CLIMATE ANALYTICS

August 2025

Decarbonising cement:

A review of EU and German policies and regulations, with recommendations for China

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About Climate Analytics

Climate Analytics is a global climate science and policy institute. Our mission is to deliver cutting-edge science, analysis and support to accelerate climate action and keep warming below 1.5°C.

Acknowledgments

This report is an output of the Sino-German Cooperation on Climate Change (SGCCC) – NDC Implementation project, which was commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) as part of the International Climate Initiative (IKI). The Ministry of Ecology and Environment of the People's Republic of China is political partner to the project. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH implements the project together with the National Center for Climate Change Strategy and International Cooperation (NCSC) of China, NewClimate Institute for Climate Policy and Global Sustainability (NCI) gGmbH, and Climate Analytics (CA) gGmbH. The IKI is a key German Federal Government instrument for supporting international climate action and biodiversity.

This report forms part of a broader study to support efforts to decarbonise the cement industry in the Chinese provinces of Anhui and Sichuan. It provides insights from Europe and Germany to serve as reference points for shaping effective regional development strategies and thus aims to contribute to China achieving its climate targets. By examining policies and regulations deployed elsewhere, it offers a comparative perspective to inform policymaking, to facilitate greenhouse gas emission mitigation at the local level. The author gratefully acknowledges the valuable reviews provided by the China Cement Association.

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How to cite: Climate Analytics (2025). Decarbonising cement: A review of European policies and regulations with recommendations for China.

Abbreviations

AVV Klima: German General Administrative Regulation on the Procurement of Climate Friendly Services
BECCS: bioenergy with carbon capture and storage
BIK: German Federal Fund for Industry and Climate Action
BNB: German Sustainable Buildings Assessment System
BMWK: German Federal Ministry of Economic Affairs and Climate Change
CCfD: carbon contracts for difference
CBAM: Carbon Border Adjustment Mechanism
CBMF: China Building Materials Federation
CCS: carbon capture and storage
CCU: carbon capture and utilisation
CCUS: carbon capture, utilisation, and storage
CCA: China Cement Association
CDI: German Cluster Decarbonisation in Industries program
CDW: construction and demolition waste
CDR: carbon dioxide removal
CEA: German Circular Economy Act
CEAP: EU Circular Economy Action Plan
CEF: Connecting Europe Facility
CEMBUREAU: European Cement Association
CES: German National Circular Economy Strategy
CNS: VDZ Climate Neutrality Scenario
CO_2: carbon dioxide
CPR: EU Construction Products Regulation
CSA: calcium sulfo-aluminate
ECRA: European Cement Research Association
EIC: European Innovation Council
EPR: extended producer responsibility
ESPR: EU Ecodesign for Sustainable Products Regulation
ETS: Emissions Trading System
ETD: EU Energy Taxation Directive
EU: European Union
EUR/tCO_2: euros per tonne of carbon dioxide
EUR: euros
FID: final investment decision
gCO_2/kg: grams of carbon dioxide per kilogram
gCO_2e/kWh: grams of carbon dioxide equivalent per kilowatt hour
GCCA: Global Cement and Concrete Association
GDIP: EU Green Deal Industrial Plan
GHG: greenhouse gas emissions
GJ: gigajoule

Gt: gigatonne
$GtCO_2$: gigatonnes of carbon dioxide
GPP: green public procurement
ICMS: the EU Industrial Carbon Management Strategy
IDDI: Industrial Deep Decarbonization Initiative
IEA: International Energy Agency
IPCEI: Important Projects of Common European Interest
kg: kilogram
$kgCO_2/t$: kilograms of carbon dioxide per tonne
$kgCO_2$ /MJ: kilograms of carbon dioxide per megajoule
LC3: Calcined clay with fine limestone
MJ: megajoule
MJ/t: megajoules per tonne
Mt: megatonne
$MtCO_2$: megatonnes of carbon dioxide
NZIA: EU Net Zero Industry Act
NZE: International Energy Agency's Net Zero Emissions scenario
R&D: research and development
RED: EU Renewable Energy Directive
RMB: Chinese renminbi
RMI: Rocky Mountain Institute
SCMs: supplementary cementitious materials
t: tonne
TSR: technical screening criteria
USD: US dollars
VDZ: German Cement Industry Association
WFD: EU Waste Framework Directive

Figures and tables

Executive Summary

Cement is an integral base material for the global economy, but it poses a major climate challenge. Cement production generates 7-8% of global carbon dioxide (CO_2) emissions and the sector's emissions trajectory is incompatible with the Paris Agreement goal of limiting warming to 1.5°C above pre-industrial levels.

In recent decades, China has been central to the boom in cement production and its associated emissions. China produces more than half the world's cement, generating 13-15% of its national CO_2 emissions. Therefore, cement sector activity is critical to meeting China's goals of peaking national emissions before 2030 and reaching carbon neutrality by 2060.

The Chinese economy has above average cement and concrete consumption. China's cement demand has been falling for several years, and China appears to have reached peak cement production. Demand is likely to continue falling for several decades, bringing significant climate benefits. Still, enhanced demand reduction and elimination of remaining sector emissions are required to meet climate goals

Successful cement sector decarbonisation requires a 'whole-of-system' approach. Significant demand reduction would greatly accelerate emissions reduction. There is considerable potential for enhanced materials efficiency, including optimised building design and extended lifespans; substitution of cement and concrete with materials such as structural steel and timber; and increased circularity through reuse and recycling of cement, concrete, and other building materials.

Concurrent efforts must decarbonise the cement production process, specifically for clinker, which generates 90% of conventional cement's CO_2. Global cement's carbon intensity has fallen by about a fifth since 1990, mostly through energy efficiency, reduced clinker content in cement, and alternative fuel use. These routes still have significant - but diminishing - emissions reduction potential. Breakthrough technologies, such as alternative binder-based cements, and electricity and renewable-powered kilns, could deliver deeper decarbonisation if they can overcome significant market entry barriers.

Many industry representatives and stakeholders consider carbon capture, utilisation and storage (CCUS) to be cement's most important emissions reduction route. However, this brings significant cost and technical challenges, and substantial deployment has yet to materialise. Most fundamentally, CCUS overdependence in any sector helps sustain residual emissions and competition for finite CO_2 storage. It thus risks mid-century achievement of net zero emissions at a global level, which is critical to reaching the Paris goals. CCUS should be minimised in favour of eliminating emissions at-source.

China's cement production has a lower than global average carbon intensity, largely due to its lower clinker ratios and high energy efficiency. However, Chinese producers have room to improve in areas including alternative fuel use and, as with global peers, development of deeper decarbonisation pathways.

China faces both universal and nationally specific challenges in getting close to a zero-emissions cement sector. The unpriced CO_2 generated by conventional cement and the high cost of transitioning industry assets are key barriers. Lack of demand for low-emissions cement, restricted green finance, and difficulties coordinating climate action across industry and the broader economy are additional concerns. Chinese companies must also balance climate efforts with falling profitability tied to falling demand. Individual decarbonisation routes face discrete challenges.

Strengthening existing and implementing new policies could help China's cement sector meet its climate goals. European approaches can serve as valuable reference points in this regard. The European Union (EU) and Germany – a leading EU member state in cement production and climate policy – have implemented, or proposed, a diverse range of policies and regulations related to demand reduction, decarbonising production, and deploying CCUS.

China's priority on decarbonising cement is to successfully integrate the sector into its Emissions Trading System (ETS). While the EU maintains the world's most-established and successful ETS, its coverage of cement has not been optimally calibrated for deep decarbonisation thus far. However, coming reforms are set to significantly improve its impact. The European example could serve as reference for China's ongoing ETS design. Numerous other EU and German policy and regulatory frameworks provide similar opportunities to inform policy- and decision-making.

This report recommends the following actions over the short, medium, and long-term[1] to create favourable conditions for deep decarbonisation of the cement sector in China:

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[1] Short-term: design and main implementation are completed by 2035; medium-term: design and main implementation are completed by 2045; longer-term: design and main implementation are completed by 2050 or extending to 2060 and beyond. Industry stakeholder actions taken in response to policies and regulations are not included in timelines.

Short-term:

- Optimise cement's ETS inclusion
- Ensure national cement and building standards are fit-for-purpose
- Improve alternative fuel availability and access
- Adopt innovative public funding mechanisms
- Improve industry access to green finance

Medium-term

- Enhance national capacity for demand reduction
- Create green lead markets through public procurement and labelling
- Ensure a smooth industry transition to a low demand, low emissions future

Longer-term

- Support continual technology breakthroughs through R&D
- Pursue limited CCUS development
- Pursue cooperation on global cement decarbonisation
- Build and maintain a supportive and integrated industrial ecosystem

Figure 1 summarises the suggested implementation schedule for these recommendations and the key objectives they could help achieve.

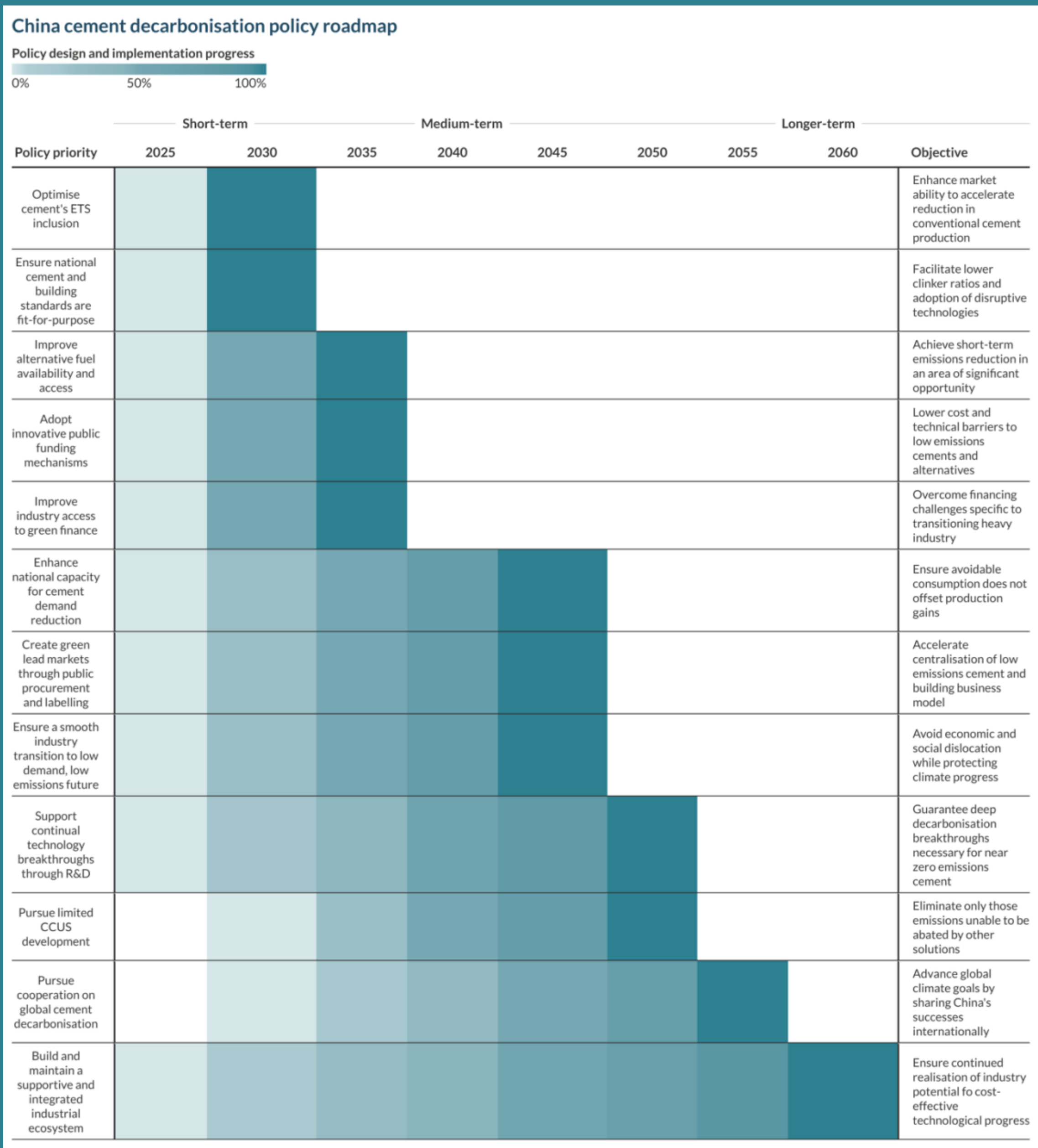

Figure 1. China cement decarbonisation policy roadmap

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Introduction and context

Cement is integral to global development and climate action. Cement is the key ingredient in concrete, which – in volume terms – is the second most widely-consumed material after water, at over 30 billion tonnes (Gt) per year.[2] Cement is also widely used in mortars and other products. Cement production surged from 1.3 Gt/year in 1990 to peak at 4.4 Gt/year in 2021, due to rapid industrialisation and urbanisation. [3] Production has since fallen to about 4.1 Gt/year (see Figure 2).[4] Cement's CO_2 emissions have risen sharply with production, to about 2.5 GtCO_2/year, or 7-8% of global CO_2 emissions.[5]

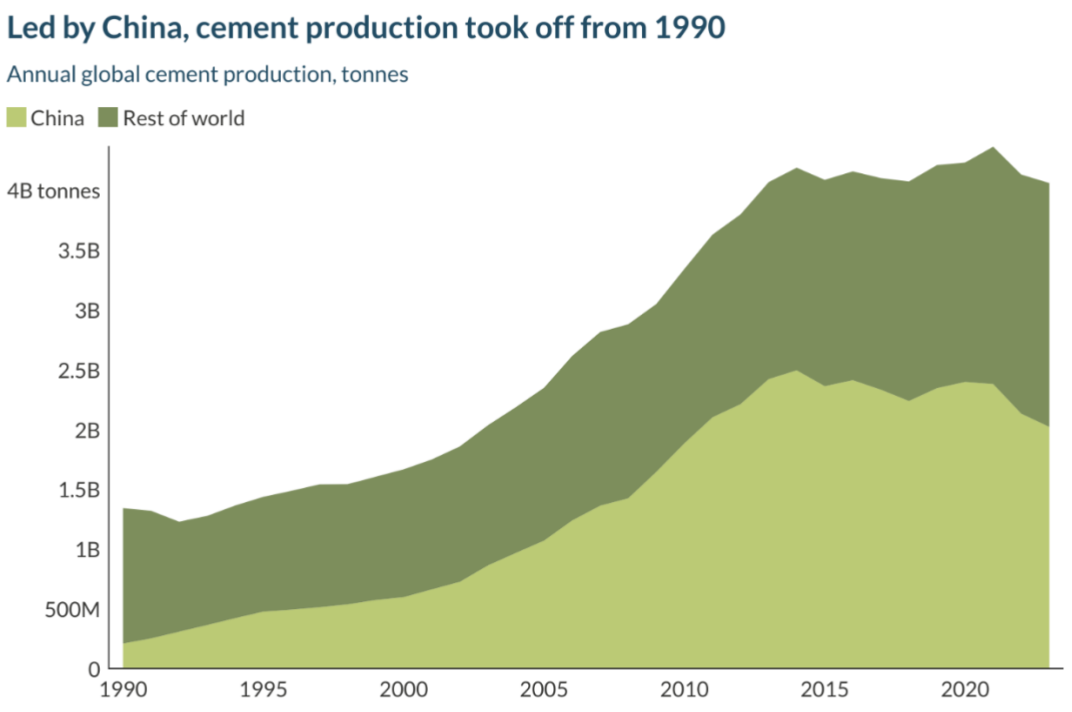

Figure 2. Global cement production (1990-2023)

In the International Energy Agency's Net Zero Emissions (NZE) scenario – which is aligned with meeting the Paris Agreement's goal of limiting warming this century to

[2] Nature, 'Concrete Needs to Lose Its Colossal Carbon Footprint'.
[3] Andrew, 'Global CO2 Emissions from Cement Production', 22 December 2023; United States Geological Survey, 'Cement Statistics and Information'.
[4] Andrew, 'Global CO2 Emissions from Cement Production', 22 December 2023; United States Geological Survey, 'Cement Statistics and Information'.
[5] Andrew, 'Global CO2 Emissions from Cement Production', 22 December 2023; Cheng et al., 'Projecting Future Carbon Emissions from Cement Production in Developing Countries'.
[6] Andrew, 'Global CO2 Emissions from Cement Production', 22 December 2023.

1.5°C above pre-industrial levels – cement sector emissions decline by 4% per annum through to 2030.[7] However, under the IEA's Stated Policies scenario, which reflects the implications of current policy, by 2050 cement emissions are still 3% higher than in 2022.[8] Cement sector decarbonisation is thus far off a Paris-aligned pace.

The cement sector faces significant challenges in aligning with a 1.5°C future. Producing clinker – the primary ingredient in conventional Portland cement – generates about 90% of the sector's emissions.[9] About 40% of clinker emissions come from using fossil fuels to generate heat of up to 1450°C for kilns.[10] The other 60% are process emissions from the chemical transformation, or 'calcination', of limestone into calcium oxide.[11] Cement's remaining 10% emissions mainly come from electricity used in crushing, grinding, blending, and other indirect applications, such as transport (see Figure 3).[12]

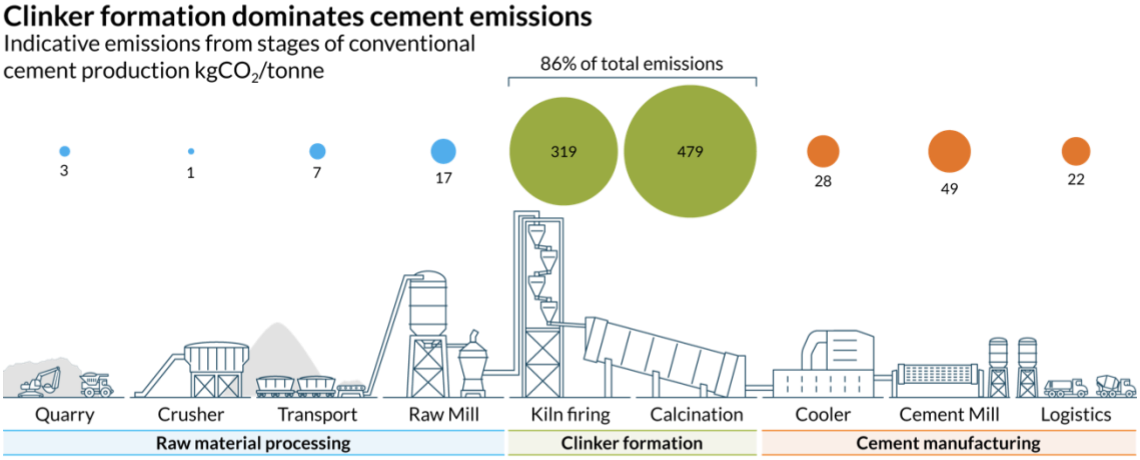

Figure 3. Indicative emissions from conventional cement production process

There has been recent progress in reducing cement's emissions intensity. The Global Cement and Concrete Association (GCCA) reports that the average carbon intensity of cement dropped by about a fifth between 1990 and 2022.[14] The IEA reports 580 $kgCO_2/t$ as the current global average.[15] One estimate of Chinese cement's carbon

[7] IEA, 'Net Zero Roadmap'.
[8] IEA, 'World Energy Outlook 2024'.
[9] Bashmakov et al., 'Industry'.
[10] Bashmakov et al.
[11] Bashmakov et al.
[12] Bashmakov et al.
[13] Thomas Czigler, Sebastian Reiter, Patrick Schulze, and Ken Somers, 'Laying the Foundation for Zero-Carbon Cement'.
[14] Global Cement and Concrete Association, 'GCCA GNR Data'.
[15] IEA, 'Cement – Analysis'.

intensity, from 2020, was lower than this, at 548 $kgCO_2/t$.[16] However, the Systems Change Lab (SCL) – a collaborative project of climate think tanks – estimates the global average must fall from its own 2020 estimate of 656 $kgCO_2/t$ to 360–370 $kgCO_2/t$ by 2030, and 55-90 $kgCO_2/t$ by 2050, to align with the goals of the Paris Agreement.[17] (Seen note on calculating the carbon intensity of cement.[18])

Cement production and cement's economic role need a rapid transformation. Successful decarbonisation requires a 'whole-of-system' approach, consisting of numerous efforts to increase use of low-emissions cement or alternatives and decrease use of high-emissions cement. This must incorporate policy interventions in building and construction and related sectors. Necessary changes include facilitating more efficient concrete production methods and uses, use of alternative lower carbon building materials, promotion of longer building lifetimes and other forms of efficiency, and end-of-life reuse and recycling of cement and other building materials. Table 1 outlines the whole-of-system approach and some key challenges and opportunities.

