EAST ASIA
PACIFIC

Thailand

World Bank Group

COUNTRY CLIMATE AND DEVELOPMENT REPORT

4.
Managing the net-zero transition

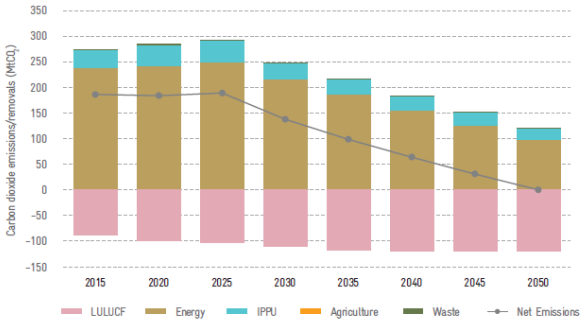
4 Managing the net-zero transition

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.[1] 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.

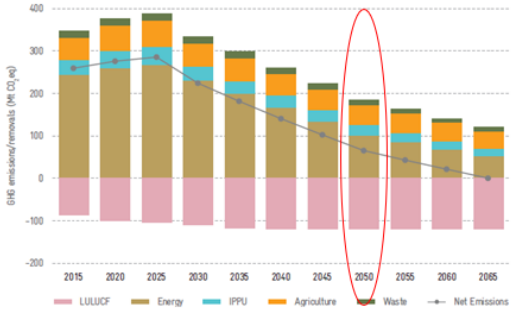
Thailand's revised Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS), submitted to the UNFCCC in November 2022, sets out a trajectory of decarbonization across all sectors which is consistent with Thailand's long-term objectives (Figure 4.1). The LT-LEDS focuses on energy and transport 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.[2]

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.[3] Even assuming the more ambitious 40 percent reduction is met by 2030,

[1] 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.

[2] 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.

[3] 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).[4] 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.

[4] 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.[5] Public-private partnerships can de-risk infrastructure investments, while regional cooperation with neighbors like

[5] 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.[6] 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.[7] 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.

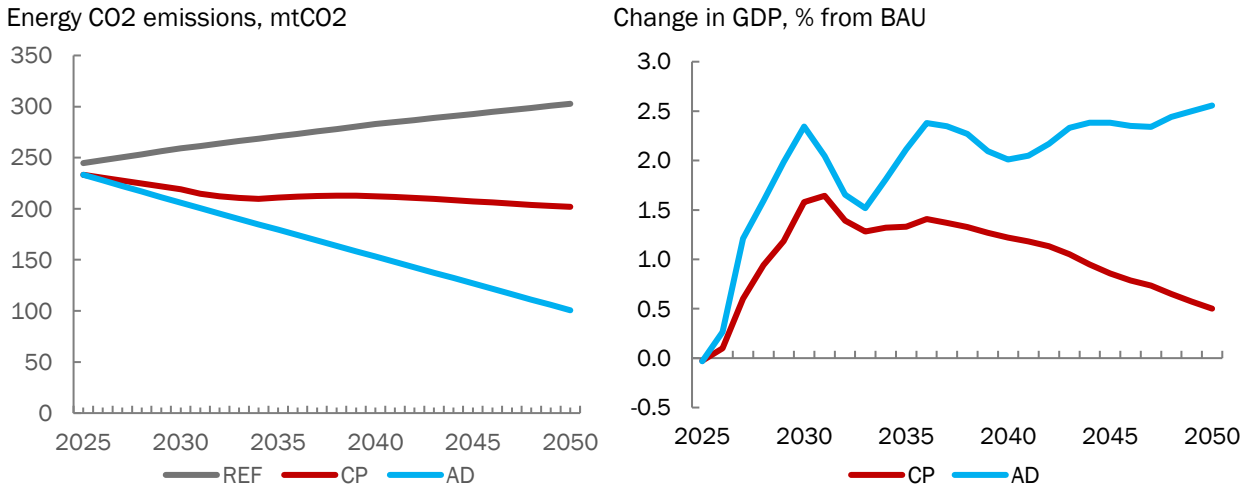
Emissions reduction will also help to insulate Thai exporters from increased risks to production associated with trading partners implementing stricter climate policies over time, and as the private sector steps up its efforts to make value chains greener. International decarbonization efforts—whether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

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

[7] 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.[8]

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.[9]

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.

[8] Steenbergen, Victor; Saurav, Abhishek. 2023. The Effect of Multinational Enterprises on Climate Change: Supply Chain Emissions, Green Technology Transfers, and Corporate Commitments. World Bank.

