TRANSITIONING THAILAND'S CEMENT INDUSTRY TOWARDS CARBON NEUTRALITY

TGC EMC

Published by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

IKI INTERNATIONAL CLIMATE INITIATIVE

Department of Alternative Energy Development and Efficiency MINISTRY OF ENERGY

TCMA THAI CEMENT MANUFACTURERS ASSOCIATION

Published by:
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices:
Bonn and Eschborn, Germany

Address:
GIZ Office Bangkok
193/63 Lake Rajada Office Complex (16th floor)
New Ratchadapisek Road, Klongtoey
Bangkok 10110 Thailand
T +66 2 661 9273

E info@giz.de
I www.giz.de/en

Programme:
Thai-German Cooperation on Energy, Mobility and Climate
(TGC EMC)

Authors:
Agora Industry
Agora Energiewende
Fraunhofer Institute for Systems and Innovation Research ISI
King Mongkut's University of Technology Thonburi

Contributing Institutions:
Thai Cement Manufacturers Association (TCMA)

In Cooperation with:
Department of Alternative Energy Development and Efficiency

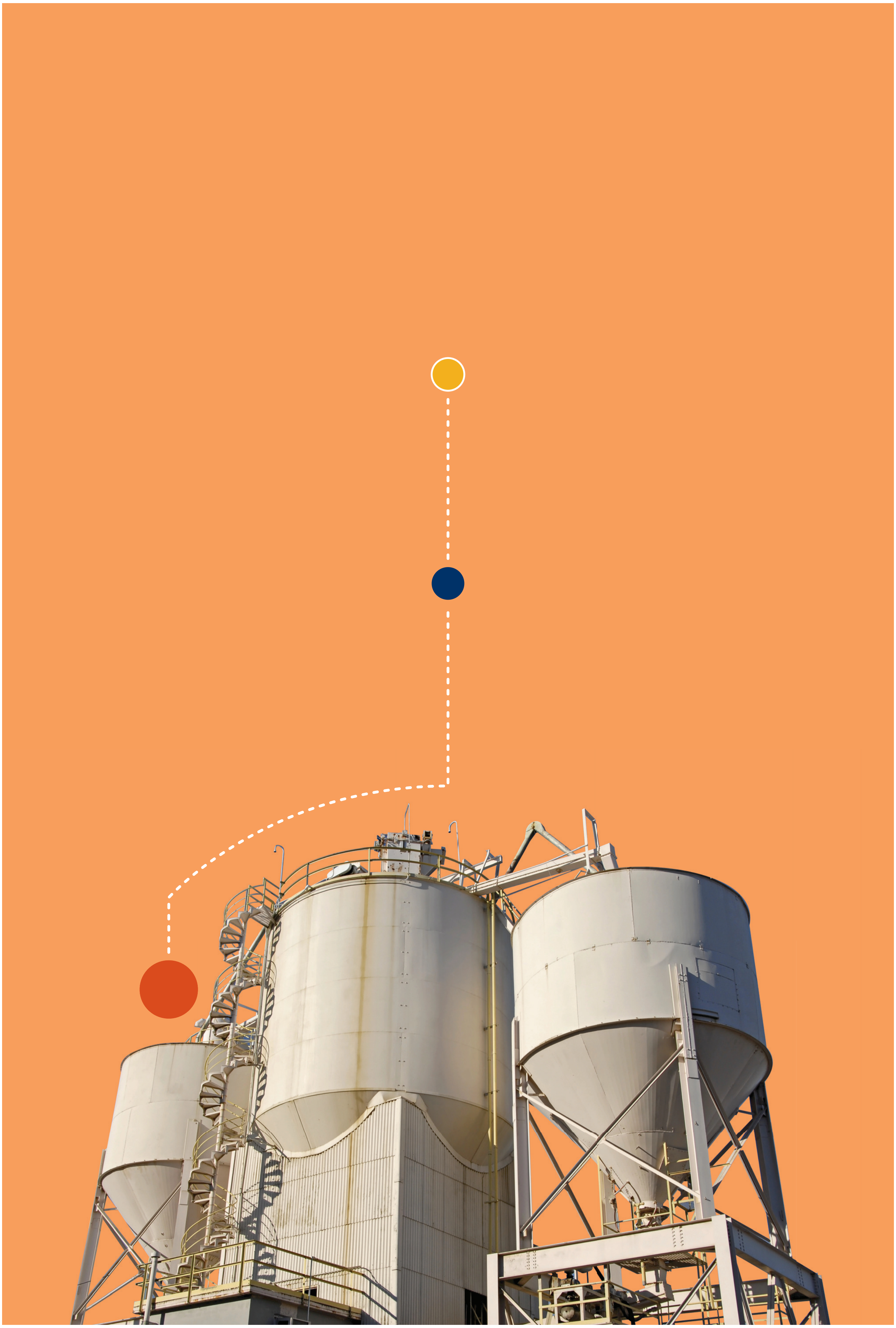
Published:
May 2026

TRANSITIONING THAILAND'S **CEMENT INDUSTRY** TOWARDS CARBON NEUTRALITY

TABLE OF CONTENTS

ABBREVIATIONS

AEDP	Alternative Energy Development Plan
BAT	Best Available Technologies
BOI	Board of Investment
BOT	Bank of Thailand
CAPEX	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCfD	Carbon Contracts for Difference
CCU/S	Carbon Capture, Utilisation and Storage
CSR	Corporate Social Responsibility
DCCE	Department of Climate Change and Environment
DEDE	Department of Alternative Energy Development and Efficiency
DPPAs	Direct Power Purchase Agreements
EEP	Energy Efficiency Plan
EERF	Energy Efficiency Revolving Fund
EPDs	Environmental Product Declarations
ESCOs	Energy Service Companies
ETS	Emissions Trading Scheme
FETCO	Federation of Thai Capital Market Organisations
GCCA	Global Cement and Concrete Association
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPP	Green Public Procurement
IPPU	Industrial Processes and Product Use
ktoe	Kilotonne of Oil Equivalent
LCA	Life Cycle Assessment
LC3	Limestone Calcined Clay Cement
LT-LEDS	Long-term Low-Carbon Greenhouse Gas Emission Development Strategies
MAC	Marginal Abatement Cost
MHESRI	Ministry of Higher Education, Science, Research and Innovation
MNRE	Ministry of Natural Resources and Environment
MOEN	Ministry of Energy
MOF	Ministry of Finance
MOI	Ministry of Interior
MOIND	Ministry of Industry
MRV	Monitoring, Reporting, and Verification
MSW	Municipal Solid Waste
MTEC	National Metal and Materials Technology Center
NDC	Nationally Determined Contributions
NEP	National Energy Plan
OPC	Ordinary Portland Cement
OPEX	Operational Expenditure
PDP	Power Development Plan
RCA	Recycled Concrete Aggregate
RDF	Refuse-Derived Fuel
ROI	Return on Investment
SDGs	Sustainable Development Goals
SEC	Securities and Exchange Commission
TCMA	Thai Cement Manufacturers Association
TGBI	Thai Green Building Institute
TGO	Thailand Greenhouse Gas Management Organization
TPA	Third Party Access
TRL	Technology Readiness Level
TSR	Thermal Substitution Rate
TVER	Thailand Voluntary Emission Reduction



PREFACE

In response to its significant emissions footprint, the Thai Cement Manufacturers Association (TCMA) developed the Thailand 2050 Net Zero & Concrete Roadmap, outlining decarbonisation pathways aligned with national goals of achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. With the release of NDC 3.0, which advances the national net-zero target to 2050, the cement industry will be required to accelerate and intensify its transition efforts. Several mitigation actions identified in the roadmap are already underway, reflecting early movement towards these goals.

Cement production in Thailand uses a highly energy-efficient dry process optimised for thermal and electrical performance. Coal remains the predominant fuel source, while electricity demand is met through a combination of grid supply and waste-heat recovery systems. Energy use contributes approximately 30 per cent of the sector's total emissions. Although biomass and waste-derived fuels are widely used, supply constraints, competition for feedstocks, particularly from the power sector, and inefficiencies in waste management systems limit their further expansion. Improvements in machinery efficiency can reduce electricity-related emissions; however, a shift towards cleaner energy sources will be necessary to secure deeper reductions.

The calcination process, a core element of cement manufacturing, accounts for roughly 60 per cent of total carbon dioxide emissions. Carbon capture, utilisation and storage (CCU/S) technologies offer the potential to address these process emissions, but they remain at early stages of development and demonstration globally and are not yet commercially viable. Thailand has not yet implemented demonstration-scale CCU/S systems. Thailand is also advancing decarbonisation efforts by promoting low-carbon hydraulic cement and initiating the phase-out of Ordinary Portland Cement (OPC). The development of low-clinker cement is expected to contribute to further emissions reductions. While supply-side measures are progressing, improving material efficiency and building practices will require stronger engagement from demand-side stakeholders, including the infrastructure and construction sectors.

Achieving deep decarbonisation in the cement industry will require robust and coherent government policies across the entire value chain. Progress will depend on coordinated action among government agencies, industry, and the public. Increasing the share of low-carbon fuels will require strategic biomass allocation and more efficient waste-management systems, particularly in coordination with the power sector.

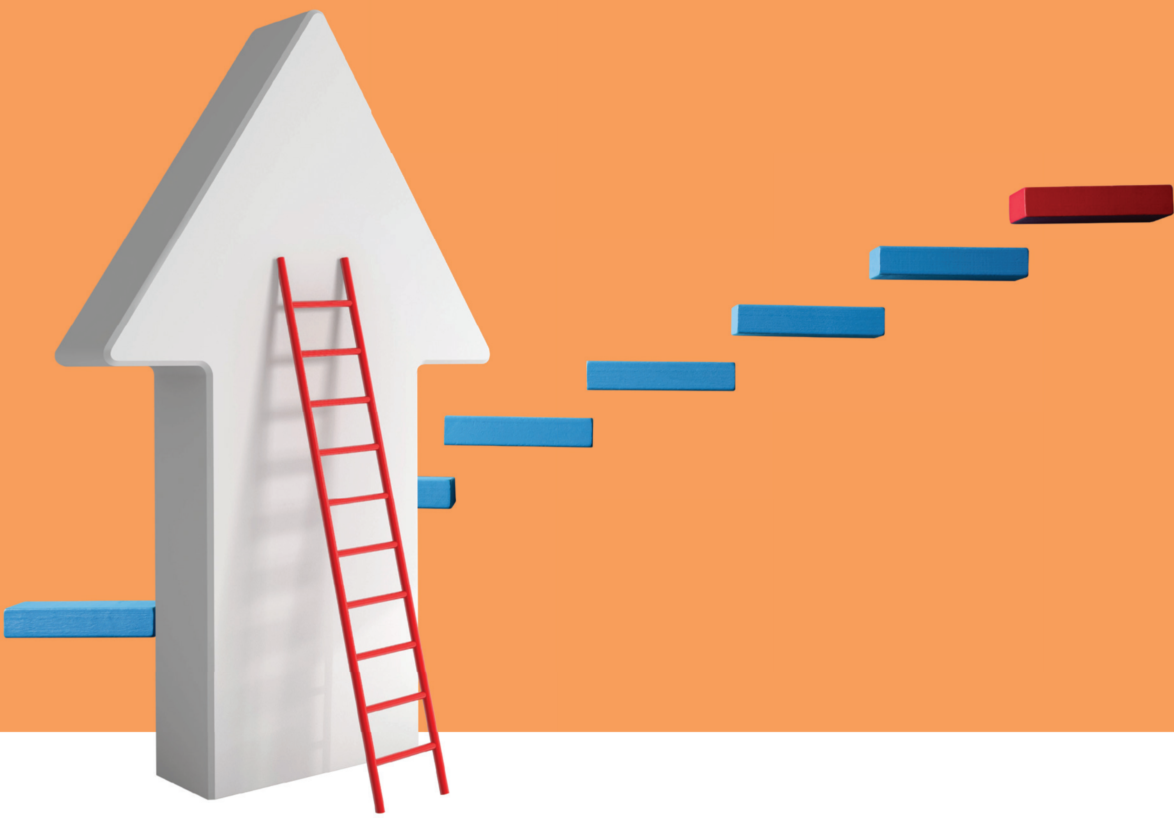
Legislation and regulatory reforms are also needed to expand the use of renewable electricity and enable future CCU/S deployment. Performance-based green procurement standards can stimulate demand for low-carbon cement in the infrastructure and construction sectors, while pricing mechanisms such as carbon pricing or tax incentives can improve the competitiveness of low-carbon cement.

The objective of this report is to identify the policy measures and enabling conditions that would make the decarbonisation targets of the Thailand 2050 Net Zero Cement and Concrete Roadmap, established by the Thai Cement Manufacturers Association (TCMA) in partnership with the Global Cement and Concrete Association (GCCA), achievable in the Thai context. Building on this roadmap, the report draws on international case studies, techno-economic assessments, and global benchmarking, particularly from other leading cement-producing nations, to evaluate a range of decarbonisation options across the cement value chain, to propose a phased policy framework spanning short-term (2025–2030), medium-term (2030–2040), and long-term (2040–2060) horizons. Critically, the report also maps the roles and responsibilities of key stakeholders to ensure that every segment of the value chain contributes to, and benefits from, Thailand's transition towards a carbon-neutral cement sector by 2050.

Chapter 1 outlines the current state of Thailand’s cement industry. Chapter 2 examines decarbonisation technologies and measures, benchmarked against global practices. Building on international policy frameworks, Chapter 3 sets out an actionable policy agenda and an interdependent set of recommendations for public and private actors. Chapter 4 identifies enabling conditions for implementation, including research and development, investment, infrastructure, regulatory reform, and cross-sectoral commitments. The report concludes with a set of metrics and milestones designed to track progress across Thailand’s decarbonisation pathways.

CHAPTER 1

OUTLOOK CHALLENGES AND OPPORTUNITIES



Key Messages

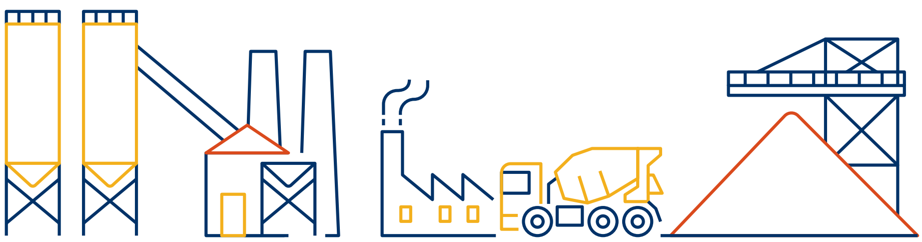
- The cement sector in Thailand has a significant environmental footprint, accounting for around eight per cent of the nation's greenhouse gas emissions and nearly half of Industrial Processes and Product Use (IPPU) emissions. Decarbonising the cement industry is therefore essential to achieving the country's carbon neutrality targets.

- About 15 per cent of coal used in the cement production is currently substituted by alternative fuels. However, further scaling up biomass and municipal solid waste is constrained by the limited resource availability, competition for feedstocks, and inefficiencies in waste -management practices.

- Up to 60 per cent of carbon dioxide emissions in cement production originate from the calcination process. Abating these emissions will require advanced technologies, including CCU/S, which remain under development and are not yet available at commercial scale.

- Low-carbon cement is becoming the standard in Thailand, supported by established industrial specifications. It is widely used in government infrastructure projects, and increasingly in the private sector, where it now accounts for around 40 per cent of building construction. Consequently, plans are underway to phase out Ordinary Portland Cement (OPC) entirely from the Thai market.

- The cement industry has established decarbonisation pathways and is exploring multiple technological options. Commercial-scale demonstrations are expected in the late 2020s; however, the lack of strong governmental policy support continues to limit progress.

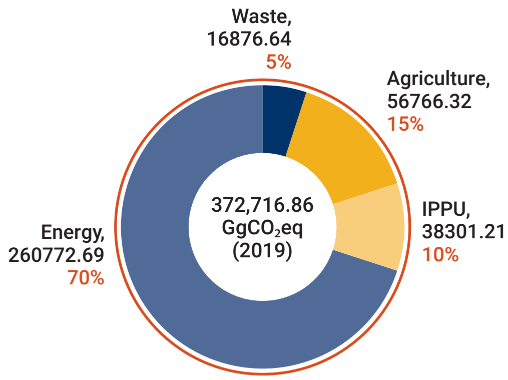


Overview of Cement Industry in Thailand

The cement industry plays a significant role in Thailand's economic development and supports national infrastructure, including transport systems, commercial buildings, and housing. In the context of global climate change, however, the sector faces increasing pressure to reduce its environmental footprint. Cement production is highly energy-intensive, and the manufacturing process emits substantial amounts of carbon dioxide (CO_2), contributing to climate risk.

Globally, more than 4 billion tonnes of cement produced in 2023 generated around 2.5 gigatonnes of carbon dioxide emissions—approximately 7–8 per cent of global emissions [1]. With global cement demand projected to grow, driven primarily by industrialisation and urbanisation in developing economies, rapid decarbonisation of the sector is essential to align with international climate objectives.

At COP26 (Conference of the Parties), Thailand committed to achieving carbon neutrality by 2050 and net-zero emissions by 2065 [2]. In 2021, total cement sales for domestic use and export reached 42.1 million tonnes, resulting in approximately 31 million tonnes of carbon dioxide emissions. This represents around eight per cent of national emissions (372 $MtCO_2$) and nearly half of emissions from the IPPU sector (Figure 1.1) [3]. Decarbonising Thailand's cement industry is therefore a critical component of the national transition to carbon neutrality. Effective action could also position Thailand as a regional leader in low-carbon cement production, with its strategic approaches serving as a valuable model for other countries.



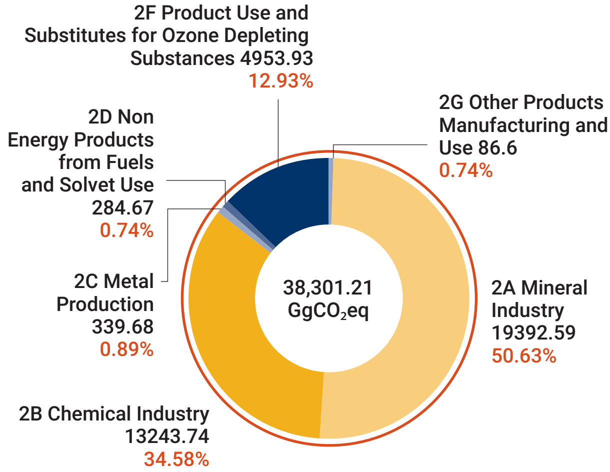


Figure 1.1:
Thailand carbon dioxide emissions and the emission from IPPU

The Thai cement industry

Seven cement manufacturers operate in Thailand, with a combined clinker production capacity of around 50 Mt per year and a total cement production capacity of around 60 Mt per year. Table 1.1 summarises these capacities.

Table 1.1: Thailand's cement production plants [4] , see original file

Cement producer	Number of plants
Siam Cement Group	5
Siam City Cement	2
TPI Polene	1
Asia Cement	1
Jalaprathan Cement	2
Thai Pride Cement	1
Globe Cement	1

Twelve cement plants and one grinding plant are currently in operation, eight of which are located in "Saraburi Province" in central Thailand. Proximity to limestone deposits minimises raw material transport costs. As a result, Saraburi accounts for approximately 80 per cent of national cement production. Figure 1.2 shows the distribution of clinker and cement plants across Thailand.

Figure 1.2: Clinker and cement plants in Thailand

In 2021, Thailand recorded cement sales of 42.1 million tonnes, of which 33.3 million tonnes (79 per cent) were consumed domestically. Around 90 per cent of surplus cement was exported to neighbouring countries, including Myanmar, Cambodia, and Laos, with additional exports to Australia, Japan, Samoa, and Malaysia [5]. Domestic and export volumes for 2021–2023 are shown in Figure 1.3.

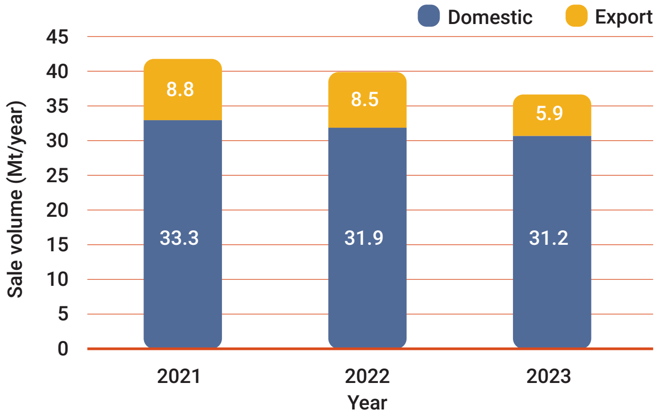
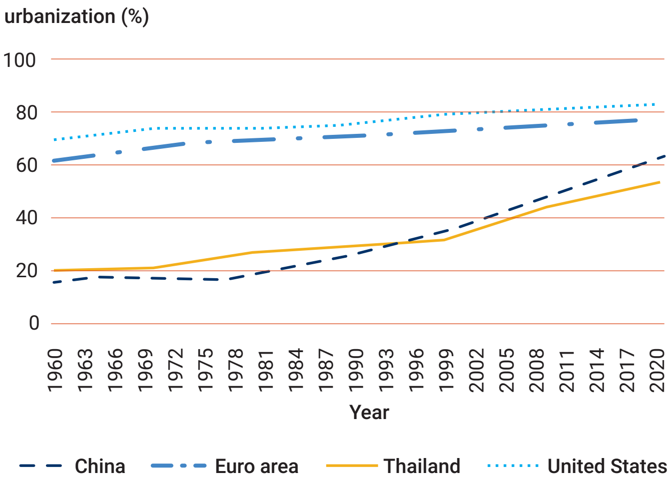


Figure 1.3: Clinker and cement production (2021-2023) [6], see original file

Thailand is experiencing demographic shifts, including population ageing, slower urbanisation rates and moderate economic growth, which are expected to limit long-term cement demand (Figure 1.4). Current per capita cement consumption is 486 kg, slightly below the global average of 525 kg but higher than levels observed in the United States and many European economies (Figure 1.5).



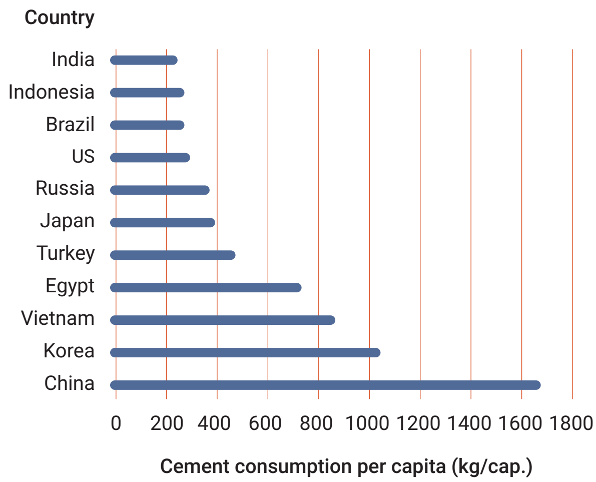


Figure 1.4: Thailand urbanisation rate in comparison [7]

Figure 1.5: Figure 1.5: Per capita consumption of cement, Year 2024 [8]

The key drivers of cement demand in Thailand are the public and the private sectors. From 2014 to 2023, construction investment ranged from 7.68% to 8.44% of gross domestic product (GDP) [9]. Over this period, cement demand from the public sector gradually increased, while demand from the private sector remained broadly stable. Approximately 60% of cement consumption is driven by government projects, including road construction, bridges, large-scale community buildings, and infrastructure maintenance. The Ministry of Transport and the Ministry of Agriculture and Cooperatives are the primary government bodies determining cement requirements.

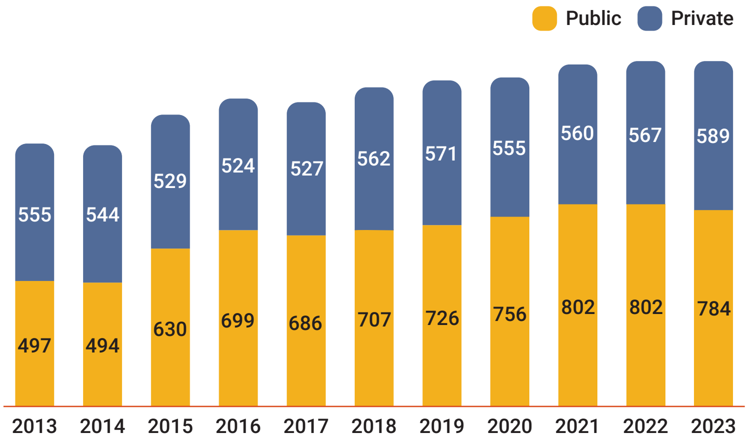


Figure 1.6: Public and private construction investment (billion baht) [9]

The remaining cement demand is generated by the private sector, primarily for residential and commercial buildings. Residential construction is projected to grow at an annual rate of 6.5% until 2025. Approximately 40% of new residential projects are concentrated in the Bangkok Metropolitan Region (BMR), which includes Bangkok and five neighbouring provinces. These areas are located in close proximity to the cement plants in Saraburi. The six first-tier tourism provinces together account for 22% of nationwide construction permits [9].

