feasible. Public-private partnerships and financial tools like carbon contracts for difference can de-risk innovation and help scale solutions.

4.3 Electrifying transport

Population growth and rising disposable incomes have spurred increased use of fossil-fueled transport over the last few decades, driving emissions upward, increasing congestion, and worsening air pollution. Road transport accounts for nearly 80 percent of the sector's energy use in Thailand, with private vehicles—cars and motorcycles—making up almost 90 percent of urban passenger travel. Public transport usage remains below 10 percent, reflecting limited modal shift. Economic growth has fueled rising travel demand, with passenger trips increasing by an average of 4.3 percent annually between 2013 and 2019. Although Thailand has promoted biofuels and hybrid vehicles, the continued dominance of fossil-fueled transport has driven a sharp rise in emissions—from 27 $MtCO_2$-eq in 1990 to 79 $MtCO_2$-eq in 2023.[51] Increased use of private vehicles has had a range of other impacts including traffic congestion, which ranked tenth globally in Bangkok in 2020, and worsening air pollution. Congestion in metropolitan areas further amplifies emissions, as idling vehicles in traffic hotspots increase fuel consumption.

Electrification offers a powerful means to cut transport emissions, with electric vehicles (EVs) providing higher energy efficiency at a lower total cost of ownership. EVs use 40–60 percent less primary energy than internal combustion engines. This means that electrification offers an opportunity to reduce GHG

[51] Tawan Champeecharoensuk, P. Abdul Salam, Shobhakar Dhakal, Nuwong Chollacoop, 2022, *Key driver analysis of greenhouse gas emissions in Thailand's public bus transport with comparative study on metropolitan Bangkok hotspots*, Energy for Sustainable Development, Volume 70, Pages 456-465.

emissions even if the generation mix continues to rely on fossil fuels. When combined with a shift to renewable sources of electricity generation and the increased use of biofuels for heavier vehicles, electrification of passenger vehicles has the potential to reduce overall transport sector emissions sharply (Figure 4.7). Moreover, EVs already have a lower total cost of ownership than ICEVs in Thailand (particularly for 2 and 3-wheelers, but also for cars: based on the World Bank's E-mobility Scoping Tool), with lower fuel and maintenance costs more than offsetting higher upfront capital costs. Rapid declines in battery costs are making EVs increasingly competitive even in terms of the upfront purchase price.

While EV sales have risen recently, complementary investments are required to accelerate adoption and reduce emissions; carbon pricing on its own will only have a limited impact. In 2023, EVs accounted for 12 percent of total car sales in Thailand, higher than other ASEAN countries such as Indonesia and Malaysia but remaining below Viet Nam. The surge in EV adoption has been underpinned by advancements in battery technology, changes in consumer preferences, and lower total costs of ownership, supported by government subsidies. The EV 3.5 package of subsidies and tax reductions will provide further support in the near term (2024-27), but soon will be unnecessary as purchase prices decline and EVs become even more cost competitive in their own right.[52] Carbon pricing on its own will only have a limited impact: the carbon tax in 2025 is low and does not affect retail prices, but even higher carbon taxes would only have a limited impact on fuel prices and EV adoption. Most important in the push to lower-emission passenger transport will be investment in charging infrastructure and decarbonization of electricity generation.[53]

Table 4.3: Transport sector outcomes under various transition scenarios

	Baseline	Current Policy	Accelerated Decarbonization
Share of EVs (cars) in new sales	50% by 2037; 100% by 2048	50% by 2035; 100% by 2046	50% by 2030; 100% by 2044
Share of EVs in stock of vehicles (2050)	70%	79%	87%
Carbon price on fuel	USD 6/tCO2e, USD 0.01 per liter	USD 25/tCO2e by 2030, USD 0.06 per liter	USD 38/tCO2e by 2030, USD 0.09 per liter

Source: World Bank analysis

Action is also needed on other modes of transport. The increased use of biofuels for heavier, harder to electrify vehicles such as trucks will be critical in meeting overall net zero targets in the transport sector. Heavy-duty vehicles (HDVs) continue to generate significant emissions due to less progress on electrification, high energy needs, limited battery range for long-haul trips, and infrastructure gaps. Addressing these residual emissions calls for complementary strategies such as shifting freight to rail, increasing biofuel use, and improving logistics efficiency. Efforts are also needed to decarbonize buses, which account for around three quarters of public transport use in Bangkok: outdated, high-emission buses average 25 years in age.

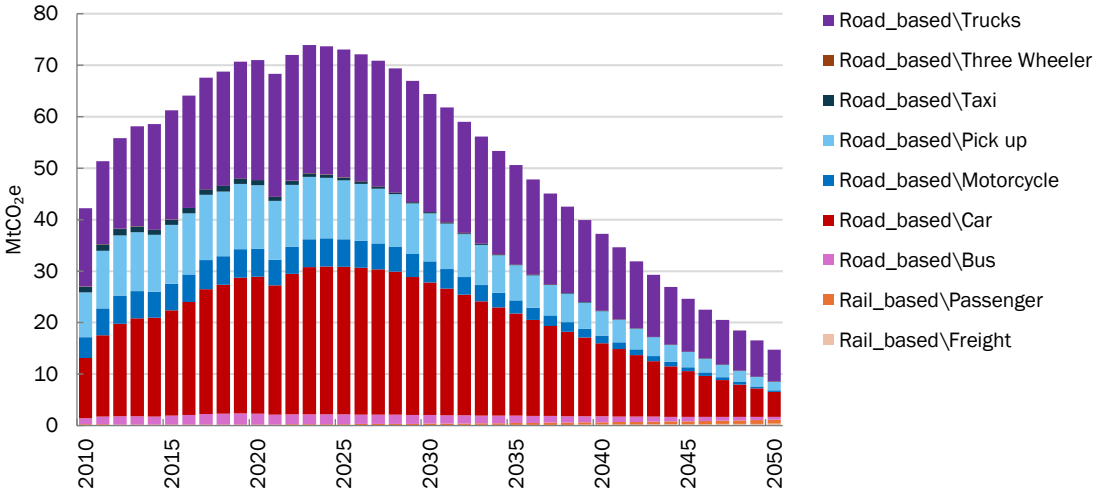
Analysis completed for this CCDR suggests that investment in mass rail transit in Bangkok could have a moderate impact on emissions, while at the same time reducing traffic congestion and travel time and improving air quality. These objectives could be further supported by the imposition of a congestion charge: modelling indicates that the two interventions together could reduce transport emissions in Bangkok (which accounts for around 30 percent of total transport sector emissions in

[52] To stimulate EV adoption, the Thai government has rolled out the EV 3.5 Measures, the second phase of the EV Package, starting in 2024 and running until 2027. As part of the EV 3.5 measures, the Government will offer subsidies, ranging from THB 50,000 to 100,000 per vehicle ($1,515 to $3,030), based on vehicle types and battery capacities. Additionally, excise tax reductions have been implemented, lowering rates from 8 percent to 2 percent for electric passenger cars.

[53] Thailand's carbon tax on fuel, starting in 2025, is set at THB200/tCO2e (approximately $6) and is integrated into the existing excise tax structure for petroleum products, including gasoline, gasohol, kerosene, jet fuel, diesel, biodiesel, liquefied petroleum gas, and fuel oil. This means that the retail prices of these fuels remain unaffected.

Thailand) by around a quarter. Investment in public transport would also provide more affordable and inclusive access to economic opportunities for lower-income households.

Figure 4.7: Transport Sector GHG Emissions by Mode and Vehicle Type for Accelerated Decarbonization Pathway



Source: World Bank analysis

Recommendations

Decarbonizing Thailand's transport sector will require a faster shift toward electrification – combined with steps to lower emissions from electricity generation – and a shift to lower-carbon fuels for vehicles that are harder to electrify. Carbon taxes will likely only have a marginal impact on fuel prices and vehicle purchasing decisions. This CCDR recommends:

- **Public charging infrastructure** is essential to accelerate EV adoption, especially for users without home chargers or concerned about range, and for users of heavier vehicles. Public investment in this infrastructure can break the chicken-and-egg cycle between charger availability and EV demand. Thailand should invest an average of US$2.2 billion per year over the next 25 years—mainly in the coming decade—in public EV charging stations to meet demand and encourage private sector participation.

- **EV purchase subsidies should be phased out** as the market matures and even the upfront price of EVs becomes cost-competitive. Public support should shift toward infrastructure development and the electrification of public vehicles, including buses. Introducing a vehicle scrappage program can accelerate the removal of older, high-emission vehicles by offering financial incentives for switching to low- or zero-emission models. Setting age limits—10–15 years for passenger cars and 7–10 for commercial vehicles—can improve air quality, safety, and fleet efficiency. Ensuring equity through targeted subsidies or soft loans will support low-income owners in making the transition.

- **For heavy-duty vehicles that are hard to electrify, encourage biofuel use as a low-carbon alternative.** Further analysis is needed of the potential for mandates and subsidies to address issues of fuel-engine compatibility and biofuel availability. As passenger cars transition away from consuming liquid fuels, additional biofuel supply should become available for heavy vehicles.

4.4 Capitalizing on low-emissions agricultural technology

Agriculture is a major contributor to greenhouse gas (GHG) emissions in Thailand, accounting for around 18 percent of the total. Rice paddies are Thailand's largest agricultural GHG source, accounting for just over half of total agricultural emissions, due to methane emissions from the anaerobic decomposition of organic matter in flooded fields and nitrous oxide from excessive fertilizer use. In the production of sugarcane and other crops, the traditional practice of burning leaves before harvest releases significant amounts of black carbon and CO_2, exacerbating air pollution and climate change. Livestock systems account for around a quarter of agricultural emissions, with about 70 percent of these livestock emissions coming from enteric fermentation and manure deposited on pasture from ruminants (cattle, goats, and sheep). The rest of livestock's emissions are from manure management from all livestock animals including from Thailand's large poultry and swine sector.

A range of climate smart technologies exist to mitigate these emissions:

- Climate-smart rice production offers a "triple win" of higher productivity, lower greenhouse gas emissions, and improved climate resilience—but success depends on combining technologies and practices tailored to local conditions. Alternate Wetting and Drying (AWD) is a water management technique that alternates between flooding and partial drying of fields. It disrupts methane-producing bacteria and can reduce methane emissions by 30–50 percent without compromising yields.
- Several innovations offer viable alternatives to agricultural burning. Sugarcane leaves can be used as biomass for energy or feed rather than burnt. Integrating rice stubble into the soil instead of open burning eliminates carbon dioxide and harmful particulate emissions while enhancing soil fertility.
- Site-Specific Nutrient Management (SSNM) can optimize fertilizer use by tailoring application rates to soil conditions, minimizing excess nitrogen that converts into nitrous oxide, a potent GHG.
- Biogas digesters can convert methane from swine production into renewable energy, offsetting 60–70 percent of a farm's fossil fuel use. Anaerobic digestion of poultry manure, though less methane-rich than swine waste, can still generate biogas for on-site energy when co-digested with crop residues, as seen in farms across Central Thailand. For larger farms, covered lagoons with methane capture systems can further enhance emission reductions. Composting manure into organic fertilizer eliminates methane from open storage and reduces synthetic fertilizer dependency. Rapid manure drying techniques, such as solar dryers, can also inhibit methane generation during storage.
- More localized strategies will be needed in areas where climate impacts, such as salinization and sea level rise, make current systems untenable. In some coastal areas, transitioning from rice to regulated, low-impact shrimp farming could be a viable climate-adaptation strategy. However, the implications for both rural livelihoods and GHG emissions must be carefully weighed in each context.

Each of these emissions-reducing measures has the potential to provide a financial benefit to farmers if promoted, but there are several constraints to adoption. Estimated marginal abatement costs are negative for each of these interventions, and up to 100 baht per kg of CO2 equivalent for optimizing use of fertilizer through SSNM, illustrating the potential to lower emissions and make a financial gain (Annex 3). However, SSNM requires affordable soil testing tools and access to advisory services—resources that remain limited. Similarly, AWD depends on reliable irrigation access—only about 25 percent of Thailand's paddy area is irrigated—and complementary investments in drainage systems and laser leveling to be effective. The high upfront costs for water efficient infrastructure, biogas

systems and precision agriculture tools pose barriers for farmers (particularly smallholders). On the other hand, outdated subsidies for synthetic fertilizers and irrigation water often undermine more sustainable alternatives. Farmer education and extension services are equally critical to bridge knowledge gaps.

To reduce emissions at the farm-level and in the broader agrifood system, attention should be given to off-farm agribusinesses. Farms are not the only source of emissions in the agrifood system. Off-farm agribusinesses also contribute through transport and energy intensive agro-processing, particularly in rice milling, chicken processing, and for other highly processed foods. Changes in off-farm businesses are not only necessary to reduce emissions, but are critical for creating incentives for farm-level adoption of climate-smart practices through prices for farm production, market access, and enforcement of national and international standards. The latter is especially important for expanding access to markets in the European Union, given policy instruments such as the European Union Deforestation Regulation.

Recommendations

As is the case with adaptation interventions in agriculture, while sector-specific solutions exist, systemic challenges to scaling these solutions highlight the need for economic incentives and policy support. Thailand can achieve significant emission reductions in agriculture by prioritizing high-impact sectors like rice and sugarcane, promoting circular economy models (e.g., waste-to-energy and compost systems), and integrating data-driven tools for monitoring. But a combination of subsidy reform, farmer training and education, and regulatory measures is required:

- **Reform subsidies**: Redirecting funds from synthetic fertilizers and irrigation water in some cases would incentivize more sustainable alternatives. For instance, subsidies for soil-testing kits would help smallholders adopt precision agriculture and SSNM practices. Subsidized green loans and credit lines (e.g. through Thailand's Energy Efficiency Fund) would incentivize investment in biogas digesters, water-efficient infrastructure, and precision agriculture tools.
- **Implement regulatory measures:** Banning open field burning of rice straw alongside other interventions, such as promoting straw incorporation into soil, would limit CO_2 and PM2.5 emissions while enhancing soil carbon storage. Anti-burning regulations or incentives would also help promote alternative uses for sugarcane leaves, while the establishment of biomass collection hubs near sugarcane belts would help replicate the success of Mitr Phol's Namo Tudsod project, which incentivizes farmers to sell sugarcane leaves as biomass for energy or livestock feed. Government-led campaigns, combined with incentives for straw balers or biomass markets, could accelerate adoption. Policies mandating manure management plans and offering tax breaks for compost sales would similarly incentivize adoption.
- **Strengthen farmer education**: Expand extension services to train farmers on AWD, SSNM, and waste-to-energy systems, leveraging peer-to-peer learning networks. For instance, pilot projects in the Chao Phraya Delta demonstrate the feasibility of AWD, but scaling requires farmer training and subsidies for water-efficient infrastructure. Promoting the use of digital tools like the Rice Crop Manager platform would enable farmers to implement SSNM through real-time, data-driven recommendations.
- **Support off-farm agribusinesses in encouraging farm-level adoption:** Leverage Thailand's large agribusinesses with established links to smallholders to champion climate-smart practices at the farm-level and throughout the supply chain. For example, through co-funding research and development projects or CSA adoption pilots; by supporting access to high-value export markets (e.g., EU); or by using green finance to provide lower interest loans or tax incentives to companies successfully encouraging farm-level adoption of CSA practices.