Enhancing materials efficiency, substitution, and circularity may significantly reduce cement demand and thus emissions in the future. Numerous technologies have already contributed to lowering cement's carbon intensity. However, as technological limits are reached and obstacles such as raw materials availability rise, the potential to further reduce emissions through traditional means, such as energy efficiency and alternative fuels, are diminishing. Potential breakthrough technologies exist but have struggled to advance commercially.

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[16] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[17] Systems Change Lab, 'Systems Change Lab'.
[18] Note on calculating the carbon intensity of cement: There are various methods for calculating CO_2 emissions from cement (and clinker) production, all typically expressed in $kgCO_2/t$. The GCCA figures quoted refer to 'net' rather than 'gross' CO_2 emissions and to 'cementitious materials'. Net and gross emissions differ on thermal fuel emissions accounting. Both include emissions from combustion of conventional fossil fuels and exclude emissions from biomass, which is considered carbon neutral. But net figures also exclude emissions from non-biogenic fossil fuels diverted from waste streams. The GCCA database also does not include CO_2 from onsite power for either measure. Cementitious materials refers to clinker and other materials with cement-like qualities, e.g. SCMs. The IEA figure is consistent with this assessment method. The SCL figure references the GCCA database, but it aligns with figures for gross emissions from 'cement equivalent', which accounts for clinker being traded between cement plants and applies the average plant-level clinker factor to estimated cement production. SCL also estimates power generation-derived CO_2. This report notes which assessment method is used where relevant. In addition, the GCCA database only assesses about a quarter of global production.

Low prioritisation of demand reduction and challenges in further transforming production processes and building practices has led the cement industry to increasingly focus on carbon capture and utilisation or storage (CCUS) as a primary source of emissions mitigation. However, CCUS also faces numerous technical, cost, and other challenges. Even when operating at full potential, cement plants with CCUS would still produce net positive emissions and help keep carbon-intensive capacity online.

Most fundamentally, excessive CCUS reliance jeopardises achievement of the Paris Agreement goals. Limiting warming to 1.5 °C requires reaching global level net zero emissions by 2050, and negative emissions thereafter, via atmospheric carbon dioxide removal (CDR).[19] To ensure this remains possible, there should be minimal residual emissions and competition for CO_2 storage from any sector. Elimination of emissions at source should be prioritised (see note on the need to avoid CCUS overdependence[20]).

Concrete also reabsorbs CO_2 as it cures. This 'recarbonation' effect is estimated to sequester the equivalent to up to 20% of CO_2 from clinker production. Recarbonation can be enhanced through various processes. But, as with CCUS, calls for greater appreciation of this carbon sink could detract from at-source emissions elimination.

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[19] IPCC, 'Synthesis Report of the IPCC Sixth Assessment Report (AR6)'.

[20] Note on the need to avoid CCUS overdependence: CCUS remains an expensive emissions abatement route and there has been relatively little improvement in learning rates and related cost reductions in recent years. Reported CO_2 capture rates are often well below claimed potential. If these trends continue, there is a high risk that CCUS overdependence will contribute to sectors such as cement sustaining significant residual emissions by mid-century. This places undue pressure on the atmospheric carbon dioxide removals that will be necessary to achieve net zero emissions globally. Projected CO_2 storage resources are theoretically sufficient in theory, but the 'bankable' share of these (those of a known size and suitable porosity for potential exploitation) remains unclear. CCUS should still be developed as a net zero option, including through further research and development, in case more innovative options for eliminating emissions fail to materialise. Yet significant deployment should be considered a last resort. See Martin-Roberts et al., 'Carbon Capture and Storage at the End of a Lost Decade'.

Decarbonising cement requires a whole-of-system approach

Main lever		Sub-lever	Main opportunities and challenges
Demand reduction	→	Materials efficiency	Cost-effective solution but attracts limited policy support
	→	Materials substitution	Potential for significant emissions reduction, pending further lifecycle assessments. Currently unable to match cement's cost, raw materials, and technical advantages
	→	Materials circularity	Potentially cost-effective decarbonisation route but depends on major changes to industrial ecosystem
Decarbonising production	→	Reduced clinker content	Proven emissions saving ability but challenged by raw materials availability and current industry standards
	→	Alternative binders and cement	Potential for deep decarbonisation but cost and technical barriers, and industry standards, continue to prevent widespread use
	→	Alternative fuels and energy	Alternative fuels have heavily contributed to decarbonisation in some jurisdictions, but global raw materials access regimes are inconsistent. Electrification and renewables have significant potential but low maturity
	→	Energy efficiency	Proven source of emissions savings but reaching the end of technical limits
CCUS			Potential to manage unavoidable emissions from conventional cement production but faces significant cost and technical barriers

Table 1. A whole-of-system approach to cement sector decarbonisation

China’s pivotal role in cement demand and supply

The global cement production boom over recent decades has been inseparable from China's economic rise. Chinese cement production increased from 209 million tonnes in 1990 to a peak of 2.5 Gt in 2014.[21] China continues to produce more than half of the world’s cement.[22] China’s industry dominance will diminish in coming years, as its economy transitions away from its most materials-intensive phase. However, even with these trends, Chinese cement production will remain comparatively strong for decades.

China’s government has committed to peak economy-wide emissions before 2030 and to reach carbon neutrality by 2060.[23] Cement currently generates 13-15% of China’s CO_2 emissions.[24] Achieving China’s, and the world’s, climate goals requires rapid scaling up of emissions mitigation solutions.

China can play a defining role in putting cement on track for economy-wide net zero emissions, but this is a more formidable task than for other sectors. In the IEA NZE, CO_2 emissions from power and heat fall 42% during 2023-2030 and 80% by 2035, while cement emissions decline 24% by 2030 and 47% by 2035.[25]

There are also various China-specific cement emissions challenges and opportunities. Chinese industry members are global leaders in areas such as energy efficiency and lowering clinker contents. They have room to improve in alternative fuels. As with most countries, Chinese producers have also made limited progress developing and deploying breakthrough production technologies or CCUS. China’s economy has higher-than-average cement and concrete consumption and relatively few current tools for rapidly reducing demand.

In addition, the peaking of Chinese cement use does not ensure the world will follow. One industry forecaster predicts Chinese consumption will fall to 900 Mt in 2050, but consumption outside China, led by developing and emerging market economies, will rise to 5.1 Gt over the same time.[26] It is critical that policymakers ensure that China’s cement decarbonisation is achieved as part of a global-level breakthrough.

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[21] Andrew, ‘Global CO2 Emissions from Cement Production’, 22 December 2023.
[22] Andrew.
[23] Climate Action Tracker, ‘China. November 2023.’
[24] Ofusu-Adarkwa, Xie, and Javed, “Forecasting CO2 Emissions of China’s Cement Industry Using a Hybrid Verhulst-GM (1,N) Model and Emissions’ Technical Conversion.”
[25] IEA, ‘Net Zero Roadmap’.
[26] CW Group, ‘Global Cement Volume Forecast Report (GCVFR)’.

Approach and outline

This report aims to inform China's response to decarbonising cement. It particularly seeks to identify and analyse policy and regulatory responses from Europe that are relevant to Chinese circumstances.

The EU, and Germany within it, are much smaller cement markets than China, and their cement production peaked much earlier and lower. Chinese cement production is also already less carbon-intensive by one measure. EU and German producers do, however, have above-average performance in some areas, most notably alternative fuel deployment. The EU and Germany also have ambitious climate policies and regulations, including for cement.

The report was prepared with the aid of extensive literature review, application of the 'Cement Sector Policy Mapping Tool'[27] to both the China and European contexts, and consultation with Chinese cement sector members and stakeholders, including through an international expert exchange in Hefei, Anhui Province, in November 2024.

Chapter two provides background on cement emissions reduction solutions at a global level. It assesses potential benefits and challenges of different approaches and how they factor into net zero emissions roadmaps for, or incorporating, cement. The chapter closes by assessing ongoing sector-wide challenges and potential policy responses.

The third chapter examines China-specific cement decarbonisation challenges and opportunities. This includes analysis of China's policy and regulatory environment relating to cement and climate, along with key priorities for reducing emissions. The fourth chapter similarly assesses the EU and Germany's cement landscape and more closely examines their various policies and regulations for decarbonising the sector. The fifth chapter explores how China's future policy formation might incorporate insights from the European context, with recommended actions.

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[27] The Cement Sector Policy Mapping Tool was adapted from NewClimate Institute's 'Policy and Actor Mapping Tool', which provides a database framework for capturing policies relevant to certain outcomes and their key characteristics. The tool was used to identify and assess policies with relevance to cement sector mitigation in China, the EU and Germany. This allowed for comparative analysis of the respective policy landscapes in these jurisdictions, with the specific aim of identifying gaps in the Chinese context and opportunities for learning from/engaging with EU and German policies. The tool captures details of objectives, functionality, and effectiveness of policies, as well as potential areas of future reform.

Decarbonising cement: challenges and solutions

This chapter begins by considering options for reducing demand for conventional, high emissions cement, followed by solutions for decarbonising cement production. It closes by considering CCUS. Technologies and processes that can leverage cement's recarbonation effect are explored in the context of these categories.

Demand reduction

Using less cement can guarantee emissions reductions from the sector. Somewhat counterintuitively, cement-based materials such as concrete have a carbon intensity that is "much lower than almost all alternative" building and construction materials, while cement itself has mid-range carbon intensity.[28] Cement's overall carbon footprint mostly results from the enormous quantities in which it is used.

Options for significantly reducing this use include minimising demand for cement in end products and decreasing demand for end products themselves. Materials efficiency, substitution, and circularity can all contribute.

Cement content in concrete can be reduced by using alternative materials and processes, such as multi-sized aggregates and improved mixing. This can reduce concrete's emissions intensity by half, without quality loss.[29] CO_2 can also be directly injected into precast concrete or absorbed in CO_2-rich environments, as part of the curing process. This can increase strength and eliminate material use, while providing a CO_2 use case. Estimates of potential emissions savings vary. Some sources record abatement potential of 50% or more CO_2 and potentially carbon neutral or negative production, dependent on processes.[30]

Global recycling and reuse rates for cement and concrete currently trail those for steel and other industrial products.[31] Yet there are options for improvement: new concrete

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[28] See Council of Engineers for the Energy Transition, 'Decarbonizing the Cement and Concrete Sector'.
[29] Habert et al., 'Environmental Impacts and Decarbonization Strategies in the Cement and Concrete Industries'.
[30] IEA, 'ETP Clean Energy Technology Guide'.
[31] Ellen MacArthur Foundation, 'Completing the Picture'.

can be produced with about 40% recycled concrete fines.[32] New technologies might also allow for recovery and reuse of unhydrated cement – which is up to 50% of the content of cured concrete – as a feedstock to recycled concrete.[33]

Major cement demand reduction options

Technology/process	Main lever	Mitigation potential	Maturity
Optimising concrete design	Materials efficiency	Up to 50% concrete CO_2 reduction using multi-sized aggregates and improved mixing	High
CO_2 mineralisation	Materials efficiency (also CO_2 use case, alternative binders and cements)	50% concrete CO_2 reduction; potential for carbon neutral or negative production, dependent on materials and process	High
Cement/concrete from recycled fines	Materials circularity	Reducing process emissions in clinker production by "factor of three" (IEA); Up to 28% CO_2 reduction from cement production/30% CO_2 reduction with enforced recarbonation (ECRA)	Medium
Unhydrated cement recycling	Materials circularity	Mitigation impact potentially high, but technological limits unknown	High
Optimising building design and use	Materials efficiency and circularity	38% built environment CO_2 reduction by 2050 and 56% thereafter by eliminating waste; prolonging building lifetimes; eliminating construction waste, reusing and recycling materials	High
Alternative building materials	Materials substitution	40% CO_2 built environment reduction by substituting timber, bamboo, and other biomaterials for concrete and other materials	High

Table 2. Major cement demand reduction options

By one estimate, adopting various materials efficiency and circularity practices – including significantly altering use of cement, concrete, and other materials – could reduce built environment emissions up to 56% per year from 2050.[35] A third of savings come from eliminating waste from building design, a third from prolonging building

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[32] IEA, 'ETP Clean Energy Technology Guide'.
[33] IEA.
[34] IEA; European Cement Research Academy, Ed, 'The ECRA Technology Papers'; Ellen MacArthur Foundation, 'Completing the Picture'; Bashmakov et al., 'Industry'.
[35] Ellen MacArthur Foundation, 'Completing the Picture'.

lifetimes, and a third from eliminating construction waste and reusing and recycling materials.[36]

On the substitution front, timber, bamboo, and other bio-materials displacing concrete and other emissions-intensive materials has been estimated as capable of reducing building sector CO_2 emissions by 40%.[37] There is, however, a need for more comprehensive lifecycle emissions analysis of cement and its alternatives.

The importance of demand reduction is evident in the observation that cement production generates the highest CO_2 emissions per unit of revenue of any industrial sector. [38] When combined with challenges in overhauling production processes outlined below, this limits industry support for supply side transformation.

Building political support for demand reduction strategies – including overhauling building practices and codes and creating a recycling and alternative materials industrial ecosystem – will also be difficult. Adoption of these approaches has traditionally trailed production-centric decarbonisation solutions.[39]

Decarbonising cement production

Numerous technologies and processes can eliminate emissions from cement production. Clinker can be reduced in a similar manner to cement and concrete demand. This is the only way to eliminate cement's process emissions at source. The main pathways are reducing the amount of clinker used to produce conventional Portland cement and developing alternative cements. Switching fuels and energy sources and enhancing energy efficiency can help eradicate cement's thermal and electricity-linked emissions.

Reducing clinker content

Reducing clinker content in cement is a frontline climate strategy. It relies on using alternative raw materials in clinker production and supplementary cementitious materials (SCMs) – including blast furnace slag from steelmaking, fly ash from coal power, or natural pozzolanic materials – in cement production.[40] Materials efficiency

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[36] Ellen MacArthur Foundation.
[37] United Nations Environment Programme, 'Building Materials and the Climate: Constructing a New Future'.
[38] Thomas Czigler, Sebastian Reiter, Patrick Schulze, and Ken Somers, 'Laying the Foundation for Zero-Carbon Cement'.
[39] Hertwich et al., 'Resource Efficiency and Climate Change'.
[40] Bashmakov et al., 'Industry'.

strategies such as clinker micronisation (reducing particle size) and optimised mixing can also reduce emissions.[41]

The clinker-to-cement ratio is an important consideration. Portland cement containing 95% clinker and 5% gypsum once accounted for almost all cement, but average clinker ratios in GCCA's global cement database fell from 0.83 in 1990 to 0.73 in 2022 and are even lower at a China level.[42]

Clinker substitution rates are limited by the chemical reactivity of SCMs but can currently reach up to 50% of blended cement by weight, without quality loss.[43] However, availability of raw materials remains a key challenge for lifting SCM content above the typical 25%.[44] Volumes of fossil-derived SCMs will also decrease as coal-based steel and power generation decline.

Calcined clay with fine limestone (LC3) is set for an important role in substituting for fossil-based SCMs.[45] LC3 is already commercially available and, through clinker substitution, has potential to reduce emissions from cement by 40-50%.[46] The Alliance for Low-Carbon Cement and Concrete has even modelled options for European clinker ratios as low as 0.4 by 2050 with LC3.[47]

Alternative binders and cements

Research on cements based on alternative binders to Portland clinker is ongoing and some options have significant potential. These include alkali-activated binders (geopolymers) and magnesium oxides from magnesium silicates. Geopolymers could reduce process emissions up to 80-90%, depending on materials and processes.[48] Other promising prospects include calcium sulfo-aluminate (CSA) and belite-ye'elimite-ferrite clinkers.[49]

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[41] IEA, 'ETP Clean Energy Technology Guide'.
[42] Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[43] IEA, 'ETP Clean Energy Technology Guide'.
[44] Habert et al., 'Environmental Impacts and Decarbonization Strategies in the Cement and Concrete Industries'.
[45] IEA, 'Energy Technology Perspectives 2023'.
[46] Bashmakov et al., 'Industry'.
[47] Alliance for Low-Carbon Cement and Concrete, 'Fast-Tracking Cement Decarbonisation: From Underperforming to Performance-Based Standards'.
[48] Lehne and Preston, 'Making Concrete Change: Innovation in Low-Carbon Cement and Concrete'.
[49] Lehne and Preston.

Major cement production decarbonisation options

Technology/process	Main lever	Mitigation potential	Maturity
Alternate raw materials in clinker production	Reducing clinker content	Up to 12% clinker CO_2 reduction	High
Clinker micronisation and advanced admixtures	Reducing clinker content	Up to 20% of cement CO_2 reduction	Medium-to-high
Blast furnace slag SCMs	Reducing clinker content	Up to 75% cement CO_2 reduction	High
Calcined clay (LC3) SCMs	Reducing clinker content	40-50% cement CO_2 reduction	High
Other SCMs: limestone, fly ash silica fume, rice husk ash, palm oil ash, cassava peel,	Reducing clinker content	Up to 40% cement CO_2 reduction	High
Cements with very high limestone content	Reducing clinker content	Up to 60% cement CO_2 reduction	Low
Magnesium oxides derived from magnesium silicates	Alternative binders and cements	In principle, production of carbon neutral or negative cement while curing	Low
Raw clay	Alternative binders and cements	High abatement potential	Low
Carbonation of calcium silicates	Alternative binders and cements	30-40% cement CO_2 reduction and 70% reduction after curing (IEA); 24-36% CO_2 reduction in cement (ECRA)	Low
Pre-hydrated calcium silicates	Alternative binders and cements	30-50% cement CO_2 reduction	Low
Alkali-activated binders	Alternative binders and cements	10-97% cement CO_2 reduction, depending on materials and processes	High
Belite calcium sulfo-aluminate clinker	Alternative binders and cements	20-30% cement CO_2 reduction	Medium
Ordinary Portland cement from non-carbonate calcium sources	Alternative binders and cements	Zero process emissions; potential carbon negative production	Low
Preheater/precalciner kilns	Energy efficiency	10-30% clinker CO_2 reduction when replacing long kilns	High
Coal to gas or oil switching	Alternative fuels and energy	7-14% clinker CO_2reduction	High
Fossil fuel to alternative fuel switching	Alternative fuels and energy	4-5% clinker CO_2 reduction	High
Concentrated solar plant for kiln heat	Alternative fuels and energy	Up to 100% of clinker thermal emissions	Medium
Hydrogen for kiln heat	Alternative fuels and energy	4% clinker CO_2 reduction	Medium
Kiln heat electrification	Alternative fuels and energy	Up to 100% of clinker thermal emissions if using renewables	Medium

Table 3. Major cement production decarbonisation options

[50] IEA, 'ETP Clean Energy Technology Guide'; European Cement Research Academy, Ed, 'The ECRA Technology Papers'; Ellen MacArthur Foundation, 'Completing the Picture'; Bashmakov et al., 'Industry'.