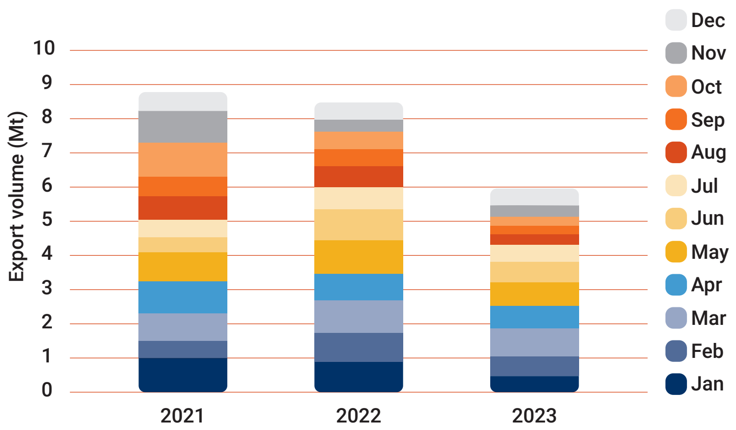


Figure 1.7: Cement export from Thailand, 2021-2023

Cement exports have declined as a share of total sales, from 20% in 2021 to 16% in 2023. This trend may accelerate a reduction in national production over time, as export volumes fall due to increasing domestic production capacity in importing countries.

Finance attribute (characteristics)

Implementing effective decarbonisation strategies in Thailand's cement industry requires a comprehensive understanding of its specific financial and operational characteristics.

- High capital investment: Decarbonising the sector will require substantial investment to introduce or adapt low-carbon technologies, including new machinery and equipment. Given the scale of capital expenditure, decarbonisation projects require clear business models and, in particular, stable and predictable government policy support.

- High downtime costs: Cement plants are designed to operate with minimal downtime. Retrofitting existing facilities with new decarbonisation technologies may require extended shutdowns, resulting in significant opportunity costs and additional expenditure.

- High fuel and freight costs: Cement producers continuously optimise operations to maximise fuel efficiency. Any intervention that increases fuel costs can materially affect production costs and overall profit margins. Additionally, the heavy weight of raw materials and finished products makes land transport expensive, meaning that longer transport distances can quickly erode profit margins.

Market characteristics

The following market characteristics, shaped by underlying economic dynamics, influence deployment models and viable business cases for new technologies:

- Regional market fragmentation: The cement market in Thailand is regionally fragmented due to high freight costs. Cement is heavy, and transporting it over long distances is expensive, so plants are typically located near raw material sources. In recent years, the export market for Thai cement has declined as neighbouring countries have developed their own plants to meet domestic demand, reducing the need for imports.

- Limited long-term offtake agreements: Cement procurement is typically conducted on a project-by-project basis rather than through long-term offtake contracts. Ready-mix companies and contractors -the immediate customers of cement producers - purchase cement as needed for specific projects. They are reluctant to agree to longer-term offtake arrangement because of uncertainty around future demand and the cyclical nature of construction markets. This model exposes cement producers to merchant risk and complicates efforts to secure credible long-term demand signals for scaling up new low-carbon technologies.

- Risk-averse customers: Customers across the value chain are risk-averse and have long adoption cycles for new products and approaches. Ready-mix companies, contractors and engineers are highly sensitive to potential risks associated with new technologies, including cost overruns, schedule delays, and performance issues. For structural applications such as high-rise buildings, bridges and other critical infrastructure, performance and safety are paramount, which can slow the uptake of innovative cement and concrete products.

Thailand's Energy and Climate Policies

Transitioning to a Low-carbon economy

Thailand has established a comprehensive strategic framework for addressing climate change, with ambitious long-term goals. The country's **Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDS)** outline its commitment to transitioning to a low-carbon economy and adapting to climate impacts. The ultimate goals are to achieve **carbon neutrality by 2050 and net-zero greenhouse gas (GHG) emissions by 2065**. To meet these targets, the LT-LEDS details mitigation actions across key sectors, including energy, manufacturing, transport, agriculture, and land use (Figure 1.8).

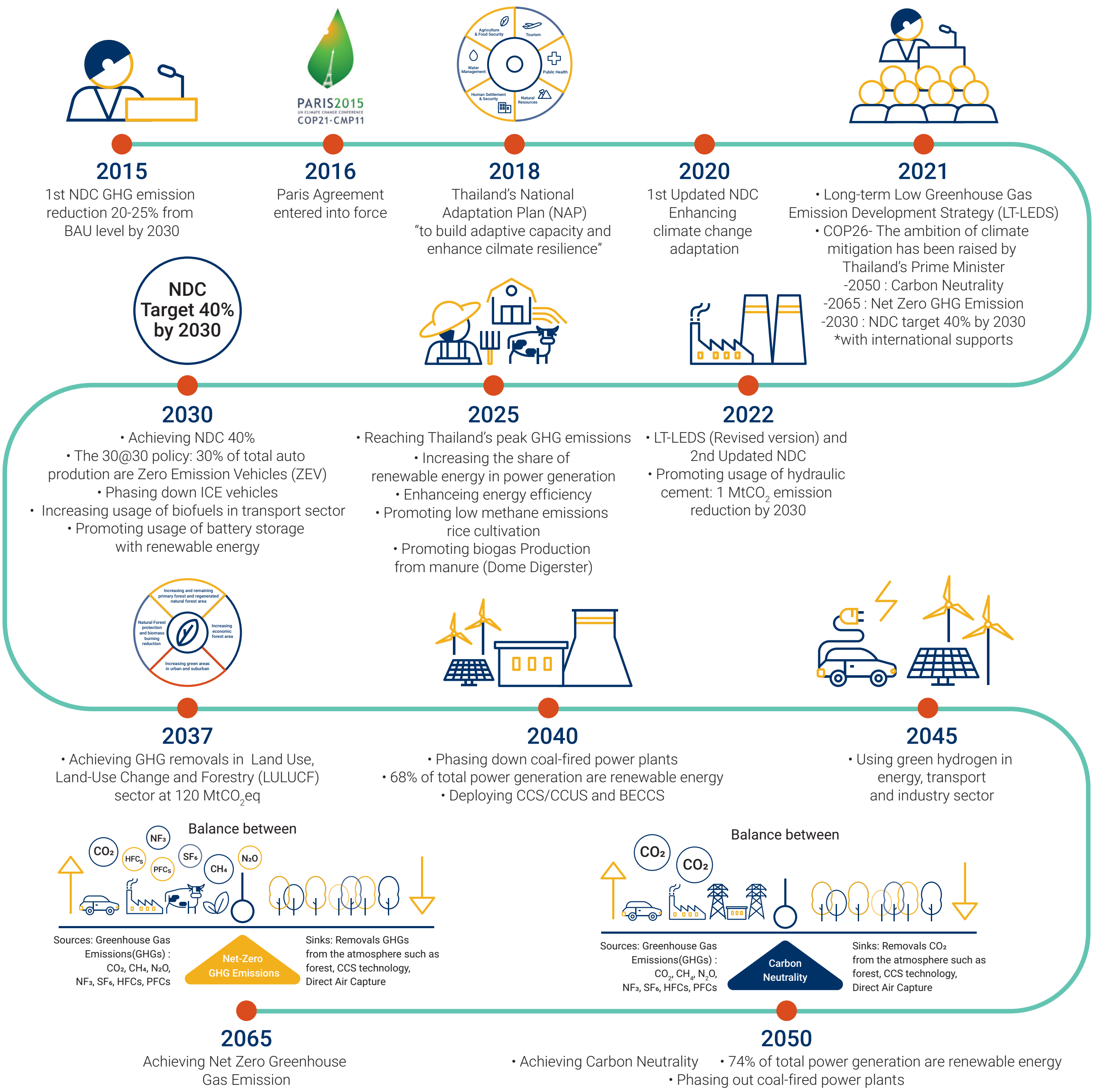


Figure 1.8: Thailand's long-term GHG emission reduction target according to NDC 2.0.

In the short term, Thailand's updated **Nationally Determined Contribution (NDC)** specifies mitigation targets for 2025–2030. The country aims to reduce its GHG emissions by **30%** relative to business-as-usual (BAU) projections by 2030, with the possibility if increasing this to **40%** subject to enhanced international support for technology, finance, and capacity building.

Within the LT-LEDS, the cement industry is identified as a priority sector for emissions reduction. The **Sectoral Action Plan for IPPU (2021–2030)** highlights **clinker substitution** as a primary measure to reduce carbon dioxide emissions through two main strategies.

1. Using **clinker substitutes** in the production of hydraulic cement.
2. Increasing the use of **cement substitutes** in ready-mixed concrete.

Looking ahead, Carbon Capture, Utilisation, and Storage (CCU/S) technologies are expected to play an important role in further decarbonising the cement industry by 2040.

In early November 2025, Thailand submitted its second Nationally Determined Contribution, or **NDC 3.0**, outlining a more ambitious goal of cutting 47% national emissions by 2037 compared with 2019 levels which is equivalent to 135.2 $MtCO_2eq$. This enhanced target aligns with the 1.5°C mitigation pathway and supports the country's commitment to achieving net-zero emissions by 2050, moving the goal forward from the earlier target year of 2065.

Thailand is also in the process of developing a **Climate Change Act**. This legislative framework is to regulate GHG emissions, promote sustainable development and enhance climate resilience. The cement industry will need to prepare for compliance with forthcoming regulations and stand ready to make use of new financial mechanisms designed to support progress towards carbon neutrality.

Legislative mechanisms in Thailand's draft climate change act

- **Comprehensive GHG Emissions Database:** Establishment of a national database monitor and track emissions.
- **National Climate Fund:** Creation of a fund, financed by carbon taxes, emissions trading schemes, government subsidies and private donations, to support mitigation and adaptation projects.
- **Emissions Trading Scheme (ETSs):** Introduction of a market-based mechanism to control and reduce GHG emissions.
- **Carbon Tax:** Imposition of a tax on manufacturers and importers of goods to internalise the environmental costs of emissions and incentivise the adoption of cleaner technologies, with revenues channelled to climate-related expenditure.
- **Carbon Credit Framework:** Development of a system for generating, managing and using carbon credits from emission reduction projects, including their use for compliance within the ETS.
- **Taxonomy Development:** Creation of a classification system for economic activities based on their environmental and climate performance.

Low-carbon Energy for Industry

Thailand's **National Energy Plan (NEP)** serves as an integrated policy framework to guide the industrial sector towards carbon neutrality (Figure 1.9). The NEP comprises five sub-plans: the Power Development Plan (PDP), the Energy Efficiency Plan (EEP), the Alternative Energy Development Plan (AEDP), the Oil Plan, and the Gas Plan. The NEP is currently being revised to align with updated NDC commitments, ensuring carbon reduction milestones are both realistic and achievable. These plans have direct implications for the decarbonisation of the cement industry.

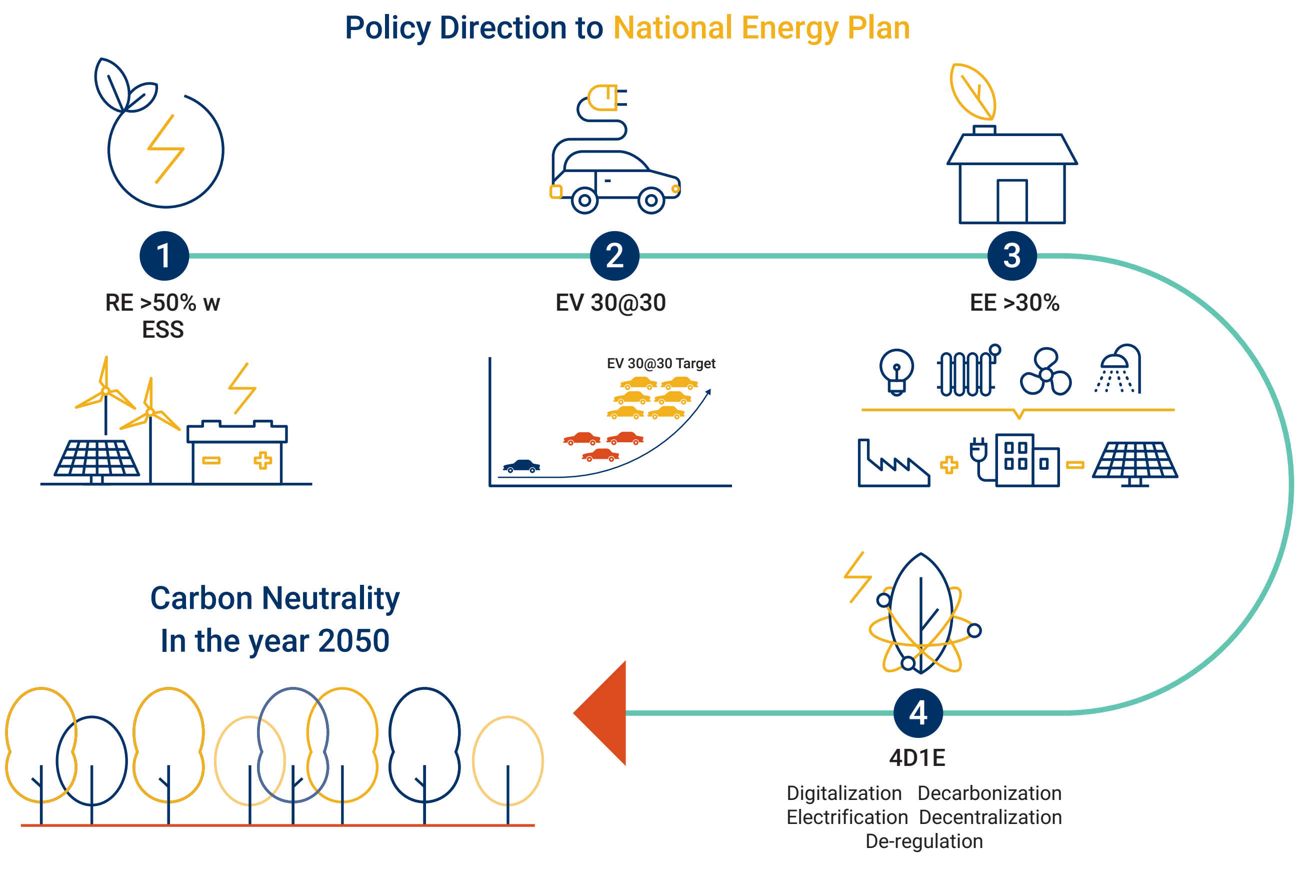


Figure 1.9: Thailand's National Energy Plan (NEP)

The "4D1E" policy is a core strategic direction of the NEP, aimed at driving the country's energy transition towards a more sustainable and low-carbon energy system. Under this framework, the PDP targets shares of renewable energy in electricity generation of 68% by 2040 and 74% by 2050. Hydrogen-based electricity is expected to account for 5% of the country's total power generation by 2037, increasing to between 25% and 75% by 2050.

The 4D1E Framework of Thailand's National Energy Plan

The "4D1E" framework stands for Digitalisation, Decentralisation, De-regulation, Decarbonisation, and Electrification. It is designed to modernise the energy sector, reduce greenhouse gas emissions, and enhance energy security.

- **Digitalisation:** Modernising the energy system through smart grids and digital technologies to improve efficiency, reliability, and the integration of renewable energy.
- **Decentralisation:** Supporting more distributed generation, including rooftop solar and other on-site renewables, as well as community-based energy solutions.
- **De-regulation:** Streamlining regulations and procedures to facilitate investment, promote competition and encourage innovation in the energy sector.
- **Decarbonisation:** Reducing reliance on fossil fuels, promoting renewable energy and implementing measures to cut emissions across sectors.
- **Electrification:** Expanding the use of electricity, particularly in the transport and industrial sectors, to displace fossil fuels and enable greater use of low-carbon power.

By implementing the 4D1E policy, Thailand is striving to achieve its energy transition goals, reduce its carbon footprint, enhance energy security, and promote economic growth through sustainable energy practices.

The **Alternative Energy Development Plan (AEDP)** 2018 aims to increase the share of renewable and alternative energy to 30% of final energy consumption by 2037. To support industrial decarbonisation, it sets 2037 targets of 7,298 ktoe for renewable electricity, 26,901 ktoe for low-carbon heat from biomass, waste, solar, and biomethane, and 4,085 ktoe for biofuels. These measures are intended to expand the use of green electricity and replace coal, bunker oil, and LPG in key industries, including non-metallic minerals, pulp and paper, food and beverage, chemicals, and textiles. Policy instruments include promoting alternative fuels for primary and co-firing applications, as well as providing investment incentives to replace fossil fuel–fired equipment with systems that use renewable or alternative fuels.

The **Energy Efficiency Plan (EEP)** 2018 aims to reduce energy intensity by 30% by 2037, with a focus on improving both thermal and electrical efficiency in industrial processes and machinery. It also emphasises modernizing laws to reflect current conditions and international standards, alongside strengthening the enforcement of energy conservation–related regulations.

Under the NEP, regulations are being amended to simplify permitting for solar installations and improve access to renewable electricity. Commercial use of hydrogen as green fuel in industry and transport is expected to begin around 2045, and coal is scheduled to be phased out by 2050. To support NEP objectives, The **Energy Conservation Promotion Fund (ENCON Fund)**, established under the Energy Conservation Promotion Act B.E. 2535 (1992), provides financial support for projects and activities related to energy conservation and efficiency.

Promoting Thailand's Carbon Market

Thailand operates a domestic carbon market programme, the **Thailand Voluntary Emission Reduction (T-VER) scheme**. T-VER enables the generation of certified carbon credits that can be used for domestic offsetting or trading. Companies participating in T-VER are exempt from income tax on net profits from the sale of domestic carbon credits until 31 October 2027. Clinker substitution in cement production is recognised as an eligible mitigation activity under T-VER.

An enhanced programme, the **Premium Thailand Voluntary Emission Reduction Programme (Premium T-VER)**, aims to strengthen Thailand's contribution to GHG emissions reduction. by aligning more closely with international standards and improving carbon credit quality. Premium T-VER projects are designed to meet the requirements of Article 6 of the Paris Agreement and other international frameworks, ensuring high-quality, internationally recognisable credits. Eligible project types include renewable energy, energy efficiency, public transport, electric vehicles, waste management, forestry and agriculture.

Leveraging green finance and investment for cement decarbonisation

The **Thailand Taxonomy** is a green taxonomy that categorises environmentally sustainable economic activities within the Thai economy. It provides a reference framework for both the public and private sectors to identify activities consistent with national sustainability and climate objectives and with emerging international practices. The taxonomy is also intended to guide capital allocation, support risk management, influence private investment decisions, and inform government incentive design.

The programme is currently in Phase 2, which focuses on sectors such as manufacturing, including cement. For the cement industry, the taxonomy's scope covers activities from raw material quarrying to cement blending. Emissions within scope include: (i) direct (Scope 1) emissions from cement production; (ii) indirect (Scope 2) emissions from purchased energy; and (iii) selected indirect (Scope 3) emissions from upstream and downstream activities in the value chain.

Table 1.2 Clinker decarbonisation pathway

Year	2020	2030	2050
Carbon intensity ($t\ CO_2/t$ cementitious product)	0.587	0.542	0.000

Enhancing demand for sustainable products

Green Public Procurement (GPP) refers to the integration of environmental considerations into public purchasing decisions. Thailand has promoted GPP since 2007 as part of its broader commitment to sustainable development and environmental protection. Implementation challenges include difficulties in measuring environmental impacts, higher upfront costs for green products and inconsistencies in procurement practices.

The 2022–2027 GPP Action Plan aims to address these challenges by encouraging central and local government entities, including state-owned enterprises, to increase both the volume and value of green procurement. Key strategies include:

- Developing or improving public procurement rules and regulations to make green procurement mandatory, with a goal that at least 30% of total purchasing value should be environmentally friendly products and services; and
- Setting indicators and detailed Joint Key Performance Indicators (KPIs) to support integration across ministries and between central and provincial levels.

Hydraulic cement, a low-carbon cement product, has been introduced to the construction sector. It is produced in accordance with Thai Industrial Standard TIS 2594, which is based on the performance-based ASTM C1157 standard. TIS 2594 requires manufacturers to control strength at specified ages and to limit cement expansion at 14 days, ensuring performance and durability and allowing the cement to be used across a wide range of applications.

To support environmental performance, green label criteria for the low-carbon cement product were developed. The criteria focus on reducing GHG emissions and other pollutants in production processes, limiting heavy metals in inks and pigments for packaging, and encouraging the use of recyclable packaging and appropriate disposal practices.

Momentum for Decarbonisation

Emissions intensity has fallen through energy efficiency, but further reductions are needed

No new kilns have been constructed in recent years. Instead, producers have invested in modernising existing kilns to improve thermal performance in a cost-effective way. Intense competition and low profit margins have encouraged all plants to improve production efficiency, resulting in lower specific CO_2 emissions for the sector.

At present, only the less energy-intensive dry process is used in Thailand. Waste-heat recovery units have been installed at all kilns to generate electricity from exhaust gases, and the remaining potential for further waste-heat recovery is considered limited. Digitalisation is now a key tool for improving energy efficiency, with intelligent centralised control systems monitoring operating conditions in real time and optimising process parameters. Proven efficiency technologies, such as high-efficiency electric motors, are widely deployed, although additional potential remains. Time-of-use electricity tariffs apply to the cement sector, encouraging plants to shift electricity-intensive operations (e.g. raw material and fuel preparation, cement grinding) to off-peak periods, thereby reducing electricity costs.

Thailand cement industry is accelerating the use of alternative low-carbon fuels and renewable electricity

Unlike in some other countries, policies to promote natural gas as a substitute for coal in cement kilns have not been implemented in Thailand. Coal currently accounts for around 85% of fuel use in cement production. All major producers are seeking to increase the use of biomass —such as agricultural residues, wood chips and other organic materials—as a partial substitute. Under the Saraburi sandbox project, the sector is also exploring Napier grass as a biofuel alternative to coal. The thermal substitution rate (TSR) of biomass is around 8% for the sector as a whole. Expansion of biomass use is constrained by feedstock availability, costs and the limited capacity of smaller operators to invest in new technologies.

The industry has also increased the use of refuse-derived fuel (RDF) to reduce coal consumption. RDF is produced from municipal solid waste (MSW) by extracting combustible fractions, such as non-recyclable plastics, paper and cardboard, and processing them into a homogeneous fuel. Total RDF use in Thailand's cement industry is approximately 0.4 million tonnes per year, corresponding to a substitution rate of less than 8%. This indicates significant remaining potential for expansion. The Thai cement industry is poised to increase RDF utilisation as part of its low-carbon transition. Ongoing efforts to improve RDF production and address waste management challenges are expected to support higher RDF utilisation in cement kilns (Figure 1.10).

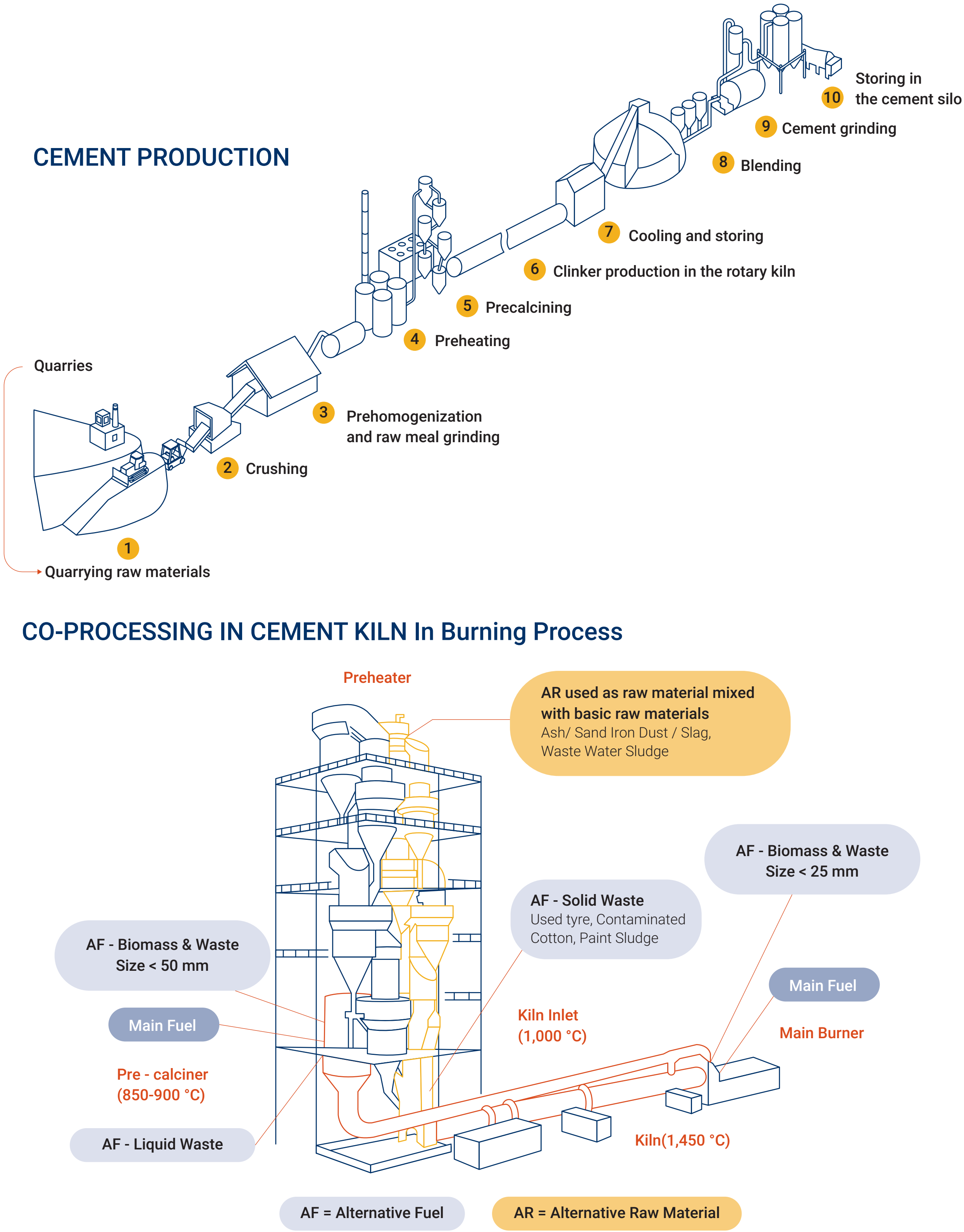


Figure 1.10: Cement co-processing circular solution (Source: TCMA)

Electricity accounts for around 12% of total energy consumption in cement production. Decarbonising this electricity through on-site photovoltaic (PV) systems can be cost-effective. Many plants have installed large solar PV systems to meet a portion of their power demand. However, during periods of low production, excess solar generation cannot always be exported to the grid, limiting utilisation.