Aligning these efforts with global climate frameworks, such as methane reduction pledges under COP28, will strengthen accountability and funding opportunities. Standardizing emission reporting across sectors will help to track progress and prioritize high-impact interventions.

4.5 Reforestation for a greener Thailand

Thailand's forestry sector will be important in achieving Thailand's overall carbon reduction targets, in additional to their role in climate adaptation. Forests in Thailand currently serve as a significant net carbon sink, absorbing 28.6 $MtCO_2e$ annually while emitting only 12.3 $MtCO_2e$, resulting in net removals of 16 $MtCO_2e$ per year and contributing substantially to the total LULUCF sector removals of 100 $MtCO_2e$. The country's Long-Term Low Emission Development Strategy (LT-LEDS) aims to enhance this role by increasing annual carbon removals to 120 $MtCO_2e$ by 2050, primarily through expanded reforestation efforts. Achieving this target would enable LULUCF to offset more than a quarter of Thailand's current emissions, solidifying forests as a central pillar in the nation's path to net-zero emissions.[54]

However, Thailand's forests are currently shrinking, with forest cover falling from 33.4 percent of land area in 2008 to 31.6 percent in 2020, despite national reforestation efforts. This decline is driven by a combination of anthropogenic and environmental pressures. Human encroachment remains the primary culprit, as illegal logging and land conversion for agriculture, urbanization, and infrastructure projects fragment critical ecosystems. In northern uplands, forests are cleared for cash crops like maize and rubber, while in coastal regions, mangrove forests—vital for carbon sequestration and coastal protection—are razed for shrimp farming. These aquaculture operations not only destroy habitats but also pollute waterways with chemical runoff, exacerbating ecological degradation. Investments in support of forest development have to date not translated into gains in tree cover.

Thailand's National Strategy (2018–2037) aims to increase forest and green area coverage to 55 percent of the country's total land area. This targeted expansion recognizes the significant economic value of Thailand's forests. Estimates suggest that the total value of both direct use (e.g., timber, tourism) and indirect use (e.g., climate mitigation and adaptation) from inland forests and coastal mangroves amounts to USD 33.3 billion per year—equivalent to 6.1 percent of GDP. To meet the LT-LEDS target, around 40 percent of Thailand's land mass would need to be covered by forest.

A substantial increase in both public and private sector funding will be essential for Thailand to meet its forestry-related targets under the LT-LEDS, let alone the 55 percent targeted under the National Strategy. According to estimates based on reforestation and maintenance costs from the Comptroller General's Office, achieving the stated forest coverage goals would require nearly US$15 billion over ten years—equivalent to 3 percent of GDP. Annual public funding for forestry, currently at approximately US$540 million, is far below the estimated need. The cost could potentially be halved to around US$7.1 billion if the land were used for economic forest plantations instead of being converted to natural forest. However, while plantations are less costly, they offer fewer benefits for biodiversity and ecosystem resilience.

Trends in recent years suggest that simply increasing spending will not be enough—strategic planning is also essential. A shift toward area-based forest management will be key to reversing these trends.

[54] The disparity between the forestry sector's net removals (16 $MtCO_2$/year) and the broader LULUCF sector's removals (100 $MtCO_2$/year) reflects differences in scope and land-use coverage. The forestry sector focuses narrowly on managed forests—such as plantations, reserves, and reforested areas—where carbon gains are constrained by mature ecosystems and active management. In contrast, the LULUCF category includes a wide range of land-based carbon sinks, such as agricultural soils, grasslands, peatlands, urban green spaces, and avoided deforestation. These non-forestry components contribute the remaining 84 $MtCO_2$/year, with peatlands and sustainable agricultural practices playing particularly important roles.

Collaboration across ministries and departments will be critical. Community based schemes offer the potential for further cost efficiencies; promising models already exist (Box 4.6)

Box 4.6: The potential of community-based forest restoration
Initiatives led by the Mae Fah Luang Foundation and the Royal Initiative Discovery Foundation have demonstrated effective community-based forest restoration, achieved strong outcomes at relatively low cost. Their success stemmed largely from empowering local communities with rights to manage forests and derive sustainable incomes from them. This community-based approach is gaining momentum. Since the passage of the Community Forest Act in November 2019, a growing number of communities have registered as community forests. Between 2011 and 2019, the total area of registered community forests increased from 0.47 to 1.22 million hectares. Each registered community is required to submit a forest management plan for approval by the Royal Forest Department (RFD), in exchange for official access rights and the ability to sustainably harvest forest products.

Recommendations

To reverse the gradual decline in forest cover and realize the environmental, economic, and emissions-reducing value of Thailand's forests, this CCDR recommends:

- **Invest in forest coverage:** Mobilize diverse funding sources—including carbon pricing revenue, private commercial forestry investment, international climate finance (e.g., REDD+), and carbon offset mechanisms—to meet LT-LEDS targets and significantly expand forest carbon removals. Achieving the stated forest coverage goals would require nearly USD 15 billion over ten years—equivalent to 3 percent of GDP.
- **Prioritize ecosystem restoration:** Focus on restoring critical ecosystems like mangroves in coastal provinces (Trat, Satun) and degraded upland watersheds with native species. Foster cross-ministerial collaboration to reconcile conflicting policies such as shrimp farming subsidies that undermine conservation efforts.
- **Promote sustainable land use:** Scale up community forestry programs granting legal management rights to locals to reduce illegal logging and encourage agroforestry practices that integrate trees with crops—boosting both farm resilience and carbon sequestration.
- **Strengthen legal frameworks and enforcement:** Establish dedicated forest protection units equipped with advanced monitoring technologies and enforce stricter penalties for illegal logging and land encroachment, while empowering local communities as effective forest guardians.
- **Integrate forest restoration into urban and regional planning:** Leverage initiatives like "Green Bangkok 2030" to increase urban green spaces and embed forest restoration goals into broader regional development strategies, enhancing biodiversity and climate resilience.

5.
Seizing green growth opportunities

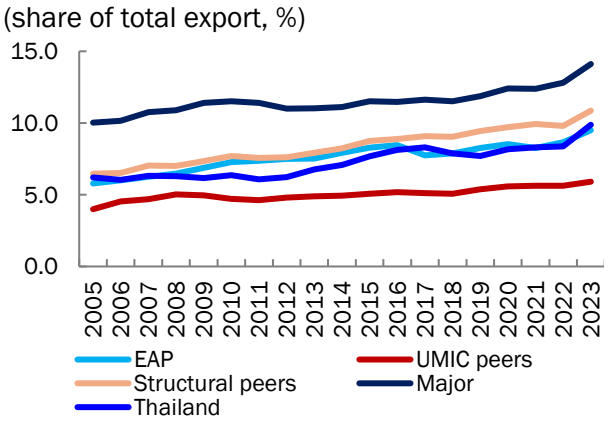
5 Seizing green growth opportunities

Beyond its own decarbonization efforts, Thailand could emerge as a supplier of low-carbon solutions to the world. At the same time as its carbon-intensive exports face risks from declining demand, Thailand is well-positioned to capitalize on growing international markets for green and climate-adaptive technologies. These include clean energy sources like solar and wind, more efficient products such as electric vehicles, and adaptation technologies like advanced air conditioners and heat pumps. Production of these technologies benefits from economies of scale, magnifying Thailand's potential economic gains once it establishes a foothold in global markets.

This would imply greater participation in green global value chains (GVCs), with Thailand situated in a region that is poised to drive the global green transition. China, for example, has become a leader in green innovation, accounting for a growing share of global R&D and patents in renewable energy and electric vehicles. Meanwhile, regional specialization and competition have helped reduce costs and expand market reach, driving (for example) Viet Nam's strength in solar panel production and Thailand's in vehicle components. These dynamics show that countries in the region are already key players in the downstream segments of green and high-efficiency product supply chains.[55]

While Thailand's green exports are growing, they continue to lag structural peers and major exporters. Thailand's exports of green products as a share of total exports have been rising steadily (Figure 5.1). However, when measured as a proportion of its total exports, Thailand's green exports share remains below structural peers and far behind major (high income) exporters of green products, as well as several countries in EAP (Figure 5.2)

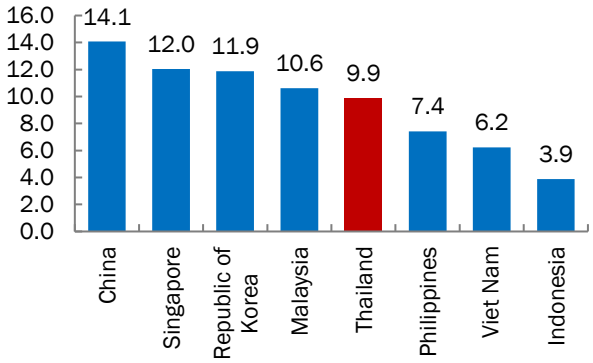
Figure 5.1: Green exports



Note: Major includes China, Germany, USA, Japan, Italy, Rep. of Korea, France, Mexico, UK, and Netherlands; Structural peers include Malaysia, Mexico, Thailand, Bulgaria, and Türkiye

Figure 5.2: Green products exports as a share of total exports

(% of country's total exports, 2023)



Source: UN Comtrade; CEPII's BACI database; World Bank staff calculations. See Mealy and Teytelboym, 2022.

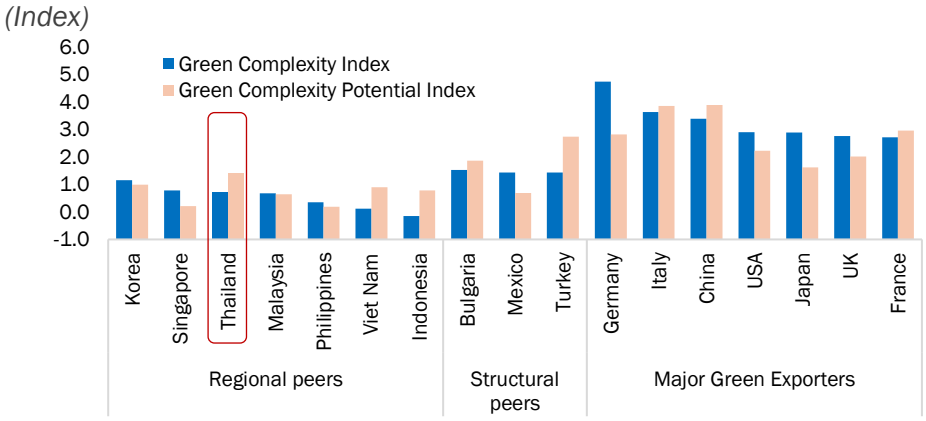
Thailand has substantial untapped potential to export more complex green products. Based on the Green Complexity Index[56], a measure of a country's *current* ability to export green complex products

[55] de Nicola, Francesca, Aaditya Mattoo, and Trang Thu Tran, 2025, "Green Technologies: Decarbonizing Development in East Asia and Pacific." Overview booklet. East Asia and Pacific Development Studies. World Bank, Washington, DC.

[56] The Green Complexity Index allows for cross-country comparison of the complexity of a country's trade in green goods based on 6-digit product classification in the Harmonized System. There are some limitations since products may be used in more than one environmental category and many products are dual use, which means they can have both environmental and non-environmental purposes. As a result, these green product classifications tend to somewhat over-estimate

competitively, Thailand's ranks higher than most regional peers but below structural peers and the major exporters of green complex products. However, among regional peers, Thailand has the highest untapped *potential* (as measured by the Green Complexity Potential index); indeed, on this measure Thailand ranks among the highest of all middle-income countries[57]. Thailand has particularly high potential to increase its participation in the value chains for energy efficient electronic appliances, electric vehicles, solar PV, and carbon capture storage technology.

Figure 5.3: Green Complexity in Exports Index and Green Potential Index



Source: UN Comtrade; CEPII's BACI database; World Bank; See Mealy and Teytelboym, 2022
Note: Green Complexity Potential measures how much potential a country has to diversify into green, complex products in the future based on its existing competitive strengths.

Thailand exhibits strong export competitiveness across various sophisticated green and renewable energy products, as measured by a high Revealed Comparative Advantage (Figure 5.4).[58] While some green products are low-complexity vegetable-based goods, most green products are sophisticated, with Product Complexity Index (PCI)[59] values above average. Notably, Thailand leads in energy-efficient air conditioning exports, with air conditioners featuring reverse cycle refrigeration showing the highest RCA and substantial export value ($719 million). Thailand is also well-positioned to benefit from the growing global demand for solar PV, given its competitiveness in solar PV components such as optical appliance parts and mounted optical elements. Exports of emerging low-carbon technologies, such as carbon capture and storage, also show strong potential.

Other Thailand exports are more carbon intensive, but offer strong potential for a green transition, especially in the automotive sector which is shifting to EVs. Some of Thailand's exports with a high RCA are carbon-intensive, including vehicles, engines, and electronic machinery. Nevertheless, these sectors present potential for green transition (Figure 5.5). For instance, Thailand's automotive sector,

environmental trade volumes and should be interpreted as maximum values. The selection of green products draws on the OECD, WTO and APEC lists, totalling 293 products classified at the 6-digit level in HS1992. See Mealy, P., and Teytelboym, A., (2022), *Economic complexity and the green economy*, Research Policy, vol. 51, issue 8.

[57] The Green Complexity Potential (GCP) Index evaluates a country's capacity to diversify into complex green products in the future. It is determined by analyzing the proximity and complexity of green products that the country is not yet competitive in. Proximity measures how closely related a new product is to the country's existing productive capabilities, while complexity reflects the technological sophistication of the product. A higher GCP suggests that a country is well-positioned to expand into advanced green sectors, leveraging its current strengths to develop competitiveness in new, complex green products.

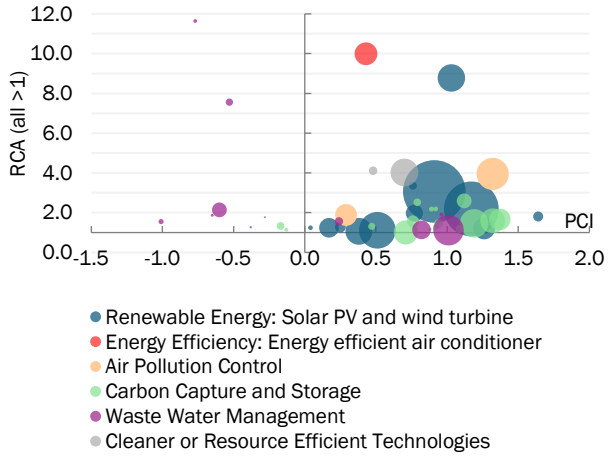
[58] Thailand's RCA for a given product is the share of that product in Thailand exports divided by the share of that product in global exports. When a country has a revealed comparative advantage for a given product (RCA >1), it is inferred to be a relatively competitive producer and exporter of that product.

[59] The Product Complexity Index (PCI) was introduced by Hidalgo and Hausmann (2009) as part of the Economic Complexity framework. It is designed to infer the technological sophistication or complexity of products based on the diversity of countries that export them and the complexity of those countries' export baskets. See Hidalgo, C., and Hausmann, R., (2009), *The building blocks of economic complexity*, PNAS, vol. 106 no. 26.

which is heavily reliant on internal combustion engine (ICE) production, is one of the country's largest manufacturing industries. However, as discussed in the next section, Thailand's automakers and parts suppliers have significant potential to adapt their technologies and production processes to support the growing electric vehicle (EV) market.