Some cements have enhanced recarbonation effects. These include cements based on calcium silicate clinkers, which cure on contact with CO_2 rather than water.[51] US producer Brimstone claims to have developed a calcium silicate cement which absorbs free CO_2 from the air, while retaining ordinary Portland clinker characteristics.[52] This could produce carbon-neutral or even negative cement if realised at commercial scale.[53]

By avoiding process emissions in clinker production, alternative binders and cements are the only solution capable of producing cement with near zero – or even negative – at-source emissions. However, emissions mitigation potential and technical maturity levels vary, and many options remain at the research and development (R&D) stage. Raw materials availability is again a challenge. Wide-ranging technical requirements for building and construction, along with current industry standards, create further barriers to higher market shares.[54]

Energy efficiency

Energy efficiency has made significant contributions to reducing cement emissions. Best-practice industry members have achieved average thermal energy use of 3000 MJ/t of clinker using precalciner kilns under optimal conditions.[55]

Waste heat recovery, increasing the proportion of dry and semi-dry processes, and switching to more efficient grinding – such as substituting vertical roller mills or high-pressure grinding rolls for ball mills – further improves efficiency (grinding accounts for about 70% of cement electricity demand).[56] Digital and mechanical technologies can enhance supply chain design and reduce energy inputs.

Replacing long kilns with precalciner kilns can reduce up to 30% of clinker CO_2.[57] However, this is a one-time gain, and other substitutions provide more marginal results. While average thermal energy demand as low as 850-2800 MJ/t for cement production is theoretically possible, further dramatic technology breakthroughs are not expected.[58]

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[51] Lehne and Preston, 'Making Concrete Change: Innovation in Low-Carbon Cement and Concrete'.
[52] Brimstone, 'Industrial Demonstrations Program Selects Brimstone for Transformational $189 Million Federal Investment to Decarbonize Cement Industry'.
[53] Brimstone.
[54] European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[55] European Cement Research Academy, Ed.
[56] Mission Possible Partnership, 'Making Net-Zero Concrete and Cement Possible'; Fennell, Davis, and Mohammed, 'Decarbonizing Cement Production'.
[57] European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[58] European Cement Research Academy, Ed.

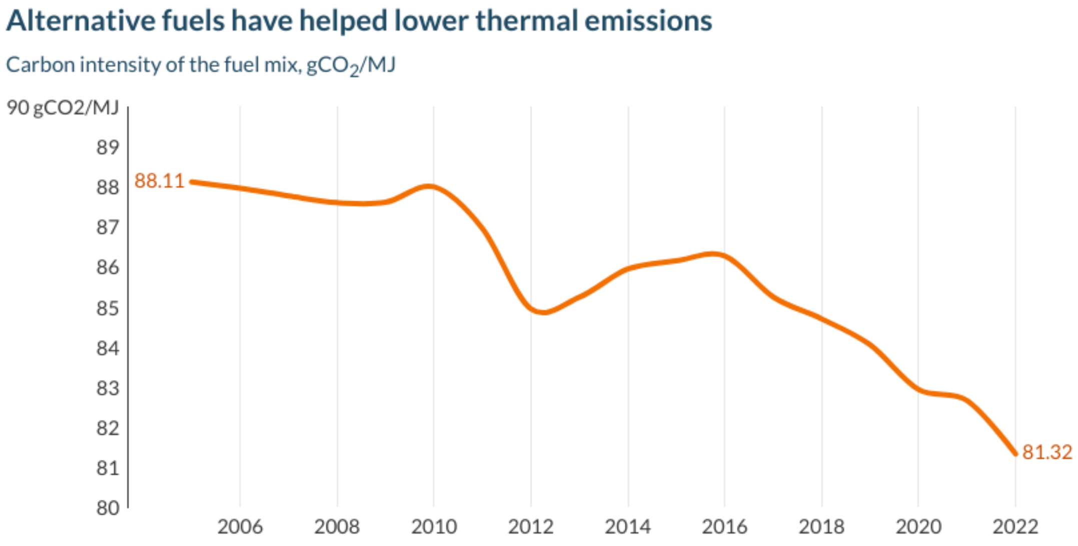

Figure 4. Carbon intensity of thermal fuel mix

Alternative fuels and energy

Replacing fossil fuels with alternative fuels such as biomass or waste-derived fuels – termed 'co-processing' – can help reduce kiln heating emissions, which account for 40% of total clinker CO_2. Currently, fossil fuels meet about 90% of energy demand for clinker production globally, and coal alone meets about 80%.[60] Up to 100% alternative fuels substitution is theoretically possible, but subject to scrutiny due to deviating calorific values and concentrations of trace elements.[61]

Alternative fuel use can aid broader climate and sustainability goals, by recovering energy from waste materials and minimising landfill methane. It is also often cost-effective. However, the specific emissions impact of cement sector co-processing is somewhat limited. A US-focused study found potential for 1-5% reductions in cement CO_2 on average, and up to 18% in limited cases.[62] The carbon intensity of thermal energy in GCCA's global dataset dropped 8% from 88 gCO_2/MJ in 2005 to 81 gCO_2/MJ in 2022.[63] This came as the alternative fossil, mixed waste, and biomass share of fuel increasing from 4% to 22.5%.[64] (see Figures 4 & 5). Counting emissions savings from

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[59] Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[60] Mission Possible Partnership, 'Making Net-Zero Concrete and Cement Possible'; IEA, 'Cement'.
[61] IEA, 'ETP Clean Energy Technology Guide'.
[62] Hasanbeigi and Bhadbhade, 'Emissions Impacts of Alternative Fuels Combustion in the Cement Industry'.
[63] Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[64] Global Cement and Concrete Association.

non-biogenic alternative fuels are, however, not recommended by many carbon accounting frameworks and institutions, including the Science Based Targets Initiative.[65]

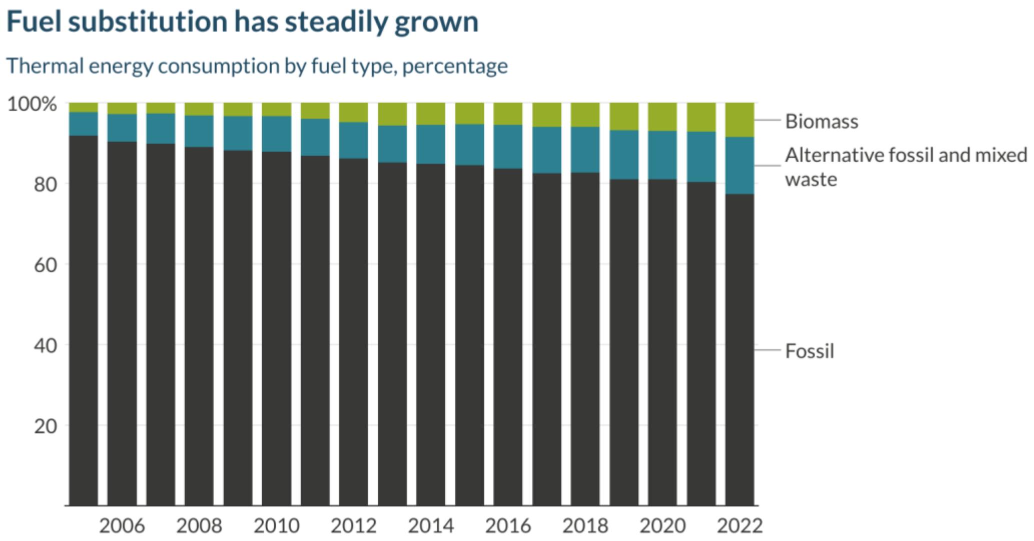

Figure 5. Alternative fuel substitution in kilns.

Options for deeper reduction of thermal emissions exist. They could theoretically be eliminated if kiln heat were generated by 100% renewable energy. Heating via concentrated solar power is at the full prototype stage.[67] Heating via hydrogen combustion and direct electric heating via resistance-based or plasma arc technologies are longer-term prospects.[68] Using decarbonised electricity for applications such as crushing, grinding and blending can reduce up to 10% of cement emissions.[69]

There are caveats regarding alternative fuels and energy sources. Strong competition and sustainability concerns surround biomass; one study found upgrading EU cement production to 90% biomass fuels would consume 19% of available European sustainable agricultural and forest residues.[70] Combustion of industrial waste is not carbon-neutral. And, to have positive climate benefits, hydrogen must not be produced from fossil fuels.

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[65] 20/08/2025 12:53:00 AM
[66] Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[67] IEA, 'ETP Clean Energy Technology Guide'.
[68] IEA.
[69] Bashmakov et al., 'Industry'.
[70] Cavalett et al., 'Paving the Way for Sustainable Decarbonization of the European Cement Industry'.

CCUS

Many stakeholders view CCUS as the primary route to mitigating cement emissions. This assumes the transition of considerable production capacity away from traditional, emissions-intensive clinker-based cement will be impossible.

Cement-linked CCUS pathways include membrane separation, oxy fuelling, physical adsorption, cryogenic capture, and calcium looping. Carbon-cured concrete is an emerging CO_2 use case. Combining CCS with biomass (BECCS) could theoretically produce partial negative emissions.[71] There is no operational commercial-scale cement CCUS project, though 48 projects are planned or under construction.[72]

CCUS overreliance poses challenges. Because 100% capture rates are not feasible, CCUS still results in net emission increases by sustaining emissions-intensive production. Proponents generally claim CO_2 capture rate of 90% or above are possible. But applying CCUS to cement production is more technically challenging, energy-intensive, and costly than many applications, with CO_2 concentrations below 20% typical in kiln flue gas.[73] As already noted, any economic sector's overreliance on CCUS also poses long-term risks to achievement of the Paris Agreement goals.

Currently-announced CCUS projects could capture 36 $MtCO_2$/year.[74] This compares with more than 60 times larger current cement sector emissions[75] and a 2050 target of 1.3 $GtCO_2$/year capture in the IEA's NZE.[76] CCUS progress will also depend on lowering energy and other costs, building transport and storage infrastructure, developing legal frameworks, and achieving social licence. Developing new CO_2 use cases is also a priority of industry; about 80% of CCU capacity now operating across all sectors serves enhanced oil recovery, which increases net global emissions.[77]

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[71] Bashmakov et al., 'Industry'.
[72] IEA, 'CCUS Projects Database'.
[73] Reid, 'Carbon Capture and Storage'.
[74] IEA, 'CCUS Projects Database'.
[75] IEA, 'World Energy Outlook 2023'.
[76] IEA.
[77] IEA, 'CCUS Projects Database'.

Major cement CCUS options

Technology	Mitigation potential	Maturity
Membrane separation	80% clinker CO_2 reduction	Medium
Oxy fuelling	95% clinker CO_2 reduction	Medium
Chemical absorption	93% clinker CO_2 reduction	Medium
Physical absorption	85-88% clinker CO_2 reduction from temperature swing absorption	Medium
Cryogenic capture	90-95% clinker CO_2 reduction from cryogenic capture combined with pressure swing absorption	Medium
Calcium looping	Calcium looping, tail end (CFD reactors): 85-91% clinker CO_2 reduction. Calcium looping, integrated (entrained flow reactors): Up to 94% clinker CO_2 reduction	Medium-to-high
Direct separation	Several projects in development can capture ~20% of clinker CO_2	Medium-to-high

Table 4. Major cement CCUS options

Future pathways

Various industry groups, institutions, and independent sources have established roadmaps for decarbonising cement in line with Paris-aligned goals or regional and national equivalents.

Industry-produced and top-down, economy-wide assessments – such as GCCA's 2050 net zero roadmap, the IEA's NZE cement guidance, and European, German, and Chinese-specific assessments – provide significant room for maintaining conventional cement's existing role (see remaining chapters and Appendix I for more details).[79]

Some assessments adopt whole-of-system approaches, with more aggressive emissions mitigation from breakthrough production technologies and extensive demand reduction, which in turn limits CCUS need. A 2021 scenario from Cao et al. establishes 2060 zero emissions cement and concrete pathways for the three leading producers — China, the

[78] IEA, 'ETP Clean Energy Technology Guide'; European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[79] Global Cement and Concrete Association, 'Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete'.

US, and India — by 2060, with minimal remaining production plants deploying CCUS.[80] Chapter three outlines China-specific details of the scenario.[81]

Reducing CCUS dependence would minimise cost and technical challenges. The Council of Engineers for the Energy Transition estimates four existing levers (efficient design in construction and concrete production; decarbonised cement and binders; fuel switching; and energy efficiency) with combined abatement cost of less than USD 20/tCO_2 could deliver up to 70% of cement emissions savings.[82] This compares with estimates of USD 60-120/tCO_2 abatement costs for cement CCS.[83]

Challenges and policy responses

There are significant barriers to decarbonising cement at sufficient speed and scale. The overarching challenge is the failure of current market settings to adequately price the climate impacts of conventional production. This leads to high supply and demand, at the expense of low emission alternatives. Improved cement coverage in carbon markets and carbon pricing is the obvious policy response to this.

The most immediate impact of higher priced conventional cement would likely be enhanced demand reduction, by emphasising the cost-saving potential available in materials efficiency, substitution, and circularity. Governments can further aid demand reduction in various ways. This includes adopting green building and circular economy strategies and supportive regulations, such as requirements for assessing, declaring, and limiting lifecycle emissions of building materials and practices.

Like-for-like substitution of high emissions cement for low emissions cement could prove more elusive, even with effective carbon pricing. Low emissions cement is as much as 45% costlier by one estimate.[84] This reflects additional production expenses. McKinsey estimates annual cement industry spending must almost double, to USD 60 billion, from 2021 levels, for net zero emissions by 2050.[85] This covers new equipment for low-emissions production and onsite CCUS. Additional spending on shared

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[80] Cao et al., 'Decarbonizing Concrete: Deep Decarbonization Pathways for the Cement and Concrete Cycle in the United States, India, and China'.
[81] European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[82] Council of Engineers for the Energy Transition, 'Overview of Strategies for Reducing CO2 Emissions in China's Cement Industry'.
[83] IEA, 'Is Carbon Capture Too Expensive?'
[84] McKinsey & Company, 'Decarbonizing Cement and Concrete Value Chains'.
[85] McKinsey & Company.

infrastructure and R&D, and any other operational disparities – energy alone accounts for 30% of operational cement expenditure[86] – will be needed.

Industry members require more policy support to decarbonise. This includes addressing fears of 'carbon leakage' of production to regions with lower carbon prices, which are particularly strong in Europe, and favour inertia.[87] Governments priorities include public investment to remove cleaner production's cost and technical barriers; increasing industry access to private finance; creating green 'lead markets' of early demand; facilitating technological breakthroughs; and providing access to infrastructure, workers, and affordable raw materials and decarbonised energy.

Emissions reduction must be coordinated among numerous actors with often disparate interests. Conversely, most global cement sectors are highly localised due to raw materials and transportation influences, with most output consumed within a few hundred kilometres of production.[88] This means that, while some jurisdictions are concerned with carbon leakage, insufficient exposure to international pressures, including consumer preferences and carbon border adjustment mechanisms (CBAM), may be a bigger problem, requiring diplomatic attention. Table 5 summarises key cement mitigation challenges and potential policy responses.

Cement decarbonisation policy priorities and responses

Priority	Main response/s
Effectively price emissions from conventional cement	Carbon markets
Decrease cement demand	Green building strategies, circular economy strategies, supportive regulations
Accelerate low emissions cement production	Public investment in industry, carbon border adjustments, green industrial strategies
Increase finance for low emissions production	Green financial frameworks, e.g. sustainable taxonomy
Increase demand for low emissions cement and cement alternatives	Green lead markets (public procurement and product labelling)
Ensure technological breakthroughs	Continued research and development and knowledge sharing
Increase market acceptance of disruptive technologies and practices	Reform of relevant legislation, regulation, codes, and standards
Meet industry needs for infrastructure, workers, energy and raw materials	Public investment and coordination, green industrial strategies, circular economy strategies
Overcome CCUS-specific challenges	CCUS strategies, supportive legislation and regulation
Enhance industry and broader economic integration	Green industrial strategies and multi-stakeholder cooperation
Enhance global-level decarbonisation	Climate diplomacy

Table 5. Cement decarbonisation policy priorities and responses

86 CEMBUREAU, 'Where Is Cement Used?'
87 CEMBUREAU, 'Cementing the European Green Deal'.
88 CEMBUREAU, 'Where Is Cement Used?'

China cement sector decarbonisation: status quo, policy and regulation, outlook

China dominates cement production, accounting for more than half the global total. Chinese cement output dramatically increased during 1990-2020.[89] China's investment-led economic model, mass migration from rural areas to cities, and nation-building projects such as the Three Gorges Dam fuelled a particularly intense production spike from 2000-2014. Cement production fell for several years from 2014 and rebounded from 2018 (see Figure 6) in line with changing business and stimulus cycles. China has been the main source of cement emissions during this unprecedented boom. Emissions increased from 152 $MtCO_2$/year in 1990 to 1.3 $GtCO_2$/year in 2020 (see Figure 7).[90]

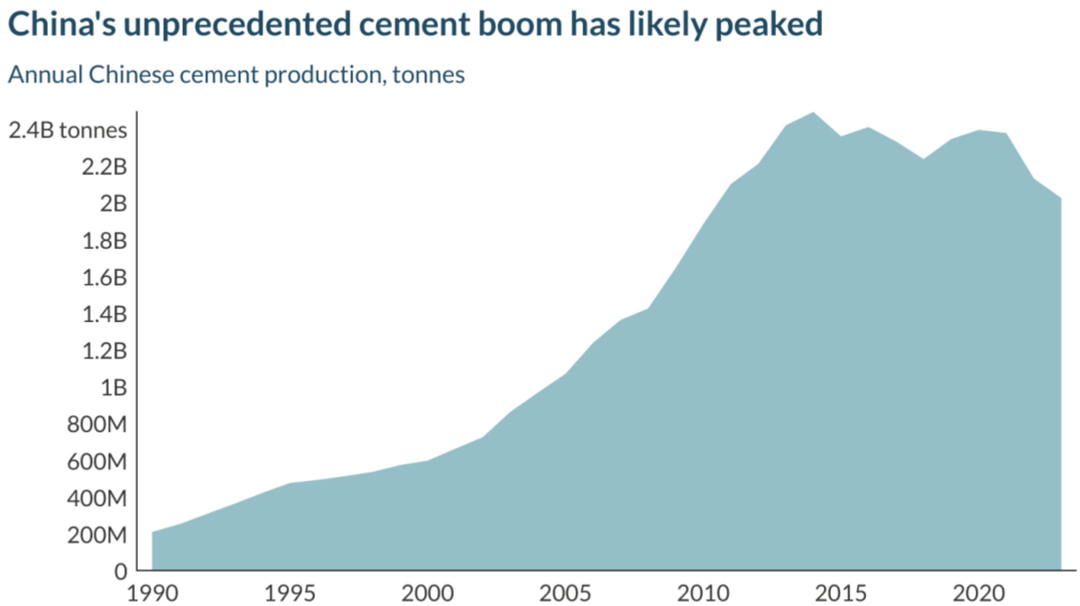

Figure 6. Chinese cement production (1990-2023)

[89] Wang et al., 'Historical Trend and Decarbonization Pathway of China's Cement Industry'.
[90] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[91] Andrew, 'Global CO2 Emissions from Cement Production', 22 December 2023.