Using emerging renewable energy carriers, such as hydrogen, in cement manufacturing remains at an early stage. Thailand is actively exploring hydrogen as a green fuel to support decarbonisation in hard-to-abate sectors, including cement. Ongoing research is assessing its technical and economic feasibility. Key challenges include high production costs and the need for substantial infrastructure investment. With continued policy support and technological progress, hydrogen could play an important role in Thailand's broader energy transition.

No CCU/S projects have yet been developed at commercial scale in Thailand

Carbon capture, and utilisation/storage (CCU/S) is the key technology for reducing process-related CO_2 emissions from cement production. Thailand has identified 13 CCU/S pilot projects across various sectors, including cement manufacturing. These initiatives include site screenings for CO_2 storage capacity, indicating a systematic approach to CCU/S development. With international collaboration and support, a pre-feasibility study is under way for a CCU facility at one cement plant to assess the technological and economic viability of capturing emissions and converting them into valuable chemical products.

Deploying CCU/S in the cement industry faces challenges, including high operating costs, technological complexity, and the need for clear regulatory frameworks. Nevertheless, combining CCU/S with electrification and increased use of renewable energy could yield substantial emissions reductions.

Under a concept developed by the TCMA, unavoidable CO_2 from calcination would be captured and converted into low-carbon methanol, linking the cement, chemical and clean energy sectors. As a large share of sectoral emissions is process-related and cannot be abated through fuel switching alone, CCU/S represents a critical high-impact mitigation option. Successful international projects such as Norcem Brevik (Norway), Holcim–TotalEnergies (France), CEMEX–Synhelion (Spain/Switzerland) and Heidelberg Materials (Germany/Sweden) demonstrate that CO_2 captured from cement plants can be used produce low-carbon fuels and chemical feedstocks, offering models that Thailand can adapt.

Thailand is currently a net importer of methanol, with rising domestic demand. Methanol is used as a chemical feedstock, including for methyl tert-butyl ether (MTBE) in gasoline blending, formaldehyde and derivative resins, acetic acid, solvents, and other intermediates used in plastics, textiles, coatings and electronics. Its role is also expanding in emerging applications such as low-carbon marine fuels and as a feedstock for sustainable aviation fuel (via methanol-to-jet processes). Producing methanol domestically from captured CO_2 would enhance energy security, reduce import dependence, support industrial competitiveness, and enable participation in new export markets for clean fuels.

TCMA's concept foresees a phased approach to supplying hydrogen for methanol synthesis. In the near term, hydrogen could be sourced from agricultural residues, biomass, and biogas, leveraging Thailand's strong bioresource potential. Over time, as renewable electricity expands, green hydrogen produced through electrolysis could support larger-scale methanol production.

Saraburi Province, as Thailand's primary cement cluster, offers a promising starting point for a CCU/S-to-methanol hub, given its concentrated CO_2 sources, existing industrial infrastructure, and established stakeholder networks. A successful project in Saraburi could serve as a model for other industrial clusters and signal Thailand's commitment to industrial decarbonisation and clean energy innovation.

Promoting low-carbon cement and recycled aggregate concrete while phasing out Ordinary Portland Cement

More recently, the industry has phased in Hydraulic Cement, a blended cement containing up to 15% ground limestone, thereby reducing clinker content and lowering emissions intensity by around 8%. Thailand introduced Thai Green Label (TGL) requirements for hydraulic cement in 2016, with a recent revision in 2024. The updated requirements include specific GHG performance requirements for different cement types and cement-based products. As a Type I ecolabel, TGL supports public and private entities in meeting commitments to use low-impact cement through green public procurement. GPP is currently voluntary, but efforts are under way to make it mandatory, which would increase demand for green products.

Thailand also applies international green building standards, such as LEED and DGNB, and has developed its own TREES (Thailand Rating of Energy and Environmental Sustainability) certification. These rating systems include criteria related to the use of Green Label-certified products and low-embodied-carbon materials.

The national recycling rate for construction waste has reached around 50–60%, below the 70–90% achieved in some advanced economies, indicating scope for improvement. The Circular Economy in Construction Industry (CECI) initiative, launched in 2018, brings together 23 private organisations to promote circular practices on construction sites. Pile heads, for example, are now used to produce recycled concrete aggregate (RCA) for recycled aggregate concrete (RAC), reducing reliance on natural aggregates. New business models are being developed to address the higher costs of RAC.

On the public sector side, regulatory measures incentivise circular practices, including tax incentives for companies engaged in recycling. The Bangkok Metropolitan Administration has established a full-scale construction waste processing facility with a capacity of 500 tonnes per day in the On Nut district, encouraging local projects to manage construction waste sustainably.

For other measures, digital technologies are also being used to shorten construction times, improve accuracy, reduce resource consumption and minimise material waste.

Limestone Calcined Clay Cement (LC3) is an innovative low-carbon cement comprising clinker, calcined clay, limestone, and gypsum. LC3 can reduce CO_2 emissions from cement production by up to 30% compared with traditional Portland cement. In Thailand, the potential of LC3 has been recognised through technical seminars and stakeholder engagement, including an "LC3 Information Day: Road to Thailand Net Zero Emission" organised by TCMA and partners in 2022. Research specific to Thai conditions has shown that LC3 formulations can deliver adequate strength and durability, suggesting technical viability. LC3 also uses locally available kaolinitic clays offering environmental benefits. It is important for the industry to consider economic benefits across the entire value chain, including concrete producers, to ensure a positive and mutually beneficial transition to low carbon cement.

Overall, the promotion of LC3 in Thailand represents a significant step towards sustainable construction and supports Thailand's efforts to reduce emissions from the cement industry.

Technology, Operational, and Financial Challenges

Cement production remains heavily reliant on fossil fuels

In cement production, fossil fuel combustion and electricity consumption account for about 30% and 5% of total CO_2 emissions, respectively. Fuel combustion occurs mainly in the clinker production stage, while electricity is used to power machinery and auxiliary systems. Coal is the primary fuel in Thailand's cement sector; alternative fuels are used at relatively low levels.

Only about 15% thermal energy per tonne of clinker in Thailand comes from non-fossil fuels, compared with a global average of around 19% and approximately 69% in Germany (Table 1.3). The non-fossil fuel share in Thailand is higher than in China, where non-fossil fuels account for only 1.8% of thermal energy.

Table 1.3: Environmental performance of Thailand's cement industry in international comparison (2018–21)

Data (2018-21)	Thailand	World	Germany	China
	[10]	[11]	[12]	[13]
Cement capacity [Mt/a]	57.4	6,605	38.2	na.
Capacity utilisation [%]	72.6	60.0	90.0	na.
Cement production [Mt/a]	45.0	4,100	34.2	2,363
Clinker production [Mt/a]	35.2	3,700	24.6	1,600
Clinker to cement ratio (%)	77.1	74.8	71.9	67.7
CO_2 [Mt]	31	8,861	20	1,370
Specific CO_2 [tCO_2/tcement]	0.679	0.635	0.585	0.580
Fuel proportion (%)				
Fossil	85.0	80.9	31.0	98.2
Biomass	6.7	6.73	0.0	
Waste	8.3	12.4	69.0	1.8
Specific thermal energy use [GJ/tclinker]	3.1	na.	3.8	2.9 (2.6-4.0)
Specific power consumption (kWh/tcement)	104	102	112	na.

Potential alternative fuels for the sector include biomass and municipal solid waste. The use of green hydrogen and renewable electricity is still at an early stage and is currently associated with high costs. The relatively low share of alternative fuels in Thailand reflects shortcomings in municipal waste management (e.g. lack of segregation at source, leading to mixed waste streams), a limited number of facilities producing waste-derived fuels and an unstable supply of biomass. Institutional, technical, and financial barriers must be addressed to scale up the use of alternative fuels in the cement sector.

Reducing process emissions is the main challenge to cutting overall emissions

Cement production is a mature process. Limestone (calcium carbonate, $CaCO_3$) is the main raw material in cement production owing to its availability and low cost. Approximately 60% of CO_2 emissions are released during calcination, when limestone is heated and decomposed into calcium oxide (CaO). Fly ash from coal-fired power plants is currently used as a partial substitute for clinker, but its availability is limited and likely to decline as the power sector decarbonises. Other alternative raw materials, process routes or binders that could economically replace limestone at scale are not yet available. The large volume of process emissions that are difficult to avoid represents a major challenge on the pathway to carbon neutrality. CCU/S will therefore be crucial for managing unavoidable CO_2 from clinker production.

Implementing decarbonisation technologies requires substantial investment

Renewable energy utilisation (solar, wind, biomass etc.) and energy efficiency improvements are the most immediately applicable measures to reduce CO_2 emissions from thermal energy and electricity consumption in cement plants. Although these technologies are commercially available, high upfront costs and thin margins in cement production can result in long payback periods. CCU/S, by contrast, remains at an early stage of development, with relatively low technology readiness levels and high research, development and deployment costs. Public financial support will be essential to accelerating demonstration and early deployment of CCU/S and other advanced decarbonisation technologies.

Emerging Opportunities for Carbon Neutrality

Institutional reforms and modernised policies to support decarbonisation

Historically, Thailand's climate policies have been constrained by institutional mandates and fragmented responsibilities. Recently, however, the establishment of the Department of Climate Change and Environment (DCCE) under the Ministry of Natural Resources and Environment has strengthened governance. The DCCE now serves as a central agency for co-ordinating national climate action, signalling Thailand's commitment to achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065.

A key element of this effort is the development of Thailand's Climate Change Act, which will introduce compulsory mechanisms such as an emissions trading scheme (ETSs) and a carbon tax to drive decarbonisation in line with NDC commitments. The legislation also envisages the creation of an environmental fund to support decarbonisation activities across sectors, expanding beyond the current system of project-based support.

In parallel, the Ministry of Energy has updated its energy plans to reflect carbon neutrality and net-zero targets. The Department of Alternative Energy Development and Efficiency (DEDE) is refining its energy efficiency strategies with a stronger focus on heating applications. The Ministry of Industry is promoting the Bio-Circular-Green (BCG) economic model, which emphasises recycling resource efficiency, and waste reduction.

Enhanced financial support and broader initiatives for industrial decarbonisation through ESG finance

The COP26 conference marked a significant impetus for clean technologies and sustainable finance. Globally, Environmental, Social, and Governance (ESG) frameworks are increasingly used to guide investment towards low-carbon activities. In Thailand, interest in ESG-aligned finance has grown, supported by collaboration between public agencies and private financial institutions.

Thailand has strengthened ESG-related policies by setting net-zero ambitions, tightening environmental regulations and offering tax incentives for green investment. Additionally, the green taxonomy provides further clarity on eligible activities, including in the cement sector.

Since the adoption of sustainable investment principles in 2015, ESG funds have gained traction. The launch of the Thai ESG Fund (Thai ESG) in 2023 — developed by the Federation of Thai Capital Market Organisations (FETCO), the Securities and Exchange Commission (SEC) and the government—represents an important step in mobilising capital for companies with strong environmental and social performance.

Leveraged public–private partnerships to advance decarbonisation in the cement sector

Public–private collaboration has been strengthened through the Saraburi Sandbox eco-innovation initiative, which seeks to translate the 2050 Net Zero Cement and Concrete Roadmap into concrete actions.

The Saraburi Sandbox is an area-based development model guided by the “3C” approach (Communication, Collaboration, Conclusion) and the “3P” framework (Public–Private–People Partnership). Under the leadership of the provincial governor, it promotes co-ordinated action and shared oversight among public authorities, industry, and civil society. Pilot projects are aligned with Thailand’s NDC targets and address policy, regulation, climate finance, technology and governance, creating a platform for transparent and measurable GHG reductions.

High regional concentration creates opportunities for collective action. Because limestone deposits are concentrated in central Thailand, around 80% of cement production is located in Saraburi Province. This high degree of regional concentration is advantageous for R&D, co-ordinated infrastructure planning and the large-scale deployment of new technologies. For capital-intensive technologies such as carbon capture utilisation and storage (CCU/S), shared infrastructure for CO_2 capture, transport and storage can significantly reduce unit costs. Cluster-based approaches also lower administrative and co-ordination complexity and can accelerate the roll-out of low-carbon technologies across the sector.

Growing awareness in the construction sector is creating markets for low-carbon cement

The construction industry is increasingly adopting green building standards and rating systems, both domestic and international. Use of environmentally friendly materials is a core criterion in these schemes, giving low-carbon cement an important role. Collaboration with professional associations and public institutions, such as architectural and engineering institutes and the National Housing Authority, can accelerate market uptake.

Some real estate developers have already committed to carbon neutrality by 2050 or earlier and are seeking to align their building portfolios with green standards. Greater awareness and demand in the construction sector will, in turn, support the ongoing decarbonisation of the cement industry. Clear political commitments and supportive policy frameworks can further accelerate this transition. Internationally, standards for building carbon accounting, including embodied emissions in materials, are emerging in jurisdictions such as China, the United Kingdom and the European Union, providing useful reference points.

Thailand 2050 Cement and Concrete Decarbonisation Pathways

Thailand's cement industry has published a 2050 Net Zero Cement & Concrete Roadmap. The roadmap integrates seven strategic levers across the value chain (Figure 1.11)

1. Efficiency in design and construction
2. Efficiency in concrete production
3. Savings in cement and binder use
4. Savings in clinker production
5. Decarbonisation of electricity
6. Carbon capture, utilisation and storage
7. CO_2 sinks and re-carbonation.

The roadmap implementation is structured in three phases:

Short Term (2020-2030)	→	Regulatory alignment, stakeholder engagement, and pilot projects
Medium Term (2030-2040)	→	Large-scale adoption of alternative fuels, digitalisation, and process optimisation
Long Term (2040-2050)	→	Full implementation of carbon-neutral technologies and achievement of net-zero emissions

Through a combination of technological advances, regulatory frameworks, industry partnerships, and financial incentives, total CO_2 emissions from Thailand's cement industry are projected to be limited to 17.5 Mt in 2030 and 8.8 Mt in 2040. By 2050, the roadmap foresees abatement of 30.3 Mt of CO_2, reducing net emissions from the sector to zero.

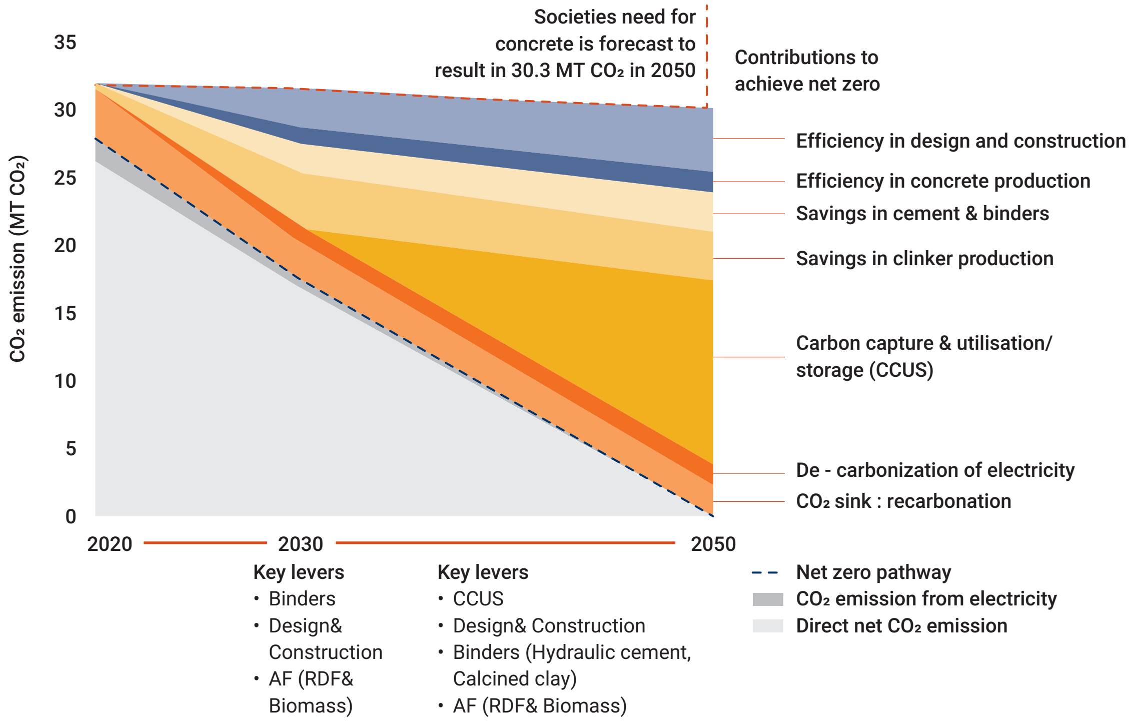
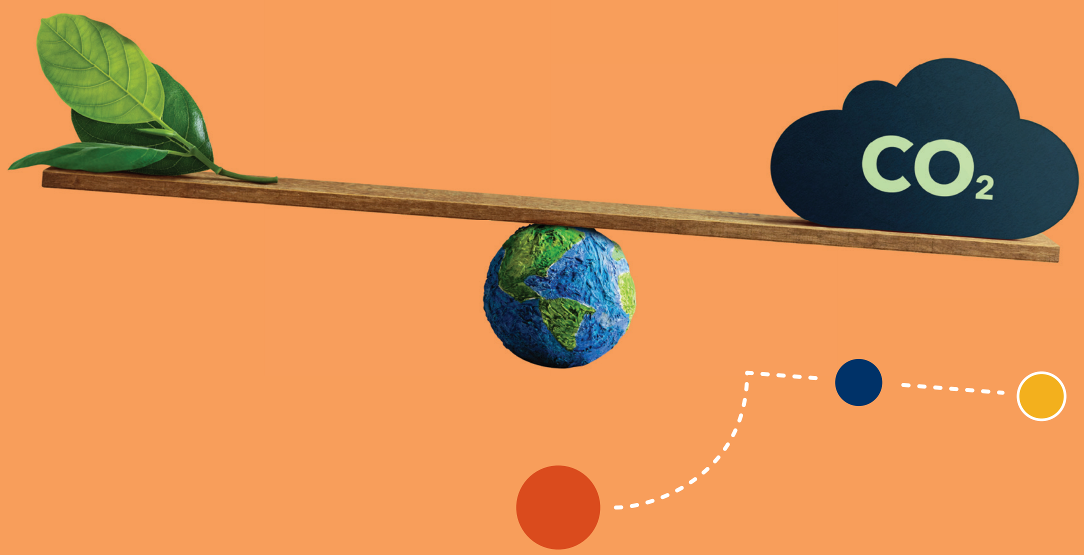


Figure 1.11: CO_2 emission and contribution of levers to achieve net zero

CHAPTER 2

DECARBONISATION OPTIONS FOR THAILAND'S CEMENT INDUSTRY TOWARDS CARBON NEUTRALITY



Key Messages

- Three key aspects underpin decarbonisation in the cement sector: low-carbon energy carriers, capture of process-related emissions, and value chain–wide optimisation.

- No country has yet achieved full decarbonisation of its cement sector. Technology pathways, policy support, and implementation remain subject to uncertainty.

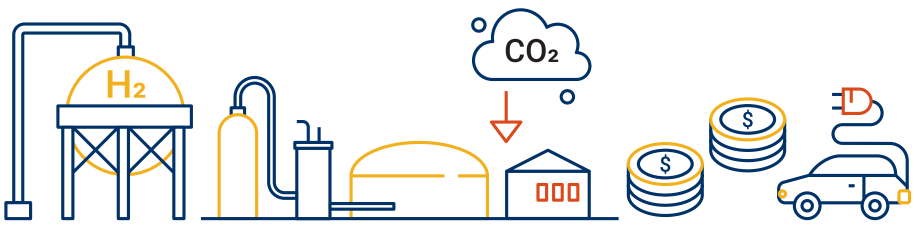
- Energy efficiency improvements have been among the most economically feasible measures globally, though savings are now approaching a plateau. Achieving deep decarbonisation will require fundamental changes in production technologies and business models.

- The use of alternative fuels, including biomass, RDF, and hydrogen, offers a high-readiness initial step, but must ultimately transition towards long-term sustainable solutions.

- Several Demand Side Management (DSM) technologies are currently viable for cement sector decarbonisation, providing system flexibility while delivering operational cost benefits.

- CCU/S can play a major role in Thailand's decarbonisation pathway but must be complemented by additional measures. Given the high capital and operating costs, financial incentives such as carbon pricing or price premiums for low-carbon products will be essential for deployment.

- Although incremental in impact, value chain actions—such as reducing limestone use and increasing clinker substitution—remain important options, governed by product performance requirements and cost considerations.



Overview of the Cement Production

Cement manufacturing consists of three key stages: (i) raw material preparation, (ii) clinker production, and (iii) cement grinding with additives (Figure 2.1). Raw materials are mixed and milled into a fine powder. Clinker is produced in high-temperature kilns, most commonly rotary kilns, followed by shaft kilns. Both fuel combustion and chemical reactions generate CO_2 emissions: typically, 30–40% from fuel use and 60–70% from the calcination of limestone to produce calcium oxide. The resulting clinker is mixed with gypsum and optional supplementary materials such as fly ash (FA), ground granulated blast-furnace slag (GGBFS), and finely ground limestone to tailor cement performance. Cement may be produced at integrated plants or at separate grinding facilities. Production methods include wet and dry processes, with the wet process being more energy-intensive due to moisture removal requirements. This process demands precise chemical control, specialised equipment, and close monitoring of material and fuel streams, as the final cement properties depend on the precise composition of the clinker.

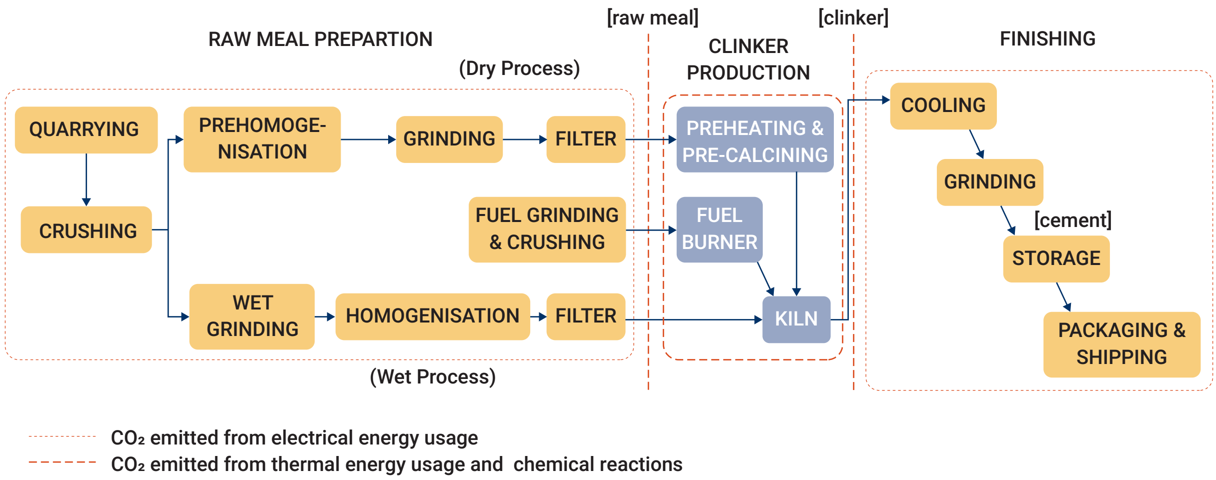


Figure 2.1: Schematic representation of the cement production process [14]

Raw meal preparation

Naturally occurring calcareous deposits—such as limestone, marl, and chalk—contain high concentrations of calcium carbonate ($CaCO_3$), an essential element in cement production. These materials are extracted using heavy machinery, typically from quarries located close to cement plants. Additional raw materials, such as iron ore, bauxite, shale, clay or sand may also be sourced to provide iron oxide, alumina and silica required to meet precise chemical and performance specifications for the raw mix. This stage may generate limited direct greenhouse gas (GHG) emissions, primarily from diesel-powered transport and quarrying equipment, but these remain a small share of total sectoral emissions.

Once extracted, the materials are crushed to pieces smaller than approximately 10 cm and transported to the plant. They are then blended to achieve the desired chemical composition in a process known as **pre-homogenisation.** Subsequently, the crushed material undergoes milling to produce a finely powdered substance known as "raw meal". Strict monitoring and control of the chemical composition of both the raw materials and the "raw meal" are carried out to maintain consistent and high-quality cement production.

Although fossil fuel consumption and thus GHG emissions in this production step are low, the electricity used to crush and mill the raw materials represents a significant share of a plant's total electricity use and operating costs. Ishak and Hashim (2015) estimated electricity consumption of about 24.5 kWh/t cement for raw material and fuel preparation.

Clinker production

Clinker production comprises three main steps: preheating, calcination, and sintering. These steps align with a temperature gradient and thus the integration of their respective heat uses is key to the thermal energy efficiency of any cement plant.