Figure 5.4: Thailand Green Complexity Index and Revealed Comparative Advantage by product

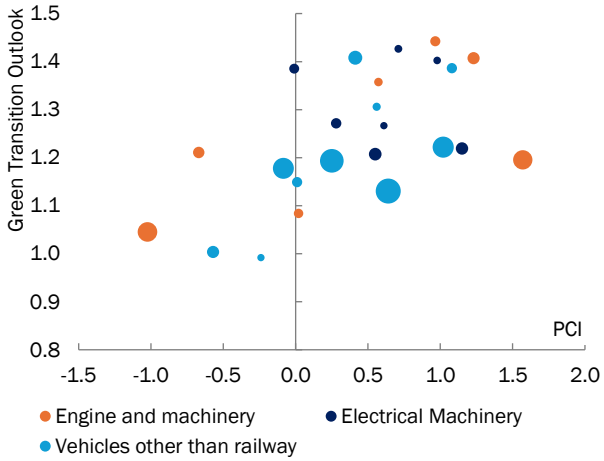
(Index)



Note: Bubble size indicates export share in total green exports
Source: UN Comtrade; CEPII's BACI database; World Bank staff calculations. See Mealy and Teytelboym, 2022

Figure 5.5: Thailand brown lock-in products (with RCA>1) and their Green Transition Outlook index

(Index)



Note: Bubble size indicates RCA (all >1), Green Transition Outlook measures the proximity of brown export products to climate-compatible exports.
Source: UN Comtrade; CEPII's BACI database; World Bank staff calculations. See Mealy and Teytelboym, 2022

Figure 5.6: Complexity and comparative advantage of selected Thai exports

Products	PCI	RCA	Export, USD'000	Notes
Air conditioners nes with reverse cycle	0.29	17.1	719,456	Energy efficient air conditioners use less
Lead monoxide (litharge, massicot)	-0.56	11.8	12,731	Chemical used in chemical recovery system
Parts and accessories of optical appliances	0.81	9.9	752,220	Solar PV
Sodium sulphites	-0.94	8.6	46,211	Chemical used in chemical recovery system
Made up fishing nets, of manmade	-0.88	7.5	98,412	
Hydrogen peroxide	0.31	4.7	62,961	Disinfectant and bleach
Motorcycle parts except saddles	0.75	4.5	664,595	Broad component of EV
Compressors for refrigerating equipment	1.31	4.2	857,010	Provide the cooling effect in a refrigerator.
Engines and motors nes	-0.28	4.2	59,515	Carbon capture storage technology
Mounted lenses, prisms, mirrors,	1.03	3.7	146,676	Solar PV
Knotted netting, nets, of natural	-0.79	3.3	8,093	
Surveying levels	1.33	2.8	26,581	Carbon capture storage technology, use for environmental purposes

Source: UN Comtrade; CEPII's BACI database; World Bank staff calculations. See Rosenow and Mealy, 2024. Note: PCI values are normalized so that that the set of all HS1992 6-digit products have a mean of 0 and standard deviation of 1.

Based on the analysis above, this chapter analyzes three manufacturing industries that have high potential to drive Thailand's future exports and growth. These are electric vehicles and their components, solar photovoltaic modules and their components, and eco-friendly air conditioners. It concludes with an assessment of the economic magnitude of emerging green opportunities, and of policies that could help Thailand to take advantage of these opportunities.

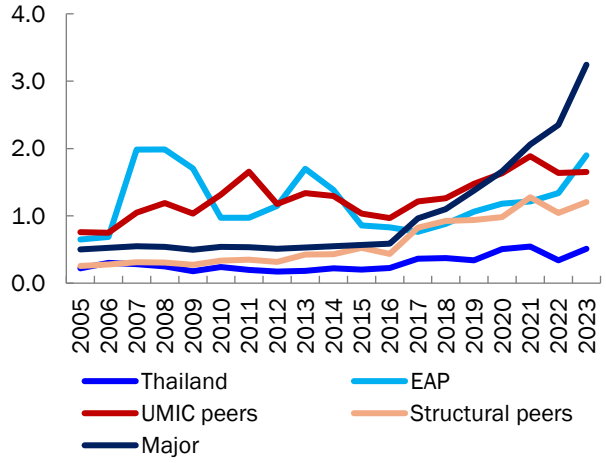
5.1 Electric vehicles and parts

The auto parts industry is an important sector for Thailand's economy, supporting both domestic vehicle manufacturing and global supply chains. In 2019, the industry generated THB 2.6 trillion in sales, accounting for roughly 15 percent of GDP. Sales were dominated by powertrain components (34 percent), followed by electrical and electronics (21 percent), chassis (19 percent), process-related parts (15 percent), and body components (11 percent).

Thailand has potential to expand EV production and increase exports, leveraging its well-established base in electrical and electronics, body, and chassis manufacturing. When considering the narrow EV value chain, which includes batteries, EV components, and fully assembled EVs, Thailand's export share remains relatively low at 0.5 percent of total exports, lagging behind its EAP and structural peers (Figure 5.7). However, the country's existing competitiveness in auto parts production can drive further transitions from internal combustion engine (ICE) vehicles to EVs. Taking a broader view of the EV value chain and including vehicle components used in both ICE and EVs, Thailand's export share reaches 4.3 percent of total exports, surpassing most ASEAN peers (Figure 5.8). This is particularly evident in subcomponents such as interior parts, vehicle bodies, and brake systems, where Thailand has a strong presence in the global market and high comparative advantage. As global demand for EVs grows, leveraging its strong auto parts sector and enhancing EV-related production capabilities could position Thailand as an EV manufacturing hub in the global market.

Figure 5.7: Narrow EV value chain exports including battery, end products and components, and the assembled EV end product.

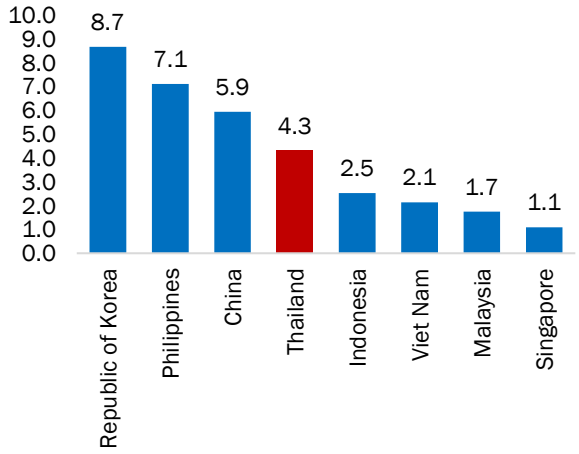
(%, share of total country's exports)



Source: World Bank staff calculations.

Figure 5.8: Broad EV value chain exports which include wider vehicle manufacturing value chain used in either ICE vehicles or EVs

(%, share of total country's exports)



Source: World Bank staff calculations.

While some ICE components will need to be adapted for EVs, many existing parts could continue to be produced with minimal modifications. A previous World Bank study helped Thailand's auto parts manufacturers, policymakers, and industry stakeholders prepare for the EV transition by identifying at-risk components and opportunities for diversification.[60] It found that more than 80 percent of

[60] In this study, 266 automotive parts were classified into four categories based on potential use in EVs:
- i) obsolete (phased out in EVs);
- ii) modified (requiring adaptation);
- iii) unchanged (remains relevant); and
- iv) enhanced (requiring new production processes to replace ICE components in EVs).

This study adopts a similar approach to that taken by several Thai financial institutions, including KTB Research (2021) in their report "Toward Production Base of EV for the Region" (in Thai), and the Kasikorn Bank Research Center (2021) in their analysis "Econ Analysis: EV Production Business," dated 5 July 2564 (in Thai).

auto parts sold can potentially be used for EVs, with 58 percent of sales remaining largely unaffected by EV adoption, and 22 percent requiring products to be modified or production processes to be enhanced. This suggests that Thailand is well placed to capitalize on increased demand for EVs, both domestically and internationally.

Nevertheless, the transition to electric vehicles will shift the demand for worker skills. There is rising demand for skilled workers in EV-related fields, including battery technology, electric drivetrains, and software integration. Job postings data reveal that over 90 percent of low-carbon technology roles require high-level skills (Box 5.2). To meet these demands, existing automotive suppliers may need to upskill their workforce or recruit international expertise. While the EV sector creates new job opportunities, studies indicate that its simpler, more automated assembly processes could result in a net reduction of employment in the automotive industry.

Box 5.2: Assessing labor demand using data on low carbon technology job postings

In 2022 Singapore and Malaysia saw the highest rates of online job postings related to low carbon technologies (LCTs), followed by Indonesia, the Philippines, Thailand, and Viet Nam with the lowest. For Indonesia, Malaysia and Thailand, approximately half of all LCT-related job openings from 2019 to 2022 were in the renewable energy sector. Thailand and Viet Nam also had a high share of job openings in the electric vehicles sector. For Thailand this was the highest at 21 percent of all LCT-related job openings.

Over 85 percent of these LCT-related job openings across the Southeast Asian countries studied are classified as high-skilled jobs. In Thailand and Viet Nam, over 90 percent of job postings relating to LCTs were for high-skilled occupations. The most common category is for 'Science and Engineering Professionals', followed by 'Business and Administration (Associate) Professionals'.

5.2 Solar photovoltaic technologies

Rising global demand for solar photovoltaic (PV) production presents a significant opportunity for Thailand to expand its role in the clean energy supply chain. According to the IEA's Roadmap to Net Zero Emissions by 2050, annual solar PV capacity additions must quadruple to 630 GW by 2030, up from 134 GW in 2020. By 2050, nearly 90 percent of global electricity will come from renewable sources, with solar PV and wind contributing almost 70 percent (IEA 2022[61]). Meeting this surge in demand requires a more than twofold increase in global production capacity for polysilicon, ingots, wafers, solar cells, and modules by 2030. As countries accelerate their clean energy transitions, securing a stable and diversified supply chain for solar PV components will be critical. With its growing solar PV export share, strong manufacturing base, and strategic location in global trade networks, Thailand has the potential to attract investment, scale up production, and integrate more deeply into the global solar PV supply chain.

Thailand's solar PV exports have grown significantly over the past decade but remain focused on final assembly, without the upstream production seen in regional peers like Malaysia. As of 2020, Thailand had 15 PV cell and module manufacturers with a total capacity of 3,200 megawatts[62]. Thailand's exports of Solar PV products have experienced a significant increase, rising from 0.5 percent of total exports in 2018 to 1.9 percent in 2023 (Figure 5.10). This export share has accelerated to well above the average of peers and mirrors the upward trends observed in Viet Nam and China.[63] Investment prospects remain positive, with a rising trend in solar PV production projects.

[61] IEA Special Report on Solar PV Global Supply Chains, 2022
[62] See Thailand PV status database 2020: Cell and module production.
[63] China accounted for 70 percent of module production in 2021, up from 50 percent in 2010. Other manufacturers include Viet Nam (5 percent), Malaysia (4 percent), Korea (4 percent) and Thailand (2 percent), with most manufacturing capacity in these countries developed by Chinese companies focusing on exports to the United States (IEA 2022).

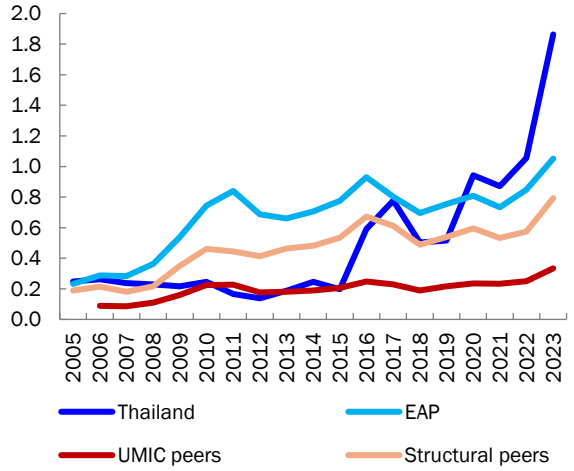
But Thailand's production is predominantly centered on the final assembly of Solar PV modules, with limited involvement in the manufacturing of high-value-added components such as solar cells, inverters, and semiconductor-grade silicon wafers. In comparison, regional peers like Malaysia have developed a more comprehensive presence across the entire solar PV supply chain, including upstream activities like polysilicon production and wafer manufacturing. This highlights the potential for Thailand to bolster its intermediate product exports and capture greater value-added opportunities within global value chains.

Figure 5.9: Key stages in the main manufacturing process for solar PV

Source: IEA 2022, ADB

Figure 5.10: Exports of Solar PV

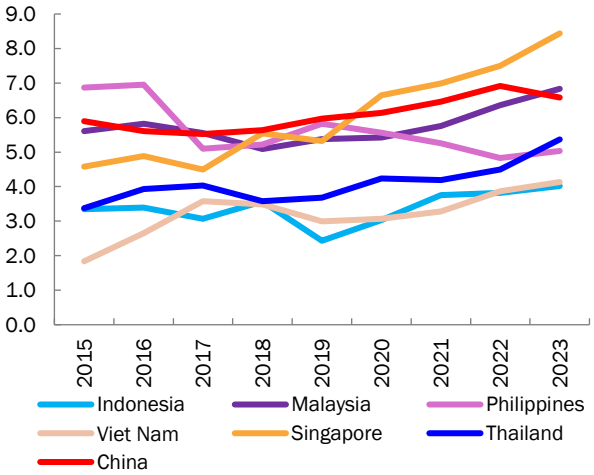
(%, share of total country's exports)



Source: World Bank staff calculations.

Figure 5.11: Total value chain of solar PV related exports, including raw materials, processed materials, subcomponents, and end products

(%, share of total country's exports)



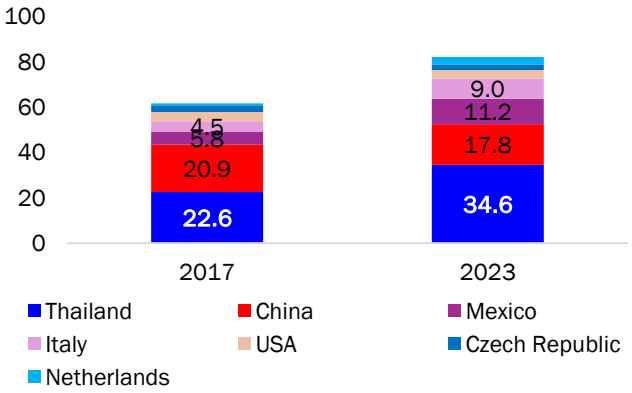
Source: World Bank staff calculations.

5.3 Air conditioners

Thailand is a hub for R-32 refrigerant manufacturing, which has a key role in the green cooling industry. The development of this industry in Thailand has been driven by global efforts to phase out high-global warming potential (GWP) refrigerants under the Montreal Protocol. R-32 technology was introduced to Thailand in 2014, and followed by collaborations with local manufacturers to scale production. Thai manufacturers received international funding and technical guidance to shift from R-22 to R-32 refrigerants, which offer higher energy efficiency and lower environmental impact. In 2016, the World Bank, through initiatives such as the Hydrochlorofluorocarbon (HCFC) Phase-Out Management Plan (HPMP), has also played a crucial role, providing technical assistance and financial support to help local firms upgrade production lines and meet international environmental

standards[64]. These efforts have positioned Thailand as a leading exporter of eco-friendly air conditioners, enhancing the country's competitiveness in the green cooling industry.