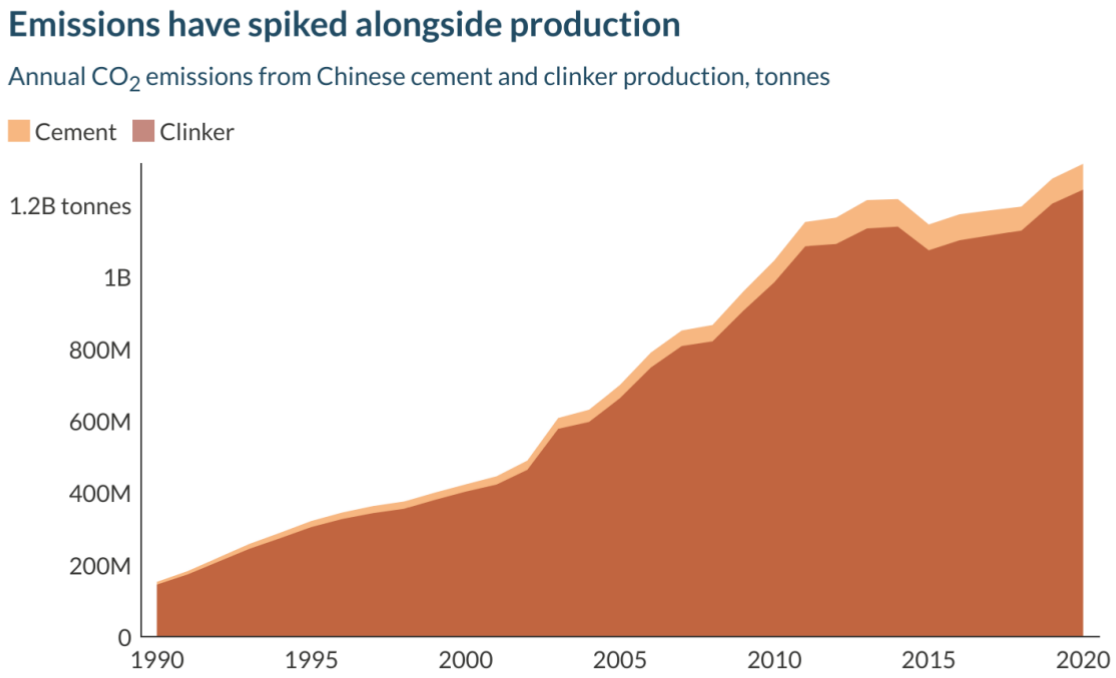

Figure 7. Chinese cement and clinker CO_2 emissions (1990-2020)

Chinese cement production has again been falling since 2021, driven by declining demand in real estate and a generally maturing economy. Cement output decreased 10% in the first half of 2024 compared with the same period in 2023.[93] The China Cement Association (CCA) said this was the lowest level since 2011.[94]

Chinese cement output could fall below 2 Gt/year in the next few years.[95] There are various estimates for long-term production levels. One industry forecaster expects 900 Mt/year demand in 2050, absent additional policy interventions.[96] A 2022 Rocky Mountain Institute (RMI)/CCA roadmap for China assumes demand falls 70% from 2021 to 750 Mt in 2050, in a carbon neutral scenario.[97] A 2023 China Building Materials Federation (CBMF) net zero roadmap sees demand reach 570 Mt by 2060. [98]

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[92] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[93] Perilli, 'Update on China, September 2024'.
[94] Perilli.
[95] Perilli.
[96] "Global Cement Volume Forecast Report (GCVFR)."
[97] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.
[98] China Building Materials Academy, 'A Carbon Neutrality Pathway for the Chinese Cement Industry'.

Cement generates 13-15% of China's CO_2 emissions, compared with the global average 7-8%. One recent estimate of the carbon intensity of Chinese cement production was 548 kgCO_2/t in 2020 – lower than the IEA-reported global average of 580 kg CO_2/t and the SCL figure of 656 kg CO_2/t.[99] Chinese clinker production had a carbon intensity of about 786 kgCO_2/t according to the same 2020 estimate (though some sources estimate this figure is significantly above 800kg CO_2/t). This China clinker figure was slightly below the average of 793 kgCO_2/t in GCCA's global coverage (see note on Chinese cement data[100]), which fell to 780 kgCO_2/t by 2022.[101]

China's higher-than-average cement and concrete consumption is a major emissions challenge. Despite slowing production, China will likely produce about 1.3 t of cement per person in 2024, or up to five times more than similarly industrialised countries.[102]

China's absolute cement emissions will likely peak with falling demand. The expected rate of decline will, however, be insufficient to align with Chinese and global climate goals. Assuming current carbon intensity and the RMI/CCA demand of 750 Mt, emissions would still be around 384 Mt in 2050. This compares with the IEA NZE, which assumes 79 MtCO_2 remaining from cement globally by this time.[103]

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[99] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[100] Note on Chinese cement data: There is a lack of comprehensive and standardised data on the carbon intensity of Chinese cement and clinker and other production information. Wu, Ng and Chen use decomposition analysis to provide a historical estimate from 1990-2020. This uses Intergovernmental Panel on Climate Change assessment guidelines, which do not appear to distinguish between net and gross emissions, while including power generation CO_2. The GCCA figures quoted here are for net CO_2 from clinker production. While this does not provide for ideal comparison, it does allow for highlighting differences arising from alternative fuel substitution, which is minimally advanced in China.
[101] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'; Global Cement and Concrete Association, 'GCCA GNR Data'.
[102] Fickling, 'China's Cement Boom Is Over. We Can All Breathe Easier'.
[103] IEA, 'Net Zero Roadmap'.

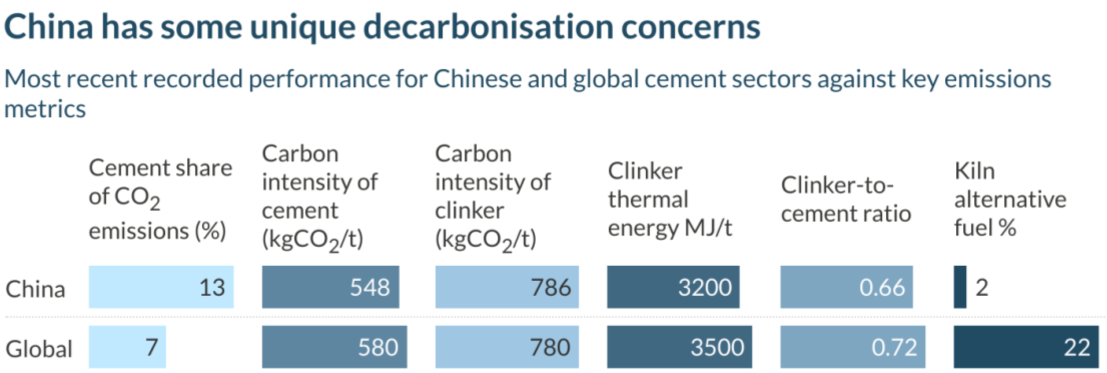

Figure 8. China cement emissions footprint in global context[104]

There has also been no definitive decline in the carbon intensity of Chinese cement in recent years. This figure dropped from 708 to 485 $kgCO_2/t$ from 2000- 2015 but rebounded to the 548 $kgCO_2/t$ figure thereafter (see Figure 9).[105]

It is important to understand the drivers of China's changing cement emissions over time. Figures 7 & 9 highlight the relative decrease in cement and clinker emissions intensity from 1990-2020 had little noticeable impact on absolute emissions. Fluctuations in the cement and broader materials intensity of China's economy have, and will continue to have, the most important climate impact.

On a carbon intensity basis, Chinese producers have made most notable savings through energy efficiency. Widespread penetration of new suspension pre-calciner kilns were a key driver of the emissions intensity decline from 2000 onwards.[106] Chinese cement producers achieved average thermal energy usage of about 3200 MJ/t of clinker by 2018, compared to 3500 MJ/t for GCCA's global coverage.[107]

China's increased clinker ratio was a key factor in the cement emissions intensity rebound since 2015. This followed restrictions on the once popular, and high admixture,

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[104] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'. RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'; Global Cement and Concrete Association, 'GCCA GNR Data'.
[105] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[106] Wu, Ng, and Chen.
[107] IEA, 'Cement – Analysis'; Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.

32.5 grade Portland cement, due to quality concerns.[108] China still maintains a below average clinker ratio of 0.66, compared with 0.72 globally, despite this.[109]

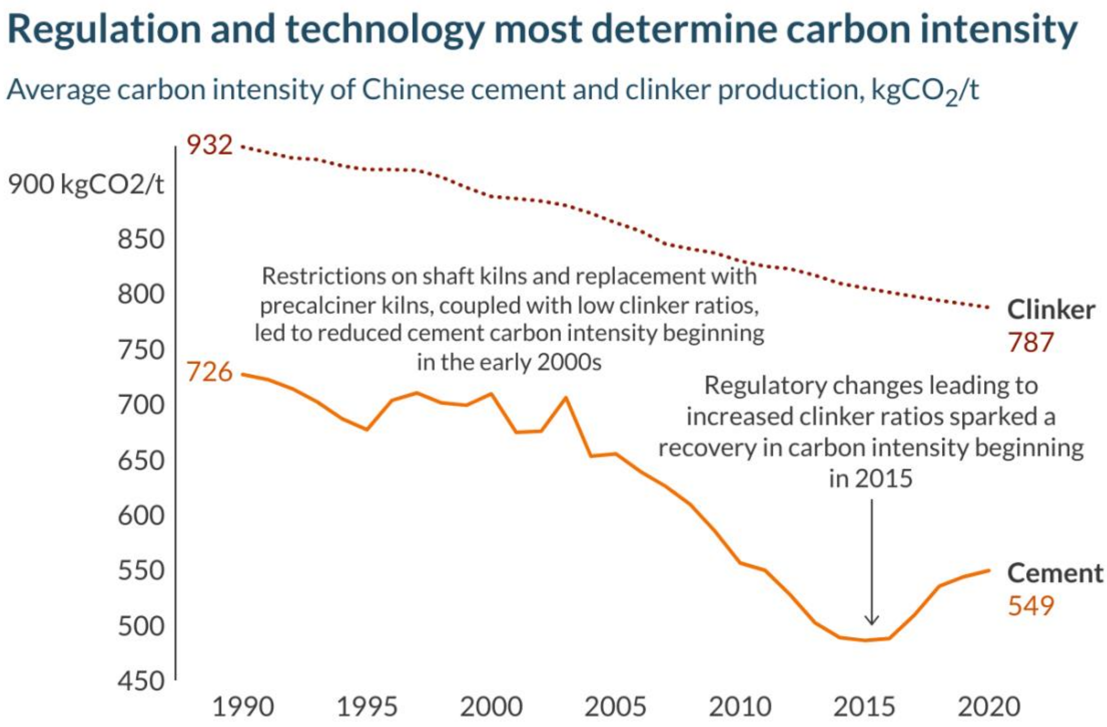

Figure 9. Chinese cement and clinker emissions intensity (1990-2020)

China's fossil-dominated thermal fuel mix is a factor in its comparatively higher clinker emissions intensity. Coal alone provides 90% of thermal energy generation, compared with 48% alternative fuel substitution in Europe, 15% in North America, and 13% in the Middle East.[111]

Policy and regulations will be critical to determining China's future cement emissions pathway. A 2023 meta study of carbon neutrality studies produced an aggregated baseline scenario of 908 $MtCO_2$ emissions remaining by 2050. An alternative low emissions scenario, reflecting strong energy efficiency, energy and materials substitution, but also CCUS deployment – which will all require strong government intervention – would see 387 $MtCO_2$ remaining. The authors concluded that further

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[108] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'.
[109] Wu, Ng, and Chen.
[110] Wu, Ng, and Chen.
[111] Clark et al., 'Assessment of Fuel Switching as a Decarbonization Strategy in the Cement Sector'.

policy attention in areas such as demand reduction and breakthrough production technologies remained critical to better alignment with global net zero goals.[112]

China's cement decarbonisation policies and regulations

The Chinese government has set 'dual carbon' targets of an economy-wide emissions peak by 2030 and carbon neutrality by 2060.[113] Chinese cement policies align with the these. In August 2024, the State Council introduced a Work Plan for Accelerating the Establishment of a Dual Control System for Carbon Emissions.[114] This refers to controlling both the carbon intensity and absolute emissions of China's economy. In 2022, China also adopted the 1+N framework, which set out how key industrial sectors will contribute to climate goals.[115]

Using the Cement Sector Policy Mapping Tool, 67 policies with cement decarbonisation relevance were logged at the national and provincial level. These included prominent guidelines and plans released in recent years:

- The Implementation Plan for Carbon Peak Achievement in the Building Materials Industry (2022) sets a target for energy consumption per unit of cement clinker – noted above as averaging about 3200 MJ/t clinker – to decrease more than 3% by 2025.[116]
- The Implementation Guidelines for Energy Saving, Carbon Reduction, Renovation and Upgrading in Key Areas of Energy-Consuming Industries (2022) sets a target for 30% of clinker production capacity to meet benchmark energy efficiency levels, which were indicated as 100 kg of standard coal/t clinker.[117]
- The Opinions on Promoting the Implementation of Ultra-Low Emissions in the Cement Industry (2024) establish that, by 2025 "ultra-low emission retrofits" (this term refers to carbon emissions but only sets non-CO_2 pollution limits) accounting for 50% of clinker capacity will be complete and 80% of clinker production capacity will be ultra-low emissions by 2028.[118]

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[112] Wang et al., 'Historical Trend and Decarbonization Pathway of China's Cement Industry'.
[113] Climate Action Tracker, 'China - November 2023 Update'.
[114] State Council, People's Republic of China, 'Work Plan to Accelerate the Establishment of a Dual-Control System for Carbon Emissions'.
[115] Climate Action Tracker, 'China. November 2023.'
[116] Government of the People's Republic of China, 'Implementation Plan for Carbon Peak Achievement in the Building Materials Industry'.
[117] Government of the People's Republic of China, 'Implementation Guidelines for Energy Saving, Carbon Reduction, Renovation and Upgrading in Key Areas of Energy-Consuming Industries'.
[118] Government of the People's Republic of China, 'Opinions on Promoting the Implementation of Ultra-Low Emissions in the Cement Industry'.

- The Special Action Plan for Energy Conservation and Carbon Reduction in the Cement Industry (2024) establishes that, by 2025, clinker capacity will be controlled at about 1.8 Gt, with 30% capacity reaching the 3% increased energy efficiency benchmark level noted above.[119]

Key industry standards also regulate Chinese cement production:

- The Energy Consumption Limit Per Unit Product of Cement Standard stipulates the limit, technical requirements, statistical scope, and calculation method of energy consumption per unit of Portland cement, and energy consumption control of new construction, reconstruction, and expansion projects.[120]
- The National Standard for General Silicate Cement specifies the classification of general-purpose silicate cement, components and materials, technical requirements – including clinker ratios – test methods, inspection rules and packaging, marking, transport, and storage arrangements.[121]

As well as being highly production-centric, these policies and regulations all adopt prescriptive and/or mandate-based approaches to decarbonising cement. Most also have indirect emissions mitigation potential; they work by placing targets or official caps on factors that can impact emissions, such as energy efficiency and production capacity.

Chinese officials are, however, currently integrating cement into the national Emissions Trading System (ETS). This will directly target CO_2 emissions and allow a more market-based approach. The ongoing design of cement's ETS integration will determine its success, but it has potential to play the leading role in sector decarbonisation. About 900 clinker-producing companies were incorporated into ETS coverage during 2024. A draft work programme was issued for comment in 2024 (see Table 6).[122]

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[119] Government of the People's Republic of China, 'Special Action Plan for Energy Conservation and Carbon Reduction in the Cement Industry'.
[120] Government of the People's Republic of China, 'Energy Consumption Limit Per Unit Product of Cement Standard', 2021.
[121] Government of the People's Republic of China, 'Energy Consumption Limit Per Unit Product of Cement Standard', n.d.
[122] Patel, 'Explainer', 23 September 2024.

Schedule for cement's inclusion in China's ETS

Timeline	Initial coverage
2024-2026: Launch and implementation. Uncapped allocation of emissions allowances for free. Formulation of benchmarking process and industry reporting and compliance mechanisms	900 companies, each with direct emissions above 26,000 tCO_2/year
2027 and beyond: Deepening and refinement. Industry benchmarking implemented, with a gradual tightening of allowances	Total coverage of ~ 1.2 $GtCO_2$/year

Table 6. Schedule for cement's inclusion in China's ETS

Some additional pieces of guidance also seek to channel more support to production of low emissions cement, rather than just restrict high emissions production. The Notice on Issuing the Implementation Plan for High-Quality Development of the Green Building Materials Industry (2023) signposts green public procurement (GPP) will be implemented in at least 100 cities, with 12,000 green building material product certificates issued by 2026.[124] GPP is a potentially rich vein of emissions savings. Almost all Chinese cement is domestically consumed and about a third is for public construction.[125] The People's Bank of China and several agencies also issued the Guidance on Further Strengthening Financial Support for Green and Low-Carbon Development in March 2024.[126] However, this is high-level guidance, and it remains unclear how cement industry members will specifically benefit.

Cement's ETS inclusion and any forthcoming acceleration in green public procurement and green finance could also increase the competitiveness of alternative building materials and practices. China has made some additional direct efforts to accelerate cement demand reduction. In 2021, the Ministry of Housing and Urban-Rural Development issued the Notice on Preventing Large-Scale Demolition and Construction in the Implementation of Urban Renewal Action. This proposed that older buildings be mainly retrofitted, and large-scale demolition and construction strictly controlled.[127].

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123 Patel, 'Explainer', 23 September 2024.
124 Government of the People's Republic of China, 'Notice on Issuing the Implementation Plan for High-Quality Development of the Green Building Materials Industry'.
125 Hasanbeigi, Springer, and Bhadbhade, 'Advancing Green Public Procurement of Steel and Cement in China'.
126 Government of the People's Republic of China, 'Guidance on Further Strengthening Financial Support for Green and Low-Carbon Development'.
127 Zhang et al., 'Assessing the Potential of Decarbonizing China's Building Construction by 2060 and Synergy with Industry Sector'.

The 14th Five-Year Plan on Circular Economy released in 2021 also includes recycling large amounts of construction and demolition waste among its key priorities.[128] There has been no notable governmental mandates or incentives specifically related to addressing cement's CCUS-specific challenges and opportunities. Support is limited to statements in various planning and policy documents.[129]

China's decarbonisation outlook

Decarbonising the China cement sector is a formidable challenge. The sector's CO_2 footprint is larger than the economy-wide emissions of all but three countries, other than China itself (the US, India, and Russia).[130] Dramatically reducing these emissions is thus also vital to global-level climate goals.

Chinese cement stakeholders consulted for this report supported the application of a broad suite of emissions reduction levers. They provided additional useful context around China-specific challenges and opportunities to achieving climate goals, which inform the remainder of this report (see Appendix II for a summary of these views).

The RMI-CCA net zero roadmap for China sees enhanced demand reduction through changing building practices producing a combined 15% emissions reduction. Cement recycling and reuse rates rise to 70% by 2060.[131] Figure 10 outlines key decarbonisation levers and performance by key metrics.

Meanwhile, Cao et al.'s 'whole-systems' scenario (see previous chapter) deploys 16 emissions reduction levers across cement manufacturing, aggregate production, concrete manufacturing, construction, use, and end-of-life. Demand reduction plays a particularly important role, eliminating a cumulative 45.7 Gt of concrete in Chinese buildings and 2.3 Gt in roadways by 2060.[132] As a result, just 18% of cement plants deploy CCUS by 2060, compared to 100% under a 'production-centric' scenario.[133]

Demand reduction

Declining Chinese cement demand due to existing structural changes will produce vital emissions savings. However, more transformational change is still required. Industry

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[128] '14th Five Year Plan on Circular Economy – Policies'.
[129] China Building Materials Academy, 'A Carbon Neutrality Pathway for the Chinese Cement Industry'.
[130] Friedlingstein et al., 'Global Carbon Budget 2024'.
[131] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.
[132] Cao et al., 'Decarbonizing Concrete: Deep Decarbonization Pathways for the Cement and Concrete Cycle in the United States, India, and China'.
[133] Cao et al.

members are already somewhat prepared for what may be necessary on climate, in addition to economic grounds. They have operated under regulations for staggering output and retiring inefficient assets, to limit excess capacity, since 2018.[134] Regulations noted above have been subsequently introduced and sector stakeholders broadly accept there will be a firm downward trajectory in production.