A preheater, consisting of up to six vertical cyclones, is utilised to heat the raw meal prior to its entry into the kiln. This is accomplished by exposing the raw meal to hot kiln exhaust gases travelling in the opposite direction, which promotes efficient chemical reactions. Depending on the moisture content of the raw material, kilns may incorporate multiple cyclone stages to capture increasing amounts of heat. Higher moisture contents mean that a higher exhaust gas temperature is desired for drying purposes, and thus, fewer preheating stages would be employed. Under typical modern operating conditions, a plant would employ five stages, achieving around 70% thermal efficiency.

Cement production also has the capacity to utilise waste materials and by-products from various industries and municipalities (e.g. old tyres, lubricants, lacquers, solvents, sewage sludge), employing them either as components in the raw mix or as fuels for pyro-processing (alternative fuels). Rotary kilns operate at extremely high temperatures (flame temperatures around 2,000°C and material temperatures near 1,450°C) and can retain material in high-temperature zones for up to 20 minutes [15]. Clinker can potentially bind toxic substances, closed monitoring and responsible handling are required for safe utilisation, or otherwise hazardous waste is generated. Given the heterogeneity of waste-derived fuels, including varying moisture content and calorific value, pre-treatment such as sorting, shredding and drying is often required. Ensuring energy efficiency, product quality and environmental safety necessitate rigorous regulation and monitoring throughout the process.

Calcination converts limestone into lime ($CaCO_3$ $CaO + CO_2$) and is the principal source of process emissions, which are unavoidable when limestone is used as the primary raw material. The calcination process can emit about 0.53 tCO_2/t clinker, representing around two-thirds of total clinker-related emissions. Modern cement plants employ a pre-calciner, where roughly 90% of calcination occurs [15]. The remainder of the carbon emissions originates from the combustion of fuel. In plants using pre-calciners technology, approximately 65% of the total fuel is utilised during this specific stage of the process. This procedure elevates the raw meal's temperature to above 900°C. Due to this lower temperature compared with the main firing, this processing stage may employ lower-quality energy carriers like low-caloric alternative fuels. It also theoretically eases electrification.

The pre-calcined meal then enters the kiln, where direct fuel combustion raises material temperatures to 1,450°C. As the kiln rotates, typically about three to five times per minute, the material progressively moves through zones of increasing heat towards the flame. This intense heat initiates chemical and physical reactions that cause the meal to partially liquefy (sinter), forming clinker. These kiln reactions involve the completion of limestone calcination, and the release of CO_2 from other minerals. Kilns that include a calciner can be shorter (since parts of the reactions are externalised) and focus on the high-temperature processes, reducing investment and increasing energy efficiency.

Finishing

The high-temperature clinker exiting the kiln is rapidly cooled from temperatures above 1,000°C to between 100°C and 250°C using a grate cooler. This cooler employs incoming combustion air to blow over the clinker, the process aided by electrically powered air blowers and heated circulating air to enhance thermal efficiency. Cement plants typically include a clinker storage facility located between the clinker production stage and the cement grinding phase. The cooled clinker can then be loaded for transport, enabling it to be traded or further processed into cement.

To produce cement, clinker is blended with various mineral components. Most cement types contain around 4–5% gypsum to regulate setting time. Additional materials—such as slag, fly ash, limestone, or other supplementary cementitious substances—may be incorporated to replace a portion of the clinker, resulting in blended cements. The clinker content in the mix can vary from as high as 95% to as low as 5%, influencing both the properties of the final product and potential applications. As clinker is the most energy- and emission-intensive component of cement (and consequently of concrete), shifting towards low-clinker cement is one of the most widely discussed strategies for partial decarbonisation, particularly as the emissions intensity of cement and concrete correlates almost linearly with the clinker share.

Options for Cement Decarbonisation

The best international practice currently refers to conventional fossil-based technologies, implying that there is no established international practice for decarbonised operations. Consequently, achieving current international best practice cannot be the goal of transforming the Thai cement sector.

International best practice cannot be defined solely by technology readiness or availability. International companies already operate in Thailand, and the respective technologies are available worldwide – the conventional cement production process itself is mature. Differences in operational efficiency, energy carrier use and cement types can be explained by market conditions, regulatory environments, and regional availability of energy carriers and raw materials.

Decarbonisation of the cement industry in Thailand may draw inspiration from the strategies and technologies being explored in Europe, but these must be adapted to the local context and capabilities, including stakeholder preferences. The high concentration of production around the metropolitan region may further enable the transition through coordinated action among cement plants in the area.

The international cement industry is grappling with the same challenges currently facing the Thai sector. No country or economic region has yet discovered and fully implemented a comprehensive solution. While decisive action may unlock new opportunities, it is also associated with significant risks.

To substantiate these observations, we outline three aspects of transformation that are being discussed in international settings, each of which can open pathways towards carbon neutrality (Figure 2.2).

First, the decarbonisation of energy use during the manufacturing phase remains the cornerstone of all mitigation efforts, owing to its close interaction with the broader energy system. It is coupled with energy efficiency as an immediate action point to reach the best available technology (BAT) levels. **Second**, the role of carbon capture, utilisation and storage (CCU/S) to address process-related emissions. **Third**, new binders and cement types—together with actions across the value chain, including reduced material consumption, circular-economy practices, and improved building design—form an essential part of the wider discussion.

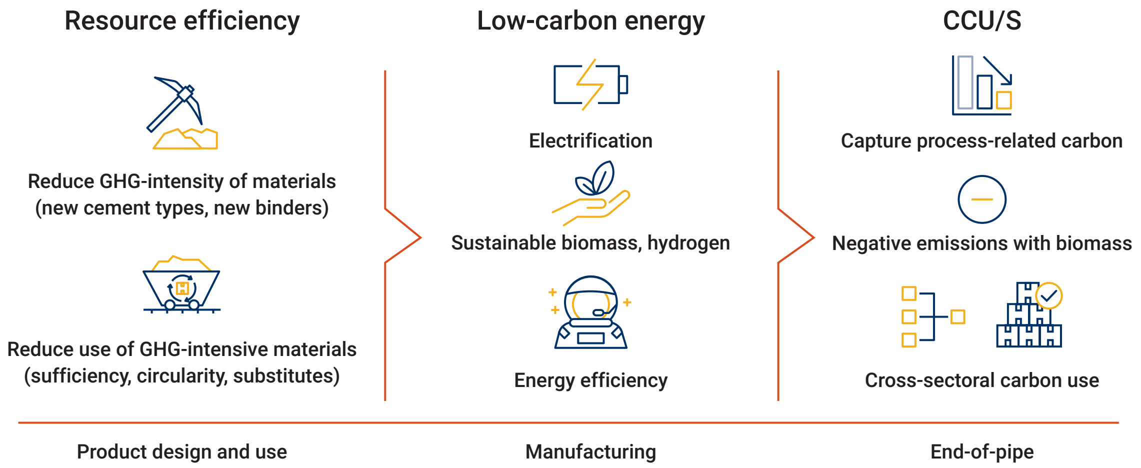


Figure 2.2: Summary of transformation concepts

Fossil fuels remain the dominant energy carriers in cement production worldwide. The carbon intensity of energy use in cement production ranges between that of natural gas and lignite. Regardless of the regional fuel mix, the global cement industry depends heavily on low-cost energy, as cement is a low-value, low-margin product. Consequently, switching to carbon-neutral energy carriers is inherently an economic challenge, with technical considerations playing a secondary role.

Low-carbon energy options exist

Fossil fuels remain the dominant energy carriers in cement production worldwide. The carbon intensity of energy use in cement production ranges between that of natural gas and lignite. Regardless of the regional fuel mix, the global cement industry depends heavily on low-cost energy, as cement is a low-value, low-margin product. Consequently, switching to carbon-neutral energy carriers is inherently an economic challenge, with technical considerations playing a secondary role.

Alternative fuels play a major role in several international cement operations; for example, some plants in Germany have both the regulatory approval and technical capability to operate temporarily on 100% alternative fuels. Their value for decarbonisation, however, depends greatly on perspective. The biogenic share of alternative fuels is considered carbon-neutral and supports at least partial decarbonisation. The fossil fraction, by contrast, requires disposal — typically through waste incineration if not used in cement kilns. Yet, according to the waste hierarchy, combustion is among the least preferred options, surpassed only by landfill. In a sustainable industrial system, these waste streams would ideally be avoided or recycled (especially waste plastic for use in the chemical industry), (especially waste plastic for use in the chemical industry); therefore, they be a long-term target for decarbonisation. However, efforts to establish waste collection, processing, and transport systems for these waste streams may in the long-term be redirected towards a circular economy.

From a technological perspective, **full electrification** of the cement production process is the "holy grail" of decarbonisation: No direct energy-related emissions, high efficiency, and comparatively low impact on surrounding infrastructure. However, the challenges involved are substantial. Solutions for technical implementation exist for **partial electrification** and may soon be available for full electrification [16, 17]. The primary barriers, however, are economic. As noted above, the most attractive characteristic of energy used in cement production is its low cost. Using electricity instead of lignite or waste is not economically viable at present. Means to address this include substantial CO_2-pricing in combination with decarbonised electricity supply, exemption of electric process heat generation from fees and taxes or direct subsidies for operational costs. In addition, the electrification of the high-capacity and energy-intensive clinker burning sites may require extensive infrastructure upgrades. An electrified cement sector will require close interaction with electricity infrastructure and power generation planning.

Development and progress of electric cement production

- **Technology readiness level (TRL):** 7 (partial) and 4 (full)
- **Technology penetration into the industry:** None to date
- **Case study:** The Leilac-2 [18] project aims to advance the calcination process step in clinker production by separating the process CO_2 from flue gases, thereby facilitating the capture of process-related emissions. The use of indirect heating in this system also allows greater fuel flexibility during calcination, including the potential use of electricity. As the rotary kiln remains unchanged, the Leilac-2 project offers a partial electrification option. Full electrification projects are not yet known.

[1] The indirect heating of the calcination stage of clinker and lime production enables fuel flexibility and carbon capture [16]. From a technical perspective, current demonstration projects show the feasibility of partial electrification of clinker (and full electrification of lime) production. Full electrification of cement requires additional technologies but are expected to be available before 2040 [17]. However, these approaches face economic and organisational challenges.

The main industrial applications for **hydrogen** are expected to arise in the steel industry—as a reducing agent for iron production—and in the chemical sector, where it can serve as a feedstock replacing fossil naphtha and natural gas. The use of hydrogen for the generation of high temperature process heat, as required in the cement sector, is another important possibility. In principle, it may be feasible to replace only the burner and fuel lines, offering a comparatively low-threshold decarbonisation option relative to the extensive redesign required for direct electrification. However, hydrogen is expected to be scarce and costly – even more so than electricity and a transition from natural gas to hydrogen infrastructure remains a subject of ongoing research and political debate.

Hydrogen as an alternative fuel for cement industry

- **Technology readiness level (TRL):** 7
- **Technology penetration:** None, aside from research and pilot projects.
- **Cost comparison (electricity, biomass, waste fuel (MSW), fossil fuels):**
  Hydrogen is expected to be significantly more expensive than competing carbon-neutral energy carriers (e.g. biomass, electricity). Its main advantage lies in the potential to serve as a near drop-in replacement, requiring relatively limited modifications to existing equipment, whereas direct electrification may entail substantial redesign or even greenfield investment. Actors often require or hope for green hydrogen gate price around 65 THB/kg, which is outside of the currently expected long-term range. With a more realistic hydrogen price of about 112 THB/kg (and by comparison, negligible costs for the conventional clinker-mix), a CO_2 price of roughly 9,500 THB per tonne would be needed to reach cost parity for hydrogen-based, fuel-emission-free cement. In the short to medium term, green hydrogen prices at scale are expected to be even higher, at around 190 THB/kg. These estimates exclude potential market premiums for low-carbon products, government subsidies or operational benefits, any of which could improve the economic case for hydrogen.
- **Case study:** The German association of cement producers (VDZ) has reported trials using hydrogen—alongside biomass—in rotary kiln burners [19]. Results showed that product quality is unaffected. However, the high costs of hydrogen rendered near-term economic viability unlikely.

Biomass is a relevant energy carrier in potential future fuel mixes in the cement industry. At present, it contributes mainly through the biogenic fractions of waste. These fractions – from municipal, industrial and commercial waste – are characterised by high moisture contents and significantly lower specific heating values than their fossil counterparts. Owing to the low heating value of many of these fractions, biomass is generally used to support calcination rather than sintering in the main firing. However, as around 60% of thermal energy is used in the calcination process, there remains potential to increase the use of low-calorific energy carriers.

The use of biomass is limited by the availability of sustainable sources. Thus, if any substantial increase is to occur in cement production, the industry will enter into competition for biomass resources. For a viable decarbonisation pathway, biomass use must be limited to genuinely sustainable potential; otherwise, apparent emissions reductions could be offset by negative impacts on other sectors such as LULUCF or agriculture. Given these constraints, a reallocation of existing biomass use between industries appears more plausible than a large expansion of total available biomass. Biomass is commonly used as a fuel in the Thai pulp and paper industry and the food-processing sector. As the principal applications in these sectors—steam generation, drying, cooking, and sterilisation—are comparatively easy to electrify using heat pumps or electric steam boilers, one possible strategy would involve shifting biomass use from these sectors to cement plants. In this model, electricity would replace biomass in the former sectors, while biomass would substitute fossil fuels in the latter.

However, several barriers would need to be addressed. These include the need for co-operation and co-ordination between industries that have historically interacted little, limited technical potential for fuel switching, the remaining lifetime of existing installations, and the willingness of firms to participate on a site-specific basis—all alongside logistical challenges associated with transporting and processing biomass. The current users of biomass in the paper and food sectors will need an incentive to part with their carbon-neutral energy carrier and switch to a more expensive one (electricity), and the cement manufacturers will also require a viable business case to abandon fossil fuel in favour of higher-priced biomass. In addition, intermediaries may be required to collect, process, and upgrade biomass to ensure quality and consistency.

When combined with CCU/S deployment in the cement sector, a substantial price on GHG emissions, combined with the option to trade negative emissions could enable the entire ecosystem of biomass redistribution.

Biomass as alternative fuel for the cement industry

- **Technology readiness level (TRL):** 9
- **Technology penetration:** varies across regions

On the global average, around 6% of fossil fuels are replaced currently by alternative fuels. In the EU, leading cement producers (Holcim, Cemex, Heidelberg, Italcementi and Lafarge) have significantly increased their substitution rates to nearly 40%, with biomass—including MBM, agricultural residues, woodchips and similar materials—accounting for around 27.5% of this share.

In the future, the cost of using alternative fuels, particularly biomass, will increase due to overall market development and the need to process and pre-treat new waste streams accordingly. Nevertheless, the comparative advantage over fossil fuels is likely to persist, especially when carbon pricing is considered.

According to the Global Cement and Concrete Association (GCCA) roadmap, the substitution rate of alternative fuels is projected to slightly exceed 40% by 2050, with biomass constituting roughly one-third of this share and fossil-derived waste comprising the remainder.

Across Europe, the cement industry currently substitutes around 46% of its fuel with alternative sources and aims to increase this further. There are no significant technical barriers to achieving a 60% substitution rate across the region by 2030. Co-processing is already contributing meaningfully to the sector's sustainability performance. Approximately 5% of the raw materials required for clinker production in Europe consist of recycled materials and ashes, resulting in an estimated 18 million tonnes of avoided CO_2 emissions annually.

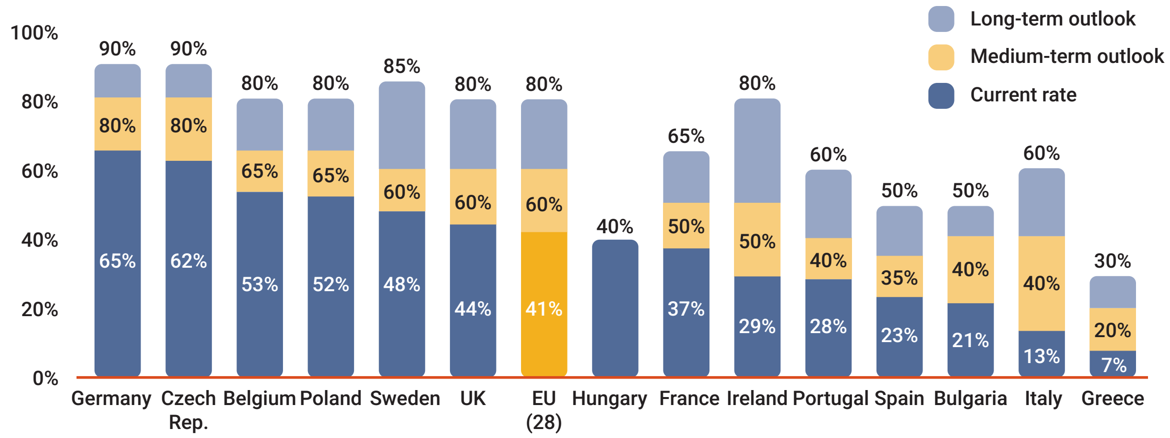


Figure : Outlook for the potential share of alternative fuels in energy use in the cement industry (Source: The European Cement Association [20])

In Germany, the Circular Economy Act and the EU Emissions Trading System (ETS) have incentivised the use of waste-derived fuels. The German cement industry aims to further increase the substitution rate of fossil fuels with waste-derived fuels, potentially reaching 80-90% in the coming years. Research and development efforts are focused on expanding the range of usable waste fuels and improving co-processing technologies. The cement industry will continue to play a key role in Germany's circular economy by utilising waste materials and reducing landfill dependency. Collaboration with waste-management companies, municipalities, and policymakers will be essential to ensuring a steady supply of waste-derived fuels. Due to its high fossil content, the role of waste-derived fuels in the decarbonisation of the cement sector is ambiguous and the addition of other strategies mentioned in this report are expected to be necessary.

In the international and European contexts, the **energy efficiency** of cement clinker production has long been a key priority, both in terms of electrical and thermal energy use (Figure 2.3). The substantial gains during the early part of the reported timeframe (up to the 1970s) have since given way to more incremental improvements – which approach a theoretical minimum of thermal energy demand. Achieving this level of energy efficiency is generally feasible, while restrictions might apply relating to raw material type and quality. While enhanced energy efficiency is often a no-regret solution, it needs to be combined with other measures to achieve full decarbonisation.

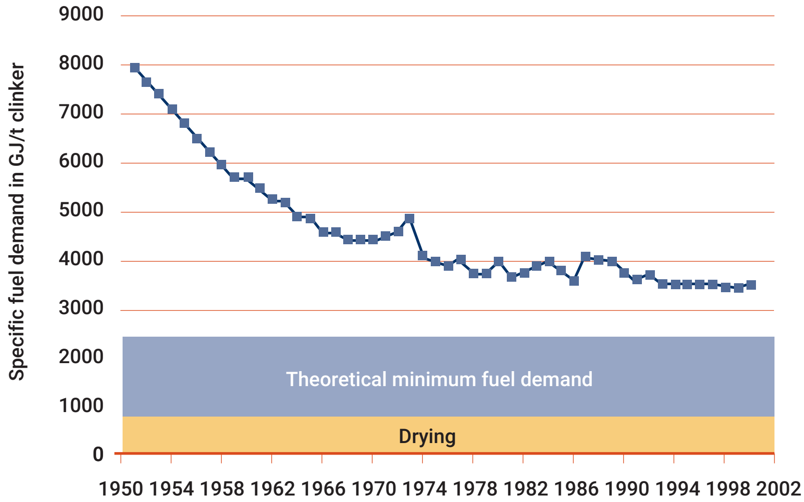


Figure 2.3: Development of specific fuel demand in clinker production in Germany up to 2002. Source: Adapted from [21]

Energy efficiency improvement in cement production processes [21, 22]

- **Grinding:** Use of ball mills for higher flexibility or vertical roller mills for higher energy efficiency addressing about 50% of total electricity demand in integrated cement plants (Germany, 2019: 112 kWh/t cement).
- **Waste heat utilisation:** Kilns in Germany achieve plant efficiencies exceeding 70%, supported by the recovery of waste heat from the kiln for drying fuels and raw materials. The heat integration along the gas stream (cooler, main firing, calcination, pre-heating) is a complex system, secondary and tertiary air streams must be considered. A grate cooler with about 75% efficiency, pre-calcination, and a 4-6 staged cyclone preheater are used. This allows smaller rotary kilns and reduces radiative heat losses.
- **Raw material:** The dry process (avoiding the addition of water to raw materials) is the more energy-efficient option, although applicability may be limited by material characteristics. Roller mills are preferred over tube mills due to their higher efficiency (approximately 13 kWh/t raw meal).
- A European association's publication expects no significant further reduction in specific energy consumption beyond approximately 3.2 GJ/t clinker (thermal) and around 90 kWh/t cement (electrical) on a European average [22].

Flexible Technologies in Cement Sector

The decarbonisation of the cement sector presents a dual challenge: reducing process-related emissions while adapting to an increasingly dynamic energy system driven by variable renewable energy (VRE). In this context, flexibility, defined as the ability to adjust energy consumption or production processes in response to external signals, has emerged as a critical enabler of both emission reduction and system integration.

Flexible industrial applications encompass systems and operational approaches that allow cement plants to respond to changing conditions. These may include switching between fuel sources, adapting to variations in raw material availability or quality, or shifting electricity-intensive operations such as grinding and milling to periods when renewable electricity is abundant and energy prices are low. Such measures not only support grid stability but also improve cost-efficiency and reduce carbon intensity. Alongside technical solutions, flexibility can be supported through demand-side strategies and appropriate market frameworks [23]. These include: (1) time-of-use or dynamic tariffs that incentivise off-peak energy consumption, (2) demand response programmes that compensate industrial users for reducing or shifting load during periods of high demand or grid stress, and (3) mechanisms that enable real-time adjustment of consumption to support grid frequency control. Enabling cement producers to participate in these mechanisms requires a combination of regulatory support, digital infrastructure, and investment in flexible technologies.

Demand-side energy management (DSM) is a strategy used to optimise how and when energy is consumed, particularly during periods of high demand or price volatility. In energy-intensive sectors such as cement, DSM plays an important role in improving operational efficiency, reducing costs, supporting the stability of the power grid and managing grid congestion. The core objectives of DSM include peak clipping, valley filling, and load shifting. Peak clipping reduces electricity demand during high-load periods, avoiding the need for peaking generation capacity. Valley filling encourages energy use during off-peak hours, thereby displacing less efficient generation and improving the overall system load factor. Load shifting refers to rescheduling electricity consumption from peak to off-peak periods, effectively flattening demand profiles and reducing pressure on the grid during high-demand intervals. [24]

Different DSM strategies can be applied to achieve these objectives. Reference [25] categorises these strategies into four primary types. The first is long-term demand reduction through process and system optimisation, which reduces baseline energy consumption and emissions by improving operational performance; although not typically considered a flexibility measure, it contributes to easing grid stress and improving overall energy-system efficiency. The second is time-of-use pricing, which offers pre-scheduled tariff variations to encourage consumers to shift energy use to off-peak hours. The third strategy is demand response, including real-time pricing mechanisms, where electricity rates vary based on wholesale market conditions and utility-led programmes that allow for remote curtailment or control of specific loads in exchange for compensation (Figure 2.4). The fourth is the provision of spinning reserve services by industrial consumers capable of rapidly reducing their load in response to grid-frequency deviations, thereby providing near-instantaneous system support. These measures are emerging as key components of cement-sector decarbonisation by reducing reliance on coal and other fossil fuels and by facilitating the integration of variable renewable electricity and the uptake of innovative, low-carbon technologies. By enabling operations to shift to low-price periods, typically when renewable generation is abundant, demand-side flexibility helps align industrial demand with clean energy supply. Moreover, flexible technologies that allow for the hybrid use of energy carriers, such as switching between electricity, hydrogen, or biofuels, provide operational adaptability that supports both emissions reduction and energy cost optimisation. As a result, these strategies offer system-wide benefits while delivering tangible economic advantages to industrial users.

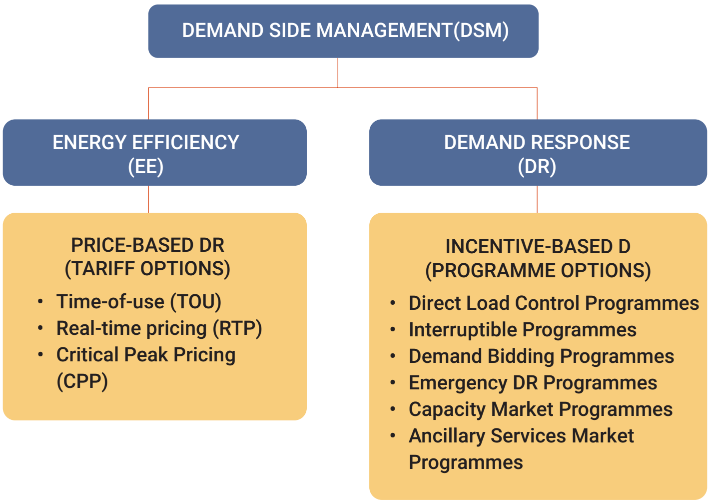


Figure 2.4: Classification of DSM

In practice, implementing demand flexibility particularly through load shifting, typically requires the integration of dedicated energy storage systems, such as thermal energy storage, hydrogen storage, or material buffers, or the deployment of process overcapacity, for example in grinding or thermal processing units. These measures allow energy-intensive operations to be decoupled from real-time electricity consumption. By contrast, load shedding involves a direct reduction in production output, which may entail short-term revenue losses. However, such measures can become economically viable when offset by energy cost savings or financial incentives offered through participation in electricity markets or grid support programmes.