Figure 5.14: Exporters of air conditioners with reverse cycle refrigeration
(%, global market share)



Note: HS code (841581) Air conditioning machines; containing a motor driven fan, other than window or wall types, incorporating a refrigerating unit and a valve for reversal of the cooling/heat cycle (reversible heat pumps)
Source: World Bank staff calculations.

Despite its strong position, Thailand faces challenges in maintaining global market share. Chinese air conditioner manufacturers benefit from advanced technology and economies of scale, enabling them to offer products at competitive prices. Additionally, China's substantial investments in research and development have led to innovations in energy efficiency and smart technologies, further enhancing their market appeal. To bolster its competitiveness, Thailand must invest in technological advancements, enhance production efficiency, and strengthen its supply chain resilience.

5.4 Policies to help Thailand capitalize on green export opportunities

Thailand's strategy to enhance green manufacturing and innovation should focus on products where it has a comparative advantage, such as solar PV components, energy-efficient appliances, and EV parts. Strengthening participation in green Global Value Chains (GVCs) will require capacity-building initiatives for SMEs, fostering public-private collaboration, and ensuring research and innovation efforts align with industry needs. A well-coordinated approach can help drive technology adoption and ensure Thailand's competitiveness in the global green economy. Box 5.3 illustrates the economic potential of Thailand's green exports. This CCDR recommends:

- **Improving Thailand's investment climate to attract foreign direct investment (FDI) and facilitate technology diffusion.** By removing market-entry barriers, ensuring fair competition, and fostering a business-friendly regulatory environment, Thailand can provide firms with greater incentives to upgrade their production processes and adopt new green technologies. A key enabler will be establishing a network of private service providers and promoting innovative business models like Energy Service Companies (ESCOs) to bridge information and financing gaps.

- **Eliminating distortionary policies and strengthening green public procurement to increase domestic demand for cleaner technologies.** Distortionary policies include subsidies for fossil fuels and fossil fuel–related technology, and barriers to trade and investment in green technologies. Average applied tariffs on green imports remain relatively high in Thailand, which

[64] See World Bank press release (2016), New Air Conditioner Technology Adopted in Thailand: World Bank and The Montreal Protocol Multilateral Fund Support Climate-Friendly Technology.

can make it harder for firms to participate in green value chains.[65] In the process of unwinding these distortions, complementary measures should be considered to support low-income beneficiaries of fuel subsidies and retraining for workers in fossil fuel industries.

- **Investing in innovation and R&D across both upstream and downstream solar PV segments to strengthen Thailand's position in the global solar PV market.** The production of key minerals used in PV manufacture is highly concentrated, with China playing a dominant role. This raises the risk of supply shortages amid rapidly growing demand. To mitigate this risk and capture a larger share of global solar PV exports, developing products that are more efficient, use fewer materials, and are more durable will be key. Investments in innovation and technology can target both upstream and downstream segments. Upstream innovation could focus on improving performance in diffusing light, reducing material use, enhancing durability, and lowering the carbon footprint. This can be complemented by product designs that add value, such as lightweight and flexible modules. Downstream innovation can leverage Thailand's expertise in solar farm development and expand into integrated applications, including combining solar PV with EV charging stations.

- **Ensuring that foreign investment in the sector builds local capacity and technology**. The EV industry has benefited from various incentives, including recently (as part of the EV 3.5 package) import duty and tax cuts, subsidies, and non-tax benefits related to visas, work permits, and land ownership. While these incentives have helped to attract foreign investment, the authorities should ensure that these investments also facilitate an infusion of international expertise to Thailand in the form of technological transfer, skills development, and employment of local workers. One approach is to incentivize foreign investors to integrate local SMEs into their supply chains to strengthen domestic supplier capacity. Additionally, the government can consider co-investing in high-value projects by providing matching grants to companies that meet technology transfer and local workforce training criteria, leveraging the existing Competitiveness Enhancement Fund.

- **Developing a skilled workforce is crucial to sustaining Thailand's green industrial transition.** The government should prioritize high-tech skill development in digital, engineering, and sustainable manufacturing while implementing targeted talent attraction policies to bridge immediate skill gaps. This should be done in close collaboration with the private sector to ensure curricula evolve alongside technological advancements. There is also a need to raise standards of basic education so that Thailand's children are better equipped to think critically, learn new skills, and fully benefit from higher education and technical training, in line with industry needs. Firms reportedly face significant difficulties finding workers with the required skills, while certain measures of cognitive (problem solving) and non-cognitive (social and leadership) skills have declined over time among new graduates. Government-supported training and certification programs—particularly for technicians such as EV mechanics and solar panel installers—are essential to build a skilled workforce and mitigate job displacement from the legacy auto sector. Additionally, funding for scholarships, training centers, incubation hubs and innovation competitions will play a key role in fostering talent development.

- **Government support for green innovation in Thailand needs refinement**. Most of the budget for green innovation and climate technology initiatives is allocated to research institutes, government agencies, higher education institutions, and researchers, with limited involvement from the private sector. Further use could be made of policy instruments that promote non-R&D-based innovation, such as vouchers for innovation, innovation finance de-risking

[65] See de Nicola, Francesca, Aaditya Mattoo, and Trang Thu Tran. 2025. *Green Technologies: Decarbonizing Development in East Asia and Pacific.* East Asia and Pacific Development Studies. Washington, DC: World Bank.

facilities, including partial credit guarantees, and early-stage support programs for startups with new green technologies.

Box 5.3: Thailand's green exports potential

As global demand for low-carbon goods grows, Thailand is well positioned to capture additional gains from green exports. This Box quantitatively assesses a selection of high-potential export opportunities under two scenarios: (1) a moderate scenario, where efforts to expand production and meet global demand are only partially realized; and (2) an ambitious scenario, where Thailand fully capitalizes on both global market opportunities and its domestic production capacity, including by pursuing the policies recommended above. The results indicate that Thailand's exports of electric vehicles and parts, solar PV components and modules, and energy-efficient air conditioners could together rise by an additional 2-3 percent of GDP by 2030, with potential to expand further in subsequent decades.

Thailand can diversify into EVs, demand for which is likely to accelerate in the next decade. On the supply side, government policies promoting EV manufacturing are enabling a rapid scale-up in production capacity—projected to reach up to 411,550 private EVs by 2027, with a target of 725,000 by 2030[66]. On the demand side, based on IEA projections, global EV adoption is expected to rise from 13 percent of private vehicle sales in 2023 to 67 percent by 2035. Thailand's robust local supply chains for auto parts (excluding batteries) position it well to expand its share of global EV exports. In the ambitious scenario, the full production capacity is realized by 2035, and at this point private EVs exports could reach USD 14.9 billion (2024 prices), equivalent to 1.2 percent of the global EV export market. However, the domestic value added from EV exports may be lower than that from ICE vehicle exports, as EVs require fewer mechanical components and parts. While previous analysis showed that up to 80 percent of existing parts can be adapted to the EV supply chain, batteries—which are largely imported—account for 40–50 percent of an EV's value, posing a challenge for maximizing local economic gains[67].

Thailand is already competitive in other segments of green value chains, such as solar PV and energy-efficient electronic appliances. In 2022, Thailand held a 4.2 percent share of global solar PV exports, accounting for nearly 2 percent of its total exports. With global demand for clean energy expected to surge, boosting competitiveness could raise Thailand's solar PV export share to 7.5 percent by 2030—on par with regional peers. Under this scenario, solar PV exports could reach USD 24.8 billion (2024p) by 2030. In addition, Thailand has a strong revealed comparative advantage in environmentally friendly appliances, such as reverse cycle refrigeration, which accounts for 35 percent of global exports in this category. These products are part of complex value chains and rely heavily on imported materials. To ensure higher and more sustainable value added, it is critical for Thailand to deepen its participation in innovation-driven segments of global value chains and to localize more of its supply chain.

Table B5.3: Green product exports opportunities projection

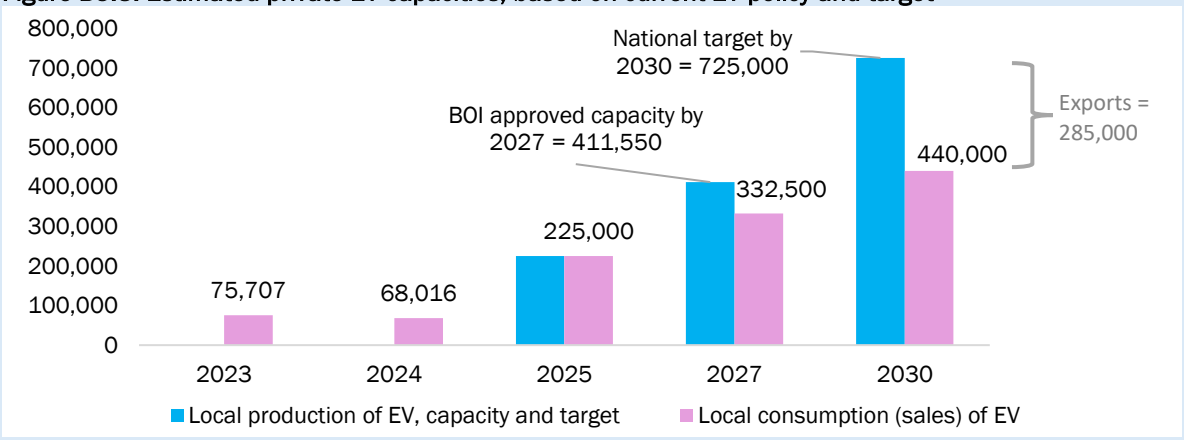
Products	Scenarios details	Global market share (%)		Exports projection, USD million 2024p	
		2023	2030	2023	2030
EV	**Moderate:** only half of the EV policy effort can be achieved	0.0	0.4	0	3,121
	Ambitious: EV policy target can be achieved by 2030	0.0	0.7	0	6,242

[66] Thansettakij (2025), The government has already paid 10 billion baht to subsidize the use of 86,200 EVs, which will emit zero pollution.
[67] Deloitte (2023) Study: The key role of battery costs in Automotive; PWC (2019), Merge ahead: Electric vehicles and the impact on the automotive supply chain.

Box 5.3: Thailand's green exports potential

Solar PV	**Moderate:** constant market share at 4.2%	4.2	4.2	4,245	13,657
	Ambitious: market share reaches 7.5% by 2030	4.2	7.5	4,245	24,791
Air conditioners with reverse cycle refrigeration	**Moderate:** market share return to 17% by 2030	34.6	17.0	1,152	700
	Ambitious: constant market share at 34.6%	34.6	34.6	1,152	1,428

Figure B5.3: Estimated private EV capacities, based on current EV policy and target



Source: National Electric Vehicle Policy Committee (EV Board), DLT, World Bank staff calculation

6.

Mobilizing finance for adaptation and transition

6 Mobilizing finance for adaptation and transition

This chapter sets out how the investments prioritized in this CCDR can be financed. It begins by consolidating the overall financing needs for the recommended adaptation and mitigation investments. It assesses which of these investments will require public financing, and which investments could be financed partially or entirely by the private sector. It then analyzes the ability of the government to meet the associated public investment needs while maintaining overall fiscal sustainability, taking into account potential revenues from carbon pricing.

With limited public resources, this chapter also reviews the potential for private sector financing of climate mitigation and adaptation efforts. The private sector has an important role to play in investing in clean energy, green manufacturing, and climate-smart agriculture. But bottlenecks include inadequate data infrastructure, unclear incentives for issuers and investors, and limited awareness and capacity to prepare green and sustainable projects. Until recently, clear, consistent, and globally accepted definitions on sustainability activities had also been lacking, which affected the quality of reporting and disclosures. The recent introduction of a taxonomy can help address these challenges, but will require rigorous implementation and capacity building across sectors.

6.1 Investment needs for adaptation and mitigation

This CCDR estimates that the additional investment needed to respond to climate change in Thailand is USD219 billion in discounted (NPV) terms over the next 25 years. This is equivalent to 2.4 percent of cumulative GDP over this period. It includes USD 105 billion for climate adaptation, USD 96 billion for mitigation, and USD 19 billion for investments in climate smart agriculture and forests, which have both adaptation and mitigation benefits (**Error! Reference source not found.**). This is the total i ncremental investment needed for key adaptation measures prioritized in this report and to achieve carbon neutrality by 2050, relative to a BAU scenario of no additional action or investment. It excludes O&M savings, most of which would accrue to the private sector. These estimates should be interpreted with caution, due to uncertainty about the future evolution of technologies, costs, climate, and other parameters.

Table 6.1: Additional climate investment needs (2025-2050), USD million

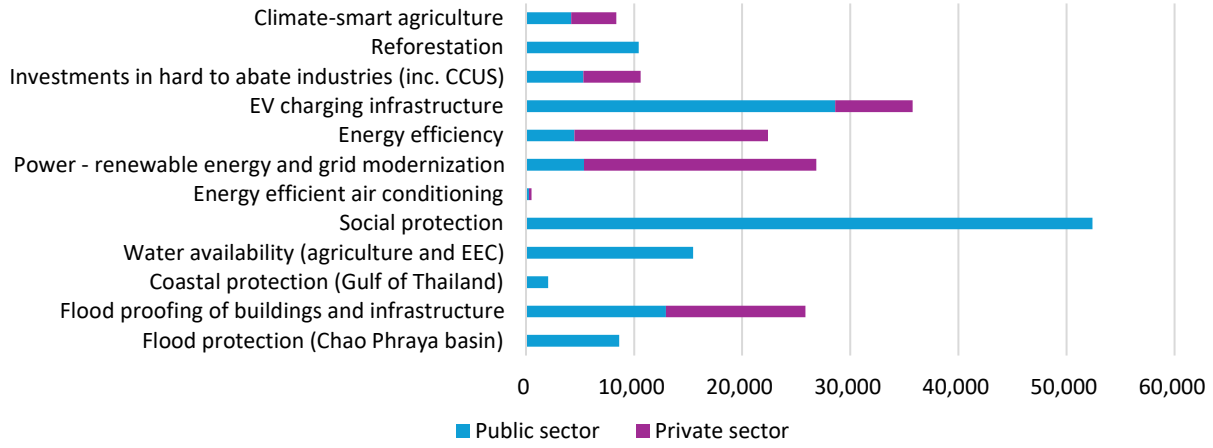
	Undiscounted, nominal				Net present value @ 6%	As % of GDP
	2025-30	2031-40	2041-50	Total		
Adaptation						
Flood protection (Chao Phraya basin)	4,700	9,400	0	14,100	8,613	0.09
Flood proofing of buildings and infrastructure	11,950	23,900	11,950	47,800	25,861	0.28
Coastal protection (Gulf of Thailand)	1,892	781	173	2,846	2,058	0.02
Water availability (agriculture and EEC)	7,265	12,092	10,955	30,311	15,451	0.15
Social protection	17,805	43,784	55,369	116,958	52,418	0.57
Energy efficient air conditioning	240	400	400	1,040	520	0.01
Total adaptation	**48,390**	**98,784**	**87,274**	**234,449**	**115,427**	**1.1**
Mitigation						
Power – renewable energy and grid modernization	32,718	6,501	(15,030)	24,189	26,864	0.29
Energy efficiency	7,127	18,332	25,952	51,411	22,394	0.24
EV charging infrastructure	26,718	20,745	10,377	57,840	35,755	0.39
Investment in hard-to-abate industries (inc. CCUS)	2,228	7,425	17,325	26,978	10,594	0.11
Total mitigation	**68,791**	**53,002**	**38,625**	**160,418**	**95,607**	**1.0**
Agriculture and forests						
Reforestation	7,500	7,500	0	15,000	10,415	0.11
Climate-smart agriculture	3,455	6,589	7,412	17,455	8,355	0.09
Total agriculture and forests	**10,955**	**14,089**	**7,412**	**32,455**	**18,770**	**0.2**
Total investment needs	**123,597**	**157,448**	**124,884**	**405,928**	**219,298**	**2.4**

Source: World Bank analysis.