A 2024 study noted the significant decarbonisation potential that exists in further enhanced, economy-wide demand reduction. It found embodied CO_2 in China's building materials could reach near zero by 2060 through aggressive energy efficiency, fuel switching, and materials efficiency.[135] Materials efficiency contributes 51% and 36% of emissions savings by 2030 and 2060 respectively. This helps limit the near-term role of CCUS to about 9% of emissions abatement by 2030[136] (see Figure 11).

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[134] Lu et al., 'Reducing China's Building Material Embodied Emissions'.
[135] Lu et al., 'Reducing China's Building Material Embodied Emissions'.
[136] Lu et al.

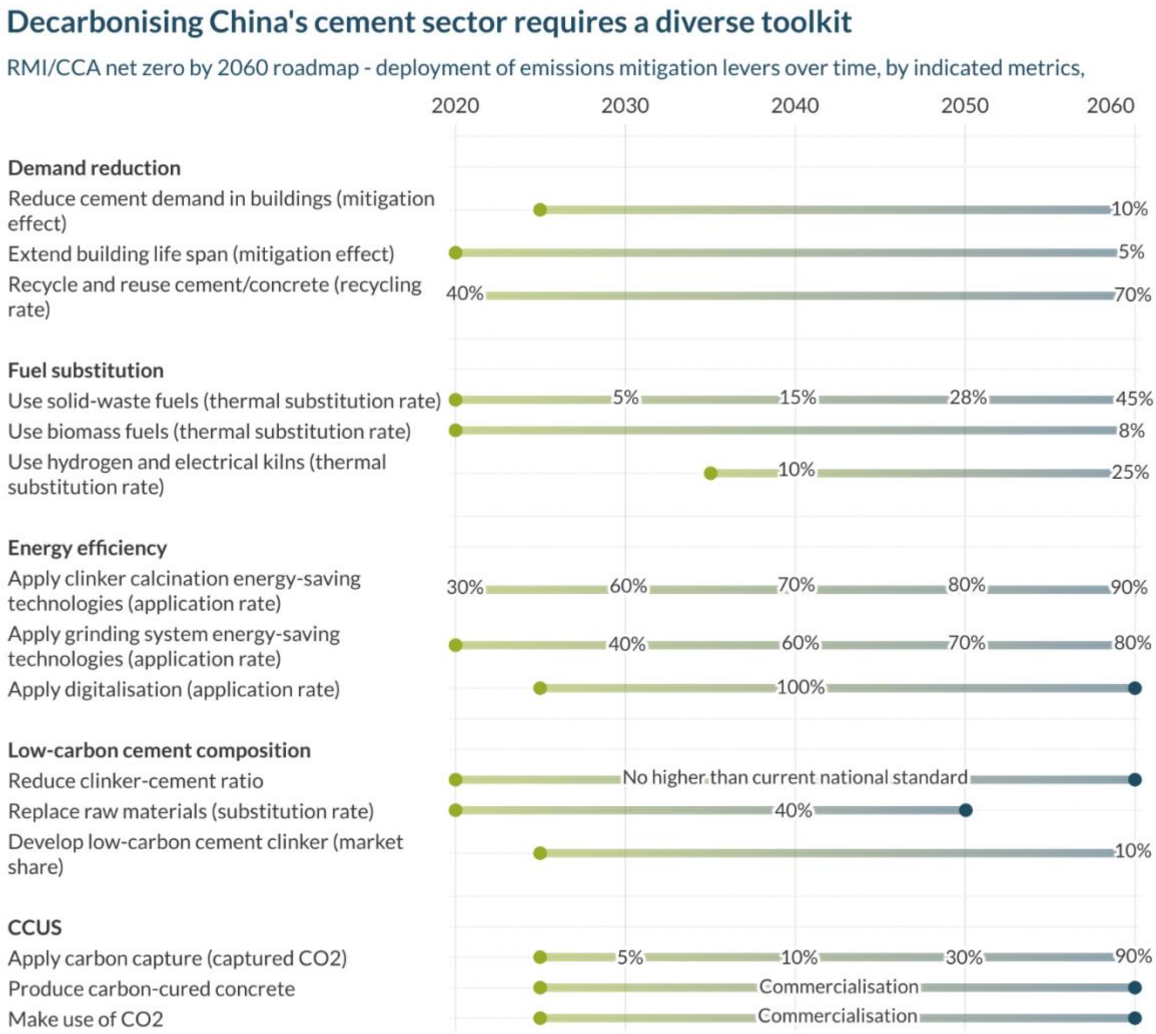

Figure 10. China cement net zero roadmap. Source: RMI/CCA[137]

[137] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.

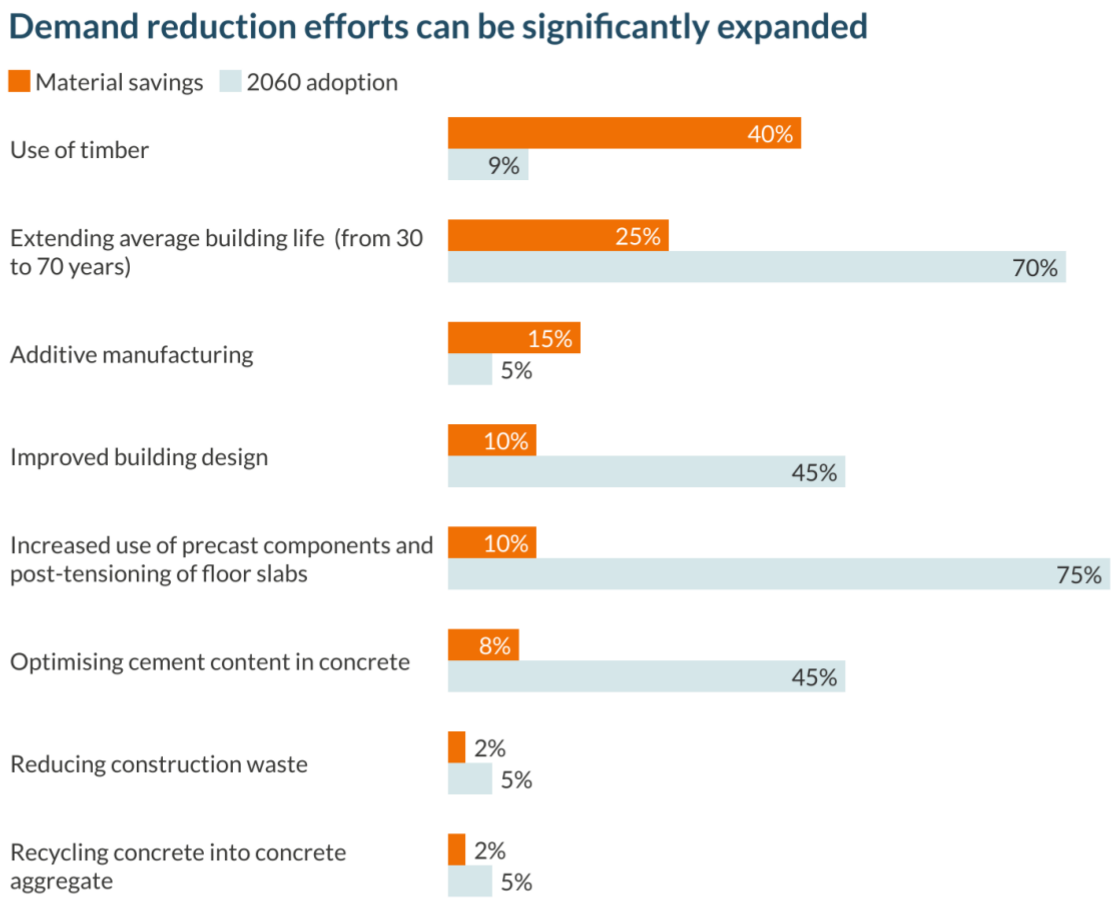

Figure 11. Materials saving potential of Chinese cement demand reduction measures

China has considerable room to improve on key materials efficiency, substitution, and circularity metrics. The current average building lifespan is 25-30 years – a quarter of that in some economies and about half the typical designed lifespan in China.[139] Reinforced concrete structures account for more than 60% and 80% of residential and non-residential buildings, respectively.[140] China has about 10% steel structural buildings, compared with 45% and 25% in the US and Europe.[141] Chinese recycling rates for construction waste are also well below the 70-90% exhibited in some economies, including Germany.[142]

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[138] Lu et al., 'Reducing China's Building Material Embodied Emissions'.
[139] Wang, Zhang, and Wang, 'Environmental Impacts of Short Building Lifespans in China Considering Time Value'.
[140] Lu et al., 'Reducing China's Building Material Embodied Emissions'.
[141] Lu et al.
[142] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.

Efforts to enhance demand reduction can benefit from strong integration of actors and interests across the entire cement value chain, from raw materials to end-of-life applications. Cement stakeholders observed that this type of integration was lacking within China. Factors which might help explain this include the prominence of state-owned enterprises with mandated limits on vertical integration. Regulated production targets and related access to credit can also incentivise production irrespective of demand, limiting needs for downstream industry engagement.

Decarbonising production

The emissions intensity of Chinese cement production must be reduced simultaneously to demand reduction. Unfortunately, there is concern around the future direction of clinker ratios – a key influence on emissions – as the cement industry contracts and consolidates. CCA contends the average will remain largely static, at about 0.66, but CBMF projects it could increase to 0.74 by 2060.[143] Fewer but bigger companies producing high-quality cements, in line with existing industry standards, could create adverse effects of this nature. Clinker ratios should be significantly decreasing globally, so policy attention that could see China aid this process would be beneficial.

Energy efficiency has been China's other traditional emissions savings strength. Future results are unlikely to match those already achieved, though RMI-CCA sees a further 14% reduction in energy consumption possible if all clinker lines upgrade to the Level 1 standard under 2021's Norm of Energy Consumption Per Unit Product of Cement.[144]

Alternative fuels deployment is the solution where Chinese producers could make up most ground on their international peers. Chinese cement plants already have proven technical capacity to incorporate solid waste at high rates.[145] China also has abundant and diverse resources suited to this purpose. The main barrier to deployment is a lack of access to affordable supplies, largely due to regulatory challenges.

Current industry standards, such as 2014's Technical Specifications for Environmental Protection of Solid Waste Co-processing in Cement Kilns and the economy-wide Solid Waste Law, treat raw material co-processing as waste disposal, rather than fuel replacement.[146] This has implications for resulting policy support. There is strong

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[143] China Building Materials Academy, 'A Carbon Neutrality Pathway for the Chinese Cement Industry'; Council of Engineers for the Energy Transition, 'Overview of Strategies for Reducing CO2 Emissions in China's Cement Industry'.
[144] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.
[145] RMI and China Cement Association.
[146] China Cement Association & National Resource Defense Council, 'Current Status of Alternative Fuels and Raw Materials Technology in China's Cement Industry and Suggestions for Industrial Development'.

competition between cement producers and power plants for solid waste, and the latter benefit from higher handling subsidies.[147]

Industry members also have limited access to tax relief and green finance for alternative fuels.[148] China additionally lacks sufficient pretreatment technology, quality assurance systems, and market acceptance protocols for co-processing.[149]

Meanwhile, reliability and cost concerns continue to preclude the deployment of breakthrough energy alternatives, including electrification, for kiln heat. Chinese industrial electricity users are not subsidised to the same level as households, and cement stakeholders indicated this makes long-term displacement of coal with electricity uncompetitive.[150] However, given appropriate future support, application of renewable-generated electricity, renewable fuels such as hydrogen, and direct heat via concentrated solar thermal, might grow rapidly. China has a formidable track record in deploying such technologies in other sectors.

As with global peers, Chinese stakeholders have not made notable progress on alternative binders and cements. For commercial reasons, China has had relatively high (but still minimal as a share of the national total) production of high belite and CSA cement, and small-scale use of enforced recarbonation in concrete.[151] Yet, exploration of the climate potential of alternative cements still occurs at the R&D stage. Conch Cement, for example, has partnered with several universities to explore composite cement with low clinker consumption, low carbon cementitious materials, low-calcium high belite clinker activation technologies, and carbon-mineralised materials.[152]

CCUS

High CCUS adoption will bring unavoidable high costs. Building a Chinese CO_2 capture plant is estimated to be three times as expensive as a clinker plant, and running it

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[147] China Cement Association & National Resource Defense Council.
[148] China Cement Association, 'Research on the Mechanism of Industrial Development of Alternative Fuel in the Cement Industry'.
[149] China Cement Association & National Resource Defense Council, 'Current Status of Alternative Fuels and Raw Materials Technology in China's Cement Industry and Suggestions for Industrial Development'.
[150] Chinese cement sector stakeholders provided to report author
[151] European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[152] Anhui Conch Cement Group Limited, '2023 Environmental, Social and Governance Report'.

increases production costs by two to three times, not including transport and storage.[153] These figures could, however, decrease by 30-40% by 2050 as deployment rises.[154]

Chinese cement companies have made some early stage CCUS progress. In 2018, Conch Cement developed a world-first cement kiln flue gas capture and purification project in Wuhu, Anhui province, though it remains at the demonstration phase.[155] The cement and broader construction sector could be a rising source of demand for captured CO_2; China's Zhejiang University is investigating CO_2-mineralised concrete technology and Huaxin Cement and Hunan University have developed brick production using cement kiln CO_2.[156] Commercialisation of these products remains some way off.

Industry stakeholders highlight the pressing need for new CO_2 transport and storage infrastructure; regulatory reform; and development of viable use cases for captured CO_2, to help offset transition costs.

Future challenges

Both nationally specific and globally shared barriers to China's cement emissions mitigation have already been identified. They include China's high cement demand and limited current abilities to reduce this, beyond the decline already predicted; diminishing returns from previously successful pathways; high costs and/or low maturity for breakthrough technologies; poor access to affordable raw materials; lack of supportive infrastructure; and lack of fit-for-purpose cement and building sector standards, regulations, and legislation.

Cost is again the biggest obstacle facing producers. Estimates of the necessary up-front investment to upgrade cement plants range from one to hundreds of millions of RMB.[157] Energy is the highest operational cost factor and switching from cheap coal could be more expensive than in other jurisdictions. CCUS will bring even greater expenses. While most costs will decrease over time, cleaner production is unlikely to reach parity with conventional production under current market settings.

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[153] Council of Engineers for the Energy Transition, 'Overview of Strategies for Reducing CO2 Emissions in China's Cement Industry'.
[154] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.
[155] European Cement Research Academy, Ed, 'The ECRA Technology Papers'.
[156] European Cement Research Academy, Ed.
[157] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.

Cement producers also note challenges attracting public investment, private finance, and consumer demand to help switch to lower emissions production. Chinese industry expansion has traditionally benefitted from significant public investment. But official cement sector policy is now firmly focused on constraining capacity, and future resource allocation could be limited.

There has been considerable growth in Chinese green finance at a general level in recent years, but this has largely been channelled to areas other than cement. More than 60% of proceeds from Chinese green bond sales went to renewable energy projects in 2021, while none went to industrial decarbonisation.[158] This is part of a global phenomenon of insufficient 'transitional finance' for emissions-intensive sectors seeking to decarbonise.[159] Overcoming the deficit requires providing financial institutions and investors with greater clarity around climate-benefitting activities. Industry members can develop credible and well-communicated transition plans. Policymakers can develop sector-specific definitions and standards to verify them.

A lack of demand for emissions-intensive goods is also a universal concern for decarbonising industries. China's government could play an indispensable role in overcoming this, by leveraging its significant procurement power and, once again, setting clear definitions as well as labelling regimes for low emissions activities.

Some structural characteristics of China's cement sector also favour inertia. About 90% of cement plants were built in the past 20 years, and 40% in the past decade, compared to 40-year operational lives.[160] There is also relatively low industry centralisation; the top 10 companies account for more than 55% of China's clinker capacity, but there are more than 3000 companies in total.[161] This makes it difficult to quickly replace old with new capacity, exchange knowledge and business practices, and provide shared infrastructure. Studies have also found high variability of environmental performance across Chinese plants, limiting the efficacy of 'one size fits all' approaches.[162]

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[158] Climate Bonds Initiative, 'Scaling a Credible Transition Finance Market in China 2023'.
[159] Shirai, 'An Overview of Approaches to Transition Finance for Hard-to-Abate Sectors'.
[160] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.
[161] China Cement Association, 'The Status of Low-Carbon Development in China's Cement Industry'.
[162] Wang et al., 'Plant-Level Green Transformation Strategy in China's Cement Industry'.

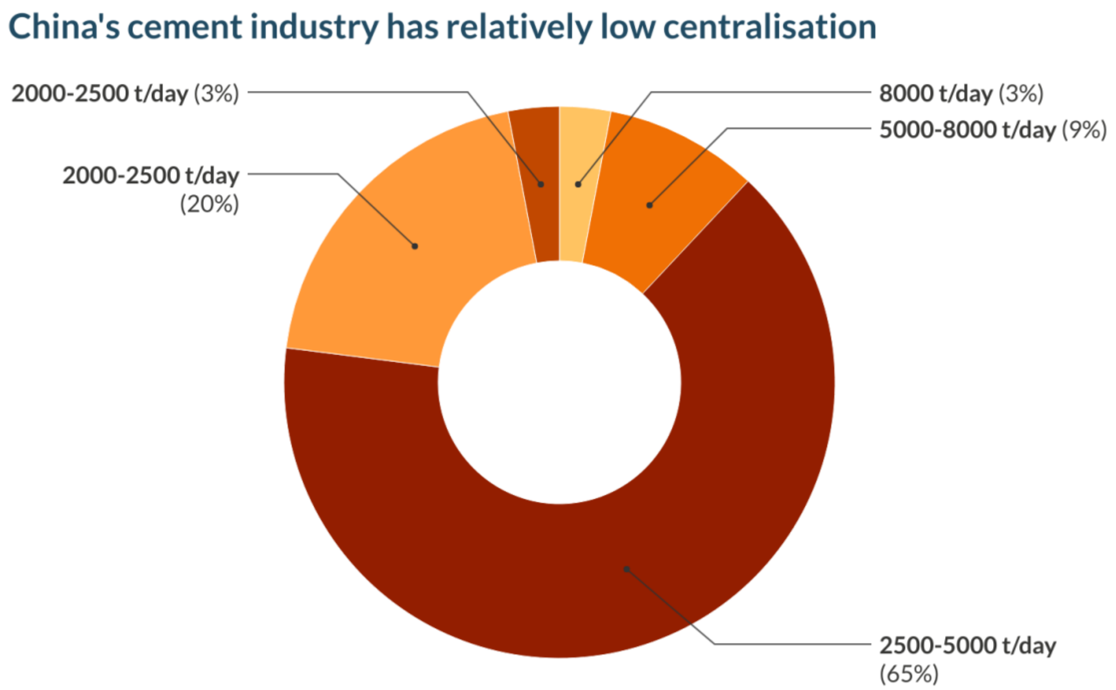

Figure 12. Share of clinker production line capacities in total China clinker capacity

As already noted, China's cement sector also has relatively little integration further along the building and construction value chain. This makes whole-of-system approaches that emphasise demand reduction difficult to implement. The sector also has minimal trade exposure, adding resistance to international climate pressure.[164]

The industry structure will, however, change in line with falling demand. Rising clinker ratio concerns notwithstanding, the fewer and larger producers which emerge from this process may make decarbonisation approaches easier to disseminate. But remaining parties will still need to balance emissions reduction with profitability concerns.