Cement production requires both electrical and thermal energy at different stages of the process. Electrical energy is used predominantly for crushing limestone, grinding raw materials, and final milling of cement, while thermal energy is required to drive the high-temperature reactions in the rotary kiln, particularly during the calcination process. The potential for flexibility differs between these two energy types and depends on the characteristics of specific unit operations.

In cement production, grinding processes and the milling of raw material, clinker and cement, are typically not tightly coupled to the continuous production flow and can be paused, rescheduled, or ramped up with minimal impact on plant operations or product quality. This flexibility is enabled by intermediate storage systems (such as silos), which serve as buffers, decoupling grinding from upstream and downstream process stages and thus allowing for effective load shifting. As illustrated in Figure 2.5, shifting grinding activities from periods of high grid demand (and high prices) to periods of lower demand (and greater renewable penetration) reduces system stress and enables the cement sector to participate in DSM. Grinding systems are particularly suitable for such flexibility measures due to their short response times (often minutes), high controllability, and minimal impact on product quality. Figure 2.5 demonstrates how load shifting, primarily in grinding, can flatten both plant-level and system-level demand profiles.

In contrast, the rotary kiln, which is core process for clinker production, must operate continuously under high-temperature conditions with considerable thermal inertia and stringent material flow requirements. This makes it far less suitable for short-term operational flexibility. Instead, potential future flexibility for the kiln lies in fuel switching between conventional fuels (e.g., coal, natural gas) and low-carbon alternatives such as hydrogen, as depicted in Figure 2.6. In a hybrid operational scenario, the kiln maintains a constant thermal load while dynamically adjusting its fuel mix in response to real-time price or carbon intensity signals. When electricity or hydrogen prices are low, hydrogen usage increases, displacing a portion of the conventional fuel, and vice versa. Figure 2.6 highlights the potential for flexible fuel-switching in continuous kiln operation without compromising operational stability [26].

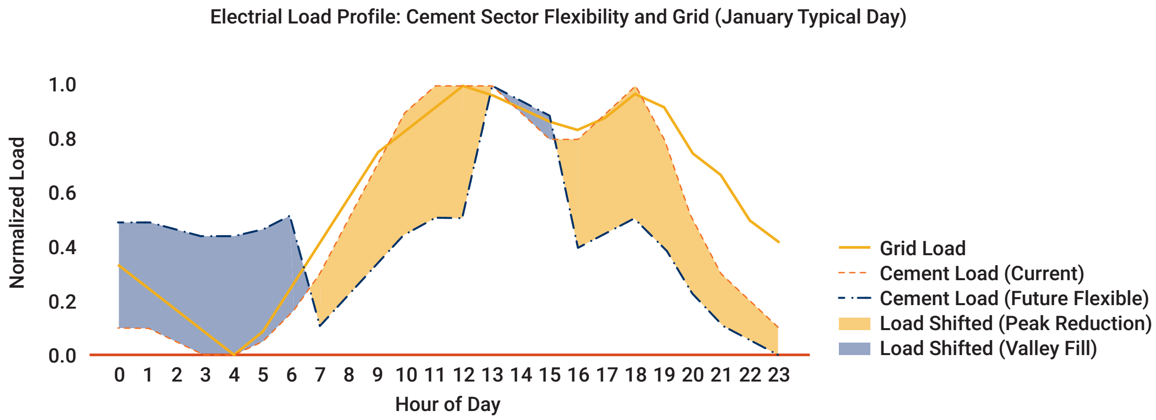


Figure 2.5: Typical electrical load profile for the Thai cement sector (normalised, January day). Current operations coincide with national grid peak periods, whereas a flexible future scenario shows load shifting to off-peak and renewable-rich hours.

Electrification of thermal processes, such as drying further enhances flexibility options. Thermal flexibility, however, remains challenging due to the continuous, high-temperature requirements of the rotary kiln. Nonetheless, emerging decarbonisation pathways such as green hydrogen combustion or advanced biofuels create new opportunities for thermal load management. On-site hydrogen production through electrolysis, combined with suitable storage, enables facilities to increase or decrease hydrogen generation in response to electricity availability, thereby transforming the hydrogen system into a flexible energy buffer while contributing to emissions reduction. In Germany's Westküste100 project, a cement kiln uses oxygen produced by an electrolyser for oxy-fuel combustion, while captured CO_2 is utilised for synthetic fuel production [27]. Biofuels such as sewage sludge also offer flexibility, particularly in their pre-treatment stages (e.g., drying and milling), which can be scheduled during off-peak energy periods. On the consumption side, cement plants can increasingly integrate on-site renewable generation and adjust their operations to reflect grid conditions. For example, Cementos Portland in Spain operates a solar PV installation at its facility and can shift certain electricity uses to periods of highest solar generation. This effectively transforms the cement plant into a flexible load capable of absorbing surplus renewable electricity and later deploying the stored energy for clinker production. Co-locating renewable generation and storage with cement kilns could enable kilns to reduce fossil firing during peak renewable output hours (e.g. midday solar generation), while relying on stored heat at other times—thereby smoothing overall demand on the grid.

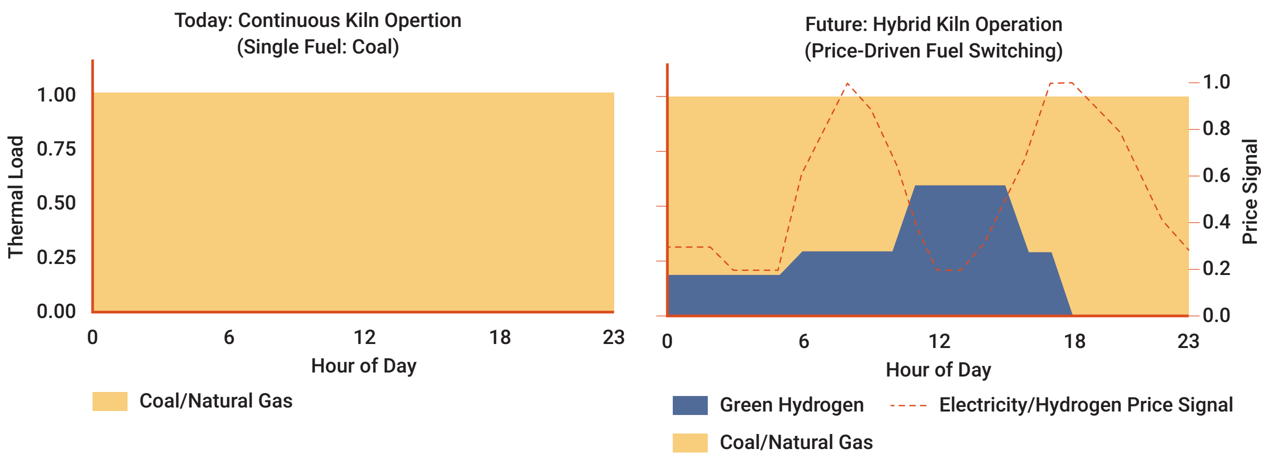


Figure 2.6: Clinker kiln operation: (Left) Present-day, continuous operation supplied by coal or natural gas; (Right) Potential future hybrid operation, dynamically switching between conventional fuel and green hydrogen in response to real-time price signals, while maintaining stable kiln operation.

In addition to fuel-switching technologies, Carbon Capture and Storage (CCS) and Carbon Capture, Utilisation, and Storage (CCU/S) can also contribute meaningfully to industrial flexibility, particularly in relation to electricity demand management and grid integration. Flexibility in CCS systems can be achieved through several operational strategies. First, load shedding can be implemented by temporarily bypassing the CCS unit, allowing CO_2 to be released directly into the atmosphere rather than captured. While this approach is compatible only with biofuel combustion, where the emissions are considered carbon-neutral, it can reduce a plant's electricity consumption during high-price periods, particularly in conventional configurations where the CCS system represents a major share of the total electrical load. If thermal processes such as the kiln are electrified in the future, bypassing the CCS system would have a more limited impact on overall electricity demand.

Second, load shifting can be implemented through the addition of solvent storage in amine scrubbing systems. In this configuration, CO_2 is absorbed into a solvent during the scrubbing phase, and the energy-intensive separation step (stripping and compression) can be delayed until electricity prices drop. This approach allows cement plants to defer high-load operations and undertake them during off-peak periods.

Lastly, partial bypass or half-load modes can allow only a portion of the flue gas to be treated by the CCS unit, enabling graded flexibility depending on the power grid's condition. Such strategies can lower operating costs and improve the commercial viability of CCS investments. These characteristics position CCS and CCU/S technologies as both emissions mitigation tools and strategic assets for operational flexibility within a low-carbon industrial system. However, it should be noted that using flexibility modes such as bypassing or partial capture will also lower the overall emissions reduction achieved by the plant compared to continuous CCS operation. In addition, such operational changes could create challenges for product labelling and certification, particularly if part of a plant's output fails to meet the criteria for low-carbon or carbon-neutral status during periods of reduced capture.

Thermal energy storage offers a way to recover and reuse high-temperature waste heat in cement plants, improving both efficiency and flexibility. Technologies such as EnergyNest's concrete batteries and Rondo's heat bricks can store heat at 500–1500°C and release it when needed, enabling processes like drying or preheating to shift based on electricity price signals. Siam Cement Group (SCG) is piloting such a system in Thailand, using off-peak renewable electricity to charge thermal storage and supply heat to kilns on demand [28, 29].

To capture the full value of operational flexibility, energy-intensive industries are increasingly exploring new business models and market participation opportunities. Cement plants, for instance, have started to operate more dynamically in response to electricity market signals.Heidelberg Materials Hellas, in partnership with the aggregator Sympower, optimises the operation of its cement and raw mills to provide several megawatts of flexible load to the Greek balancing market without affecting production [30]. Similar strategies are emerging across sectors. In Sweden, Uddeholm AB adjusts the operation of its electric furnaces to deliver up to 13 MW of fast demand response for frequency containment reserves through Sympower's platform [31], while Boliden provides about 8 MW of flexible demand from its ore grinding mills into the same market [32]. In the aluminium sector, Rio Tinto's Tiwai Point smelter in New Zealand signed a 20-year contract that allows the utility to curtail up to 185 MW of load when grid conditions require it [33]. Aggregators such as Sympower, Enel X and Voltus are enabling this transformation with digital platforms that pool industrial loads and monetise them in electricity markets. Sympower alone manages over 1.4 GW of flexible capacity across Europe, covering a range of industrial sectors including cement, steel and paper. These developments are supported by regulatory efforts and demonstration projects such as the IndustRE project, funded under Horizon 2020, which piloted business models for demand-side flexibility in the cement and chemical sectors [34]. Together, these examples show that flexible operation is no longer just a technical option; it is becoming a viable commercial strategy that can reduce energy costs, support grid stability and generate new revenue streams for industrial operators.

Several challenges must be addressed. High capital investment is required for technologies such as hydrogen or electric kilns, pre-heaters and calciners, electrolysers, and CCS units. Their profitability often depends on regulatory incentives, carbon pricing, guaranteed offtake agreements, and demand response programmes. Flexibility introduces complexity to process operation, requiring digital controls and predictive maintenance systems to ensure process stability and product quality.

Policy and regulatory frameworks play a decisive role in unlocking the flexibility potential of cement plants. Access to electricity markets, time-of-use tariffs, and carbon pricing are central to incentivising demand-side response and investment in flexible technologies. In Europe, regulatory reforms have enabled cement plants to participate in balancing and ancillary service markets by offering controllable loads from grinding operations. In Switzerland and Sweden, for example, automated mill controls allow cement producers to provide fast frequency reserves without disrupting output [35]. In Asia, China has piloted cement participation in industrial demand response programmes, supported by grid operators that recognise process buffers as valid flexibility resources.

Process-related emissions can be addressed

Process-related emissions – i.e. CO_2 released from the limestone content of the raw material during calcination – create a significant challenge that is highly specific to cement production. About 65% of greenhouse gas (GHG) emissions in modern cement plants are process-related and can thus not be reduced by fuel switching to less emission-intensive energy carriers. As a complement to other mitigation options, **carbon capture** utilisation **and/or storage (CCU/S)** is of high interest for many cement producers and their associations worldwide [36, 37]. This type of technology is a centrepiece of many sectoral decarbonisation roadmaps and industry decarbonisation studies. The expected contribution of carbon capture and storage and/or use to decarbonisation within the confines of the cement production process (i.e. excluding measures further down the value chain) amounts to around 40-50% and is thus the single largest individual mitigation technology in these strategies. Existing considerations highlight that (a) the technology can be economically attractive, and (b) it creates a substantial contribution to emission avoidance, while (c) at the same time failing to deliver full decarbonisation. Reservations against a strong role for CCU/S are held by some stakeholders, highlighting risks of underground storage and transport of CO_2, as well as a particular strategic argument: If CCU/S is allowed and enabled, the incentive to decarbonise other sectors, but also other emission sources within the sector – in particular energy-related emissions of clinker production – may be diminished. The deployment of fossil-based CCU/S could therefore retain a viable business case for fossil value chains, prolonging fossil supply and thus hindering decarbonisation efforts in other areas. Barriers to the deployment of CCU/S in cement production are similar to those faced by the technology more broadly. While CCU/S is technologically advanced and, in some cases, close to maturity, significant economic, technical and regulatory challenges remain. The need for infrastructure for large-scale CO_2 transport and storage creates additional organisational and regulatory hurdles. Although CCU/S may be relatively competitive in certain contexts, additional costs must be compensated for, for example through CO_2 pricing mechanisms or market premiums for low-carbon products.

CCU/S for cement industry

- A range of technologies is available. Amine-based absorption (MEA) is regarded as a mature option, with a technology readiness level (TRL) of 8–9. Other technologies (calcium-looping, adsorption with pressure and temperature differences, oxyfuel) are considered to range between TRL 5 and 7 [22]. Indirect calcination technologies also intersect with opportunities for partial electrification (see above).

- Post-combustion capture processes require significant energy input, particularly for solvent regeneration, and may necessitate substantial investment to retrofit existing facilities. Additional regulatory challenges relate to the transport and storage of CO_2, alongside the capital requirements for developing the associated infrastructure.

- Capture costs alone are estimated at €40–80 per tonne of CO_2 [21]. Although potentially competitive under European carbon-pricing conditions, further costs associated with CO_2 transport and storage raise the total cost to approximately €150 per tonne of CO_2.

Actions along the value chain are possible

Process-related emissions in cement production are often perceived as unavoidable – although this is a simplified narrative. In practice, with current technology, raw materials, and levels of activity, process-related emissions cannot be completely avoided. In principle, however, **primary avoidance** of greenhouse gas (GHG) emissions is possible. New production technologies may be able to reduce the amount of limestone required while delivering equivalent product performance. These alternative binders make more efficient use of functional compounds in clinker and alter the production processes significantly. However, to date, these technologies remain relatively expensive and would require the replacement of major production facilities, as well as substantial regulatory changes. The market potential of new binders is estimated to be about 5%.

As another option, alternative main components substituting limestone-based clinker are being explored. Their use does not represent a fundamentally different direction in cement manufacturing, but rather a shift from existing clinker substitutes (e.g. blast furnace slag and fly ash) to other supplementary materials. Industry publications increasingly focus on these types of cement, which can deliver primary GHG emission reductions and are already established within European standards (CEM II–CEM V). However, cement types with very low clinker content face significant application constraints and currently account for only small market shares. Several technological pathways and concepts exist, each with distinct advantages and challenges [22].

Limestone-based clinker as the main ingredient is not without technical alternatives. Geopolymers, a group of alternative materials, may function as substitute binders and enable new types of cement and concrete. However, the lack of established standards for these products remains a key barrier, and several formulations rely on industrial by-products that are scarce or expected to become scarce. As a result, geopolymers play no or only a marginal role in current manufacturer roadmaps. Existing strategies also assign only limited mitigation potential to reductions in overall cement production volumes. Nevertheless, several options along the value chain could significantly reduce cement demand. These include reductions in per-capita living space, increased adoption of circular-economy approaches, more efficient use of cement in buildings through a higher share of precast elements, and the substitution of concrete with alternative construction materials. Additional demand-side strategies may also apply. In their most far-reaching form, strict adoption of these measures could result in a system in which remaining emissions from cement manufacturing are sufficiently low to be offset by natural carbon sinks, potentially eliminating the need for CCU/S. However, the societal and political costs associated with such a level of transformation would be substantial— especially in growing economies, where visible improvements in material living standards remain a central factor in political legitimacy.

[2] Projects of companies also active in Thailand include pilot and demonstration plants in Europe [36]. It includes CCU/S on-site and re-carbonisation during the use phase to balance greenhouse gas emissions during production. The resulting product is described as "net-zero" via a mass-balance [37]. However, this approach involves resource shuffling and therefore does not represent decarbonisation, but merely a first step.

[3] Recent examples of efforts to create new cement types include calcined-clay/limestone cement with higher-than-usual shares of supplementary cementitious material ([21]).

CHAPTER 3

A VISION FOR CARBON-NEUTRAL THAI CEMENT FUTURE

Key Messages

- Thai Cement Manufacturers Association (TCMA), together with the Global Cement and Concrete Association (GCCA), has set out strategies for reducing carbon emissions and is actively exploring various options to achieve net-zero emissions by 2050.

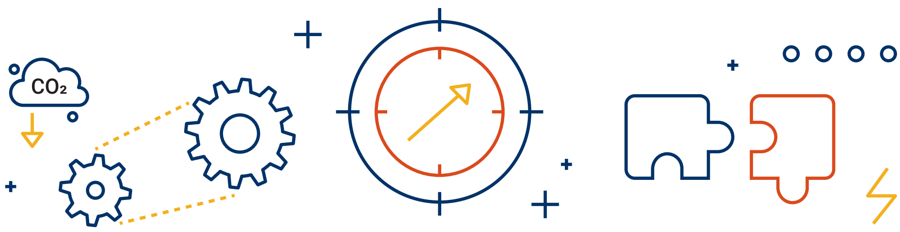
- Long-term energy assessments estimate that energy consumption in the Thai cement sector is about 2,900 ktoe per year. Although the efficiency of equipment in the cement production will improve, electricity consumption is expected to rise substantially due to the adoption of carbon capture and utilisation technologies.

- Policy measures must be carefully coordinated at different stages across industries and along the value chain to ensure a comprehensive approach. The initial phase should focus on identifying technically feasible pathways tailored to each industry. Such an integrated approach ensures that every segment of the supply chain plays a significant role and derives mutual benefits from the decarbonisation efforts.

- Developing carbon pricing mechanisms, such as Carbon Contracts for Difference (CCfD) and carbon credits, can mitigate operational expenditure (OPEX) risks for early adopters by offsetting higher costs and uncertainties associated with future carbon prices. These mechanisms can improve the financial viability of low-carbon technologies and stimulate investment by strengthening the economic case for green innovation.

- Effective decarbonisation efforts require the creation of business models that integrate the entire supply chain, enabling all stakeholders to participate and benefit. However, to address systemic challenges such as market inertia, uncertainty, and demand issues, the implementation of comprehensive and coherent policies is essential. Key measures include capacity-building programmes, supportive regulatory frameworks, targeted financial incentives, and robust green-procurement policies.

- The long-term policy framework should aim to make low-carbon cement production financially viable, stimulate demand for low-carbon concrete, and develop the infrastructure needed to support a circular and net-zero manufacturing system. Enabling a circular-economy ecosystem and providing incentives for recycled materials and renewable energy will be essential for achieving lasting environmental benefits.



Long-term Energy Assessment and Abatement Cost

To enable the decarbonisation of the cement and concrete sector, the decarbonisation roadmap has been developed by TCMA, as detailed in Chapter 1. The actions required to achieve net-zero emissions are structured into three implementation phases.

Short Term (2020–2030)	⟶	Regulatory alignment, stakeholder engagement, and pilot projects
Medium Term (2030–2040)	⟶	Large-scale adoption of alternative fuels, digitalisation, and process optimisation
Long Term (2040–2050)	⟶	Full implementation of carbon-neutral technologies and achievement of net-zero emissions

Figure 3.1 illustrates the projected percentage contributions of various measures and technologies towards achieving net-zero emissions and associated CO_2 savings by 2050 organised across seven strategic levers. Each lever comprises one or more greenhouse gas (GHG) mitigation measures or technologies, which deliver varying levels of contribution and CO_2 emission reductions. The smallest contributions, at approximately 5%, are expected to come from the increased use of clean electricity in production plants and from improvements in process optimisation and control within concrete production. Slightly higher contributions, in the range of 8–10%, are projected from the natural uptake of CO_2 by concrete, and from savings in cement and binders. A more significant impact, contributing around 12–15%, is anticipated from improvements in thermal efficiency, advances in design and construction, and emission reductions at the plant level through the use of alternative fuels and hydrogen. The most significant contribution, however—accounting for approximately 45% of total CO_2 emission reductions—is expected to result from the deployment of carbon capture, utilisation and storage (CCU/S) technologies.

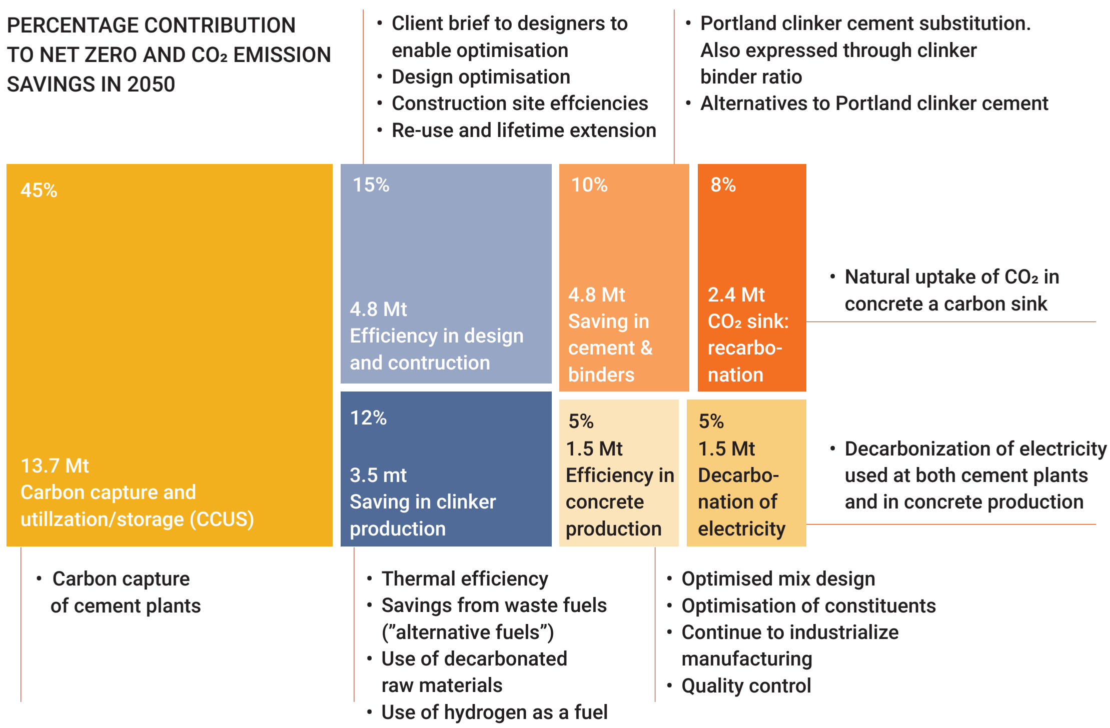


Figure 3.1: Percentage contribution to Net Zero and CO_2 emission savings in 2050 [TCMA's decarbonisation roadmap]

To achieve these decarbonisation pathways, adjustments to the energy profile—specifically the fuel mix used in cement production—must be implemented to shift towards cleaner and low-carbon sources. These adjustments can be estimated using energy and mass balance analyses, with the results indicating the fuel composition of the decarbonisation pathways in 2020, 2030, 2040 and 2050, as well as their respective energy consumption (ktoe/year) and CO_2 emissions (Mt/year). This analysis must incorporate specific assumptions that are fully aligned with mitigation measures or technologies outlined in the decarbonisation roadmap, ensuring that the pathways are accurately and consistently represented. The results of this analysis can provide valuable guidance on how cement plants can optimise their internal operations—such as adjusting fuel—while also supporting the implementation of GHG mitigation measures beyond the production process, including improvements in design and construction efficiency and preparation for the integration of CCU/S technologies in the medium- and long-term phases. The assumptions applied for the assessment of fuel composition fuel proportion and energy consumption are summarised in Table 3.1.

Table 3.1: Assumptions for the fuel-proportion and energy-consumption assessment

Description	Unit	2020	2030	2050
Domestic cement consumption	Mt/year	33.3	33.1	30.3
Specific fuel energy demand	GJ/t clinker	3.0	3.6	3.5
Specific electrical energy demand	kWh/t cement	104	97	90
	kWh/t clinker	-	-	-
Thermal substitution rate of alternative fuel (including green hydrogen)	%	18	30	50 (10)
Clinker-to-cement ratio	%	77	70	65
Clinker CO_2 emission factor*	kg CO_2/t clinker	532	532	532
Binder-saving potential through design & construction efficiency	%	-	10	15
Binder saving potential through innovation in concrete	%	-	3	5

*This value represents only CO_2 emissions from the calcination process and excludes emissions from thermal energy and electricity use

Fuels-proportion and energy-consumption scenarios on decarbonisation pathway

Energy consumption for cement production is assessed in line with Thailand's cement decarbonisation levers and pathways, as illustrated in Figure 3.2. The assessment is based on published data from the Thai Cement Manufacturers Association (TCMA)

The energy consumption is estimated at 3,176 ktoe in 2020. Coal use is responsible for the majority at 70.5% of the total energy consumption while electrical energy from the grid comes second at 16.2%. Through the success of promoting material and design efficiency and increasing the use of alternative fuels (biomass and refuse-derived fuel), the total energy consumption for cement production will be approximately 2,726 ktoe in 2030. The corresponding share of coal use is 31.4% while that of alternative fuel is as high as 51.1%. The assessment further indicates that electricity demand will increase significantly with the introduction of carbon capture, utilisation and storage (CCU/S) into the production process from 2040 onwards. Under the assessed scenario, hydrogen is projected to account for approximately 10.2% of total energy use by 2050.