Notes: These investment estimates are largely based on the results of bottom-up sectoral analysis, though in some instances (e.g. irrigation, climate-smart agriculture) the estimates rely more on cross-country experience/data and international benchmarks. "% of GDP" figures are calculated by dividing the NPV of recommended investments by the NPV of projected future GDP.

The bulk of adaptation spending is expected to be done by the public sector, while the private sector will take on more than half the investments in mitigation (Figure 6.1). In the energy sector, for example, clean energy investments are expected to be made primarily by private producers, benefiting from reform to open up the power market and establish a carbon price signal, as well as public investments in grid modernization. In the transport sector, the shift to e-mobility and biofuels is expected to be financed primarily by individual vehicle owners and EV companies. On the other hand, when it comes to adaptation, the public sector will be primarily responsible for spending on adaptive social protection, flood prevention, and water security, given the public goods aspects of many of the required interventions. Indeed when it comes to addressing flooding in the Chao Phraya basin, the proposed "Nine Plans" (which would be publicly financed) are effective in reducing the potential impact of flooding and will reduce the costs needed to flood-proof individual buildings and structures (the burden of which would likely fall more on the private sector). The additional public spending on adaptation would average around 1 percent of GDP per year over the next 25 years, equivalent to around USD 7.5 billion per year, a substantial addition to the estimated 117-137 billion THB (3.4-4 billion USD) currently being spent on the climate agenda annually.[68] At present, the scale of the budget for adaptation and mitigation needs in Thailand can only be inferred through proxies such as budgets allocated to climate change and environmental objectives, underscoring the need for more comprehensive climate budget tagging.[69]

Figure 6.1: Climate investment needs by sector, NPV (USD million)



Source: World Bank analysis.

6.2 Financing climate-related public spending needs

The introduction of carbon pricing instruments has the potential to generate significant public revenues for Thailand. In line with NDC targets, we assume that a carbon price is phased in between 2026 and 2030, and reaches a target value of USD 25 per tCO2e in 2030. Beyond 2030, the price

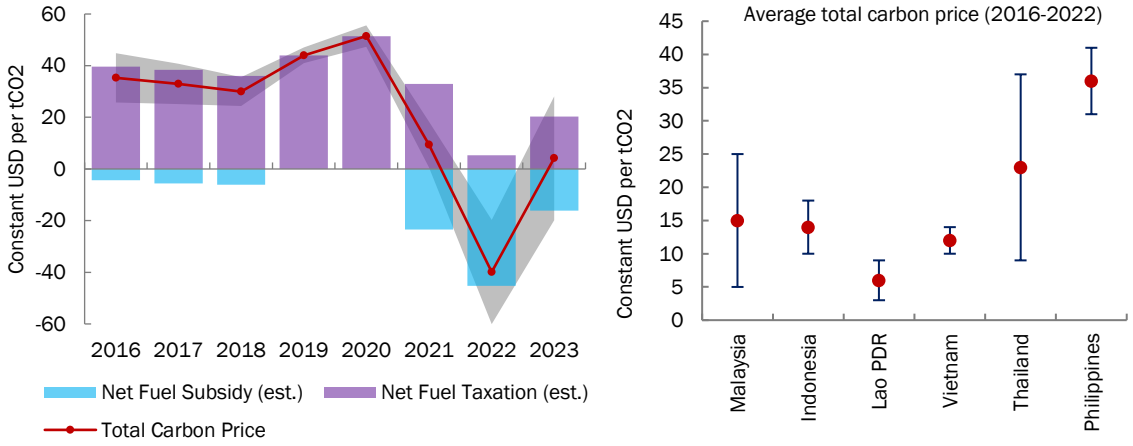
[68] According to the Thailand's Budgetary Appropriation Act, in 2025 the government has allocated 136,851 million THB (about USD 4 billion) of budget under the Strategy for Eco-Friendly Development and Growth. This number has been increasing continuously since 2021 at around 4.2 percent per year.

[69] The actual public budget allocation for climate change objectives could be higher as some projects are partially relevant to the green sustainability agenda but are not included under climate-related strategies. Climate budget tagging in the Government Fiscal Management Information System (GFMIS) could help ensure that climate-related expenditures are tracked and adaptation and mitigation contributions identified.

grows steadily by 2.25 percent per year to provide a price signal that incentivizes ongoing emissions reductions.[70] Under this trajectory, carbon price revenues are projected to reach close to 1 percent of GDP in 2030, remaining at this level through most of the projection period as the price rises while emissions decline.

Such a pathway for carbon pricing would restore and then build upon the effective 'total carbon price' that was in place in Thailand prior to the pandemic, during which time substantial fuel excises were in place. In the aftermath of the pandemic, excise taxes on fuel were cut and subsidies on natural gas and electricity were introduced to provide cost of living relief (Figure 6.2).

Figure 6.2: Total carbon price in Thailand and peer countries



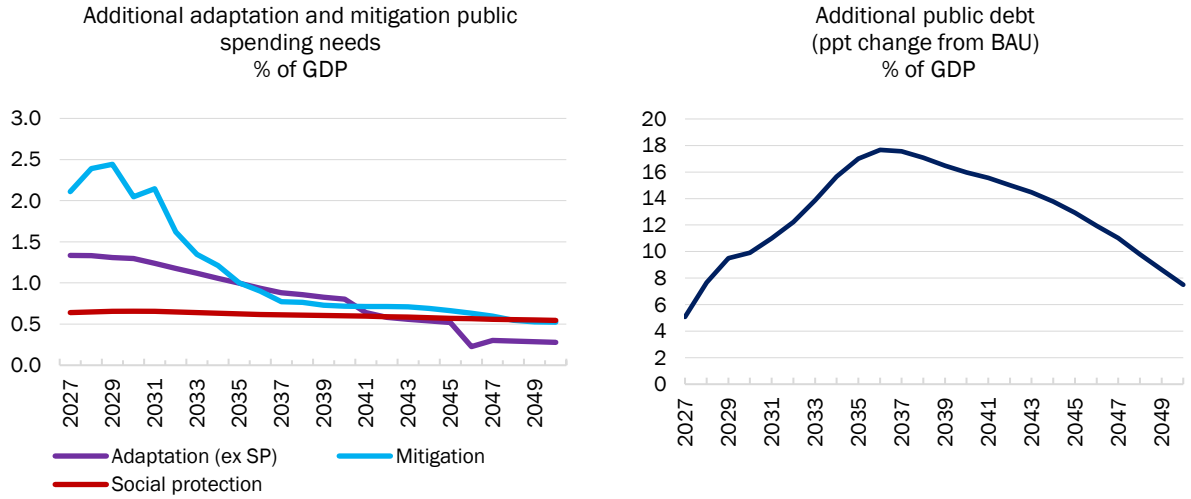
Carbon taxes will impose a regressive burden on households in the short term, but these effects can be mitigated through compensatory transfers. Carbon taxes impact households through multiple channels. Firstly, they directly increase the cost of energy and energy-intensive services like transportation, reducing real incomes. This effect is pronounced if households have limited access to cleaner, cheaper fuel alternatives. Secondly, there is an indirect impact via the labor market. Job opportunities in carbon-intensive sectors would diminish, while new opportunities may emerge in greener sectors as investments rise. Current analysis indicates that the price and real income effects of carbon taxes are negative and regressive, disproportionately affecting poorer households. In contrast, labor market effects are positive and more evenly distributed across income levels. Taking all effects into account, the poorest decile could face a decline of almost 20 percent in real welfare compared to a business-as-usual scenario (Figure 6.3).

Figure 6.3: Distributional impacts of carbon taxes on household incomes by decile

[70] 2.25 percent is the annual growth rate for the social cost of carbon recommended by the World Bank.

On the other hand, the revenue generated by carbon taxes will help to finance mitigation and adaptation investments, as well as increased social protection spending, each of which would help to offset these welfare losses. These expenditure needs are largest over the next decade, and then – with the exception of social protection spending – taper over time (Figure 6.4). After accounting for the impact of additional carbon price revenues, the marginal impact on public debt (relative to the BAU scenario) is projected to peak in 2036 before declining due to the decline in additional spending and the increase in GDP (around 4 percent higher than in the BAU case) associated with making the recommended adaptation and mitigation investments.[71]

Figure 6.4: Climate spending and impact on public debt



Additional tax and social protection reforms would further mitigate fiscal risks associated with climate-related investments, while improving the welfare of the poorest. Previous work has shown progressive reforms to Value Added Tax (VAT), personal income tax, and property taxes could together increase revenues by 3.5 percentage points of GDP. Other things remaining equal, these reforms would be more than sufficient to finance the additional climate spending needs highlighted in this CCDR and avoid the need for additional public debt over the longer term (though Thailand will also face pressures to

[71] The 4 percent increase in GDP by 2050 relative to BAU is based on a scenario (in MFMod) in which the adaptation investments recommended in Chapter 3 are made, as well as the mitigation investments and reforms (including carbon pricing) associated with the Accelerated Decarbonization scenario in Chapter 4. The cost of the recommended public adaptation and mitigation spending is quantified in Table 6.1 and Figure 6.1. Carbon revenues are used to meet these additional public spending needs with debt financing any residual climate-related public spending.

increase public spending in other areas over the same period).[72] This work also showed that a combination of VAT and social assistance reforms could increase net revenues by around 0.6 percent of GDP, while reducing poverty and inequality (by 3.6 and 2.6 percentage points respectively). This would involve increasing the VAT base rate from 7 percent to 10 percent and cutting exemptions, the impact of which on lower-income households would be more than offset by additional, more targeted cash transfers (through Old Age Allowance and State Welfare Card payments), which could be provided at a fiscal cost well below the additional VAT revenues generated.

6.3 Planning and budgeting constraints for climate action

Thailand faces fragmentation among its central fiscal authorities, with no single entity overseeing the achievement of economic, fiscal, or climate change targets from an integrated perspective. The National Economic and Social Development Council (NESDC) develops a 5-year national development plan which aligns climate objectives with broader economic and social goals, including the United Nations Sustainable Development Goals (SDGs). But NESDC's role in the budget process is limited to providing strategic direction through developing an annual budget allocation strategy together with the Budget Bureau. It is important that the government continues to refine its public investment management procedures and capabilities to ensure that high-priority climate investments are properly designed, screened, budgeted for, and implemented in a coordinated manner.

Fragmentation disconnects the planning function from the budgeting system which results in multiple strategy documents/plans being prepared and essentially unfunded. NESDC focuses exclusively on planning without anchoring these plans into a medium-term fiscal framework (MTFF). There are overlapping processes, rules, and operating procedures required by different agencies that impose a very high transaction cost for ministries, departments, and agencies, and also dilute institutional accountability for results.

Moreover, the lack of a fully operational medium-term economic and fiscal framework limits Thailand's ability to project realistic fiscal costs of proposed climate actions.[73] The government has multiple, overlapping multi-year plans related to climate adaptation and mitigation, but these plans are not effectively linked or informed by the medium-term resource envelope, and proposed investments are not costed, appraised, and prioritized. This makes it extremely difficult for the single-year budget system to allocate resources consistent with these plans. Moreover, the current MTFF is a rolling annual framework that is updated each year. As a result, the Bureau of Budget (BOB) does not use the expenditure projections of the outer years as a base for annual budget requests in the future years. This means that every year agencies are required to submit budget requests – even for multi-year projects that have received funding in the past. Budget requests are then debated and sometimes not approved or delayed. This disincentives agencies from undertaking multi-year climate projects.

Climate priorities are not systematically taken into account either in budget prioritization or monitoring and evaluation. Although Thailand has begun piloting climate change cost-benefit analysis (CCBA) in the Ministry of Agriculture and Cooperatives (MOAC) and the Ministry of Energy (MOEN), CCBA is not systematically taken into account by either the BOB or the Legislature as they consider budget prioritization. Moreover, monitoring and evaluation of climate expenditures is technically challenging

[72] The Thailand Public Revenue and Spending Assessment (2023) shows that such revenue reforms could fund a substantially larger increase in social protection spending than what is recommended in this CCDR (i.e. more than encompassing the increase in social protection spending recommended here for climate adaptation purposes), as well as additional spending in other areas, while reducing debt to GDP to around 40 percent by 2050, from just below 70 percent as at mid-2025.

[73] Thailand has a five-year National Development Plan, four-year Government Administrative Plan, 32 annual Ministerial Operating Plans, 76 Provincial Development Plans, 18 Regional/Cluster Development Plans, and more than 5,000 local authority development plans.

due to the long gestation of climate-related investments. Detailed project-based evaluations are limited in number and no climate-related projects have been evaluated recently.

To address these challenges, Thailand may need to transform its economic and fiscal institutions to mount more effective whole-of-government responses. This includes building stronger technical capabilities in policy analysis, enhancing coordination of government-wide actions (including between national and local levels), and adopting a more integrated approach linking economic policies, budget planning, and climate adaptation efforts. Refining the current MTFF, implementing a robust expenditure review and policy/program evaluation system, and further fiscal decentralization would help Thailand plan for long-term economic stability and align fiscal policies with sustainability and climate resilience goals.

6.4 Mobilizing private capital

Thailand needs to mobilize climate finance at scale to support the climate transition. Private capital will have to complement public resources to help Thailand close its climate investment gap. The financial sector can play an active role in supporting this by helping mobilize and allocate capital through a variety of instruments such as sustainability-themed bonds, green loans, insurance etc.

With substantial growth in recent years, Thailand's thematic bond market has played an increasing role in channeling private capital towards climate investment. According to the Thai Bond Market Association (ThaiBMA), the value of issuance of sustainability-themed bonds, referred to as Environment, Social and Governance (ESG) bonds in Thailand, has been growing fast, recording a compound annual growth rate (CAGR) of 104.3 percent between 2019 and 2024 (Figure 6.5). This market is dominated by sustainability bonds (around 70 percent of total market value) which finance projects with combined green and social objectives. Green bonds and sustainability-linked bonds (SLB) account for around 17 percent and 11 percent respectively.

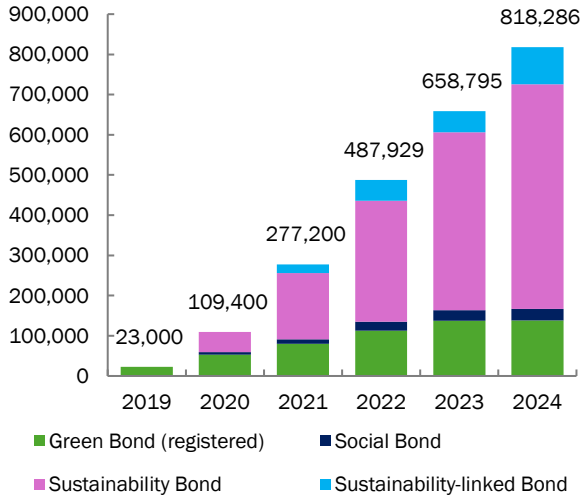
The Thai government has been the largest issuer of Thailand's sustainability bonds, accounting for almost 70 percent of the total ESG bond market (Figure 6.6). Since the Covid-19 pandemic, the government has issued multiple sovereign bonds to mobilize green finance. In November 2024, the government issued a milestone 30-billion-baht sovereign SLB, the first in Asia and only third globally, with key performance indicators (KPIs) and sustainability performance targets (SPTs) linked to greenhouse gas emissions and the sales of electric vehicles. The SLB mobilized additional climate finance to Thailand from a broad range of investors including life insurance companies, funds, financial institutions, securities firms, asset management companies and foreign investors. As of January 2025, the ThaiBMA data estimates the outstanding value of government's green and sustainability bonds is as high as 529.5 billion THB (15.4 billion USD), or around 66.8 percent of the total outstanding value of all ESG bonds in Thailand.