Given the scale of necessary transformation, and its global-level importance, there is great need to overcome these various challenges. This requires optimally calibrated and well-resourced policies and regulations, drawing on global best practice. Table 7 outlines key Chinese priorities, barriers, and potential responses.

China does have significant assets and abilities to leverage in service of progress. It has a world-leading record of quickly developing industrial ecosystems and value chains for

[163] China Cement Association, 'The Status of Low-Carbon Development in China's Cement Industry'.
[164] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.

clean industries. It also has a strong presence of state-owned enterprises and a long tradition of centralised planning. These assets could, if properly leveraged, relatively quickly help shift patterns of supply and demand for cement and other goods.

China's policy options for decarbonising cement

Priority	Barrier/s	Potential response/s
Whole-of-system change		
	High cost of low-emissions alternatives to conventional cement	Public investment in industry
	Lack of financial support for transition	Public investment in industry, access to green finance
	Lack of demand for low-emissions goods	Green public procurement and labelling
	Low industry centralisation	Green industrial strategies, multi-stakeholder cooperation
Reduce cement demand		
	Centrality of high cement demand to Chinese development model	Green industrial strategies, standards reform
	Lack of industry integration with building and construction	Green industrial strategies, multi-stakeholder cooperation
	Poor materials efficiency, substitution, and circularity	Green building and circular economy strategies
Decarbonise production		
Lower clinker-to-cement ratio	Current production standards require high ratio	Standards reform
Enhance energy efficiency	Diminishing returns from existing technologies	Prioritise alternative emissions abatement levers, enhanced R&D
Increase alternative fuel deployment	Poor industry access to affordable raw materials	Circular economy strategies, reform of regulations and standards, improved green finance, improved quality assurance protocols
Electrify/deploy renewable kiln heat	Poor industry access to affordable renewable electricity/energy, lack of technological readiness	Regulatory reform, green industrial strategies
Develop alternative clinkers and cements	Lack of technological readiness, lack of market acceptance	Enhanced R&D, standards reform
Implement CCUS		
	High cost/technical barriers to implementation at scale	Prioritise alternative abatement levers, public investment in industry, access to green finance
	Lack of supporting infrastructure	CCUS-specific industrial strategies
	Lack of supportive legislation and regulation	Legislative and regulatory reform

Table 7. Key China cement decarbonisation priorities, barriers, and potential policy responses

EU and German cement decarbonisation: status quo, policy and regulation, outlook

The EU accounts for 6-7% of global cement production.[165] Germany is a leading EU producer, but produces less than 1% of global output.[166] Cement currently generates a lower percentage of EU and German emissions than in China, at 4% and 2% respectively.[167] EU and Germany cement sector emissions have also fallen for many years, in absolute and carbon intensity terms (see note on European vs EU cement figures[168]). Cement emissions intensity has declined by about 18% in Europe since 1990 and about 22% in Germany over this same period.[169]

Depending on the assessment method, European and German cement and clinker emissions vary in relation to Chinese equivalents. In 2020 – when the China figures were 548 $kgCO_2$/t for cement and 786 $kgCO_2$/t for clinker – Europe had a carbon intensity of 647 $kgCO_2$/t of cement and 814 $kgCO_2$/t of clinker using the most comparable assessment method. For the same year, Germany had an emissions intensity of 624 $kgCO_2$/t of cement and 810 $kgCO_2$/t of clinker (see Figure 13). European and German carbon intensities are lower when using the GCCA and IEA assessment method. Europe had carbon intensity of 553 $kgCO_2$/t for cement and 712 $kgCO_2$/t for clinker, while Germany had carbon intensity of 465 $kgCO_2$/t for cement and 654 $kgCO_2$/t for clinker.[170]

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[165] Liao et al., 'China's Provincial Process CO2 Emissions from Cement Production during 1993–2019'.
[166] VDZ, 'Decarbonising Cement and Concrete'.
[167] CEMBUREAU, 'Cementing the European Green Deal'; VDZ, 'Decarbonising Cement and Concrete'.
[168] Note on European vs EU cement figures: available data on the production and emissions profile of the European Cement Association (CEMBUREAU) membership – which goes beyond the 27 current EU member states – are more extensive in terms of metrics and historical coverage. Their use is thus prioritised in this report. When 'European' figures are mentioned, this refers to CEMBUREAU data. When 'EU' figures are mentioned, this refers to production in the EU 27 member states. There are resulting differences in estimates around production, emissions levels and other characteristics.
[169] VDZ, 'Decarbonising Cement and Concrete'.
[170] Global Cement and Concrete Association, 'GCCA GNR Data'.

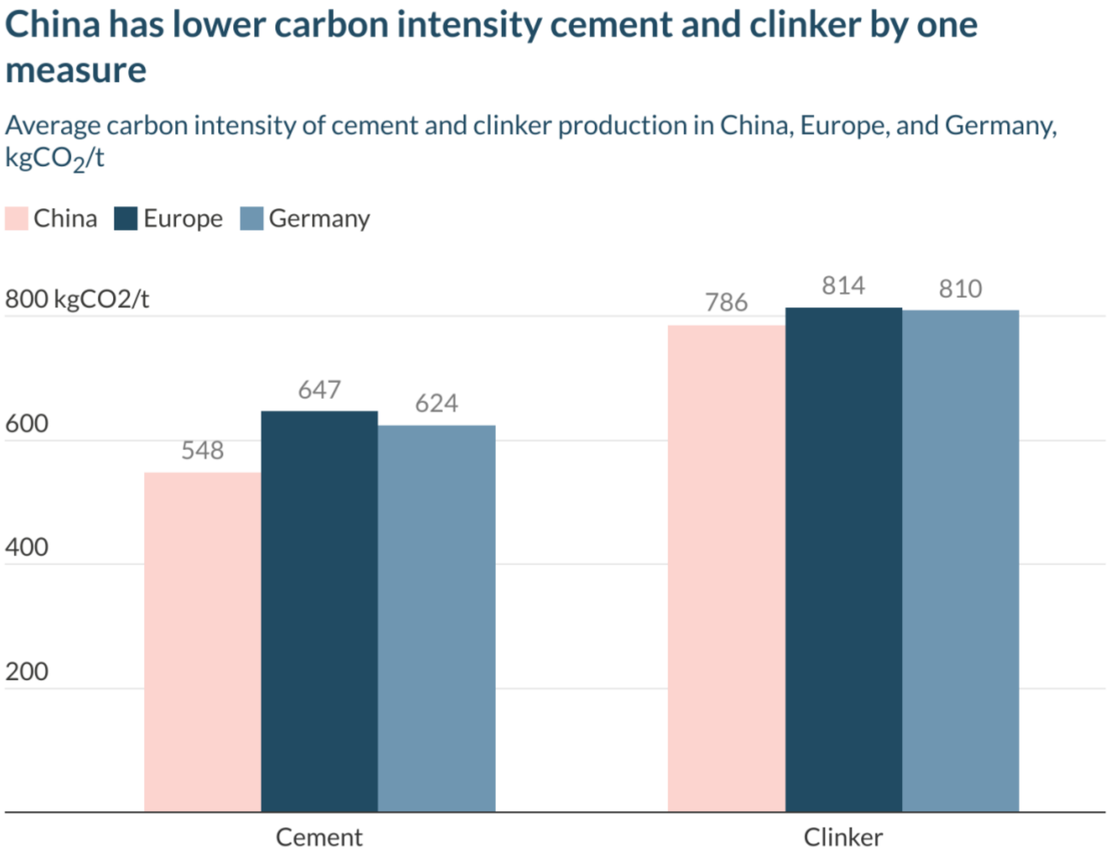

Figure 13. Comparative Chinese, European, and German cement and clinker emissions intensities

There are some key differences between European, German and Chinese production profiles. European and German producers have high clinker ratios of 0.77 and 0.75, respectively, compared with China's 0.66.[172] This is influenced by factors including differing market demands, raw materials availability, and regulatory environments. China's leading energy efficiency helps to lower its clinker emissions intensity, but it has well below 10% alternative fuel substitution.[173] Alternative fuels provide about half of thermal energy for European cement production, with some plants reaching occasional

[171] Wu, Ng, and Chen, 'Deciphering the CO2 Emissions and Emission Intensity of Cement Sector in China through Decomposition Analysis'; Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[172] European Commission Joint Research Centre, 'Deep Decarbonisation of Industry: The Cement Sector'.
[173] RMI and China Cement Association, 'Toward Net Zero: Decarbonization Roadmap for China's Cement Industry, 2022'.

100% rates. Germany is in turn a European leader, with national average alternative fuel usage of 65%.[174]

As in China, demand fluctuations have played key roles in determining absolute levels of European cement emissions. The European cement use profile is, however, dramatically different to that of China. European cement production fell from 225.6 Mt in 2001 to 182.1 Mt in 2019, while China likely only reached peak output in the past few years.[175] Per capita European cement consumption was also estimated at 376 kg per person in 2021, compared to 1.3 t per person for China in 2024.[176]

Rather than the fundamental restructuring seen in China, recent contractions in European output have often followed isolated economic shocks. European and German cement and clinker production peaked in 2007, then fell sharply following the global financial crisis. Production also dropped around 2021-22, coinciding with the 2022 Russian invasion of Ukraine and tail-end of the Covid-19 pandemic (see Figure 14).

As in China, European cement producers face diminishing returns from existing options for decarbonising production. They have also made relatively little progress on deploying breakthrough technologies for deep decarbonisation at-source.

Europe is noticeably more advanced than global peers in CCUS development. It hosts more than half of planned global cement-linked CCUS projects.[177] While none are currently operational, Heidelberg Materials has taken final investment decisions (FID) on two developments: a retrofit of its Brevik plant in Norway, expected to be operating in 2025, and the Leilac-2 project in Germany, which could commence in 2026.[178]

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174 European Commission Joint Research Centre, 'Deep Decarbonisation of Industry: The Cement Sector'.
175 CEMBUREAU, 'CEMBUREAU's Net Zero Roadmap'.
176 Onestone Consulting Limited, 'The Cement Industry in Europe at the Crossroads - Cement Lime Gypsum'.
177 Zoco, Perez Pena, and Lei, 'Carbon Capture, Utilization and Storage (CCUS) Is the Technology with the Highest Mitigation Potential to Decarbonize the Cement Industry'.
178 Heidelberg Materials, 'CCUS: More Future with Less CO_2'.

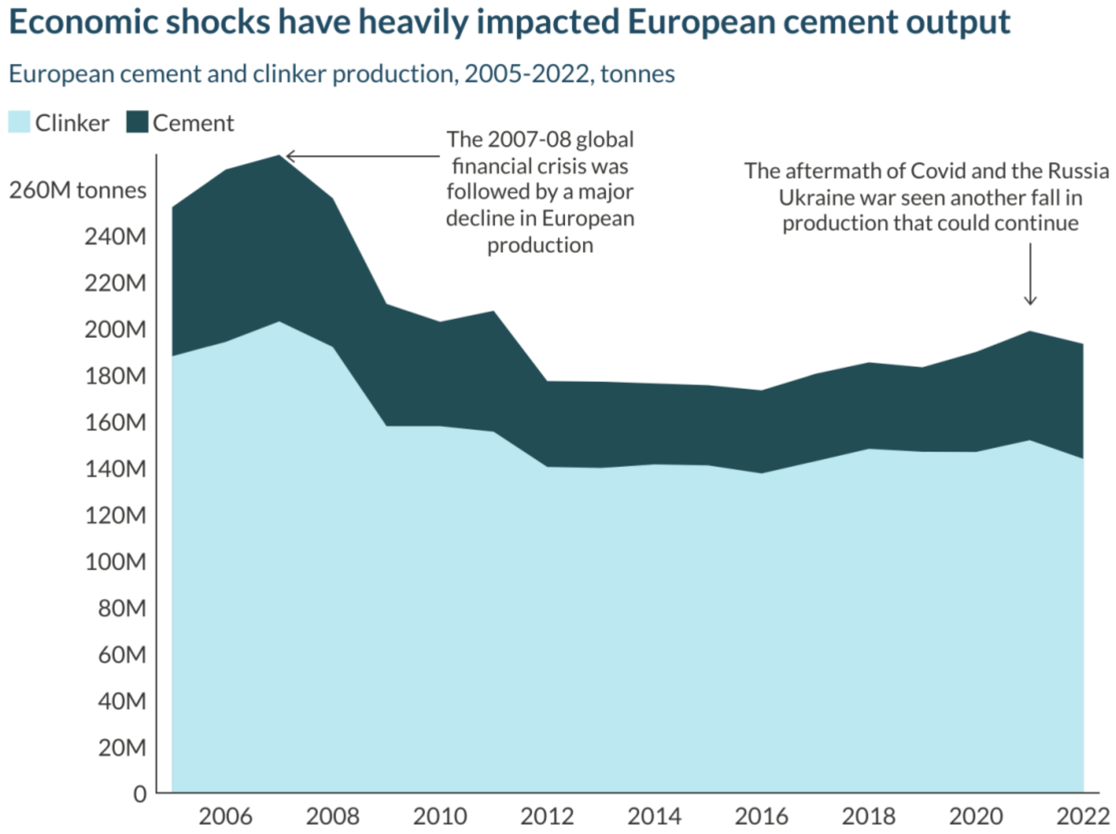

Figure 14. European clinker and cement production (2005-2022)

Future priorities and challenges

European cement producers face different future production and decarbonisation considerations than their Chinese counterparts. First, potential emissions savings from natural demand reduction are far smaller than those available in China, even as a relative share of cement-linked CO_2. Cement output will likely also remain relatively flat in the near-to-long term. One industry forecaster expects production in the 27 EU member states to drop from the 179.5 Mt estimated in 2021, to about 171.3 Mt/year between 2025-2030.[180]

As with China, Europe faces complex considerations on enhanced demand reduction, though for somewhat opposite reasons. The EU and Germany already have

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[179] Global Cement and Concrete Association, 'GCCA GNR ("Getting the Numbers Right") Database'.
[180] Onestone Consulting Limited, 'The Cement Industry in Europe at the Crossroads - Cement Lime Gypsum'.

comparatively high materials efficiency, substitution, and circularity-enhancing frameworks and have pledged to build on these under the European Green Deal, Germany's Federal Climate Change Act, and related policies.

However, European cement stakeholders, and related policy outcomes, generally oppose further industry contraction and seek to protect future economic competitiveness.[181] Fears of potential carbon leakage are high. The European Cement Association (CEMBUREAU) has consistently called for continuation of cement's expansive free allowance coverage under the EU ETS and a strong CBAM regime.[182]

European producers do still have significant opportunity to replace production capacity with cleaner assets: about 30% of cement kilns will reach the end of their investment lives by 2030.[183] They could achieve significant emissions abatement through further lowering clinker content. The main European and German industry-produced cement zero roadmaps (from CEMBUREAU and VDZ, respectively) see ratios fall to 0.50 by 2050.[184] Near total fuel substitution is also targeted. Enhanced demand reduction and breakthroughs in at-source technologies also contribute considerable emissions savings, but CCUS accounts for about 50% in each roadmap.[185]

European and German roadmaps even envision cement making longer-term carbon-negative contributions; CCUS with BECCS delivers negative emissions after 2050 in the VDZ assessment.[186] Integration of cement with concrete and building and construction sector interests also play important roles in European and German industry decarbonisation planning (see Appendix I for more details).

The European cement sector faces similar challenges to those identified globally and in China, as well as some novel ones. European climate action has traditionally also benefitted from high levels of diverse policy and regulatory support. This remains the case for cement.

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[181] European Commission, 'A European Green Deal - Striving to Be the First Climate-Neutral Continent'.
[182] CEMBUREAU, 'Carbon Border Mechanisms: Enabling the Industry to Deliver Carbon Neutrality Investments'.
[183] Climate Bonds Initiative, 'Concrete Policies to Underpin the Cement Transition'.
[184] CEMBUREAU, 'Cementing the European Green Deal'; VDZ, 'Decarbonising Cement and Concrete'.
[185] CEMBUREAU, 'Cementing the European Green Deal'; VDZ, 'Decarbonising Cement and Concrete'.
[186] VDZ, 'Decarbonising Cement and Concrete'.

EU and German policies and regulations for decarbonising cement

The EU, and Germany within it, have a comprehensive policy and regulatory apparatus for addressing climate change. The European Climate Law legislates carbon neutrality by 2050 and a 55% emission reduction by 2030 on a 1990 baseline.[187] The European Green Deal is the masterplan for achieving these goals. The Fit-for-55 legislative package operationalises the Green Deal and its various plans.[188]

Member state policies must at least align with and ideally increase ambition relative to those of the EU. Germany is among the most climate-ambitious EU member states. Its Federal Climate Change Act targets 65% emissions reduction by 2030, 88% reduction by 2040 and carbon neutrality by 2045.[189]

Numerous EU and German policies nested within this framework have cement relevance; more than 50 policies in the EU and Germany (or with their involvement at the international level) were identified through the Cement Sector Policy Mapping Tool.

Table 8 outlines the most important EU and German cement decarbonisation policies. The remainder of this chapter explores these in detail, including outlining any impact achieved thus far or future potential. A case study also considers the specific regulations that helped Europe lead on alternative fuels deployment.

These investigations should be framed by the observation that EU and German actions require continued reform and resourcing to deliver a Paris-aligned cement sector. These improvements continue to occur, and identifying ongoing weaknesses also has value.

Pricing conventional cement's emissions

The EU ETS and its supportive regulations works to internalise the cost of CO_2, in economy-wide decision-making. The EU ETS has potential for whole-of-system cement-related emissions reduction, by levelling the playing field for conventional cement and climate-friendly alternatives, including both low emissions cement and other building materials and practices.

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[187] European Commission, 'European Climate Law'.
[188] European Commission, 'Policy Scenarios for Delivering the European Green Deal'.
[189] Federal Government of Germany, Federal Climate Change Act (Bundes-Klimaschutzgesetz).

The EU and Germany's cement decarbonisation landscape

Goal	Main priorities	Key EU policies	Key German policies
Achieve whole-of-system change	Price conventional cement's emissions	EU ETS	
Reduce cement demand	Enhance materials efficiency, substitution, and efficiency	Circular Economy Plan, Waste & Landfill Directives, Construction Products (CPR) and Ecodesign (ESPR) Regulations, Level(s)	Circular Economy Strategy and Act, Sustainable Building Assessment System
Decarbonise cement production	Guard against carbon leakage and lost competitiveness	Carbon Border Adjustment Mechanism. Green industrial strategies, e.g. Green Deal Industrial Plan	
	Lower cost and technical barriers	EU Innovation Fund	Carbon contracts for difference for emissions-intensive industries
	Create green markets	CCPR, ESPR, Level(s)	Green lead markets proposal - GPP and low carbon cement labels, AVV Klima regulation
	Increase green finance	EU Taxonomy for Sustainable Activities	
	Regulate energy usage and pollution levels	Renewable Energy Directive, Energy Efficiency Directive, Energy Taxation Directive, Industrial Emissions Directive	Energy Efficiency Act
	Meet infrastructure, workforce, raw materials, and energy needs	Connecting Europe Facility, Important Projects of Common European Interest (IPCEI), Trans-European Networks for Energy	National Hydrogen Strategy, National Biomass Strategy, Systems Development Strategy
	Advance technological breakthroughs	Horizon Europe	Competence Centre on Climate Change Mitigation in Energy-intensive Industries
Address CCUS-specific challenges	Develop infrastructure, overhaul regulations, lower costs	Industrial Carbon Management Strategy	Carbon Management Strategy
Coordinate activity across actors and sectors	Enhance multi-stakeholder coordination	IPCEI, green industrial strategies	Cluster Decarbonisation in Industries program
Expand global ambition on cement decarbonisation	Enhance cross-border cooperation		Climate Club

Table 8. Key EU and German cement climate policy challenge, priorities, and responses

The EU ETS is the world's most established carbon market. Companies buy, trade, or are granted for free, rights to emit (allowances). These interactions set a carbon price, to change patterns of production and consumption and drive down emissions. The EU ETS also generates revenue by auctioning allowances, which funds programs such as the EU Innovation Fund.[190]

The ETS sets a progressively diminishing top-down cap on absolute emissions for covered facilities. This offers advantages over bottom-up, carbon intensity-based carbon markets. The cap covers the power and emissions-intensive industry sectors, including cement. An 'ETS 2' is currently in development and due to be operational by 2027. This will cover fuel used in transportation and heating in the building sector.[191]

The ETS has played a critical role in the EU achieving a net reduction of 31% in greenhouse gas (GHG) emissions by 2022, based on a 1990 baseline.[192] However, EU cement producers have largely been shielded from contributing to this aggregate effort. They face higher technical challenges and abatement costs relative to other sectors, and cement is included among a list of ETS-covered sectors considered at risk of carbon leakage. These factors have led to high regulatory support for business-as-usual activity.