Based on this energy assessment, the most immediate priority for meeting the decarbonisation pathway is to accelerate the use of alternative fuels including biomass and refuse-derived fuel, alongside renewable electricity in cement production.

In line with the decarbonisation pathway and the fuel-use profile described above, carbon dioxide (CO_2) emissions from the cement industry are illustrated in Figure 3.3.

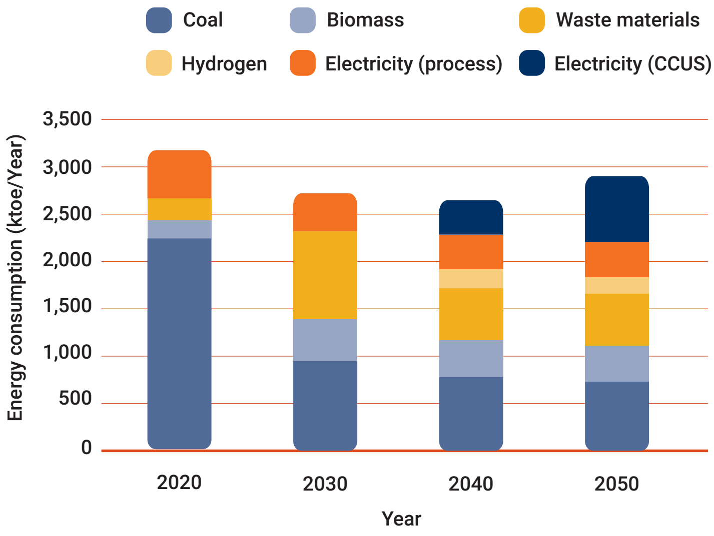


Figure 3.2: Energy consumption in cement production under the decarbonisation pathway

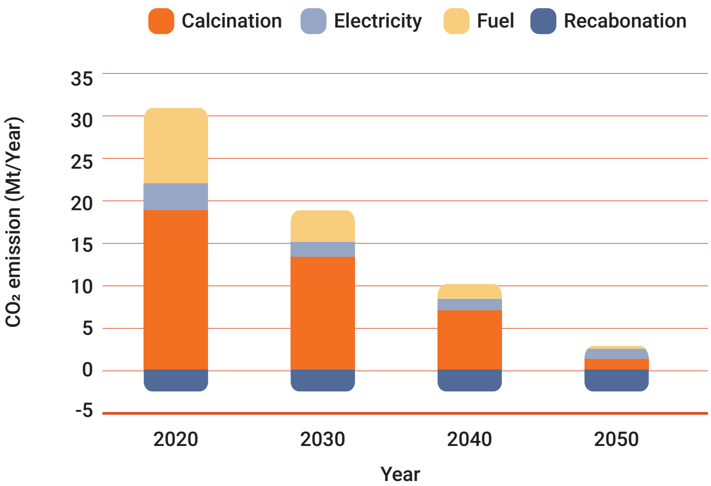


Figure 3.3: CO_2 emission assessed under the 2050 cement and concrete decarbonisation pathway

Abatement cost of key measures

A techno-economic assessment of decarbonisation in the cement industry is examined using the CO_2 marginal abatement cost (MAC). The cost represents the monetary value per unit of realised or estimated CO_2 reduced by a technology or decarbonisation measure (baht/tonneCO_2). Figure 3.4 illustrates a comparison of the abatement costs of four key measures: renewable electricity, clinker substitution, alternative fuels, and carbon capture, utilisation and storage (CCU/S).

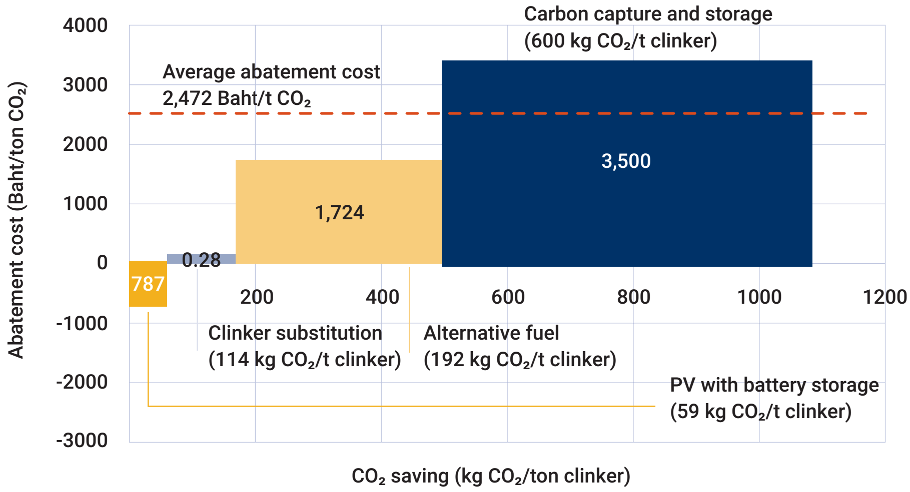


Figure 3.4: Abatement cost of key decarbonisation measures for Thailand's cement industry

On-site photovoltaic (PV) systems with battery storage present the most cost-effective decarbonisation measure by providing clean electricity to power electrically driven processes across the cement production chain, including raw material preparation, fuel preparation, cement grinding and packaging. At present, electricity generated from PV systems is lower in cost than electricity supplied from the national grid.

Calcined clay cement (LC3) can potentially reduce carbon dioxide emissions by up to 40% compared with Ordinary Portland Cement. Thailand has successfully launched hydraulic cement for use in both public and private construction projects. LC3 is envisaged as the next step to further reduce CO_2 emissions. As LC3 contains a lower share of clinker and calcined clay production requires less process energy, the marginal abatement cost of LC3 increases only slightly. However, additional costs related to chemical treatment, including cement additives and/or concrete admixtures, are typically required to ensure practical concrete workability. These costs arise from the higher water demand associated with calcined clay. Such factors must be carefully considered in the economic feasibility assessment of LC3 and may pose a significant challenge for industry adoption.

Clinker production requires substantial amounts of thermal energy. Coal remains a major fuel source, although alternative fuels—including biomass and waste-derived fuel (RDF)—have seen increasing use in recent years. Their cost is approximately 20% lower than that of coal. However, the long-term availability of biomass and RDF is uncertain, as other sectors—particularly the power sector—also rely on these resources for decarbonisation. Hydrogen is being assessed as a potential clean fuel in the medium- and long-term. Based on discussions with the cement association, this study assumes that hydrogen will account for around 10% of total thermal energy demand by 2050. Based on the fuel mix shown in Figure 3.4, the abatement cost of alternative fuels is estimated at 1,724 baht per tonne of CO_2

Carbon capture and storage (CCS) is the only technology capable of directly addressing CO_2 emissions from the cement calcination process. Research and studies on CCS technology are ongoing and several pilot projects have been developed for demonstration purposes. Among the available CCS options, oxy-fuel combustion is likely the most cost-effective with moderate technology readiness level (TRL 6) for the cement industry. Based on the compiled data, the technology abatement cost is estimated at approximately 3,500 baht per tonne of CO_2, making it the most expensive decarbonisation measure assessed.

According to the techno-economic analysis above, the average carbon abatement cost for cement sector decarbonisation in Thailand is estimated at approximately 2,472 baht per tonne of CO_2.

Overall, the assessment indicates that the expanded use of alternative fuels—including biomass and refuse-derived fuel—as well as renewable electricity, represents some of the most critical measures for achieving the decarbonisation pathway. To ensure effective implementation, co-ordinated action across multiple fronts is required, including the introduction of new legislation, revisions to existing policies, and the development of appropriate financial mechanisms. The following section therefore outlines key enabling components and stakeholder roles required to support a decarbonised cement sector in the future.

Key Components of the Decarbonised Cement Future

Globally, the cement industry is advancing a range of technologies to achieve carbon neutrality. These efforts include the development of improved manufacturing processes and carbon capture technologies, supported by significant funding from governments and international bodies. In Thailand, however, each cement kiln currently emits several thousand tonnes of CO_2 per day in the absence of robust policy incentives and strong regulatory requirements.

Existing Thai policies are assessed against international policy frameworks and actions to identify opportunities to accelerate policy development and innovation in support of the large-scale deployment of low-carbon cement technologies. The cement sector will require substantial and sustained policy support to transition to net-zero emissions, overcoming economic, technical, regulatory, and social barriers. A coherent and comprehensive policy framework is therefore required, focusing on low-carbon energy supply, CO_2 infrastructure for utilisation and storage, production processes, and downstream demand creation for low-carbon cement. Such a framework will be essential to overcoming deployment barriers and enhancing the sector's circularity and long-term sustainability.

Table 3.1: Comparison of Policy Measures for Cement Decarbonisation in Thailand and Globally

Aspect	Policy Measure in Global Perspective	Policy Measure in Thailand
Status	Policy measures are at an early stage. In the Asia Pacific region, policy frameworks are yet to be established.	Currently, there is no policy framework for the industry decarbonisation roadmap for Thailand. However, TCMA has implemented the **'Thailand 2050 Net Zero Cement & Concrete Roadmap'**, aligned with Thailand's NDC. Government policy and financial incentives are expected to play a supporting role in enabling the roadmap implementation.
Supporting laws and regulations	The EU Net-Zero Industry Act proposes financial incentives and funding opportunities to support the development and implementation of low-carbon technologies within the cement industry. This includes grants, subsidies, and loans to facilitate investment in innovative production processes and carbon capture technologies.	Thailand's first Climate Change Act (public hearing held in March 2024 on the draft prepared by the Department of Climate Change and Environment) is expected to be enacted in the next two years, covering (GIZ, 2024) [38]: - Climate change master plan - Carbon tax system (to be administered by the Ministry of Finance) - Carbon credit issuance (to be registered with the Thailand Greenhouse Gas Management Organisation). - Green taxonomy (e.g., Phase I issued by the Bank of Thailand in 2023) and mandatory greenhouse gas reporting
Market-based carbon pricing	ETS schemes are the most widely used market-based carbon pricing mechanisms to incentivise cement producers to reduce emissions. Examples include the EU-ETS, California ETS, and China ETS.	Carbon pricing mechanisms are not yet fully operational in Thailand. The recent development includes the establishment of a carbon pricing framework, which is expected to be incorporated into the forthcoming Climate Change Act in Thailand.
Carbon tax	Carbon tax is a market-based policy tool that places a price on CO_2 emissions by internalising the social cost of carbon. It provides an economic incentive for decarbonisation while generating government revenue that can support climate initiatives or social programmes. Unlike emissions trading systems, which cap total emissions, a carbon tax sets a clear price signal that helps guide investment decisions towards low-carbon technologies.	As of 2025, Thailand has officially introduced a carbon tax through the existing excise tax framework on oil and petroleum products, approved by the Cabinet in January 2025. The initial tax rate is 200 baht per tonne of CO_2 equivalent, covering fuels such as gasoline, diesel, LPG, and jet fuel, though it will not immediately raise retail prices. Although its short-term impact is modest, the policy represents a key step in building the institutional framework for stronger climate action and supporting the transition towards a low-carbon economy.

Aspect	Policy Measure in Global Perspective	Policy Measure in Thailand
• **Carbon Contracts for Difference (CCfD)**	The European Commission approved the first Carbon Contracts for Difference (CCfD) scheme under the new Guidelines on State Aid for climate, environmental protection and energy (2022). The German Federal Ministry for Economic Affairs and Climate Protection (BMWK) initiated the first bidding process with a total volume of EUR 4 billion. With this funding scheme, Germany is taking a pioneering role in Europe and internationally in the field of state aid for climate protection.	CCfDs represent a novel market-based funding mechanism and have not yet been introduced in Thailand.
• **Border adjustment tariff**	CBAM will apply in its definitive regime from 2026, with a transitional phase from 2023 to 2025. This gradual introduction is aligned with the phase-out of free allowances under the EU Emissions Trading System (ETS) to support the decarbonisation of EU industry.	Thai exporters are likely to be affected by CBAM measures implemented by major trading partners such as the EU, the United States and China. In response, Thailand is making significant progress in developing a domestic CBAM framework, intended to operate alongside other carbon pricing instruments such as a carbon tax and a future ETS.
• **Direct funding for CCU/S infrastructure**	Approximately $800 million has been allocated in the EU to support six cement CCU/S, demonstrating strong public backing for large-scale deployment.	Current CCU/S initiatives in the cement sector are concentrated in Saraburi Province, primarily through a public–private partnership (PPP) model under the Saraburi Sandbox initiative. At present, dedicated regulations and funding mechanisms for CCU/S deployment in cement are limited. A national CCU/S Technology Roadmap is under development to define strategic priorities and key technologies aligned with Thailand's decarbonisation objectives. In parallel, Thailand has seen strong momentum in R&D and demonstration projects, largely driven by the petroleum, petrochemical and power sectors.
• **Green public procurement**	Creates a viable market for low- emission cement through GPP commitments. Policies in place for green public procurement of concrete products in Germany, the Netherlands, the UK, and Sweden.	The National Action Plan on the Promotion of Green Public Procurement 2022-2027 was approved in 2022 (Switchasia, 2022) [39], encouraging government agencies to procure at least 30% of their total spending in environmentally friendly products and services.

Thailand has significantly strengthened its climate commitments, announcing targets to achieve carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. The industry sector significantly contributes to the country's emissions. The cement industry - among the highest energy intensive sectors in the country - needs to align its targets to complement national targets. At COP27 in 2022, the Thai Cement Manufacturers Association (TCMA), together with the Global Cement and Concrete Association, launched the Thailand Chapter: Net Zero Cement & Concrete Roadmap 2050 (GCCA, 2024) [40]. The roadmap defines three implementation phases: the Initial phase (2010–2020), the Decade to Deliver (2020–2030), and Full Deployment (2030–2050).

The roadmap proposes a phased policy approach to advancing low-carbon cement manufacturing. In the short term (2025–2030), the priority should be to establish foundational enabling conditions, including clear standards for low-carbon cement and the initiation of pilot projects to demonstrate technical and commercial feasibility. The medium-term strategy (2030-2040) should build on these foundations by strengthening market demand through targeted incentives, scaling up successful pilots, and developing robust infrastructure to support recycling and circular-economy practices. In the long term (2040–2060), policy efforts should focus on fostering continuous innovation, enabling the full deployment of recycled materials and renewable energy, and embedding comprehensive policies frameworks that support widespread adoption and durable environmental benefits.

While the goal for achieving carbon neutrality in the cement industry is set for 2050, policy support must continue beyond this milestone, extending up to 2060. This extended support will be crucial to ensuring the comprehensive implementation of low-carbon technologies and maintaining stability in the sector's decarbonisation efforts. Sustained and adaptive policy measures will be required to address emerging challenges and to support the long-term integration of sustainable practices across the industry.

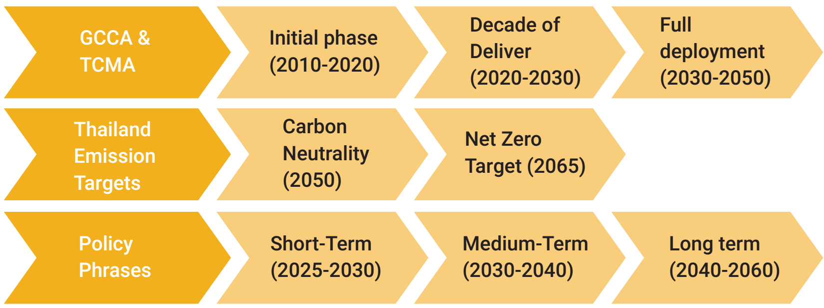


Figure 3.5: Summary of the decarbonisation pathway, policy phases, and respective timeline for the cement sector

Mapping the Roles of Stakeholders

Thailand bears a growing responsibility for greenhouse gas emissions and must step up by providing financial support and resources to advance research, development, and commercialisation of zero-emission best available technologies (BAT) is expected to strengthen its contribution by mobilising financial resources and policy support to advance research, development, demonstration, and commercial deployment of zero-emission best available technologies (BAT). Effective industrial decarbonisation requires collaboration across multiple levels of government and across sectors. This includes engaging a broad array of participants, including public authorities, private-sector actors, international organisations, and the research and innovation community, to accelerate the deployment of low-carbon technologies and materials. Well-crafted policy frameworks are essential, including targeted investments in research and development for new technologies such as carbon capture and storage (CCS), promoting knowledge sharing, facilitating technology transfer and capacity building, and aligning with international standards and regulations. Simply developing a transition plan is not enough; plans must be credible, sufficiently ambitious, and supported by effective implementation mechanisms. Understanding the quality, feasibility, and ambition of transition plans is a growing area of policy attention in cement production. Policymakers should regularly assess and, where necessary, strengthen transition plans to ensure alignment with national climate objectives. By implementing these approaches, stakeholders can contribute to a more sustainable future for the cement industry, lowering emissions and environmental impacts while meeting the continued demand for construction materials. Decarbonisation of both demand and production will require co-ordinated action by a wide range of stakeholders, including governments, industry, labour organisations, financial institutions, and civil society

Table 3.2: Mapping the roles of government and corporates in the implementation of policies

Policy area	Objective	Government role	Corporate role
1. Establish carbon pricing mechanism and strengthen the national carbon market	Accelerate decarbonisation in Thailand's cement sector through **effective carbon pricing mechanisms.**	Establish and enforce a national carbon pricing system, such as an emissions trading scheme or carbon tax, tailored to Thailand's industrial context.	Prepare for compliance with the carbon pricing mechanism, manage carbon credits or liabilities, and ensure accurate emissions reporting and verification.
2. Leverage carbon-linked green procurement policies	Increase the adoption of low-carbon cement in Thailand **by integrating climate-related criteria into procurement processes.**	Develop and implement green procurement policies for public projects emphasising low-carbon cement, incorporating life-cycle assessments and carbon footprint metrics.	Invest in and adopt low-carbon cement technologies, support green procurement initiatives, and help drive market demand for sustainable building materials.
3. Leverage ESG Finance	Enhance financial support for carbon neutrality in the Thai cement sector through **ESG-focused financial instruments.**	Create a transparent, science-based, green taxonomy specific to Thailand's cement industry, develop financial instruments to support low-carbon transitions, and encourage ESG investments.	Develop pragmatic transition plans for carbon reduction, improve ESG-related disclosures and reporting, and seek financial support through green and ESG investments.
4. Promote a circular economy for solid waste fuels	**Increase the use of solid waste as an alternative fuel in Thailand's cement industry** to reduce emissions and support waste management.	Enhance waste management infrastructure to upscale RDF production, establish standards and regulations for the use of solid waste fuels, and offer incentives for using alternative fuels.	Invest in and adopt solid waste fuel technologies, comply with fuel quality standards, and actively participate in the development of the solid waste fuel market.

Effective, well-structured, and equitable policy packages require input from all these parties. Government plays a pivotal role in shaping and co-ordinating the transition strategy, raising awareness among stakeholders, and offering targeted incentives to encourage the adoption of new technologies for decarbonising the cement industry. Additionally, public authorities are responsible for establishing the regulatory frameworks and institutional arrangements needed to ensure these technologies are effectively deployed and scaled implemented successfully. The decarbonisation solutions (as mentioned in chapter 2) and policy packages (suggested in this chapter) address the entire supply chain (see Figure 3.6), encompassing the following stages:

- Upstream: The initial supply chain, which includes the extraction and processing of raw materials, and the provision of clean and low-carbon energy.
- Midstream: The core industrial stages of the supply chain, such as manufacturing and production processes as well as associated logistics and transportation activities.
- Downstream: The final stages of the supply chain, including distribution, use in construction, consumption, and end-of-life management, as well as infrastructure development and asset utilisation

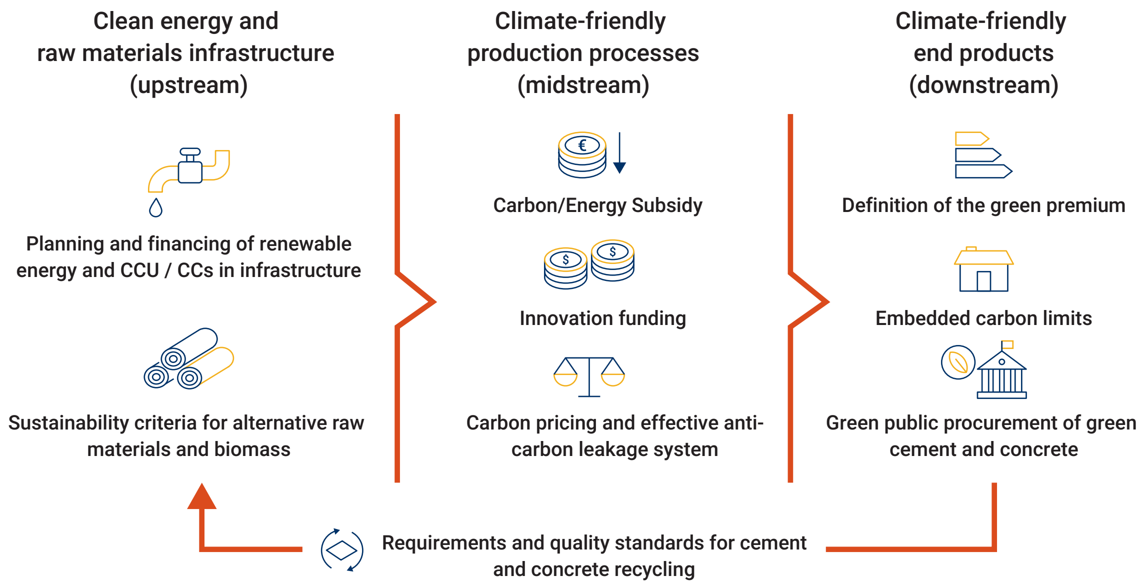


Figure 3.6: Summary of decarbonisation pathway for the Cement Sector Supply Chain

Policy measures need to be well coordinated both within and between these stages and across different industries to ensure a comprehensive approach. In the initial phase, efforts should focus on establishing technically viable and sector-specific pathways. Following this, it is crucial to develop robust and bankable business models that accommodate the needs and responsibilities of all actors and components within the supply chain. Such a holistic approach helps ensure that every part of the supply chain both contributes to, and benefits from, decarbonisation efforts.

CHAPTER 4

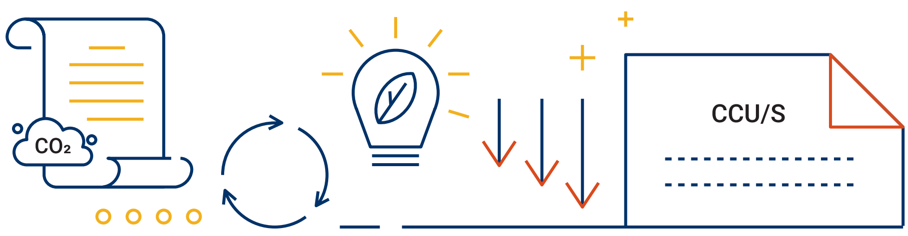
POLICY RECOMMENDATIONS AND ACTIONS FOR DECARBONISATION

Key Messages

- A comprehensive policy package is recommended to support the cement sector's transition to carbon neutrality, including:

  - Accelerating renewable energy utilisation and infrastructure development;
  - Strategic implementation of carbon capture utilisation and storage (CCU/S);
  - Establishing carbon pricing mechanism for effective decarbonisation actions
  - Establishing Carbon Contract for Difference (CCfD);
  - Strengthening green finance to support the carbon neutrality transition
  - Leveraging carbon-linked green procurement policies to expand demand for low-carbon cement;.
  - Promoting a circular economy to achieve large-scale production and application of solid waste fuels.

- Most policy measures will need to be implemented immediately if the sector is to achieve its carbon neutrality objective.



Barriers to Cement Decarbonisation

A range of policy measures and regulations has been implemented to support the decarbonisation of Thai industries (see Chapter 1). However, accelerating decarbonisation in the cement sector will require additional, sector-specific strategies, stronger legislative enforcement and dedicated financial mechanisms. These additional measures are essential to addressing existing constraints (summarised in Table 4.1) and to establishing the enabling conditions necessary for a successful transition.

Table 4.1: Barrier identification for decarbonisation of Thailand's cement sector

• **Financial barrier**	- High capital and operating costs, combined with relatively low profit margins. - Insufficient incentives for low-carbon cement production, including the absence of market-based carbon-pricing mechanisms (e.g. emissions trading systems, carbon taxes, premium pricing for low-carbon cement) as well as the lack of government-backed subsidy schemes (e.g. Carbon Contracts for Difference, grants, loan guarantees). - Limited access to the green finance for implementing decarbonisation projects.
• **Regulatory barrier**	- Regulatory uncertainties arising from evolving and potentially inconsistent regulations. - The absence of sector-specific policies to promote low-carbon and renewable energy use and to support innovation in breakthrough technologies. - Inadequate green public procurement policies to stimulate demand for low-carbon cement in construction projects undertaken by central and local government agencies. - Circular economy initiatives currently rely on voluntary approaches, which are generally less effective than mandatory mechanisms.
• **Technical barrier**	- Innovative technologies remain at an early stage of development (e.g. Hydrogen, Electrification, CCU/S, Cement substitution materials) - A lack of infrastructure to support decarbonization, including CO_2 storage infrastructure, power transmission grid - Limited R&D capacity and technical expertise, which impede the rapid deployment of advanced decarbonisation technologies
• **Social barrier**	- Low levels of public and industry awareness of the climate impacts associated with cement production. - Limited collaboration across the cement value chain.