Private sector issuance of sustainability-themed bonds accounts for the remaining 30.5 percent of total ESG bonds outstanding, with green bonds being the most common instrument. Most of the proceeds from green bonds issued by Thai corporates are allocated to fund climate change mitigation projects in the energy and transport sectors. As of January 2025, long-term corporate green bonds have an outstanding value of 120 billion THB, 10 percent of which are foreign bonds. The number of issuing companies is still very limited: all outstanding corporate ESG bonds originate from only 22 companies, the majority of which are in energy and banking. For the sustainability bonds and SLBs, the sizes of private issuances are much smaller. Complementing capital market instruments, banks are also offering sustainable finance products in the form of green loans to businesses and individuals. Recently, many private companies in Thailand have been securing green loans and Sustainability-Linked Loans (SLLs) with commercial banks. Though there is no existing market size estimation yet, current trends suggest that the green loan market is growing.

The growth of the sustainable finance market in Thailand reflects a concerted effort to strengthen the overall sustainable finance ecosystem. The Working Group on Sustainable Finance was established to implement reforms across five pillars: taxonomy, data, products and services, incentives, and human capital. In 2022, the Thai Bankers' Association (TBA) issued an ESG Declaration with six priorities to guide member banks. Since 2023, the Bank of Thailand has been requiring banks to assess climate-related financial risks and offer green financial products. The first phase of the Thailand Taxonomy, launched in July 2023, covers the energy and transport sectors, with Phase 2—expanding to agriculture, construction and real estate, manufacturing, and waste management sectors—launched in May 2025. The taxonomy aims to standardize asset classification and support green and transition finance. Separately, the Securities and Exchange Commission (SEC) mandated ESG and climate risk disclosure in listed companies' annual reports, aligning with TCFD recommendations. In June 2025, the SEC also waived filing fees for sustainable debt instruments aligned with the Thailand Taxonomy or the Asean Taxonomy. On the banking side, commercial banks are encouraged to support lending for a greener, climate-resilient economy. For example, through the "Financing the Transition Program" supported by the Bank of Thailand (BOT), eight commercial banks are offering green loan products tailored for SME's needs.

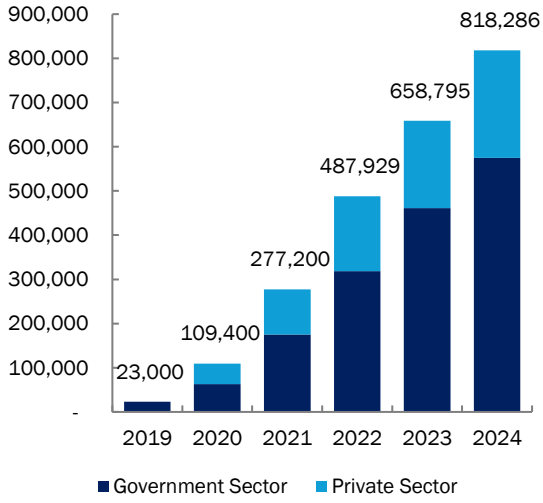
Despite these developments, the green and sustainable finance markets have not yet reached the scale required to meet Thailand's climate goals. While Thailand leads many regional peers, its sustainable debt market[74] remains relatively shallow—with issuance averaging around 1 percent of GDP per year in recent years— and well below levels seen in advanced economies and some emerging market and developing economy (EMDE) peers. Among 94 economies with sustainable debt issuances between 2018 and 2022, Thailand ranks 42nd in market depth[75], ahead of Viet Nam (44th), Indonesia (46th), Malaysia (50th), and the Philippines (75th), but trails far behind regional outlier Singapore, which ranks 2nd with outstanding sustainable debt exceeding 16.7 percent of GDP.

Figure 6.5: Thailand's ESG bonds outstanding value (2019-2024) by type of bonds, in million THB



Source: ThaiBMA, 2024 Bond Market Highlights

Figure 6.6: Thailand's ESG bonds outstanding value (2019-2024) by type of issuers, in million THB



Source: ThaiBMA 2024, Bond Market Highlights

[74] Including the issuance of both sustainable loans and sustainable bonds.
[75] Defined as total outstanding sustainable loans and bonds at a given point in time.

Demand side challenges – including limited awareness, expertise and policy incentives, a lack of bankable pipeline projects, and high issuance costs – constrain further market growth. ESG and climate finance literacy remains low among borrowers in Thailand, especially mid-sized corporates and SMEs, limiting demand for sustainability-linked loans, green credit lines, and labeled sustainable bonds. While large firms have made progress, smaller enterprises often lack the resources and expertise to adopt ESG-aligned financial strategies. Policy incentives for green finance also remain limited: existing tax measures, such as those for energy efficiency, are not comprehensive enough to drive industrial decarbonization, EV adoption, or circular economy efforts. In contrast, peers like Viet Nam and Malaysia offer more structured tax incentives. The pipeline of bankable climate projects remains limited due to regulatory uncertainty, inadequate de-risking tools and weak revenue structures. High costs of issuing sustainable bonds and accessing green loans further dampen demand.

Investors also face several supply-side constraints, including most importantly information barriers. In the past, sustainable finance in Thailand has been held back by inconsistent green finance definitions and a lack of standardized methodologies for identifying green assets, creating information barriers for financial institutions, which in turn have contributed to increased uncertainty and heightened greenwashing risks. While the introduction of the taxonomy aims to address these gaps, its early-stage implementation requires greater capacity building and policy support. Further, financial institutions have limited capacity to originate green assets and there is also a lack of standardized financial instruments. These challenges constrain investment in many mitigation-oriented green sectors such as EV infrastructure, renewables, and industrial decarbonization, as well as other sectors of importance to climate objectives such as blue finance and adaptation finance. Another issue concerns the lack of alignment between the financial architecture and the long-term nature of climate investments. Banks primarily offer 3–7 year loans, while green infrastructure projects require 15–20 year financing. This maturity mismatch, coupled with the absence of a green securitization framework, limits capital recycling and pressures banks' capital buffers under Basel III, constraining new green lending. At the same time, without standardized climate risk assessments or capital requirements, green assets are priced like conventional loans, overlooking transition and physical risks. High FX hedging costs, limited local-currency instruments, and the lack of credit enhancements—such as first-loss guarantees—deter foreign investment and inhibit large-scale private sector financing.

6.5 Carbon finance

Although small, Thailand's voluntary carbon market is growing rapidly and could play an important role in financing climate investment. Thailand is emerging as a regional leader in carbon finance, with a domestic registry, a successful Article 6.2 transaction, and rapidly growing market infrastructure. The Thailand Voluntary Emission Reduction Program (T-VER), managed by TGO, underpins the voluntary carbon market by certifying emission reductions across sectors like renewable energy, agriculture, and forestry. Since 2013, T-VER has grown steadily, with credits issued increasing at a 63 percent CAGR between 2016–2022. Average issuance prices rose from 35 THB (1.06 USD) in 2020 to 107 THB (3.23 USD) in 2022, pushing total trading value to 146.7 million THB (4.4 million USD).[76]

Thailand could further capture opportunities to mobilize climate finance from the carbon credit market, both domestically and internationally. Despite recent increases, the price of carbon credits in Thailand remains relatively low compared to advanced markets. Even at peak secondary market prices of 1,700–2,076 THB (51–63 USD), T-VER credits still trade below EU (USD 82) and UK (USD 56) allowances. This presents an opportunity for Thai businesses to tap into higher-value international markets by developing high-quality credits. TGO's adoption of Verra's VCS and introduction of T-VER

[76] The biggest purchases of carbon credits are organizations in the manufacturing, banking and finance, transport, and real estate industries, although a growing area of demand is the need to offset emissions from events. See Leenoi, P., (2023), *Carbon Credits A Mechanism for Achieving Sustainability Targets*, Krungsri Research.

premium standards are important steps. Domestically, initiatives like the FTIX trading platform and regulatory sandboxes led by TGO, ERC, and FTI aim to improve market efficiency. However, further efforts are needed to reduce market fragmentation, scale up project aggregation, and strengthen the regulatory framework to support a robust, export-ready carbon market.

Building on this momentum, Thailand's Low Carbon City (LCC) Program is laying the institutional and technical foundation to dramatically scale carbon finance flows into the country. The program goes beyond traditional project-level interventions by establishing national systems that treat carbon credits as formal financial assets—integrated into investment planning, budget execution, and public financial management. Specifically, Thailand is creating a comprehensive architecture that enables both the origination and monetization of credits tied to infrastructure upgrades in the public sector (such as schools, hospitals, street lighting, and water treatment plants), while simultaneously building mechanisms to procure verified emission reductions from private actors who decarbonize their buildings, vehicles, or operations. These credits are then eligible for sale into domestic and international carbon markets, positioning Thailand as a trusted supplier of high-quality, measurable, and verifiable climate outcomes.

This ambitious effort makes Thailand one of the first upper-middle-income countries to design a carbon market system embedded within national investment programs. Under the LCC, agencies such as the Department of Climate Change & Environment (DCCE) under the Ministry of Natural Resources and Environment (MONRE), the Public Debt Management Office (PDMO) under the Ministry of Finance (MOF), EXIM Bank, Bangkok Metropolitan Administration (BMA), and Industrial Estate Authority of Thailand (IEAT) are piloting transaction models that link concessional lending and performance-based grants to the generation of carbon assets, with support from digital MRV systems and internationally accepted verification protocols. The Stock Exchange of Thailand (SET) is working with regulators to enable cross-border credit sales, while the Securities Exchange Commission, Bank of Thailand, and Ministry of Finance are exploring how to treat carbon as a tradeable financial instrument. If successful, the LCC's integrated model, combining public investment, carbon credit generation, regulatory oversight, and market access, could offer a replicable blueprint for peer countries seeking to leverage carbon markets to finance green infrastructure and meet their climate goals.

6.6 Insurance

Insurance currently plays a relatively limited role as a source of financing for climate adaptation and resilience. Current insurance solutions do not adequately cover climate and natural disaster risks, which could impact the agricultural sectors and the broader economy. Thailand's crop insurance program currently covers a few key agricultural products, such as rice, sugarcane, and rubber. Climate risk coverage in forestry, fishery, energy, and tourism is still missing. For properties, coverage for floods and windstorms is usually available as an add-on to standard insurance products for homes, automobiles, and Industrial All Risks (IAR), where buyers pay an additional premium for limited coverage of the climate-related risks. Additionally, climate-vulnerable groups such as smallholder farmers, MSMEs, informal workers, and low-income individuals have limited access to life and health insurance, which offer protection in the face of severe climate disasters and increasing pollution.

The government and the insurance industry have taken steps to expand the incorporation of climate risks into different aspects of national, industry and company strategies. The Thai government has explored options to expand disaster risk finance mechanisms and reduce financial risks associated with natural disasters. For example, Thailand's National Catastrophe Insurance Fund (NCIF) was established in 2012 to help the country manage the financial impact of major natural disasters, particularly floods and other catastrophic events. The NCIF is funded through a combination of public and private sources, including government contributions, premiums paid by insured entities, and international support. The government has also explored options for issuing catastrophe bonds.

Insurance companies have been developing products that incentivize risk reduction behaviors. For instance, companies may reduce premiums if basic flood protection measures are implemented. In June 2025, a sandbox has been announced to pilot weather index insurance that utilizes GIS and IoT technology to provide parametric flood coverage for crops. Several insurers are also starting to incorporate climate risk models into their pricing and underwriting practices to better assess and manage potential losses. Finally, AI, geospatial analytics, and satellite imagery can significantly strengthen climate risk underwriting, making insurance products more scalable and investable. Combined with parametric insurance, sovereign risk pools, and tools like catastrophe bonds, these innovations deepen market capacity and attract institutional capital. For example, China's Weather Index Insurance project (2020–2023) exemplifies this potential: digitizing 72 index-based products and partnering with major agri-insurers provided $470 million in coverage to over 46,000 rural households. The shift to parametric payouts enabled faster disbursements during climate shocks and COVID-19, strengthening both household resilience and market efficiency.

6.7 How can the financial sector further contribute to Thailand's climate goals?

Building on recent progress in advancing sustainable finance, Thailand could take additional steps to further enhance climate risk management in the financial system ("greening finance") and accelerate capital allocations towards sustainable investment to capture new opportunities ("financing green"):

- **Enhance climate risk monitoring in portfolios and expand the scope of evaluation to non-financial corporates**: The banking sector should incorporate physical and transition risks in their risk assessment and management process, yet only large counterparties and listed companies in Thailand have adopted climate risk assessments. Both regulators and banks should help encourage private companies to conduct proper climate risk assessments, including the emission profile of their activities, to reduce the information gaps for banks in providing climate finance, as well as managing the risk associated with it.

- **Broaden climate finance product offerings to support green sectors.** Incentives could be provided to encourage financial institutions to deepen the offering of products like green loans, green bonds, and sustainability-linked bonds and loans. In addition, more sectors beyond energy and transport should be encouraged to upscale green investment and gain access to climate finance. For example, institutional capital mobilization for green buildings and infrastructure remains crucial to scale green finance in Thailand's real estate and infrastructure sectors. Specifically, green mortgage-backed securities are underutilized, presenting an opportunity for local banks to aggregate green mortgages into investable tranches for pension funds and sovereign wealth funds. At the same time, Thailand could further mobilize institutional capital toward green building and infrastructure by expanding use of green and sustainability-linked asset-backed securities (ABS), real estate investment trusts (REITs) for certified buildings, and securitized energy performance contracts (EPCs). To further increase private-sector participation in green infrastructure, de-risking financial instruments are essential. Innovations such as outcome-linked bonds (e.g., carbon emission reduction-linked bonds, Plastic Waste Reduction-Linked Bonds) should also be explored.

- **Provide climate financial solutions that are customized to fit MSME needs:** SMEs are particularly vulnerable to the impacts of climate change, yet they often lack the financial resources, incentives and expertise needed to adapt. Given these challenges, extra support must be provided to MSMEs. Policymakers should enforce or incentivize private financial institutions to provide accessible, affordable financing options like green loans and grants with favorable terms, i.e. lower rates and longer tenor, to MSMEs. For example, since most companies face their greatest carbon footprint challenges in Scope 3—particularly within their supply chains—the leading 1 percent of firms can play a catalytic role in driving decarbonization efforts downstream. These companies are well-positioned to engage their supply chain

partners, especially SMEs, which often lack both climate awareness and access to financing. An ecosystem and platform-based approach can help bring these SMEs into the fold. Sustainable-linked supply chain finance and mechanisms like Energy Service Company (ESCO) models and on-bill financing could be instrumental in enabling this transition. Provision of capacity-building programs and training can be helpful in the long run. Microinsurance for vulnerable communities and index-based models for quick payouts could also be developed to enable MSMEs to access financing, for example, after a major flood that disrupts business.