The ETS grants covered installations a certain number of emissions allowances for free. In the first two ETS periods (2005-2007 and 2008-2012), most allowances were free across all sectors. Subsequent periods saw increased auctioning in the power sector, but cement and other industries continue to benefit from up to 100% free allowances.[193]

Allowance allocation is determined by product-specific benchmarks relating to average emissions of the most efficient 10% of EU ETS installations, as determined by the Free Allowance Regulation. The main cement benchmark is based on conventional emissions-intensive clinker.[194] This invites less ambition than if the benchmark were based on cement, which would introduce more opportunities for ambitious decarbonisation via reduction of clinker and potential elimination via alternative binders.

European cement, moreover, has a relatively high average clinker ratio. The ETS design leaves this challenge unaddressed. In fact, analysts have argued cement may be the only energy-intensive industry for which the ETS undermines the most effective lever for decarbonisation, by granting free allowances to production of the intermediate product that should be most avoided.[195] As well as hampering efforts to decarbonise production, poor regulatory design and unpriced emissions can lessen demand reduction.

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190 European Commission, 'What Is the EU ETS?'
191 European Commission, 'ETS2'.
192 'Total Net Greenhouse Gas Emission Trends and Projections in Europe'.
193 Carbon Market Watch, 'Concrete Solutions for Decarbonising the EU's Cement Sector'.
194 European Commission, 'EU Emissions Trading System (ETS) – Update of the Free Allocation Rules'.
195 ECOS, 'ECOS Feedback on EU Emissions Trading System (ETS) Update of Activity Level Changes Regulation'.

There will, however, be future improvement of cement's coverage under the EU ETS. Fit-for-55 introduced a scheduled phase out of free allowances from 2026-2034, while the EU CBAM will be progressively scaled up at the same time (see Figure 15).[196]

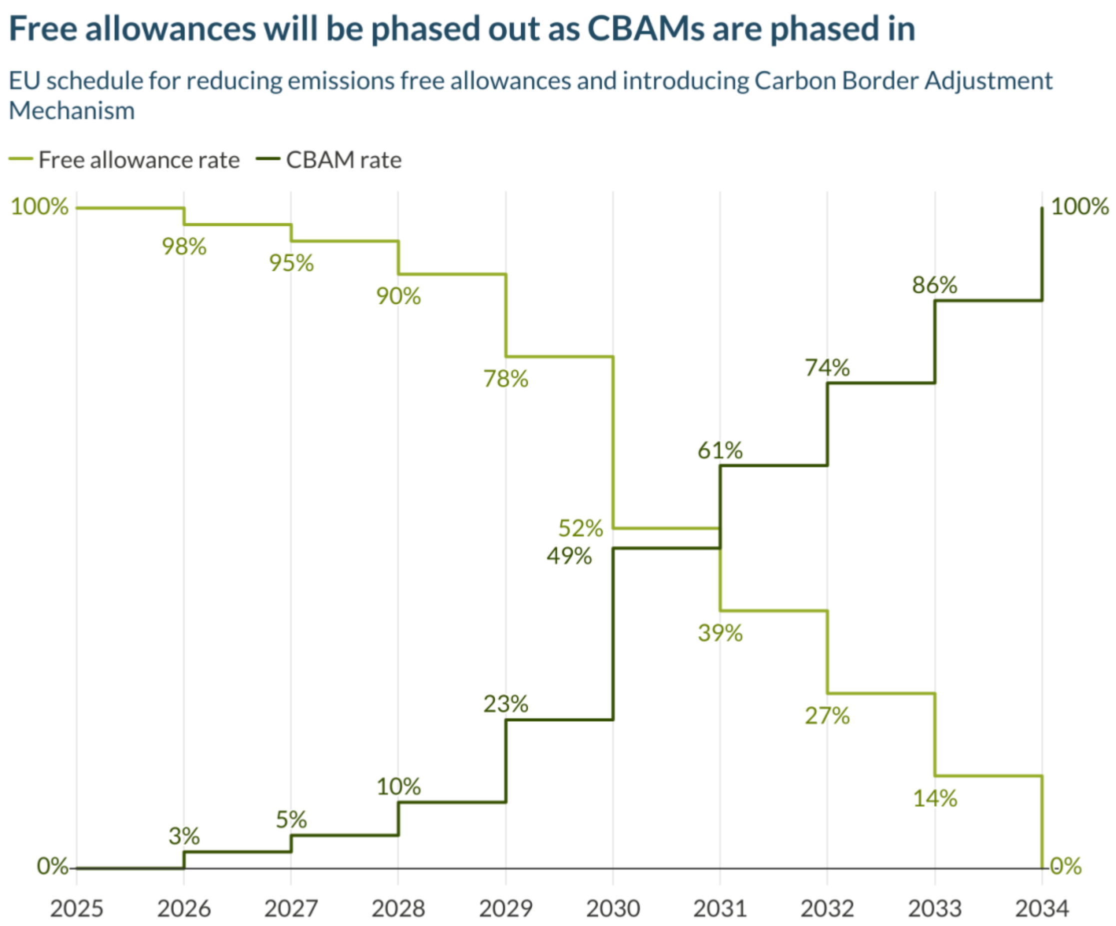

Figure 15. EU ETS schedule for phasing out free allowances and phasing in CBAMs

By one estimate, EU cement producers could see a cumulative increase of EUR 13 billion in carbon pricing exposure from 2026-2030.[198] But an earlier phaseout of free allowances, e.g. by 2030, and more ambitious benchmark reform could incentivise quicker and deeper action.[199]

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[196] European Commission, 'What Is the EU ETS?'
[197] European Commission.
[198] Climate Bonds Initiative, 'Concrete Policies to Underpin the Cement Transition'.
[199] Alliance for Low-Carbon Cement and Concrete, 'Fast-Tracking Cement Decarbonisation: From Underperforming to Performance-Based Standards'.

Enhancing materials efficiency, substitution, and circularity

Reducing cement demand is an important climate solution. European policymakers and industry members have paid less direct attention to this lever than to decarbonising production at-source and CCUS. However, the EU, led by Germany, has generally strong levels and ongoing reform priorities around materials efficiency, substitution, and circularity, including as they relate to cement.

Numerous factors – including raw materials availability, demographic trends, consumer preferences, and the influence these exert on building codes and regulations – have led to Europe having a strong baseline level of avoided cement demand, relative to countries such as China. Europe has building lifespans of up to 100 years and higher market penetration of non-concrete materials and average construction waste recycling rates.[200]

Climate and sustainability-focused European policymaking has helped to continually consolidate these advantages. The continent has developed comprehensive circular economy and green building strategies to influence consumer and producer behaviour, often backed by legislated requirements.

The EU Circular Economy Action Plan (CEAP) was introduced in 2015 and included 54 actions, four legislative changes on waste, and targets for landfill, reuse, and recycling rates to be met by 2030 and 2035.[201] A new CEAP was delivered in 2020, but a 2019 progress report noted earlier plans have likely played a significant role in important outcomes, including the rate of recovered and recycled materials in new EU goods increasing from 3.4% to 11.7% during 2004-2016.[202]

The EU's 2020 CEAP listed cement as a priority sector for the first time. It noted improved efficiency could save 80% of emissions from materials extraction, manufacturing of construction products, and construction and renovation activities. It also committed the EU to deliver a Strategy for a Sustainable Built Environment. This strategy could better target cement-specific demand reduction, but it is yet to arrive.[203] The EU did, however, introduce the Renovation Wave programme in 2020, which aims to double the renovation rate for new buildings by 2030 to help improve energy use, lifecycle thinking, and carbon sink effects. The carbon sink language does not reference cement, but it does consider cement-substitutable materials such as timber.[204]

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[200] Andersen and Negendahl, 'Lifespan Prediction of Existing Building Typologies'.
[201] European Commission, 'Circular Economy Action Plan - European Commission'.
[202] 'Report on the Implementation of the Circular Economy Action Plan - European Commission'.
[203] European Commission, 'Circular Economy Action Plan - European Commission'.
[204] European Commission, 'Renovation Wave'.

The success or failure of green building and circular economy strategies is determined by their supportive regulations. The EU has, or is seeking to develop, useful tools in this regard. The Energy Performance of Buildings Directive aims to put the EU on course for a fully decarbonised building stock by 2050, including through development of a new standard for zero emission buildings.[205]

The EU Construction Products Regulation (CPR) provides a common technical language for assessing construction product performance and requires manufacturers to assess and submit lifecycle sustainability reports. This will allow tracking of progress and establishment of embodied carbon thresholds. The regulation will also aid the creation of new EU rules for GPP for building materials, which are scheduled to be established from the end of 2026.[206]

A 2024 CPR revision did not, however, establish mandatory requirements for climate and environment assessment and reporting the results to consumers, as some campaigners called for.[207] Cement was also left outside the scope of the separate Ecodesign for Sustainable Products Regulation (ESPR), which imposes more stringent requirements and disclosure via digital passports. Cement producers have until 2029 to improve their sustainability outcomes or potentially be covered by the ESPR.[208]

The EU's Level(s) system is also a useful tool for lifecycle sustainability assessments of the built environment, which is important information in the context of displacing conventional high emissions cement. Level(s) provides a common language on sustainability and circularity and an easy and free user entry point for what was previously a costly and complex process.[209]

The EU Waste Framework Directive (WFD) regulates economy-wide avoidance and subsequent management of waste. A five-level hierarchy clarifying roles and responsibilities around waste management is central to the WFD. In order of priority, the hierarchy is:

- Prevention
- Preparation for reuse
- Recycling
- Other recovery
- Disposal

[205] European Commission, 'Energy Performance of Buildings Directive'.
[206] European Commission, 'Construction Products Regulation'.
[207] ECOS, 'Crossroads for Construction Products'.
[208] European Commission, 'Ecodesign for Sustainable Products Regulation'.
[209] European Commission, 'Level(s)'.

The WFD designates when waste become secondary raw materials, including fuels. Construction and demolition waste (CDW) is also a WFD priority waste stream. Related targets for re-use, recycling, or other recovery are currently non-binding, and the latest requirement for a minimum of 70% (by weight) expired in 2020.[210] A renewed, increased, and binding target would be beneficial.

Germany introduced its own new Circular Economy Strategy (CES) in 2024. This aims to increase resource efficiency, waste avoidance, and sustainable growth in advance of EU commitments. The CES notes that industrial sector circular economy-boosting actions could reduce emissions 30-50% by 2050, while also adding economic value. An integrated approach to climate and circular economy could also decrease emissions abatement costs for cement, concrete, and other goods 45%/tCO_2 by 2045.[211]

The CES commits Germany to increase use of low emissions building materials, including recycled concrete, cement substitutes, or bio-based building materials. It aims to double the share of recycled materials across all industries and reduce municipal waste a further 10% by 2030. A new digital product passport will also be introduced, to increase circularity awareness and innovation in construction and other sectors.[212]

The CES actions are ambitious, but Germany has a long record of setting and achieving strong circular economy goals. Its Circular Economy Act – most recently updated in 2012 – helped inform and build on EU commitments such as the WFD, including its waste hierarchy, and facilitated target-setting across key areas of interest.[213]

In 2022, Germany's municipal waste recycling rate reached 67.7%, exceeding a 65% target set in 2020. Rates of above 90% material recycling and recovery have been achieved for CDW.[214] Most CDW is currently reused in roadworks and does not directly substitute for new cement and concrete. However, raw materials access is a prerequisite of any new industrial activity, meaning Germany is well-prepared for anticipated advances in recycling technologies and processes using these materials. German and EU management of waste streams have already played a vital role in their world-leading alternative fuel deployment for cement.

Germany's Sustainable Buildings Assessment System (BNB) also provides a framework for lifecycle emissions assessments of buildings, and consideration of these in publicly

[210] European Commission, 'European Waste Framework Directive'.
[211] German Federal Ministry for Environment, Nature Conservation and Nuclear Safety, 'The National Circular Economy Strategy: Fundamentals for the Process of Transforming to a Circular Economy'.
[212] German Federal Ministry for Environment, Nature Conservation and Nuclear Safety.
[213] Federal Government of Germany, 'Circular Economy Act'.
[214] Tsydenova, Becker, and Walther, 'Optimised Design of Concrete Recycling Networks'.

funded construction projects. BNB includes some mandatory requirements, including that all federal buildings must meet its Silver Standard, which requires obtaining 65% of all assessment points. Germany reconsidered the BNB's design in 2021, seeking to introduce assessment of the climate footprint of building materials including cement.[215] This outcome is now being advanced through Germany's 'lead markets for climate friendly materials' proposal and the national General Administrative Regulation on the Procurement of Climate Friendly Services (AVV Klima) regulation (see 'Creating green lead markets')**.**

EU and German policies relevant to cement demand reduction thus far have mainly proven the utility of clear targets and obligations around materials usage, from waste avoidance to end-of-life applications. The more direct regulation of the carbon intensity of building materials and the built environment is likely to play a larger future role in promoting alternative practices and product uses.

Case study: European and German policies for advancing alternative fuel deployment

The EU, and particularly Germany, are world leaders in deploying alternative fuels in place of traditional fossil fuels in cement kilns. Significant use was achieved several decades ago, initially on commercial rather than environmental grounds, as producers sought lower energy bills.

Strong national compliance with EU circular economy and waste management regulations, coupled with strong industry enthusiasm and public acceptance, are most credited with facilitating Europe's co-processing success. Raw material access has been the essential prerequisite, with development of supporting pretreatment and other technologies and processes, new market structures, value chain members, and infrastructure, flowing from this.

European producers began using hazardous waste in the 1980s, due to its similar specifications to traditional coal and fuel oil. From the beginning, local dynamics and responses exerted outsized influence on industry access to suitable fuels. This is clear from the high penetration of used oil achieved in French cement-making, which peaked at annual use of 150,000 t. Beginning in the mid-1980s, the French government introduced financial incentives and

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[215] Steinmann et al., 'Green Public Procurement in Construction - Driving Public Purchase towards Truly Green Construction Products and Materials'.

tracking tools to curb illegal disposal of used oil. But, with limited recycling capacity, it needed a buyer, leading to cement interest.

Other European governments have since used landfill bans and taxation regimes to achieve the same effect seen in France, of diverting high priority waste streams to the cement sector. The France example also highlights the importance of supportive regulations and assessments. The French government prioritised energy recovery in cement kilns, based on encouraging lifecycle environment assessments. But the EU prioritised materials over energy recovery from used oil – such as use in lubricants – which limited its cement-specific deployment elsewhere in the bloc.

The European cement industry turned to non-hazardous waste, including biomass, in the late 1990s. This followed introduction and compliance with new regulations such as the EU Landfill Directive, which resulted in significant increases in disposal costs through bans on recyclable and organic waste .

The Landfill Directive remains in force. From 2030, it will introduce restrictions on all waste suitable for recycling or other material or energy recovery. The Directive currently requires EU member states to implement national strategies for progressively reducing biodegradable waste sent to landfills, which could also benefit cement.

The EU's introduction of the 'extended producer responsibility' (EPR) principle, requiring producers to take responsibility for the entire lifecycle of their products, has been credited with aiding development of a cement market for used tyres. Tyre manufacturers in countries such as France and Poland have formed shared companies to manage end-of-life applications as a result.

EPR is embedded into the EU's Waste Framework Directive (WFD), alongside the similarly important 'polluter pays principle' and rules on when waste becomes secondary raw materials, and the regulatory implications of this.

The EU Industrial Emissions Directive can also influence cement's fuel mix, by setting limits on pollutants such as dust, nitrogen oxide, and sulphur dioxide from production and requiring cleaner-burning inputs.

While the EU ETS is not currently optimised to incentivise deep cement decarbonisation, it has likely played some role in fuel switching. The ETS benchmark for cement being based on clinker production means that the carbon intensity of the fuel mix influences about 40% of relevant emissions.

Given the frequent economic advantages involved, direct financial support does not appear to have played a significant role in European cement's fuel switching. There has, however, been some limited government capital expenditure assistance, as with the EU's financial support to Poland building its first waste shredding line for refuse-derived fuel, in the early 2000s.

European standards have also been configured to advance alternative fuel use. This includes EN 197-1, which specifies the composition, specifications, and conformity criteria for common cements, and EN 15359, which focuses on the classification, sampling, and testing of solid shredded waste.

European cement stakeholders have further noted the importance of low levels of bureaucracy in approving co-processing of waste. Industry members have aided this by pursuing high levels of transparency and quality assurance around alternative fuel use. The sector has engaged early and consistently with relevant stakeholders – including NGOs, governments, the waste sector, and the media – to sell the environmental benefits of alternative fuels. It has remained committed to strong monitoring and public disclosure around pollution and emissions levels as substitution rates have advanced.

German leadership

Germany is in turn an alternative fuels leader within Europe. German cement manufacturers began co-processing car tyres in the 1980s, followed by contaminated oils. As in France, the sector was a valuable early customer for waste diverted from landfill. New technical solutions and market structures were again built on this framework. Germany went from a 2% thermal replacement rate in the 1980s to almost every cement plant being fitted with a waste pretreatment system by 1990. Germany has progressively expanded its range of co-processed raw materials, including animal meal and sewage sludge, to reach substitution rates above 67% by 2019.

Much of Germany's success can again be attributed to the regulatory environment. Germany was one of the first European countries to implement landfill limiting policies in the 1990s, leading to the recycling of almost half of its municipal waste by 2001. It introduced additional requirements in 2005, which went beyond the intervening EU Landfill Directive, including mandating all municipal solid waste be pre-treated prior to final disposal.

Germany introduced stronger regulatory oversight of waste management through 2012's Circular Economy Act (CEA). German states develop their waste management legislation in accordance with the CEA and local municipalities play a key role in ensuring compliance. Germany was also an early adopter of the polluter pays principle in the 1990s.

German cement industry association VDZ has worked to enhance transparency and quality assurance around co-processing, by gathering and publicising extensive cement plant emissions data. The resulting public acceptance has also been assessed as contributing to strong alternative fuels uptake.

Sources : de Beer et al., IFC, Edwards, Supino et al.[216]

Guarding against carbon leakage and lost industrial competitiveness

The EU's CBAM is an important mechanism for increasing ambition on cement decarbonisation. It establishes a framework for protecting EU industry as they seek to lower emissions, by ensuring goods from rival producers are subject to the same carbon taxation levels, including through import fees if necessary.

The CBAM will be successively phased in by 2034. Cement is among the first sectors covered. CBAM will help alleviate carbon leakage fears and allow stronger climate ambition. It will be accompanied by a phase-out of ETS free allowances, bringing higher-impact exposure to carbon prices.[217]

The EU's green industrial strategies perform a similar dual role of protecting industry while advancing decarbonisation. They include the Green Deal Industrial Plan (GDIP) and its associated Net Zero Industrial Act (NZIA). These documents set out plans for coordinating activity among various stakeholders and addressing barriers to low emissions industrial output.