[9] 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).[10] Biomass, hydropower, solar, and wind are the main renewable

[10] 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.[11]

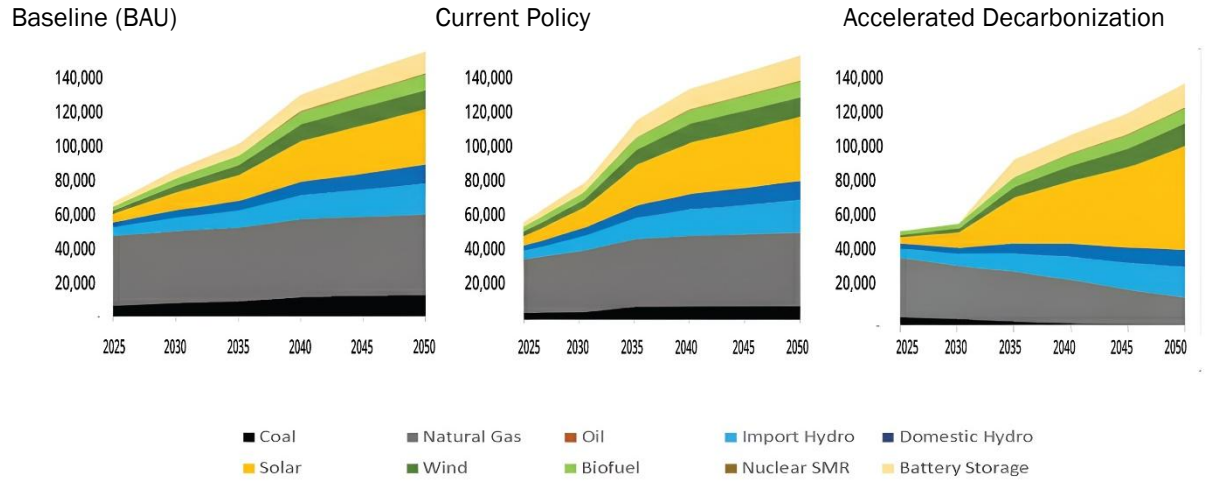
On the other hand, maintaining system stability as the share of intermittent sources grows will require the integration of sufficient reserve margins, storage, and demand-side management. Under the baseline, a system dominated by conventional fossil fuel generation typically has stability and predictable 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.

[11] 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.[12] 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

[12] 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

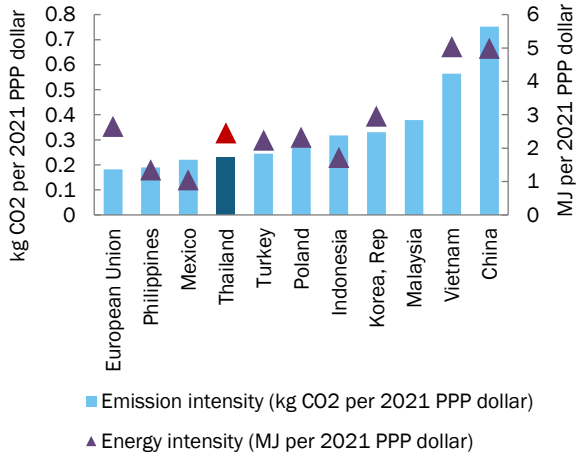
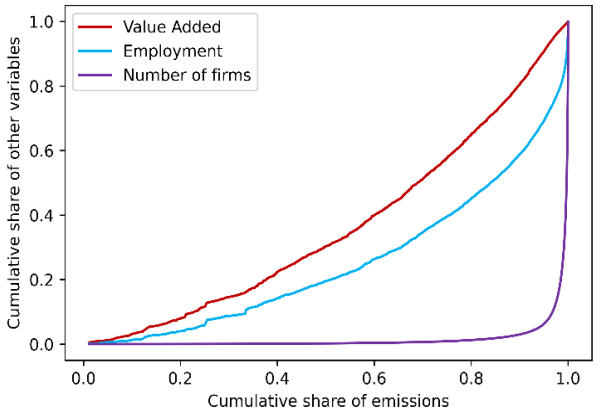