- **Further strengthen the sustainable finance ecosystem through improved climate finance tracking, taxonomy implementation, and enhanced disclosure practices.** More accurate climate finance data are required to support optimal decisions for capital allocations. Going forward, standardized tracking definitions and methodologies should be applied to systematically track and monitor the sources and use of climate finance against key climate policy objectives. With frameworks and tools such as the Thailand Taxonomy in place, the next step is rigorous implementation, which requires both regulatory and industry actions to develop practical guidelines, enhance enforcement, incentivize adoption, build capacity, and foster collaboration. To build a more robust green finance ecosystem, the government and regulators could also strengthen ESG disclosure requirements for both private companies and banks.

- **Thailand is well-positioned to lead carbon market development in the region by advancing legal, regulatory, and market infrastructure reforms that enhance the credibility, liquidity, and international accessibility of its carbon credits.** As the country prepares to launch a national Emissions Trading System (ETS) and expand its voluntary market (T-VER), coordination among financial, environmental, and capital market regulators will be essential to fully integrate carbon into the financial system.

- **Key actions to help establish Thailand as a regional carbon finance hub include**:
    - **Formalize accounting treatment of carbon credits**: The Securities and Exchange Commission (SEC) can issue guidance on the accounting and financial treatment of carbon credits across different markets—international, domestic voluntary, and compliance—to enable banks and corporates to treat them as standardized financial instruments for investment and risk management purposes.
    - **Pursue international certification for T-VER Premium**: TGO could seek CORSIA certification for T-VER Premium credits, opening new aviation-sector demand and bolstering international credibility. In parallel, TGO could work with ASEAN counterparts to explore the creation of A-VER (ASEAN Verified Emission Reduction) credits—a shared regional standard that meets international quality thresholds while leveraging local management and lowering certification costs.
    - **Expand exchange infrastructure for carbon trading**: The Stock Exchange of Thailand (SET) could establish a unified carbon exchange that serves both the domestic ETS and the international voluntary market, including high-integrity bilateral Article 6 trades. To maximize market access and reduce transaction costs, SET can explore interoperability with other regional platforms such as Malaysia's Bursa Carbon Exchange and global registries like Verra or Gold Standard.
    - **Enable aggregation and securitization**: Regulators and market players could also facilitate the bundling of credits from smaller projects—particularly in agriculture, industry, and MSME sectors—into aggregated carbon portfolios that can be securitized or sold through standardized auction mechanisms, attracting institutional investors and reducing per-credit costs.

7.

A roadmap for resilient, low-carbon development

7 A roadmap for resilient, low-carbon development

This section provides a structured, actionable outline of the report's recommendations for policymakers. To guide implementation, the recommendations are prioritized with reference to their direct impacts (on adaptation, mitigation, green growth, and climate financing objectives), their co-benefits for Thailand's broader socio-economic development, and the desired time frame for implementation. Five key sets of measures (highlighted in blue) – on flood mitigation, water security, social protection, carbon pricing, and energy – emerge as the highest priority recommendations most deserving of urgent attention.

Priority Area	Key Actions	Direct impacts*	Development co-benefits	Time frame
Adapting to climate change				
Flood mitigation	Commence full implementation of the "Nine Plans" and complementary flood protection measures	Very high	High	Short-term
Coastal protection	Scale up nature-based solutions as part of an integrated approach to coastal protection	High	Medium	Medium-term
Water security	Pursue a multi-pronged strategy to address water deficits in the EEC. Integrate provincial water planning and mobilize finance to strengthen water storage in the drought prone agricultural areas in the north and north-east.	Very high	High	Short-term
Heat stress	Support policies and investments to help cool indoor public and residential spaces, paying particular attention to the most vulnerable	High	Medium	Medium-term
Agriculture	Repurpose public expenditure in agriculture away from distortionary price support schemes to R&D, extension and supporting climate smart agricultural (CSA) technologies.	High	High	Short-term
Social protection	Increase benefit generosity of programs such as the SWC. Integrate programs through the establishment of unified social registry and improve targeting by hybrid PMTs	Very high	High	Short-term
Supporting low-emissions growth				
Carbon pricing	Expedite the approval of the Climate Change Act to resolve private sector uncertainty and lay the groundwork for a transparent carbon pricing framework.	Very high	High	Short-term
Energy	Pursue market structure reform to promote competition in the power sector and accelerate adoption of renewable energy (RE). Invest in grid modernization and regional integration to enhance energy security and enable a renewables-led transition.	Very high	High	Short-term
Industry	Strengthen energy efficiency standards across buildings, appliances and industrial equipment and provide targeted subsidies and low-interest loans to households and businesses to accelerate adoption of energy efficient technologies. Enforce standards for low-carbon cement, mandating Environmental Product Declarations (EPDs) and incentivize clinker substitution.	High	Medium	Short-term
Transport	Invest in public charging infrastructure to accelerate EV adoption. Implement biofuel incentives for hard-to-electrify vehicles.	Very high	Medium	Short-term
Agriculture	Support investment in biogas digesters, precision agricultural tools, implement anti-crop residue burning regulations and strengthen farmer education on emissions reducing techniques.	High	Medium	Medium-term
Forestry	Invest in afforestation, prioritizing the restoration of critical ecosystems like mangroves in coastal provinces and degraded upland watersheds	High	Medium	Medium-term
Seizing the economic opportunities associated with global decarbonization				
Investment climate	Remove market-entry barriers, ensure fair competition and foster business-friendly regulatory environment to attract FDI	High	Very high	Medium-term
Foreign investment	Ensure that foreign investment in the EV industry builds local capacity	High	High	Short-term
Skills	Prioritize high-tech skill development in digital, engineering and sustainable manufacturing while implementing targeted talent attraction policies to bridge skill gaps in the short run	High	Very high	Medium-term

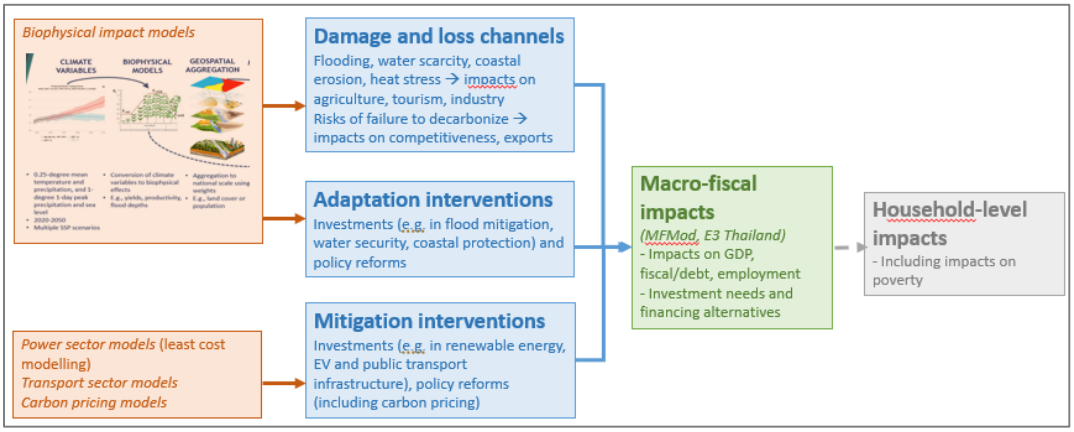
Priority Area	Key Actions	Direct impacts*	Development co-benefits	Time frame
Fiscal policy	Review government support for green innovation and utilize newer and relatively underutilized instruments such as vouchers for innovation, innovation finance de-risking facilities, partial credit guarantees, early-stage support program for startups etc.	High	Medium	Medium-term
Mobilizing finance for green and resilient development				
Fiscal policy	Explore opportunities to boost domestic revenue mobilization beyond carbon pricing instruments. Efficient and equitable opportunities may exist in VAT exemptions, personal income tax and property taxes	High	Very high	Medium-term
Financial sector	Incentivize financial institutions to deepen offerings of green loans, green bonds and other sustainability-linked products, including products accessible and affordable to suit the needs of MSMEs. Strengthen sustainable finance ecosystem through improved climate finance tracking, taxonomy implementation and enhanced disclosure practices	High	High	Short-term
Carbon market	Strengthen market infrastructure for carbon credit issuance and trading and further promote carbon market innovation	High	Medium	Short-term

*Direct impacts are impacts relevant to Thailand's adaptation, mitigation, green growth and/or climate financing objectives.
The highest priority recommendations to emerge from applying the three criteria set out in this table are highlighted in blue.

Annex 1: The modelling approach in this CCDR

The economic and social impacts of climate change and climate actions are modelled in several steps (Figure A1.1). First, separate biophysical impact models are used to assess the sectoral impacts of various climate scenarios specific to Thailand that are likely to become more frequent and severe over the coming decades. Second, we use the results from these models to quantitatively assess the economic damages and losses that Thailand faces from climate change. We then estimate the potential impacts of policy responses and priority investments to boost climate resilience and reduce emissions using two complementary macroeconomic models. Finally, we use spatial analysis, microsimulations, and other techniques to assess the distributional impacts of climate change and actions.

Figure A1.1: Structure of the modelling approach



Within this framework we consider the differing physical impacts of "wet/warm" and "dry/hot" climate scenarios, compared to a benchmark (BAU) where there is no additional climate change over the 2025 to 2050 period. Climate scenarios are obtained from the World Bank's Climate Change Knowledge Portal for 30 General Circulation Models (GCMs) from the Coupled Model Intercomparison Project 6 (CMIP6) suite of model outputs. Each GCM has up to five combinations of Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathway (RCP) emissions scenario runs available. We select climate scenarios in such a way as to capture the broadest range of climate change effects across GCMs within relevant SSP-RCP projections. For this study, we consider climate projections for SSP2-4.5 and SSP3-7.0 as the two most likely scenarios. SSP2-4.5 represents a global mitigation scenario consistent with current climate commitments and 2030 targets and SSP3-7.0 a scenario in which warming reaches 4°C by 2100 due to lax climate policies or a reduction in ecosystems and oceans' ability to capture carbon. Wet/warm and dry/hot scenarios are constructed by taking the 10th and 90th percentiles of mean precipitation and temperature changes across SSP2-4.5 and SSP3-7.0 GCMs.

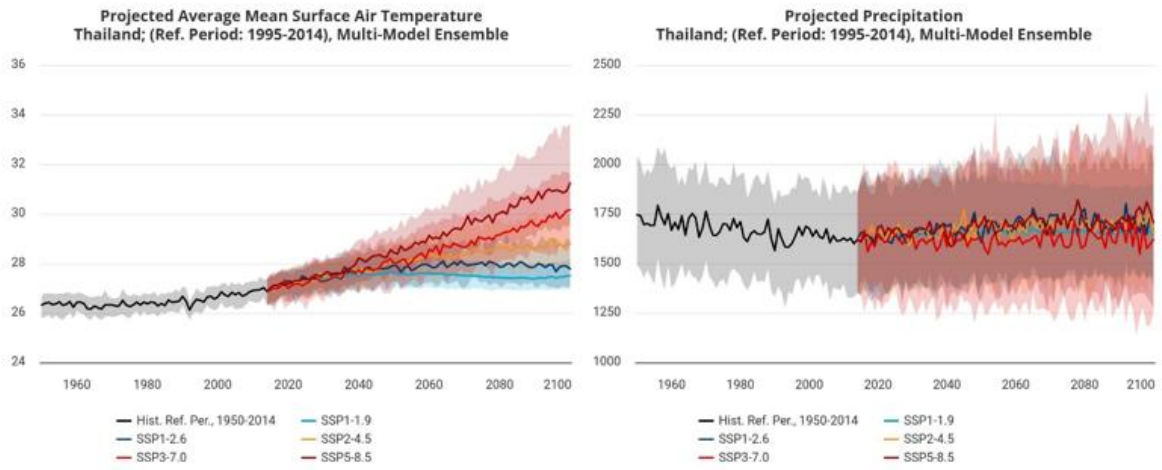
Two macroeconomic models are used to estimate economy-wide impacts. The combination of models allows for a comparison of a range of impacts and will also provide different insights based on respective model capabilities and assumptions:

- **The World Bank's Macro-Fiscal Model (MFMod) is a comprehensive macro-structural econometric tool that simulates the flow of funds throughout the entire economy.** It maps out the core identities of national accounts, balance of payments, labor markets, and financial sectors. Macrostructural models are designed to quantify the economic and behavioral underpinnings of economic variables. These models establish structural relationships that align with economic theory and generate equilibrium outcomes over the long term while also

reflecting the short-term dynamics observed in real-world economies (Burns et al. 2019).[77] The enhanced climate-aware version, CC-MFMod (Burns, Jooste and Schwerhoff, 2021), incorporates the economy-wide effects of climate-related natural disasters.[78] By integrating the MFMod with a technology diffusion model, it becomes possible to evaluate the effectiveness and macro impacts of mitigation policies. MFMod has the added benefit of providing detailed insights into fiscal and balance of payments impacts.

- **E3-Thailand is a macro-econometric model that was built specifically to look at climate-economy interactions in Thailand.** The model is highly empirical and represents the national accounting system, linked to energy consumption and emissions. Using econometric equations for 43 economic sectors, it does not assume equilibrium outcomes in either the short or long runs. It relaxes common modelling assumptions of perfect knowledge, fully rational optimizing behavior, fully flexible markets and a fixed money supply. Prices do not necessarily move to market-clearing rates and there are resources (e.g. labor) that are unused. The level of production is determined by the level of aggregate demand, unless supply constraints (e.g. full employment) are breached. There is an output gap between what the economy could produce (potential output) and what the economy is actually producing. These features of E3-Thailand mean that the impact of a policy depends on both its efficiency of the allocation of scarce resources and how the policy impacts on aggregate demand (i.e. stimulus or austerity effects).

Figure A1.2: Projected climate variables across a range of SSP-RCPs



The modeling is based on specific assumptions which imply the need for caution in interpreting the results. There is substantial uncertainty at every stage of modelling. The physical estimates of climate damages are partial and include only direct effects for the specified channels. How the direct effects spread throughout the economy is also not well known; the E3-Thailand simulations assume that impacts on labor affect capital productivity, and vice versa, while the MFMod simulations assume that labor there are no knock-on effects between labor and capital. Finally, rates of build-back and how the effects accumulate over time are not yet well known; the E3-Thailand simulations assume that useful capital is rebuilt while the MFMod simulations constrain how much is built back.

[77] Burns, Andrew; Campagne, B., Jooste, C., Stephan, D., Thanh Bui, T., (2019), The World Bank Macro-Fiscal Model: Technical Description, World Bank Policy Research Working Paper 8965.
[78] Burns, Andrew; Jooste, C., and Schwerhoff, G., (2021), Climate Modeling for Macroeconomic Policy: A Case Study for Pakistan, World Bank Policy Research Working Paper 9780.

Annex 2: Resolving dual water challenges in Khon Kaen Province

Like many provinces in the Northeast of Thailand, Khon Kaen Province has faced perennial water challenges. The area experiences extreme drought and floods every year. In 2021, flood events lasted for three months on average. On the other hand, water insecurity is an important contributing factor to deepening poverty, especially among low-income agriculturists. The existing flood defense infrastructure, such as flood walls, has been inadequate and outdated for comprehensive water management as it by design does not address the regional issue of water scarcity. Technical solution identified in the province is to increase the ability to retain water from the wet season by three main measures: (1) increase the number of small-scale retention ponds; (2) increase the capacities of retention in canals and smaller river networks through check dams; and (3) increase the capacities of groundwater and reservoir.