Recommended Policies for Cement Value Chain by Timeline

The success of the cement industry's decarbonisation hinges on robust and consistent policy support. Such policies must be aligned across the cement value chain, from upstream to downstream, to effectively stimulate demand for green cement, facilitate investment in the transformation of cement companies, and enable the scaling up of new clean technologies. Table 4.2 presents recommended policies covering the entire cement value chain and their corresponding implementation timelines, in line with the policy vision outlined in Chapter 3.

Table 4.2: Recommended policies and implementation period

Long term (2040-2060)	- Coal phase-out		- Zero waste to landfill enforcement
Medium term (2030-2040)	- Criteria for new raw materials - Subsidies for green energy	- Carbon Contract for Difference (CCfD)	- Offtake agreement for new low-carbon cement - Building carbon codes and labelling
Short term (2025-2030)	- Appropriate alternative fuel (AF) allocation - Third party access (TPA) for the cement industry - CCU/S infrastructure development - Innovative funding	- Emission Trading Scheme (ETSs) - Carbon taxes for fuels - Loan guarantee	- Performance-based GPP - Green premium for low-carbon cement - Environmental Product Declaration (EPDs) framework establishment for cement and concrete - Enhanced waste management
Existing policy measures	- Alternative energy development plan (AEDP) - Power development plan (PDP) - Gas plan	- Energy efficiency plan (EEP) - ESG funds	- Low-carbon cement/ concrete standards - Eco labels - Green public procurement (GPP) - Waste management regulation
Cement value chain	Upstream (Clean energy, raw materials, infrastructure)	Midstream (Climate-friendly production processes)	Downstream (Climate-friendly end products)

Based on the country's context and level of readiness, the recommended policies are categorised into three implementation phases: short term (2025–2030), medium term (2030–2040), and long term (2040–2060).

Short term (2025 – 2030)

This period is critical for Thailand to develop a comprehensive policy framework that aligns and prepares industries to achieve shared national carbon-neutrality targets. Achieving this will require a joint effort by industry, industry associations, asset developers, contractors, architects, civil society and government.

Effective and mandatory regulations are required to encourage industries to adopt energy- and resource-efficiency measures and to shift towards alternative energy sources, such as biomass and solar power. To support efficiency improvements and renewable energy uptake, the government must provide incentives for renewable energy projects (e.g. tax incentives, renewable energy certificates (RECs), etc.), subsidies for green electricity and mandatory efficiency targets. These recommendations also align with existing energy transition plans that promote solar energy projects, biofuel projects, grid modernisation initiatives, etc.

Similar implementation measures are required across upstream and downstream stages of the cement supply chain. The policy frameworks must support green construction throughout the supply chain (e.g., design, material selection, etc.), recycling and reuse, such as banning landfill waste disposal to minimise environmental impacts, and end-of-life management for materials incorporating alternative materials such as ground limestone, fly ash and calcined clay.

Additionally, the development of carbon mechanisms, such as Carbon Contracts for Difference (CCfD) and carbon credits can reduce operational expenditure (OPEX) risks for early adopters, who face higher costs and uncertainty around the future of carbon pricing. Carbon-based mechanisms can enhance the financial viability of low-carbon technologies and encourage investment by improving the economic case for green industrial initiatives. However, to address challenges such as inertia, uncertainty and demand constraints, additional policy measures are required. Carbon-based mechanisms alone are insufficient to accelerate the transition, as market dynamics are influenced by factors beyond price signals. Accordingly, the forthcoming Climate Change Act for hard-to-abate industries, such as cement, will need to be integrated with complementary and supportive policies, such as regulations and subsidies, to effectively drive the transition.

The government will therefore play a crucial role in designing and managing the transition strategy, raising awareness, and providing incentives to encourage companies and key stakeholders to adopt new technologies. This includes establishing a robust regulatory framework to ensure that these technologies are deployed in a timely and effective manner.

Medium term (2030 – 2040)

Medium-term policies should aim to bridge short-term measures and long-term objectives. The government, in collaboration with industry associations, should promote the optimisation of concrete mix designs to improve both performance and sustainability, with an emphasis on reducing cement content and increasing the use of innovative materials. To stimulate demand for green cement, support investment in the modernisation of cement companies and their assets, and facilitate the adoption of clean technologies, policies must be coherent and well aligned. Prioritising strategies to improve the efficiency of cement clinker use, such as clinker substitution and the use of hydraulic cement, is crucial to reducing carbon emissions from production. Policy tools can mitigate the risks associated with low-carbon cement through offtake agreements, which are implemented in other hard-to-abate sectors, such as the steel sector in Europe. These agreements involve a commitment to purchase a product in the future, with contract terms specified well in advance, thereby ensuring long-term demand certainty. Such commitments carry inherent risks, but public authorities can play a role in managing these risks.

Public procurement is also a key lever for the cement sector. The government can enhance green public procurement through offtake agreements, which would provide certainty for future demand for low-carbon cement and help reduce greenhouse gas (GHG) emissions. Funding mechanisms to direct capital to cement production in developing markets thereby incentivising institutional investors and multilateral banks, could also be considered, linking capital to emission reduction. The need to achieve sustained emissions reductions by 2040 means that investments and policies should foster both the scale and speed of pilot projects. Additionally, targeted research and development (R&D) initiatives can provide capital expenditure (CAPEX) support for innovative low-carbon technologies.

Building on the short-term plan, further investment in scaling up the use of renewable raw materials and clean energy sources should be encouraged to further reduce the carbon footprint of construction materials, supported by flexible policy frameworks. These regulations include specific actions, such as streamlining and accelerating the permitting process for certain solar installations and the refurbishment of renewable energy power plants. They also designate renewable power plants as being of overriding public interest, which helps to remove obstacles to new permitting procedures. By integrating these policy measures, a more sustainable construction industry can be developed one that significantly reduces carbon emissions and resource use.

Long term (2040 – 2060)

In this phase, the deployment of carbon capture technologies at full scale in cement production could significantly reduce, and potentially eliminate, process emissions, and pave the way for carbon-negative concrete in the longer term. Public policy will be crucial to enabling both the cement industry and the broader value chain to achieve decarbonisation across the life of cement and concrete. A robust policy framework will need to be established through a collaborative effort involving industry stakeholders, policymakers and governments. This framework should aim to ensure the financial viability of low-carbon cement manufacturing, stimulate demand for low-carbon concrete products, and support the development of infrastructure necessary for a circular and net-zero manufacturing system. Additionally, the promotion of circular economy principles and the creation of incentives for the use of recycled materials and renewable energy will be crucial to delivering lasting environmental benefits.

To facilitate decarbonisation across the entire cement value chain, specific policies have been developed for the upstream, midstream, and downstream stages. The key policies for each stage of the value chain are outlined below.

Upstream policies

Upstream policies are designed to address decarbonisation efforts related to fuel use, raw material use and the development of essential infrastructure in the cement industry.

• Accelerate renewable energy utilisation and infrastructure development

The cement industry is highly energy-intensive, and requires substantial amounts of renewable heat and electricity to decarbonise the production process. To keep the announced cement roadmap on track, renewable energy sources will need to substitute most fossil fuel use by 2030.

Thailand, as an agricultural economy, can significantly benefit from using agricultural biomass residues as a viable alternative to coal for heat generation in clinker production. The draft Alternative Energy Development Plan (AEDP) aims to boost the industrial use of biomass. However, accelerating decarbonisation efforts across all sectors of the economy are intensifying competition for biomass resources. A major challenge is the geographical mismatch between industrial energy demand and the availability of sustainably produced biomass. Therefore, well-designed policies and targeted financing mechanisms are essential to enabling optimal, area-based allocation of biomass resources across industries for both heating and power generation. A stable, long-term policy framework will encourage the cement industry to invest in renewable technologies.

Electricity currently accounts for approximately 13% of total energy consumption in cement production. While advancements in grinding machines and processes can help reduce this demand, the deployment of Carbon Capture, Utilisation and Storage (CCU/S), a critical technology for comprehensive decarbonisation, is energy-intensive and is projected to approximately double the cement industry's current electricity demand. This puts additional pressure on electricity grid infrastructure infrastructure, necessitating the development of long-distance electricity transmission solutions. Therefore, a robust regulatory framework is required to ensure that the cement industry has access to sufficient, reliable and affordable renewable electricity.

Importantly, relevant ministerial legislation and regulations will need to be modernised to support the growing demand for renewable energy. This involves reducing regulatory bottlenecks and accelerating permitting processes. Direct power purchase agreements (PPAs), supported by third party access (TPA), offer a compelling solution. Under PPAs, cement producers can secure access to clean electricity at predictable costs without requiring significant upfront investments in new technologies or processes. This model, already adopted by many large energy users, represents a “quick win” for the cement industry. It allows producers to reduce emissions without adversely affecting profitability, while simultaneously supporting job creation and economic activity within the renewable energy sector. By adopting PPAs, the cement industry can strengthen its role as a leader in the transition to a low-carbon economy.

Hydrogen offers significant potential as a key fuel for the cement sector over the medium to long term, but its commercial deployment will require substantial investment in infrastructure, as well as subsidies and tax incentives. A national hydrogen strategy and associated production standards will need to be developed. These should cover the development of efficient production facilities, the establishment of robust storage and distribution networks, and upgrades to existing systems to ensure hydrogen can be handled safely and cost-effectively.

Strategic implementation of carbon capture utilisation and storage (CCU/S)

Carbon dioxide emissions from the calcination process account for approximately 60% of total emissions of cement production. Carbon capture, utilisation, and storage (CCU/S) is thus a critical technology for mitigating these process emissions. In 2024, the Global Cement and Concrete Association (GCCA) announced a target to have CCU/S fully operational at approximately 10 cement plants worldwide.

In Thailand, a collaborative effort involving public and private stakeholders, including academic and research institutes, has resulted in the development of a CCU/S technology roadmap. This roadmap is crucial to guiding Thailand towards its 2050 carbon-neutrality target. It aims to assess and prioritise key CCU/S technologies, propose comprehensive regulatory frameworks, set strategic goals and directions, outline research approaches, and establish development timelines for CCU/S technologies tailored to Thailand's specific context.

For Thailand's cement industry, carbon capture and utilisation (CCU) is a priority, primarily due to geological constraints on CO_2 storage in areas where cement plants are located. The Thai Cement Manufacturers Association (TCMA) is actively developing a carbon capture research testbed. The captured carbon from this initiative will be utilised to produce methanol, which can serve as a fuel or a feedstock for various chemical industries. To ensure the continued advancement of CCU technologies from research and development to pilot-scale deployment and eventual scale-up, an innovative public–private partnership (PPP) funding model is essential. Furthermore, a clear, coherent and supportive regulatory framework will be vital to effectively govern CCU/S activities nationwide.

Midstream policies

• Establishing carbon pricing mechanism for effective decarbonisation actions

Thailand has long operated a national voluntary carbon market, under which carbon credits are issued in accordance with the accounting protocols of registered CO_2 mitigation projects under the Thailand Voluntary Emission Reduction (TVER) initiative. In fiscal year 2023, the average price of TVER credits across all project types was THB 87.68 per tonne of carbon dioxide equivalent (tCO_2eq). Buyers typically include companies or individuals undertaking corporate social responsibility (CSR) activities and purchasing credits to offset emissions and achieve carbon neutrality at the organisational, product, event or individual level. Sellers, or project developers, may include public or private organisations across various sectors, as well as individuals or community groups.

While the voluntary carbon market has laid an important foundation for emission reduction efforts, Thailand will need to begin establishing and implementing mandatory carbon pricing mechanisms, such as an emissions trading system (ETSs) or a carbon tax, to drive a more robust and effective low-carbon transition. Mandatory schemes offer stronger and more predictable incentives for industry to reduce emissions, enhance accountability and accelerate the adoption of sustainable practices.

To enhance the effectiveness of carbon pricing, Thailand should consider implementing a Carbon Border Adjustment Mechanism (CBAM) to level the playing field for domestic industries by accounting for the carbon footprint of imported goods. Revenue generated from carbon pricing should be reinvested into industrial decarbonisation technologies, sustainable infrastructure, fostering innovation and green growth. Clear and consistent regulatory policies are essential to provide a predictable transition pathway and reduce barriers to the adoption of low-carbon technologies.

The government will need to ensure that the carbon market operates at an appropriate carbon price to incentivise meaningful actions from manufacturers. For instance, in sectors such as cement, where carbon abatement costs are high—particularly with the adoption of carbon capture, utilisation and storage (CCU/S) and clean fuels such as hydrogen—the current carbon price is insufficient to drive structural market transformation. Policymakers should prioritise carbon price predictability, as rapid price fluctuations can create uncertainty for companies, particularly when planning long-term investments in climate action.

On the corporate side, the cement industry, with its relatively strong data availability and quality, is well-positioned to participate in the carbon trading market. Cement producers should prepare for inclusion by effectively managing their carbon assets, setting clear emissions reduction targets, developing clear and actionable roadmaps, and actively engaging in the monitoring, reporting and verification (MRV) of emissions. By taking these steps, the industry can position itself as a leader in the low-carbon transition, driving both environmental and economic benefits.

In summary, while Thailand's voluntary carbon market has been well established and provided a strong foundation, the introduction of mandatory carbon pricing, supported by complementary policies such as CBAM and the strategic reinvestment of revenues into carbon reduction technologies, is critical to achieving a sustainable, low-carbon transition. Both government and industry will need to work collaboratively to ensure a smooth and effective transition.

Market-based carbon pricing [41]

Carbon pricing is a market-based strategy for reducing carbon emissions by making polluters—both companies and consumers—pay for the environmental damage they cause. This is typically achieved through one of two main approaches:

- Cap-and-trade: This system sets an overall limit, or "cap," on emissions that decreases over time. Companies can buy or sell permits that allow them to emit a certain amount of carbon. Since the total number of permits is limited by the cap, this system ensures that total emissions decline overtime.
- Carbon taxes: A direct tax is placed on carbon emissions, most commonly applied to fossil fuels.

Many regions worldwide have adopted carbon pricing schemes, and some have specifically included the cement industry.

- Europe: The EU Emissions Trading System (EU ETS) has been in place since 2005 and has cut emissions by more than 35% in covered industries. The UK and Switzerland also have their own schemes; Switzerland's is linked to the EU ETS, allowing for a larger, shared carbon market.
- North America: In the US, some states have emissions trading programmes; however, only California currently uses a cap-and-trade system that includes the cement industry. In Canada, both provincial and federal programmes cover cement. The schemes in Quebec and California are linked, creating a shared market.
- China: The government began operating its national emissions trading system in 2021. The cement sector's emissions are regulated under the ETS.
- Other Countries: While carbon pricing exists elsewhere, it often focuses on the power sector and does not yet include cement. However, a group of 20 developing countries known as the V20 has committed to adopting carbon pricing by 2025.

● Establishing carbon contract for difference (CCfD)

Since the early 2000s, Thailand has operated the Energy Efficiency Revolving Fund (EERF) as a cornerstone public subsidy programme to drive renewable energy adoption and improve energy efficiency in the industrial sector. Established to incentivise private-sector investment, the EERF offers companies access to loans with below-market interest rates for upgrading to energy-efficient technologies. By reducing financial barriers, the initiative has accelerated the adoption of sustainable energy practices while supporting industrial growth and competitiveness. Complementing this effort is the ESCO Revolving Fund, a financing mechanism designed to incentivise private-sector investment in viable renewable energy and energy efficiency projects through Energy Service Companies (ESCOs). The programme supports six financing models: equity financing, venture capital, equipment leasing, partial credit guarantees, carbon credit trading and technical assistance. Under both frameworks, supported projects are required to deploy commercially proven technologies and demonstrate a favourable return on investment (ROI), ensuring economic viability.

Carbon Contracts for Difference (CCfDs), which have not yet been implemented in Thailand represent an innovative public funding mechanism designed to accelerate the deployment of emerging low-carbon or carbon-neutral technologies aligned with the 1.5°C climate objective. At their core, CCfDs are long-term agreements between governments and industrial companies to subsidise emission reductions achieved through decarbonisation projects.

Under the mechanism, a fixed carbon strike price is agreed between the government and the participating company, providing a guaranteed effective carbon price for emission reductions relative to conventional technologies over a defined period. Where the prevailing market carbon price falls below the agreed strike price, the government compensates the company for the difference. This arrangement establishes a stable and predictable carbon price signal, reducing investment risk and lowering the cost of capital for low- and zero-emission technologies. By addressing the "valley of death" — the gap between technological innovation and commercial deployment — CCfDs can support the scale-up of emerging technologies towards commercial viability and competitiveness (see Figure 4.1).

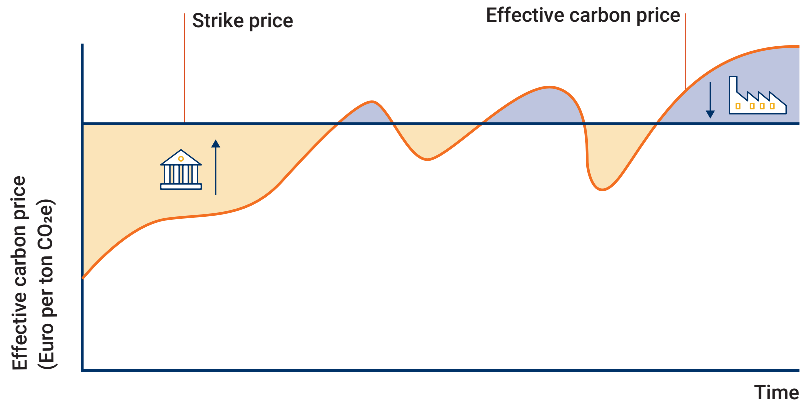


Figure 4.1: :Basic functioning of a two-sided CCfD

Moreover, CCfDs help to counteract the late-mover advantage, (where firms delay investment in unproven technologies until after initial commercialisation) by making early-stage decarbonisation projects more financially attractive. This approach can accelerate the adoption of transformative technologies, thereby aligning industrial development with long-term climate objectives.

Carbon Contracts for Difference [42]

Carbon Contracts for Difference (CCfDs) offer a range of flexible design options. For Carbon Capture and Storage (CCS) projects, these design features need to address the inherent complexity of the CCS value chain, which depends critically on the reliable delivery and availability of CO_2 transport and storage (T&S) infrastructure. The table below provides a comparative analysis of early CCfD schemes implemented in the Netherlands, the UK, and Denmark, which are specifically designed to accelerate CCS deployment within its respective national contexts.

Key characteristics of three CCS incentive schemes

	Dutch SDE ++	UK Industrial CCS Contract	Danish CCUS Fund (First Round)
Allocated funding	€23 bn total over first three rounds, of which €9.2 bn awarded to 5.6 Mtpa of CCS projects	£20 bn for as-yet undetermined Mtpa over two 'Track 1' clusters	€1.1 bn to first tender for 0.43 Mtpa. €3.6 bn remain available for restructured fund
Project eligibility	Industrial CCS projects that can be operational within six years of the contract award	Industrial CCS projects required to be operational by 2027	Any CCS project that can reduce the national CO_2 emissions inventory and be operational in 2026
Selection criteria	Competitive based on the subsidy required	Negotiated and based on several cost and non-cost factors	Competitive based on subsidy required and additional CO_2 abatement volumes
Contract duration	15 years	10 years with option to extend up to 5 years	Up to 20 years (future tenders are expected to have 15-years terms)
Reference price	EU ETS price (with a price floor set at two-thirds the projected price)	Pre-determined linearly increasing price for 10 years. UK ETS for additional years	EU ETS price
Bid price	Includes all costs – capped according to technology category	Separate CAPEX and OPEX components	Includes all costs
Revenue from voluntary carbon markets	Revenues are expected to be incorporated into the bid price	Additional revenue is not initially permitted, but would be subject to a 90% deduction	Revenues are expected to be incorporated into the bid price – otherwise subject to a 90% deduction
Performance criteria	Subsidy paid based on verified CO_2 storage volumes	Minimum capture rates, start-up periods and CO_2 specifications requirement apply	Penalties apply if offered minimum and additional CO_2 volumes are not delivered
Cross-chain risks	No exemption for T&S unavailability	A modified subsidy continues during T&S unavailability for at least 36 months	No exemption for T&S unavailability
CO_2 T&S costs	Negotiated between project and CO_2 off-taker	Subsidy includes regulated tariff, passed through to the network operator	Negotiated between project developer and CO_2 off-taker

Enhancing green finance to support the carbon neutrality transition

Green finance in Thailand has gained significant momentum over the past decade as both the government and private sector have increasingly recognised the importance of sustainability and addressing climate change-related risks. In the early 2010s, Thailand began to develop a framework for green finance, largely driven by international trends and the country's participation in climate agreements like the Paris Agreement. The government took steps to encourage investment in green initiatives, although private-sector engagement remained relatively limited. Government and private banks, as well as other financial institutions, in Thailand began exploring green finance products, but these efforts were initially modest in scale. Green bonds and loans were not yet widespread; nevertheless, awareness of environmental impacts increased, and green projects began to receive greater attention.

In 2017, the Bank of Thailand (BOT) and the Securities and Exchange Commission (SEC) launched a set of guidelines to foster the development of green bonds and other sustainable financial instruments. This provided a clearer regulatory framework for private-sector actors to raise funds for environmentally sustainable projects. As a result, the green bond market began to show early signs of growth. Private banks and corporations started issuing green bonds to finance renewable energy projects, energy-efficiency programmes and infrastructure that supports sustainable development objectives.

In 2020, Thailand introduced its Green Finance Development Plan, which aimed to create a more structured approach for both private and public investment in green projects. The plan emphasised the need for green financial instruments and further clarified policies related to green bonds, loans, and investments. In this phase, private companies, especially in the energy, real estate, and transportation sectors, began to increasingly adopt sustainable practices and to turn to green finance to fund them. For instance, companies in the renewable energy sector (e.g. wind and solar) and those involved in energy-efficient infrastructure began using green financing options to scale up their operations. As global awareness of climate change increased, Thailand also became more integrated into international green finance networks. This integration helped attract foreign investors seeking to support sustainable projects in Southeast Asia, contributing to the continued expansion of Thailand's green finance market. The government has also been promoting green finance through incentives such as tax breaks and subsidies for green investments. Private-sector actors are encouraged to invest in projects that contribute to Thailand's commitment to the Paris Agreement and its sustainable development goals (SDGs).

While private green finance in Thailand has made substantial progress, the market still faces challenges such as a lack of uniform green certification standards, limited access to green investment opportunities in certain sectors, and the need for more suitable financial products tailored to smaller companies or projects.

A government-led green taxonomy, should be established specifically for the cement sector to define criteria for economic activities that are aligned with a net-zero sectoral pathway by 2050. A comprehensive system of financial standards and tools should be introduced to provide a coherent a financial support framework for stakeholders pursuing a low-carbon transition.

The Bank of Thailand (BOT) has been actively involved in the development of sustainable finance and the integration of environmental considerations into the country's financial system. One of the key elements in this context is the concept of a taxonomy, which is used to provide clear guidelines on which economic activities can be considered sustainable. While Thailand does not yet have a fully developed national green taxonomy like the EU Taxonomy, the Bank of Thailand has been involved in initiatives to advance the development of sustainable finance and align domestic practices with international frameworks.

Corporations, meanwhile, should prepare to access financial support by developing clear and credible short-, medium-, and long-term transition strategies or action plans, and by strengthening carbon emissions accounting and reporting practices (see Figure 4.2).

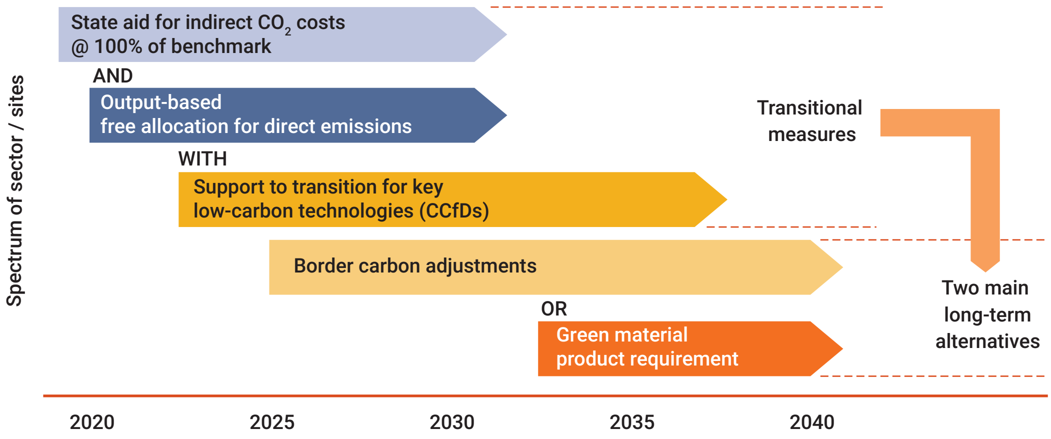


Figure 4.2: :Short-, medium-, and long-term policy instruments for carbon leakage protection [43]

Downstream policies

• Deploying green procurement where embodied carbon is integrated

Infrastructure and construction are major drivers of cement demand, making these sectors instrumental in the transition towards carbon neutrality. To achieve meaningful reductions in carbon emissions, green procurement policies must be systematically and strategically integrated across the supply chain.