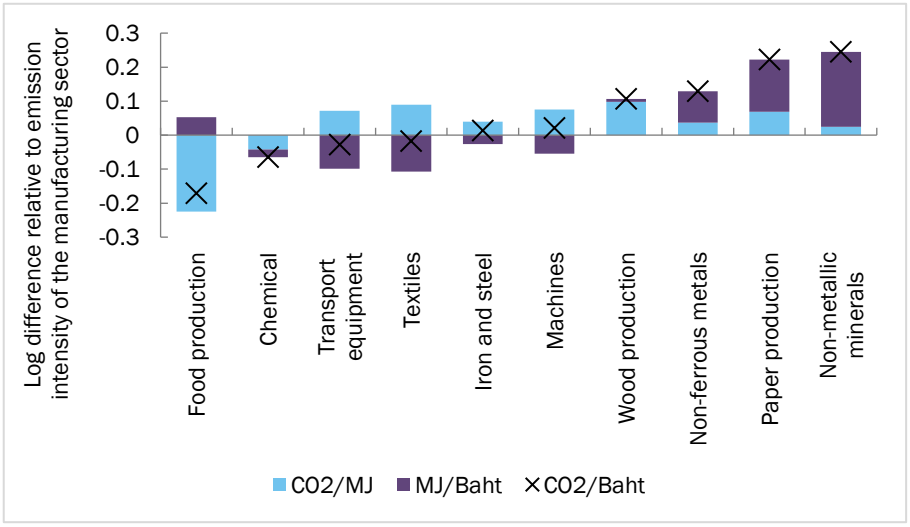
Figure 4.5: Concentration of emissions, value added, and employment across Thai manufacturing firms



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.[13] 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.

[13] 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.[14] 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[15], 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)[16]. 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.

[14] 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.

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

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

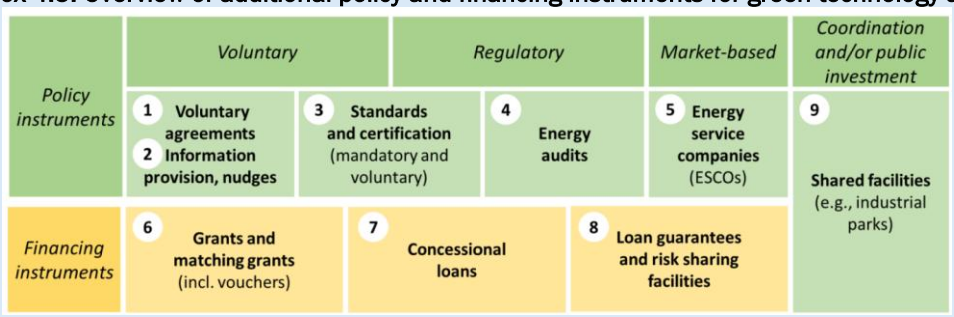
Public awareness campaigns can further drive behavioral change across residential, commercial, and industrial sectors. Embedding clear efficiency targets into national energy strategies will not only curb emissions but also delay the need for new power generation and lower long-term system costs. This 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.[17] 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,

[17] 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.[18] 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

[18] 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.[19] 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.[20]

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.

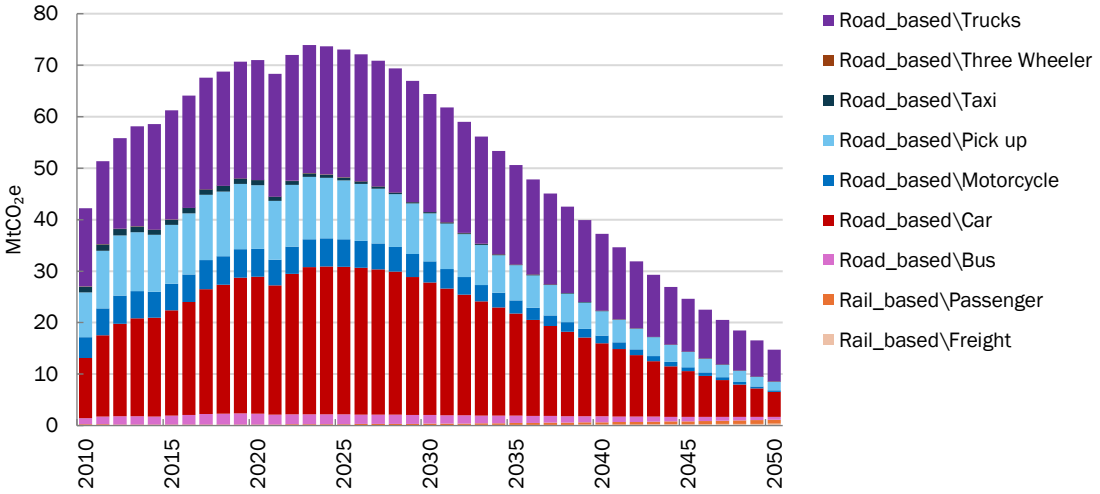
Analysis completed for this CCDR suggests that investment in mass rail transit in Bangkok could have a moderate impact on emissions, while at the same time reducing traffic congestion and travel time and improving air quality. These objectives could be further supported by the imposition of a congestion 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

[19] 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.

[20] 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.[21]

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.

[21] 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.

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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