While technical solutions to the dual problem of water scarcity/insecurity and frequent floods may be known, translating these ideas into policy and practice requires overcoming a series of institutional hurdles that hinder coordination across multiple government agencies. In particular, in Thailand's inter-governmental arrangement, which some academics have characterized as "fragmented centralism", orchestrating coordinated government actions across sectors and across levels of government is a recurrent institutional challenge.

An academic study (Nikomborirak 2016) noted the following:

> Water management under normal circumstances is highly fragmented with more than 32 laws involving 40 state departments and 8 committees at the national level. Different state authorities oversee own narrow mandate be it allocation of irrigated water, dredging of canals, regulation of land use, supervision of the use of underground water, construction of transport infrastructure, operation of dams, etc. In the absence of due coordination among these authorities, water management in Thailand is far from being "integrated".[79]

Khon Kaen's Attempt

The Khon Kaen Province set out to tackle these common problems of institutional fragmentation in its water sector with an integrated approach to planning water resource management, involving multiple sectoral agencies and local stakeholders around the Khon Kaen Provincial Sub-Committee of the Nam Phong River Basin Committee.[80] Reflecting the fragmented institutional structure, the sub-committee include representatives from 14 regional and provincial agencies.[81] As an innovative addition to this approach, the province also approached the private sector mobilize financing for "quick & easy but effective" local solutions. The Provincial Governor formed a technical working group (TWG) with support from national and local researchers to fill the technical capacity gaps in developing a rigorous, integrated water resource management plan (IWRMP).

The main objective of the formulation of the integrated plan was to consolidate the water management projects, proposal, and budget allocation for shared visions for a medium- to long-term area water plan. With technical support by the academics, the TWG identified areas vulnerable to water scarcity and flood risks for prioritization, developed a geo-spatial database covering water for domestic use, water in irrigation areas, water in rainfed areas, water quality, meteorology, and hydrology data, and

[79] Nikomborirak, D., (2016), Climate Change and Institutional Challenges for Developing Countries: The Case of Water Resource Management in Thailand, TDRI Research Report.
[80] The 2018 Water Resources Act established 22 river basin committees nationwide as area-based, as opposed to function- or sector-based institutional platform to facilitate multi-sectoral and multi-level approaches to water resource management.
[81] These include the Khon Kaen Office of Agriculture and Cooperatives, The Khon Kaen Office of Agricultural Land Reform Office, Khon Kaen Royal Irrigation Project, Khon Kaen City Planning and Public Works, Regional Office of Water Resources (Office 3), Director Office of Ubon Rat Dam, other representatives from local administration and Water User Organizations.

flood and drought risks mapping. Through a series of workshops, including on proposal development, and consultation sessions with water-related agencies in the province, the TWG promoted inter-agency coordination and negotiation for joint identification of priority investment projects. The integrated plan also serves as a template for local governments to identify their own priority water projects. The provincial governor holds some leverage in ensuring that local government projects align with the IWRMP because all elected local governments are required to obtain the governor's endorsement of their budget proposals before submitting them through the annual budget preparation process.

A positive outcome of this integrated approach is the memorandum of understanding (MOU) signed by five municipal governments in the Khon Kaen metropolitan area and the Khon Kaen University to develop a joint urban flood risk management project.

Figure Annex 2.1: The MOU among 5 Municipalities and KKU on water drainage and flood infrastructure

Source: Faculty of Engineering, Khon Kaen University

Aided by the data-driven, participatory planning process, IWRMP has also facilitated local climate adaptation and spurred positive local collective action. For example, in the Sub-district of Sri Bun Rueng, one of the areas of high vulnerability to both drought and floods, TWG (mainly through its academic partners) offered capacity building and data support to help farmers in the area improve their agricultural management (e.g., better scheduling of the crop cycle to minimize damage from floods) and the SAO to develop a local water resource management plan in line with IWRMP. The process involved strong buy-in and participation from the local water user organizations not only to collect the data necessary for analysis from villagers but also to obtain local support for recommended adjustments to agricultural practices.

The province has been successful in mobilizing private financing for small-scale water infrastructure projects. According to the provincial governor, around 200 such projects have already been secured, including small check dams or weirs to retain water on the upstream side during dry seasons. The private sector has managed to build these small assets at an average cost of THB 70,000, around 30 percent saving compared to the average cost incurred by the public sector for similar projects. In another case, a large private sugarcane producer chose to build a retention pond to absorb and retain rainwater for flood prevention during rainy seasons and distribute it to the surrounding farms mostly cultivated by sugarcane farmers supplying the firm. This dual-purpose infrastructure with semi-public use also meets the investing firm's commercial interests.

Promises and Limitations of IWRMP

Integrated planning to address the multi-sectoral nature of water scarcity and flood risks has long been advocated in Thailand. But this may be easier said than done in practice. The ongoing attempt in Khon Kaen shows both its promises and limitations precisely because of the prevailing institutional realities that have made the integrated approach an attractive alternative in the first place.

IWRMP is a technocratic approach that addresses the lack of critical data, information, and analysis needed for area-based water sector policy-making. It involves multiple sectoral agencies sharing analyses and identifying coordinated solutions, rather than each agency focusing solely on its own specific problems. It offers a wealth of information to help government-decision-makers identify and develop projects for priority local problems based on objective criteria of urgency and environmental and economic impacts at the local level. Furthermore, incorporating a participatory planning and consultation process into data-driven spatial and hydrological analysis enhances the likelihood of securing essential support from a range stakeholders, from regional representatives of national sectoral agencies, local water users, and the private sector (Koontanakulvong et al, 2023).[82] This buy-in is necessary, although not sufficient by itself, for the effective execution of the plan's contents.

Yet the limitations of the approach are also palpable from the example of Khon Kaen. First, it is not easy to pull off truly integrated planning in Thailand's fragmented and highly centralized public administration sectoral/functional agencies have a strong incentive to follow their legal mandates and vertical directives. In Khon Kaen, a critical success factor was the proactive leadership by the provincial governor, himself an appointee of the Ministry of Interior with limited formal authority over the provincial offices of the national sectoral agencies and insufficient budget to leverage and induce inter-agency cooperation. It is far from obvious that similar leadership can be expected in other provinces.

Provincial offices of sectoral agencies, key participants of the provincial integrated planning, do not enjoy autonomy of decisions vis-à-vis their ministry headquarters on project prioritization and budget allocation/execution. Therefore, it cannot always be expected that the national ministries will honor the priorities and the projects agreed at the provincial level. Yet it is these national agencies that hold the largest budget.

Even if the sectoral agencies, with full blessing of their ministry headquarters, were to fully embrace the integrated plan and agree to execute its priority projects, there still remain certain gaps in the current institutional setup of the water sector in Thailand. By far the largest agency in terms of budget is the Royal Irrigation Department (RID). But by its legal mandate, its remit is limited to the so-called irrigated areas. As of circa 2014, these covered only around 20 percent of the cultivated areas and 10 percent of country's land area (Nikomborirak 2016, p. 12). Water resource management in the remaining 90 percent of the country is responsibility of myriad agencies such as the Department of Ground Water Resources (MONRE), Department of Public Works and Town & Country Planning (Ministry of Interior). These (and other) agencies address water sector needs and issues in the vast non-irrigated areas, but only from their specific sectoral perspective. An integrated plan is unlikely to overcome this inherent institutional constraint.

A final set of major constraints evident from the otherwise promising initiatives in Khon Kaen is the well-known (and well-documented) problem of weak local governments. Large water infrastructure does not serve its full purpose unless it is connected to end users through well-functioning "last-mile" infrastructure. By law, RID is mandated to transfer small infrastructure works to elected local governments for operations and maintenance (O&M) once the assets are built. However, due to the combination of low technical capacity as well as limited budget and weak political incentive to prioritize

[82] Koontanakulvong, S., P. Ruangrassamee and A. Fahmi., (2023), Partnership Enhancement in Water Management in Asia and the Pacific, UNESCO.

asset maintenance, small assets such as water pumps to bring water from large irrigation canals to farms often go under-maintained and poorly operated. According to the above-cited academic study which conducted a survey of 51 local administrations in 6 provinces that experienced frequent floods or droughts, "35 per cent indicated that they do not have a specific budget allocated to water management and that when the disaster strikes, they rely on emergency slush funds or assistance from the central government" (Nikomboriarak 2016). The same study cited RID information that 80 percent of the assets transferred to local governments still required financial support for maintenance.

Table Annex 2.1: Budget allocation for departments in integrated water resource plan 2022-2023 (top 5 agencies)

Unit: Million Baht			
Ministry	Department	2022	2023
Agriculture and Cooperatives	Department of Royal Irrigation	39,826	42,024
Natural Resources and Environment	Department of Water Resources	4,380	5,606
	Department of Groundwater Resources	2,014	2,586
Interior	Department of Public Works and Town & Country Planning	4,768	5,206
Public Enterprise	Metropolitan Waterworks Authority	3,174	4,510

Implications and Lessons

The Khon Kaen example demonstrates the potential of integrated planning with strong participation of academic researchers. A similar approach, but perhaps broadened beyond a single sector to cover the full range of sectors/topics relevant to climate change, could be adopted nationwide. Specific sectors/topics to be prioritized may vary from one province to another depending on local context. Data-driven, participatory development of provincial climate change plans could follow the Khon Kaen approach. It is possible to develop a robust integrated plan if a province can procure a strong academic partner (Koontanakulvong S., 2024). This, however, does not guarantee that the plan will have the necessary buy-in from all the government agencies whose actions are necessary for its effective implementation. Hence the importance of proactive provincial leadership as a precondition of success, as in Khon Kaen.

A robust plan also needs to be linked effectively to annual budgets if its content is to be implemented. A typical weakness of a technocratic plan is its weak link to annual budgets. A plan's content may be limited to overall diagnosis and general statements of policy intents without identifying concrete projects, or even if these are identified, without costing them. On the contrary, it may identify too many projects for an annual budget to afford and yet may not offer any basis or criteria to facilitate prioritization. Designating climate change as an integrated budget program and its operationalization at the provincial level might mitigate the common problem of misalignment between a plan and a budget. To enhance the plan's value as a prioritization device, it can offer both data and criteria that line agencies and sub-national administrative organizations could use to arrive at their own priority projects rather than to try to use the integrated plan as a detailed listing of public investment projects.

Another limitation of an integrated plan is the challenge of "last-mile" connections. A gap in Khon Kaen was LAO's inability to identify technically sound projects in line with the overall thrust of the IWRMP. Sustained support may be needed to help LAO's build up the necessary technical capacity for project development, although that alone will not address the equally binding constraint of limited political incentives on the part of many LAOs to prioritize actions such as operations and maintenance of small-scale water schemes. Measures to empower water user groups, such as limited public funding to support their activities, national/provincial grants conditioned on the evidence that user groups were consulted, etc., may be a useful supplement to capacity building of LAOs. In the long run, Thailand may need to refine its complex intergovernmental arrangement away from the "fragmented centralism" to

"decentralization by design", one where sub-national governments are administratively and fiscally empowered with clear assignments of functions.

A promising line of short-term solutions is the mobilization of private finances for small-scale climate-related investments as demonstrated in the Khon Kaen example. Given the likelihood that many LAOs will remain unable (or unwilling) to prioritize actions such as operations and maintenance of small-scale water schemes for some years, the private sector may be in the best position to fill these gaps. The government could encourage private sector involvement by (i) actively disseminating successful (or promising) examples from Khon Kaen and elsewhere (mostly for the benefit of sub-national administrative organizations elsewhere) and (ii) devising modest incentive schemes to entice private firms to finance these small schemes (e.g., partial tax credit for public/semi-public investment that meets climate change criteria).

Annex 3: GHG emission mitigation practices, benefits and costs and marginal abatement costs

Crop	Options/Thai Example	Annual Emission Reduction (kg of CO_2-eq/rai)	Net Benefit (+/-) (Baht/rai)	Marginal Abatement Cost (Baht/CO_2-eq)	Source
Rice	Alternate Wetting and Drying (AWD)	42.77 kg CO_2-eq/rai (20% reduction in cultivation: 3/4 of reduction from reducing waterlogging)	Average 680 Baht from cost reduction and higher yield	-15.9 Baht per kg CO_2-eq	OAE (2020) Nipon Poapongsakorn et al. (2023)
	Stubble and Straw Incorporation Instead of Crop Residue Burning	7.42 – 24.74 kg CO_2-eq/rai from stopping burning	Average 253 Baht	-15.7 Baht per kg CO_2-eq	OAE (2020) Nipon Poapongsakorn et al. (2025)
	Optimum Use of Suitable Fertilizer (Site-Specific Nutrient Management)	0.5 -14.7 kg CO_2-eq/rai (5%-62% reduction from GHG from fertilizer use)	650 – 940 Baht	-104.6 Baht per kg CO_2-eq	OAE (2020) Fatma K., Sureyya Betul R. and Ali Volkan B. (2024)
Sugarcane	Optimum Use of Fertilizer (Site-Specific Nutrient Management)	30 kg CO_2-eq /rai from 20% reduction in fertilizer use	1,000 – 2,000 Baht after the payback period (Depending on the prices of fertilizer & sugarcane)	-50 Baht per kg CO_2-eq	Petchaluck et al. (2023) OPSMOAC (2024)
	Selling sugarcane leaves	25 kg CO_2-eq /rai from stopping the residue burn	900 – 1,500 Baht/ rai (direct selling to sugar factories) or 50 – 100 Baht/ rai (selling to middleman)	-48 Baht per kg CO_2-eq or -3 Baht per kg CO_2-eq	Petchaluck et al. (2023) Mitr Phol Modern Farm(2024)
Swine farms	Electricity and Biogas - generating Technologies	60 kg CO_2-eq /swine	4 Baht 154 Baht/ a swine Annually after 2-year payback period [3] 1,000 Baht/ swine Calculated from the Net Present Value of the 15-year adoption	-2.6 Baht per kg CO_2-eq	Pollution control department (2011) Bangkokbiz (2022) TDRI's survey & interview Chatchawan Chaichana et al. (2024) (Dennehy et al.,2017)
	Selling manure as compost	382.66 kg CO_2-eq / swine/ life cycle	2,800 Baht /ton (after the payback period of 3-4 years)	-0.1 Baht per kg CO_2-eq	Li et al. (2021) FAO (2022) Jenjira Sunthornphan (2015)

Crop	Options/Thai Example	Annual Emission Reduction (kg of CO_2-eq/rai)	Net Benefit (+/-) (Baht/rai)	Marginal Abatement Cost (Baht/CO_2-eq)	Source
			30 – 40 Baht /swine Depending on the size (after 1-to-2-year payback period)		
Chicken farms	Energy-efficient systems (like LED lighting and solar-powered equipment)	5-10 tons CO_2-eq	39,000 – 88,000 Baht after the payback period (1-3 years)	-8.47 Baht per kg CO_2-eq	Thawat (2017)
	Anaerobic digestion systems with electricity generator	100-200 tons CO_2-eq	200,000 - 500,000 Baht after the payback period (5-10 years)	-2.33 Baht per kg CO_2-eq	Liebetrau J et.al. (2021) Ulusoy, Y. et.al. (2021)

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