The cement industry has made significant strides in enhancing environmental sustainability. Low-carbon cement products have been standardised for various construction applications, and the Thai Green Label Programme has been established to make eco-friendly goods and services available to market participants. Many government infrastructure projects have already adopted low-carbon cement, reinforcing its role in sustainable development. Looking ahead, the industry is expected to phase out Ordinary Portland cement (OPC), transitioning to a market dominated by low-carbon alternatives. Cement producers are actively developing next-generation low-carbon cement types, such as Limestone Calcined Clay Cement (LC3), to further minimise emissions. In parallel, advanced production technologies are being progressively deployed to enhance efficiency and sustainability. As a result, the market is expected to offer a wider range of low-carbon cement products with varying embodied-emission levels over the medium to long term. In this context, performance-based labels such as Environmental Product Declarations (EPDs) and Carbon Footprints of Products (CFPs) play a critical role in providing transparent, comparable data, thereby enabling purchasers to align their procurement decisions with sustainability objectives.

Reducing carbon emissions in construction also requires improvements in structural efficiency, material optimisation and recycling, measures that can collectively cut emissions by up to 15%. While the majority of emissions in the building sector currently arise from operational energy use, the ongoing transition to clean electricity means that embodied carbon in construction materials, particularly cement, will increasingly become the primary source of emissions. Life Cycle Assessment (LCA) is a crucial tool for integrating embodied-carbon considerations into procurement practices. By establishing EPDs for cement products, LCAs can be more easily applied, streamlined, facilitating the decarbonisation of construction and stimulating increasing demand for low-carbon cement. Although GPP is currently voluntary in Thailand, making it mandatory would significantly accelerate the achievement of broader environmental and sustainability objectives.

A phased implementation strategy could begin with central government and local authority procurement projects, as well as leading real estate developers, to establish a strong market precedent. By fostering demand and reinforcing the supply chain for low-carbon cement and other sustainable building materials, these initiatives can support long-term transformation in the construction sector, ensuring a more sustainable built environment over time.

• Promoting a circular economy to achieve large-scale production and application of waste-derived fuels

Circular economy approaches have been promoted to mitigate carbon emissions by improving resource efficiency, increasing the use of recycled materials, and minimising waste generation from industrial production processes.

In the cement industry, materials such as fly ash (a byproduct of coal-fired power plants), slag (from steel production), and silica fume have been widely used as alternative raw materials, substituting for a portion of clinker in cement production, thereby helping to reduce environmental impacts. However, with the global push to phase out fossil fuels, the availability of these by-products is expected to decline in Thailand, creating a significant challenge for the long-term sustainability of cement production.

Recycled cement, or more specifically the use of recycled materials in cement production, is an emerging trend in construction. Crushed concrete from demolished buildings can be reused as aggregate in new cement mixes. This reduces the need for natural aggregates, which are often mined and can result in environmental degradation. Some companies and projects in Thailand are at an early stage of implementing these methods (ref). However, large-scale adoption is unlikely in the near term, due to challenges related to cost, regulatory barriers, and the need for further technical advances in recycling processes. To promote the use of recycled cement, the government should take the lead by integrating recycled concrete aggregates (RCA) into public construction projects. Targeted technology upgrades, supported through government programmes or climate finance, can help lower production costs, while capacity-building and training programmes would improve operational practices and strengthen environmental awareness.

Waste-derived fuels offer considerable potential as an alternative energy source for emissions reduction in the cement industry and could deliver substantial benefits if deployed at scale. At present, biomass accounts for only around 7% of fuel use in Thailand's cement sector. The classification of cement kiln co-processing as a form of waste treatment, rather than as the use of alternative fuels, in current standards may limit the development and large-scale application of waste-derived fuels. Existing subsidies for waste treatment provide only limited economic incentives for cement producers to adopt such fuels.

To unlock this potential, the government should strengthen municipal solid waste collection and sorting systems, promote the establishment and standardisation of a solid waste fuel industry capable of supplying high-quality fuels with consistent calorific value, and reinforce the technical and administrative frameworks required for their safe use. At the same time, the government should provide targeted incentives, including subsidies, to cement producers to encourage promote the use of solid waste fuels.

On the corporate side, cement producers can play a pivotal role by signalling long-term demand for high-quality waste-derived fuels, thereby supporting the development of relevant standards and associated industries. Large cement groups, environmental industry companies, and infrastructure investment funds should be encouraged to engage in the advanced processing industry of combustible waste and to produce standardised alternative fuel products.

Recommended Policy Actions by Decarbonisation Levers

The following section presents recommended actions for both the government and the cement sector, organised around the seven decarbonisation technology levers outlined in TCMA's roadmap. These levers include:

1. Efficiency in design and construction
2. Efficiency in concrete production
3. Material savings in cement and binders
4. Efficiency improvements in clinker production
5. Decarbonisation of electricity
6. Carbon capture, utilisation, and storage (CCU/S)
7. CO_2 sink through recarbonation

It is worth noting that no specific policy actions have been identified to date for the seventh lever on CO_2 sinks.

Lever 1: Efficiency improvements in clinker production

The Thailand cement decarbonisation roadmap estimates that switching from coal to biomass and waste-derived fuels can reduce CO_2 emissions by around 12% by 2050, equivalent to approximately 3.6 $MtCO_2$ per year.

Currently, biomass and waste-derived fuels account for around 15% of the thermal input in cement production. To optimise the limited supply of waste resources and biomass across the economy, careful planning, prioritisation and allocation are required, alongside the implementation of supportive policy measures and initiatives to ensure that this transition is successful. In parallel, advanced technologies such as green hydrogen and electrified heating technologies will continue to be researched and assessed for potential long-term development and deployment.

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 1.1:** Develop a robust and well-justified policy framework for the optimal allocation of limited alternative fuel resources, i.e. biomass and waste-derived fuels, for industrial heating and power generation across sectors. The policy should align with the goals of the country's Nationally Determined Contribution (NDC) while addressing relevant economic and competitiveness challenges.	MOEN, MOI, MOIND	✓		
• **Task 1.2:** Establish and implement quality standards for solid waste used as fuel at cement plants.	MOIND, MOEN	✓		
• **Task 1.3:** Improve waste management practices for better waste sorting in both industry and communities to enhance alternative fuel use and circularity in the cement sector.	MOIND, MOI, MOEN	✓		
• **Task 1.4:** Introduce financial instruments and policy mechanisms, such as carbon pricing and carbon taxes, to incentivise cement plants to utilise alternative fuels.	MNRE, MOEN, MOF	✓		
• **Task 1.5:** Conduct targeted research and demonstration activities on advanced cement kiln technology that uses hydrogen or electricity as energy sources for heating. In parallel, the government should plan and develop enabling infrastructure, including power grid upgrades and hydrogen transportation networks, to facilitate the long-term deployment of advanced fuel technology.	MOEN, MHESRI, Cement industry	✓		

Lever 2: Material savings in cement and binders

Replacing clinker with alternative cementitious materials could reduce CO_2 emissions by approximately 3.0 Mt per year by 2050. Low-carbon cements are already standardised and actively promoted in Thailand's infrastructure and construction sectors.

To further advance decarbonisation, the development of novel cement types with lower embodied energy and emissions is essential. Limestone Calcined Clay Cement (LC3), which has a high technology readiness level (TRL) and relies on locally available raw materials, is particularly promising as a next-generation low-carbon cement. Key policy and industry actions under this lever are summarised below.

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 2.1:** Conduct targeted research studies on novel low-carbon cement, such as LC3 or other alternatives, with a focus on technology development, regulatory considerations, and viable financial models.	MHESRI, Cement industry	✓	✓	
• **Task 2.2:** Develop performance-based industrial standards, i.e. Environmental Product Declaration (EPDs), and a green procurement mechanism for low-carbon cements to enable their commercial uptake by end users in both the infrastructure and construction sectors.	MOIND, MNRE, MOI	✓		
• **Task 2.3:** Support tax exemptions, fiscal incentives and other financial measures in the construction, installation, and upgrading of manufacturing technologies for low-carbon cement production.	BOI, MOF, MOIND	✓	✓	
• **Task 2.4:** Engage stakeholders and build capacity across the value chain to accelerate the adoption of the new low-carbon cement products.	MOIND, Cement industry	✓		

Lever 3: Electricity Decarbonisation and Efficiency Enhancement in Cement Manufacturing

The cement industry is actively adopting a range of energy-efficient technologies, such as smart process control, high-efficiency motors, and optimised material handling and internal transport systems. It has also begun to scale up the use of renewable electricity, particularly solar power. However, full electricity decarbonisation will require securing substantially larger volumes of renewable electricity. To effectively integrate these increased volumes, robust demand-side energy management measures, such as grid flexibility solutions and electricity storage, are essential. Taken together, these measures could enable a potential reduction of approximately 1.5 $MtCO_2$ by 2050.

This lever aims to increase the share of renewable electricity and improve energy efficiency in cement production while ensuring commensurate CO_2 reductions.

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 3.1:** Amend regulations and rules to enable third party access (TPA) to the power-grid to facilitate industrial access to clean electricity.	MOEN	✓		
• **Task 3.2:** Strengthen electricity grid infrastructure and implement demand-side management measures (e.g., demand flexibility) to facilitate the cement industry's transition to clean electricity.	MOEN, Cement industry	✓		

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 3.3:** Establish targeted government financial support mechanisms, such as investment subsidies for machinery, and tax exemptions, to support industry's transition to high-efficiency equipment and energy storage technologies.	BOI, MOEN, MOF	✓		
• **Task 3.4:** Enhance technical capacity and financial expertise to operationalise taxonomy-consistent decarbonisation investments in cement production, ensuring both technological robustness and bankable, investment-grade financial structures.	BOT, Securities and Exchange Commission (SEC), Financial institutions, Cement industry	✓		

Lever 4: Efficiency in design and construction

This lever focuses on implementing policies that maximise opportunities for carbon reduction across the cement sector's value chain. It aims to facilitate decarbonisation across the entire life cycle by promoting the adoption of materially efficient design and construction practices and by leveraging the carbon-reduction benefits of cement and concrete applications.

Short-term actions include developing policies that enable the effective and timely implementation of decarbonisation strategies within the sector. By fostering a supportive legislative and business environment, this lever can accelerate industrial decarbonisation across the cement industry and its broader value chain.

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 4.1:** Establish credible embodied-carbon information and disclosure tools (e.g. Environmental Product Declaration: EPDs) to enable the selection of lower-carbon cement and concrete, as well as to promote carbon footprint assessment in the construction projects.	MNRE, TGO, MTEC	✓		
• **Task 4.2:** Mandate performance-based Green Public Procurement (GPP) that incorporates carbon-emission assessments for central and local government construction contracts.	MNRE, MOF, MOI	✓		
• **Task 4.3:** Develop a life-cycle carbon rating system for the built environment and integrate it into building codes and/or building labelling schemes, using performance-based assessment approaches to evaluate the life-cycle carbon footprints of infrastructure and construction projects.	MNRE, TGO, MOEN, MOI, TGBI	✓		
• **Task 4.4:** Implement resource-efficiency and circular-economy policies that encourage the minimisation of material footprints, the elimination of waste, and the optimal reuse and recycling of built environment materials across their entire life cycles.	MNRE, MOIND, MOI	✓		
• **Task 4.5:** Promote the adoption of low-carbon freight and logistic solutions (e.g. using electric trucks) for concrete and aggregates logistics.	Cement and concrete industry	✓		

Lever 5: Facilitating the deployment of carbon capture utilisation and storage (CCU/S)

Approximately 61.3% of the total CO_2 emissions from cement production originate from the calcination of calcium carbonate ($CaCO_3$)—a significantly larger share than emissions from fossil fuel combustion for process heat. CCU/S therefore represents the single most important technological option for deep decarbonisation in the cement sector, with the potential to reduce emissions by up to 13.6 $MtCO_2$ by 2050. No other currently available technology offers mitigation potential at a comparable scale.

At present, no CCU/S demonstration projects have been deployed in Thailand's cement sector. A comprehensive assessment of CCU/S potential and feasibility is therefore required. This should include, at a minimum:

- Identification of technical, regulatory and infrastructural requirements for CCU/S deployment, as well as the enabling policy framework required to support implementation.
- Close and sustain collaboration between industry and relevant government agencies and local authorities.

Action	Stakeholders	Short-term 2025-2030	Medium-term 2030-2040	Long-term 2040-2060
• **Task 5.1:** Continue research to advance transformative, lower-TRL CCU/S technologies and accelerate technological maturity and commercial-scale deployment Support the development of a dedicated CCU/S roadmap for the cement industry, aligned with national strategies and cross-sectoral decarbonisation plans	MNRE, MOEN, Research institutions, Cement industry	✓		
• **Task 5.2:** Implement initiatives to raise public awareness and understanding of CCU/S in communities located near potential project development sites.	MNRE, MOEN, academic institutes, Cement industry	✓	✓	
• **Task 5.3:** Support the development of CCU/S pilot projects through climate finance instruments, international cooperation, and other financial mechanisms. Develop prototype business models to support early deployment. A single commercial-scale pilot in Saraburi Province may be sufficient for national learning and replication.	MNRE, MOEN, academic institutes, Cement industry		✓	✓
• **Task 5.4:** Establish dedicated financing mechanisms, such as Carbon Contracts for Difference (CCfDs), to enable the commercial deployment of CCU/S technologies and improve long-term investment viability.	MNRE, MOEN, MOF, Cement industry		✓	✓

Monitoring of Policy Actions through Indicators

Two types of key performance indicators are required to monitor progress and ensure the successful decarbonisation of the cement sector.

- **Leading indicators** provide early signals of progress in technology readiness, market adoption capacity, and initial deployment of key technologies.
- **Lagging indicators** enable retrospective assessment of whether decarbonisation technologies have been successfully scaled and implemented (e.g. measuring progress against net-zero targets).

The indicators outlined below can be used to track industry milestones and evaluate decarbonisation progress over time. Together, they enable integrated monitoring of both leading and lagging outcomes and can be updated and communicated regularly. These milestones serve as critical checkpoints to build stakeholder confidence and inform adjustments to policies and support measures where necessary.

Recommended Indicators for Monitoring

Track	Leading indicators / milestones	Lagging indicators / milestones
Overall	- Total investment in low-carbon cement	- Volume of low-carbon cement produced - Emissions intensity per tonne of cement (industry-wide)
Coordinated procurement model to unlock demand-pull across tracks	- Government and private-sector adoption of common methodologies and standards for embodied carbon in cement and concrete (e.g. standardised LCA methodology, EPD templates) - EPDs for low-carbon cement and concrete products established and made widely available - Commitments by major public and private sector buyers to procure low-carbon materials	- Share of government procurement covered by low-carbon materials standards - Emissions intensity of government-purchased cement and concrete - Share of private-sector cement procurement covered by low-carbon materials standards
Clinker substitution, energy efficiency, and alternative fuels	- Successful demonstrations of LC3-type and ternary blends in key applications (e.g., road and highway paving) by 2030 - Adoption or planned adoption of LC3-type and ternary blends - Total investment in energy efficiency, and alternative fuel technologies	- Clinker factor (clinker share of cement mix by weight) industry-wide - Energy efficiency improvement relative to baseline - Alternative fuels share of industry energy consumption
CCU/S	- One commercial-scale demonstration by 2035, including demonstration of alternative capture technologies - Project finance models for CCU/S established by 2035	- CCU/S retrofits of existing plants, integration into new-build plants, associated capital formation
Alternative production methods	- One commercial-scale demonstration by 2030 - Demonstrated technological success at commercial scale by 2030 - Initial cost reductions by 2030, consistent with commercial competitiveness with traditional production and CCU/S - Products accepted under existing standards and adopted by large customers - Project finance model for greenfield deployments established by 2030	- Number of new greenfield plants using alternative production methods and associated capital investment
Alternative binder chemistries	- Entry of alternative binders into the national standardisation process (timing varies with TRL)	- Market share, initially in non-structural applications

REFERENCE

[1] The European Cement Association, Activity Report 2023, Brussels, Belgium, 2023.

[2] Office of Natural Resources and Environmental Policy and Planning, Thailand Long-Term Low Greenhouse Gas Emission Development Strategy (Revised Version), Ministry of Natural Resources and Environment, Bangkok, Thailand, 2022.

[3] Office of the National Economic and Social Development Council, Thailand's Fourth Biennial Update Report (BUR4), Ministry of Natural Resources and Environment, Bangkok, Thailand, 2023. [Online]. Available: https://unfccc.int/sites/default/files/resource/Thailand_BUR4_final_28122022.pdf

[4] United Nations Population Division, World Urbanization Prospects: 2018 Revision, 2024. [Online]. Available: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

[5] Department of Primary Industries and Mines, The Situation of Cement Industry in Thailand, Year 2023, Ministry of Industry, Bangkok, Thailand, 2023.

[6] Office of Industrial Economics, Industrial Statistics, 2024. [Online]. Available: https://www.oie.go.th/view/1/statistics/TH-TH

[7] Cemnet.com, "Thailand's low-carbon transition," 2024. [Online]. Available: https://www.cemnet.com/Articles/story/176194/thailand-s-low-carbon-transition.html

[8] CareEdge Research, Research Report on Cement Industry, 2024. [Online]. Available: https://www.andhracements.com/Research%20Report%20on%20Cement%20Industry%20-%20Final.pdf

[9] Krungsri Research, Thailand Industry Outlook 2024–26: Construction Contractor, Bangkok, Thailand, 2024.

[10] Thailand Cement Manufacturer Association (TCMA), A Report on Supporting the Cement Industry to Reduce Thailand's CO_2 Emissions, Bangkok, Thailand, 2022.

[11] Global Cement and Concrete Association (GCCA), GNR 2.0 – GCCA in Numbers, 2019. [Online]. Available: https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/

[12] Verein Deutscher Zementwerke (VDZ), Zahlen und Daten 2021, Düsseldorf, Germany, 2021.

[13] RMI and China Cement Association, Towards Net Zero: Decarbonisation Roadmap for China's Cement Industry, 2022. [Online]. Available: https://rmi.org/insight/net-zero-decarbonization-in-chinas-cement-industry/

[14] S. A. Ishak and H. Hashim, "Low carbon measures for cement plant—A review," J. Cleaner Production, vol. 103, pp. 260–274, 2015.

[15] Verein Deutscher Zementwerke e. V., Zement-Taschenbuch, 51st ed., Düsseldorf, Germany: Verlag Bau + Technik GmbH, 2008. [Online]. Available: https://www.vdz-online.de/wissensportal/publikationen/zement-taschenbuch-2008

[16] LEILAC, "How it works," 2023. [Online]. Available: https://www.leilac.com/technology/#how-it-works.

[17] Fraunhofer ISI, Direct Electrification of Industrial Process Heat: Technologies, Potentials and Future Prospects for the EU, Study for Agora Industry, 2024. [Online]. Available: https://www.agora-industry.org/publications/direct-electrification-of-industrial-process-heat

[18] LEILAC, Leilac-2 Demonstration Plant FEED Study Summary (Public Version), 2023. [Online]. Available: https://www.leilac.com/wp-content/uploads/2023/10/2023-10-15-Leilac-2-Public-FEED-Study.pdf

[19] GlobalCement, "H_2 in cement: Lessons learned," 2022. [Online]. Available: https://www.globalcement.com/magazine/articles/1283-h2-in-cement-lessons-learned

[20] Ecofys, Status and Prospects of Co-processing of Waste in EU Cement Plants, 2017. [Online]. Available: https://coprocessamento.org.br/wp-content/uploads/2019/09/Ecofys_Status_prospects_coprocessing_waste_EU_cement_plants-20170426.pdf

[21] VDZ, Dekarbonisierung von Zement und Beton – Minderungspfade und Handlungsstrategien, Düsseldorf, Germany, 2020. [Online]. Available: https://www.vdz-online.de/fileadmin/wissensportal/publikationen/zementindustrie/VDZ-Studie_Dekarbonisierung_Zement_Beton_2020.pdf

[22] European Cement Research Academy (ECRA), Technology Papers 2022, 2022. [Online]. Available: https://api.ecra-online.org/fileadmin/files/tp/ECRA_Technology_Papers_2022.pdf

[23] IEEE, Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads, 2017. [Online]. Available: https://ieeexplore.ieee.org/document/5930335

[24] A. Summerbell et al., "Cost and carbon reductions from industrial demand-side management: Study of potential savings at a cement plant," Applied Energy, vol. 197, pp. 100–113, 2017.

[25] M. Mossie, et al., "Energy demand flexibility potential in cement industries: How does it contribute to energy supply security and environmental sustainability?" Applied Energy, vol. 377, Art. no. 122, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306261924019913

[26] M. Schneider, "Process technology for efficient and sustainable cement production," Cement and Concrete Research, vol. 78, pp. 14–23, 2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0008884615001453

[27] CO_2 Value Europe, "HYBRIT: Hydrogen-based direct reduction for iron and steel production," CO_2 Value Europe Project Database. [Online]. Available: https://database.co2value.eu/projects/287

[28] B. Davis, "Hot rocks could increase duration of thermal storage solutions," New Energy World, Jan. 31, 2024. [Online]. Available: https://knowledge.energyinst.org/new-energy-world/article?id=138551

[29] X. Liu, X. Li, and R. Yang, "High-temperature thermal storage-based cement manufacturing for decarbonization," Discover Chemical Engineering, vol. 3, Art. no. 8, 2022.

[30] Sympower, "Sympower goes live in Greece's balancing markets," Nov. 1, 2024. [Online]. Available: https://sympower.net/news/sympower-goes-live-in-greeces-balancing-markets

[31] Sympower, "Uddeholm's steel production makes material gains with demand response," Case Study, Apr. 23, 2024. [Online]. Available: https://sympower.net/case-studies/uddeholm-steel-production

[32] Sympower, "Boliden Aitik – Using grinding mills' flexibility to earn revenue," Case Study, Feb. 19, 2023. [Online]. Available: https://sympower.net/case-studies/boliden-aitik

[33] Rio Tinto, "Long-term future for New Zealand's Tiwai Point aluminium smelter secured with new power deals," Press Release, May 31, 2024. [Online]. Available: https://www.riotinto.com/en/news/releases/2024/long-term-future-for-new-zealands-tiwai-point-aluminium-smelter-secured-with-new-power-deals

[34] European Commission, "Innovative business models for market uptake of renewable electricity: Unlocking the potential for flexibility in industrial electricity use (IndustRE)," CORDIS Project No. 646191. [Online]. Available European Industrial Energy Days, "Harnessing waste heat to decarbonise cement and steel." [Online]. Available: https://www.european-industrial-energy-days.com/articles/harnessing-waste-heat-decarbonise-cement-steel

[35] European Industrial Energy Days, "Harnessing waste heat to decarbonise cement and steel." [Online]. Available: https://www.european-industrial-energy-days.com/articles/harnessing-waste-heat-decarbonise-cement-steel

[36] Heidelberg Materials, "CO_2-Abscheidung und -speicherung," 2025. [Online]. Available: https://www.heidelbergmaterials.com/de/nachhaltigkeit/wir-dekarbonisieren-die-bauindustrie/ccus

[37] Heidelberg Materials, evoZero | Capture the Imagination, 2025. [Online]. Available: https://www.evozero.com/system/files/2025-11/DNV%27s%20Assurance%20Statement_HM_evoZero%20EACs_2025%206%20May%20-%205%20June_15Oct25_Signed.pdf

[38] Thai-German Corporation, "Thailand's first climate change act strengthened through public hearing, affirms its progressive milestone," 2024. [Online]. Available: https://www.thai-german-cooperation.info/news/thailands-first-climate-change-act-strengthened-through-public-hearing-affirms-its-progressive-milestone/ SwitchAsia, "Thailand approves Green Integration Policy (2022–2027)," 2022. [Online]. Available: https://www.switch-asia.eu/news/thailand-approves-green-integration-policy-2022-2027/

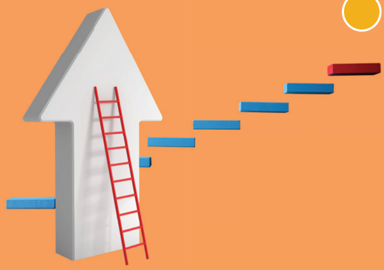
[39] Global Cement and Concrete Association. (2024). Thai Cement Manufacturers Association – Mission 2023 and the Net Zero Cement and Concrete Roadmap 2050. https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-study-tcma/ . Last visited 1.7.2025.

[40] Global Cement and Concrete Association, "Thai Cement Manufacturers Association – Mission 2023 and the Net Zero Cement and Concrete Roadmap 2050," 2024. [Online]. Available: https://gccassociation.org/2050-net-zero-roadmap-one-year-on/action-progress-case-study-tcma/

[41] Global Cement and Concrete Association, "Carbon pricing." [Online]. Available: https://gccassociation.org/concretefuture/carbon-pricing/

[42] Clean Air Task Force, "Designing carbon contracts for difference." [Online]. Available: https://www.catf.us/resource/designing-carbon-contracts-for-difference/

[43] Agora Energiewende and Wuppertal Institute, Breakthrough Strategies for Climate-Neutral Industry in Europe: Policy and Technology Pathways for Raising EU Climate Ambition, Publication No. 208/02-S-2021/EN, Apr. 21, 2021. [Online]. Available: https://www.agora-energiewende.org/fileadmin/Projekte/2020/2020_10_Clean_Industry_Package/A-EW_208_Strategies-Climate-Neutral-Industry-EU_Study_WEB.pdf




CO_2


CO_2