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[216] de Beer et al., 'Status and Prospects of Co- Processing of Waste in EU Cement Plants'; International Finance Corporation, 'Increasing the Use of Alternative Fuels at Cement Plants: International Best Practice'; Edwards, 'The German Cement Sector - Driving to Growth?'; Supino et al., 'Sustainability in the EU Cement Industry'.

[217] European Commission, 'Fit for 55: Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality'.

The GDIP aims to maintain or even enhance industrial competitiveness simultaneous to emissions reduction. The NZIA specifically aims to enhance European green manufacturing, and includes several cement-relevant pledges, including on CCUS. Some of the most notable pledges concern the establishment of:

- An EU market for CO_2 storage services, and CO_2 storage capacity of at least 50 Mt/year by 2030, to aid industrial decarbonisation
- 'Net zero training academies' with an initial 100,000 worker participants, and designated strategic projects that benefit from expedited government approvals
- New mandatory rules in public procurement, auctions, and other schemes to boost demand for other low emissions products

Europe's cement-related green industrial strategies remain works in progress. But there is some cause for optimism. The EU has had notable past success in delivering decarbonisation alongside economic opportunity. As noted above, the EU cut its GHG emissions 31% by 2022. The EU's environmental goods and services sector in turn grew at a faster rate than the broader economy between 2010-2021.[218]

Lowering cost and technical barriers

EU ETS reforms could help lower cost disparities between high and low emissions cement. But greater governmental intervention will still be required to make low emissions cement cost-effective and technically mature.

The EU Innovation Fund (complemented by the EU Modernisation Fund in low-income countries) plays the key role here. The Fund is directly financed by ETS allowance auctions. Revisions in 2023 increased its capacity from the proceeds of 450 million to 530 million allowances. The total fund size depends on associated carbon prices. It may amount to EUR 40 billion from 2020-2030 based on a 75 EUR/tCO_2 price.[219]

The Innovation Fund has funded 13 projects directly connected with cement – the second-highest for any sector.[220] The average project contribution of EUR 149.2 million is almost three times the generic average. Eleven of 13 projects funded target CCUS, while the remaining two focus on clinker substitution and fuel switching. The Innovation Fund has also funded sustainable building material projects, which might reduce cement demand, and other cement-linked outcomes, such as CO_2 storage and transportation.

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218 How to build and fund a better EU green industrial policy
219 European Commission, 'What Is the Innovation Fund?'
220 European Commission, 'Innovation Fund Projects'.

Cement projects funded by EU Innovation Fund

Round	Project acronym and description	Country	EU funding (EUR)
2022	GeZero: Net carbon negative cement plant with full CCS chain	Germany	190M
2022	IFESTOS: CCS for zero carbon cement and concrete, with regional industry synergies	Greece	234M
2022	KOdeCO net zero: end-to-end CCS project	Croatia	117M
2022	EVEREST: improved calcination and CCS for largest European lime plant	Germany	229M
2022	GO4ZERO: Demonstration of flue gas recirculation and concentration paired with full CCS	Belgium	230M
2022	ERACLITUS: Expanding range of clinker substitutes	Spain	4.5M
2021	CLYNGAS: Substitution of petroleum coke with synthetic gas (syngas) from gasification of stabilised refuse-derived fuel	Spain	4.4M
2021	C2B: Carbon2Business	Germany	110M
2021	ANRAV: CCUS value-chain and cluster in Eastern Europe	Bulgaria	190M
2021	GO4ECOPLANET: Capturing and liquefying CO2	Poland	228M
2021	CalCC: CCS for lime production integrated with shared transport and storage infrastructure	France	125M
2021	OLYMPUS: CCS using OxyCalciner technology	Greece	124M
2020	K6: Oxy-fuel kiln with CCS	France	153M

Table 9. Innovation Fund projects for cement sector decarbonisation

The Innovation Fund's heavy CCUS focus reflects significant industry interest, as well as significant cost and technical hurdles in this sector. To better align with the Paris Agreement goals, the Fund would need to pay far more attention to technologies for deep decarbonisation at source. Some options remain at the R&D stage, but some are relatively mature and suitable for funding.

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[221] European Commission.

Innovation Fund cement projects are still in development. However, a 2022 progress report on the Fund's overall effectiveness noted that projects funded thus far were on track to reduce 77.4 $MtCO_2$-equivalent in their first 10 years (greater than the annual emissions of all but 47 countries, globally).[222] The Fund's scale has also significantly increased since this time. The Innovation Fund, moreover, serves as a good model for directing revenue from ETS allowance auctions to further climate-benefitting outcomes.

Germany similarly recognises the need for public investment in decarbonising cement and other heavy industries, in addition to carbon pricing. The Federal Fund for Industry and Climate Action (BIK) provides grants to small-to-medium-sized enterprises for investment and research, development, and innovation in two modules: industrial decarbonisation projects and CCUS investments and innovation.[223]

In 2024, Germany also launched a 'carbon contracts for difference (CCfD) program for energy-intensive industries', targeting larger operations.[224] This program is most relevant to decarbonising cement production. But it could also theoretically enhance creation of demand-reducing materials.

CCfDs compensate costs incurred from investing in new or retrofitted plants. Support is benchmarked against changes in EU ETS carbon prices, to help limit public risk relative to open-ended subsidies. If changes in carbon pricing render low-emissions production cheaper than conventional production, companies pay back the difference.

Projects receiving funding under the German CCfD program must demonstrate they can achieve a 60% emission reduction in three years and 90% emission reduction in 15 years, relative to the best-performing EU ETS installations.[225] Projects are selected through open competitive bids and assessed against two criteria: aid requested per tCO_2 avoided (lower amounts are prioritised) and speed at which significant emissions abatement can be achieved.[226]

The first bidding round, in 2024, allocated a maximum of EUR 2.8 billion to 15 successful companies, though project details were not initially released. A second round, with an expected EUR 19 billion capacity, is now open and will conclude in 2025.[227]

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222 European Commission, *Innovation Fund Progress Report*. European Commission.
223 FI Group, 'Federal Funding for Industry and Climate Protection (BIK)'.
224 Federal Ministry for Economic Affairs and Climate Action, 'First Round of Carbon Contracts for Difference Launched'; European Commission, 'EU Taxonomy for Sustainable Activities'.
225 Federal Ministry for Economic Affairs and Climate Action, 'First Round of Carbon Contracts for Difference Launched'.
226 Federal Ministry for Economic Affairs and Climate Action.
227 Federal Ministry for Economic Affairs and Climate Action.

It is again too early to assess the success of the CCfD model. Industry members have also stressed that they will still require additional supportive conditions, such as reduced energy costs, tax obligations, and limited bureaucracy, to decarbonise while remaining competitive.[228]

Still, the German government estimates the program could save up to 350 $MtCO_2$ across covered sectors by 2045. This is about a third of industrial emissions savings required under national climate targets. [229] The 'additionality' of the model — requiring ambition above that required by the ETS — is beneficial. The CCfD model also limits the risk of unproductive spending, which is valuable for resource-constrained governments.

Creating green lead markets

Lack of demand is a major challenge for low emissions cement and some of its alternatives. Governments can play a key role in overcoming this problem by creating 'lead markets'. They can leverage their significant buying power to provide revenue for low emission producers. This can incentivise continued investment, cost reductions, and long-term displacement of high emissions cement as the industry standard.

GPP is a potentially potent tool, given that government purchases account for about a quarter of spending on construction projects globally.[230] Clear and consistent definitions and labelling regimes for low emission goods are a vital complement to GPP. They can have additional utility in motivating private decision-making.

The EU has GPP rules that set out the process by which public authorities purchase goods, services, and works with reduced lifecycle climate and environmental impact, in line with regulations such as the EU Procurement Directive. However, there are no mandatory requirements and member states determine the degree to which they apply the rules.[231] GPP has been largely ineffective in the context of EU cement or other materials, but reforms are scheduled by the end of 2026.

Improvement could include introduction of mandatory quotas and aligning GPP criteria to the EU Taxonomy for Sustainable Activities, including its cement-specific criteria, or with other lead market frameworks, such as that proposed by Germany. The EU could

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[228] 'Germany Awards First Companies with Pioneering "Climate Contract" Scheme to Slash Industry Emissions'.
[229] Federal Ministry for Economic Affairs and Climate Action, 'First Round of Carbon Contracts for Difference Launched'.
[230] Steinmann et al., 'Green Public Procurement in Construction - Driving Public Purchase towards Truly Green Construction Products and Materials'.
[231] European Commission, 'Green Public Procurement'.

also improve cement's coverage under product labelling regimes such as the CPR and ESPR.

Germany has already made greater national level progress on GPP. Its AVV Klima regulation of 2022 built on the established BNB system, to specify how climate protection is considered in government purchasing processes. [232] AVV Klima includes a useful requirement that authorities apply a 'shadow carbon price' to calculate and consider impacts of avoidance or causation of GHG emissions in competitive bidding processes. The regulation also requires the forecasting of lifecycle emissions, to allow for a climate-centric comparison of different building materials and practices.

But AVV Klima is still considered difficult to apply in practice, particularly for large-scale projects. Its shadow carbon price is also set low, in alignment with Germany's Fuel Emissions Trading Act.[233] This started at just EUR 25/tCO_2 in 2021 and is expected to rise to EUR 55-65/tCO_2 in 2026. It compares with a more accurate EUR 300/tCO_2 assessment of the social cost of carbon, which the German Environment Agency has applied as of 2024.[234]

In 2024, Germany's Federal Ministry for Economic Affairs and Climate Action (BMWK) unveiled a proposal for 'lead markets for climate friendly materials', including cement. BMWK has worked with other stakeholders on a proposal for enhanced GPP, product definitions and labelling, which it ideally seeks to apply in the EU common market.[235]

Consultation around the lead market proposals has already led to positive outcomes, including development of a five-tiered classification system for low emission cement to inform future procurement:

- D: 400-500 $kgCO_2$/t
- C: 300-400 $kgCO_2$/t
- B: 200-300 $kgCO_2$/t
- A: 100-200 $kgCO_2$/t
- Near-zero: below 100 $kgCO_2$/t[236]

The range of emissions recognises difficulties in applying a one-size-fits-all approach. The upper range is achievable when recalling the average global cement footprint of 580 $kgCO_2$/t, when assessed with a similar method. The lower range is ambitious but,

[232] BMWK, 'Lead Markets for Climate-Friendly Basic Materials'.
Tech for Net Zero Alliance, 'Tech for Net Zero 2023 Green Public Procurement Policy Paper'.
[234] Moore et al., 'Synthesis of Evidence Yields High Social Cost of Carbon Due to Structural Model Variation and Uncertainties'.
[235] European Commission, 'Circular Economy Action Plan - European Commission'.
[236] 'VDZ Introduces CO_2 Label for Cement'.

recalling emerging options for low-to- negative emissions from alternative binders and cements, not unachievable. German cement industry organisation VDZ has since announced it will publicly promote the new classifications through a voluntary cement labelling system.[237]

BMWK has proposed incorporating the new cement definitions in future activities, including procurement aligned with AVV Klima. It will also advocate for minimum GPP requirements at the EU level, aligned with CPR and ESPR, and continue to advocate for government-led low emissions demand globally, through bodies such as the Industrial Deep Decarbonization Initiative (IDDI).

Other rules, such as production standards and building codes, also strongly influence market development for low emissions goods. The main European cement standard, EN 197-1, for example, has allowed adoption of decarbonisation-boosting practices such as alternative fuel use. But it has likely also served as a handbrake on deeper decarbonisation, in a similar manner as EU ETS benchmarking regulations.

The EU would ideally move to a performance-based cement standard, which could again accommodate lower emissions alternatives to conventional cement. This could set parameters around strength, durability, and environmental and climate footprint, as well as desired use and impact, and help predict long-term cement behaviours via best practice testing and calculation methods.[238] The European Commission's industry directorate has indicated some support for developing such a standard in future.[239]

Increasing green finance

A lack of private finance sufficient to fund low emissions investments is another cement challenge. As noted in the China context, heavy industrial sectors have traditionally struggled to attract finance for emissions abatement relative to more easily decarbonised sectors. Some European producers have, however, started developing their own frameworks and instruments to promote and leverage their climate and broader environmental achievements.[240] The EU has aided industry through the Taxonomy for Sustainable Activities and related mechanisms and regulations.

The EU Taxonomy defines sustainable activities, to inform decision-making by investors, including purchasers of European Green Bonds. Companies covered by the EU's Corporate Sustainability Reporting Directive are legally required to report the degree to which their activities align with the taxonomy. To classify as sustainable, activities must

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[237] BMWK, 'Lead Markets for Climate-Friendly Basic Materials'.
[238] Alliance for Low-Carbon Cement and Concrete, 'Fast-Tracking Cement Decarbonisation: From Underperforming to Performance-Based Standards'.
[239] Climate Bonds Initiative, 'Concrete Policies to Underpin the Cement Transition'.
[240] Heidelberg Materials, 'Green Finance Framework'.

satisfy numerous requirements, including sector-specific 'technical screening criteria' (TSR).

The TSR concerning cement's contribution to climate change mitigation involves manufacturing grey clinker while generating less than 722 $kgCO_2/t$, or manufacturing cement from grey clinker or alternative binder while generating less than 469 $kgCO_2/t$.[241] These are relatively low thresholds; only 11% of EU cement plants are estimated to operate below them.[242]

The Taxonomy also has potential to channel finance towards cement demand reduction, through its built environment coverage. However, the TSR here are not as rigid as they could be. Requirements to assess the lifecycle GHG emissions of buildings only apply to large projects (covering 5000m^2 and above) and information is not required to be disclosed unless there is investor request.[243]

The EU Taxonomy's potential impact on financial flows remains unclear. Future details around changing levels of compliance over time will be beneficial. The TSR for cement invite ambition, but transitional industries face a considerable challenge in overcoming investor doubts as to the legitimacy of their climate contributions. The TSR's suggested incorporation into a mandatory EU GPP platform could be a significant breakthrough. Stronger carbon pricing of cement, and other fiscal and regulatory incentives and impositions, could also invite greater Taxonomy alignment. The Taxonomy's coverage of the built environment should be improved for additional impact.

Regulating energy usage and pollution levels

The EU also issues several policy directives that can indirectly contribute to cement decarbonisation, via regulation of industry energy use and pollution levels.

The Renewable Energy Directive (RED) sets progressively upgraded targets for EU renewable energy use. The target share for renewables in gross final energy consumption is currently 42.5% by 2030. The RED has already been a key factor in increasing the renewables share of EU energy consumption to date, from 14% in 2010 to 25% in 2023.[244]

Helpfully, the RED was extended to cement and other industrial sectors in 2023. This started small, with an indicative target of a 1.6% annual increase in industrial renewable energy use, and a binding target for renewable fuels of non-biological origin meeting

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[241] European Commission, 'EU Taxonomy for Sustainable Activities'.
[242] Voetmann, 'EU Taxonomy Will Heavily Impact the Cement Industry'.
[243] Environmental Coalition on Standards, 'Why Does the EU Taxonomy Miss the Mark on Construction?'
[244] European Commission, 'Renewable Energy Directive'.

42% of total hydrogen demand for industry by 2030. These industry-specific requirements will ideally be strengthened in future. The RED's other 2023 upgrades, to improve approvals processes for renewable projects and require member states to develop new high renewables potential zones, could also benefit cement industry access to affordable decarbonised energy.[245]

The Energy Efficiency Directive mandates continuous EU energy efficiency improvements. As well as upgraded targets (an 11.7% reduction in EU final energy consumption by 2030, compared to projected usage of 846 Mt of oil equivalent), the most recent directive legally established 'energy efficiency first' as a fundamental principle of EU energy policy. This requires governments to consider energy efficiency measures in all relevant policy and major investment decisions.[246]

The EU's Energy Taxation Directive (ETD) also has a role to play in industrial decarbonisation. The ETD provides a framework for taxing energy products, including electricity and fuels. This includes setting minimum rates of excise duty, to encourage lower energy use and lower emissions. ETD reforms that could further accelerate decarbonisation have been proposed but so far not delivered. Cement producers have called for tax exemptions to encourage electrification of industrial processes.[247]

The EU Industrial Emissions Directive regulates non-CO_2 pollutants in 50,000 of the EU's largest industrial applications, including for cement. It specifies how to control emissions through application of a list of Best Available Techniques. A positive coincidental effect of some forms of reduced pollution can be reduced climate-warming emissions from energy and raw material feedstocks.[248]

Germany applies EU directives around energy and pollution and often raises their ambition through domestic requirements. For example, Germany's Energy Efficiency Act of 2023 established the country's first legal framework for energy efficiency. It included a stipulation that companies with high energy consumption (more than 2.5 gigawatt hours per year) must develop and publish plans for implementing economically viable energy efficiency measures. However, the Act imposes its most stringent conditions on data centres rather than industrial operations.

European regulations around energy and pollution do not directly target carbon emissions. But they can play an important role complementing the ETS, which does.

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[245] European Commission.
[246] European Commission, 'Energy Efficiency Directive'.
[247] CEMBUREAU, 'Cementing the European Green Deal'.
[248] European Parliament and Council of the European Union, 'Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on Industrial Emissions (Integrated Pollution Prevention and Control)'.

More cement-specific binding commitments under these directives would be helpful. Regulations such as the RED, which not only impose new requirements, but can increase industry access to the inputs required to meet requirements, are most valuable.

Meeting infrastructure, workforce, energy, and raw material needs

Decarbonising cement requires increasing industry access to considerable new infrastructure, skilled workers, decarbonised energy, and alternative raw materials. Industry members cannot act alone on this front. Government interventions are essential. Some EU and German policies contribute to meeting these needs. In addition to the RED on renewable energy, circular economy actions can enhance access to raw materials such as fly ash and blast furnace slag for SCMs, as well as waste streams for alternative fuels and concrete recycling.

The EU's green industrial strategies, led by the GDIP and its supporting NZIA once more, also identify industry needs and seek to mobilise resources and attention needed to meet them. This can include providing direct fiscal support – such as funding shared infrastructure, training workers, and subsidising some industrial inputs – and removing bureaucratic barriers, such as long project approval times and legislative and regulatory restrictions on certain materials and practices.

Officials delivering these strategies can call on a range of valuable tools. The Connecting Europe Facility (CEF), for example, funds developments which enhance interconnectivity and integration, supply security, and decarbonisation in European energy markets, alongside transport and digital commitments. The CEF has a budget of EUR 5.84 billion for energy investments for the 2021-27 period.[249]

CEF allocated EUR 1.2 billion to 41 cross-border energy infrastructure projects in 2024. This included funding 21 infrastructure development studies related to hydrogen's role in decarbonising industry.[250] CEF has also led on developing cross-border CO_2. transportation and storage infrastructure, which is highly cement-relevant. About EUR 680 million in CEF funding has been allocated to this outcome so far.[251] CEF could enhance EU-wide provision of alternative fuels and renewable energy to decarbonise cement, though efforts thus far have largely targeted transport and power sector needs.

CEF energy funding is also aligned with projects designated as of common interest under the Trans-European Networks for Energy policy framework. This designation

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[249] European Commission, 'Connecting Europe Facility - European Commission'.
[250] European Commission.
[251] European Commission.

accords additional support, including streamlined permit-granting and environmental assessment procedures and points of contact.[252]

Important Projects of Common European Interest (IPCEI) are a separate but similarly valuable strategic instrument. They bring together knowledge, expertise, financial resources, and numerous actors to tackle important societal challenges, including resolving market failures. IPCEIs create large-scale consortia focused on solving problems in select, strategic value chains. The EUR 5.2 billion Hy2Use IPCEI from 2022 is an example of cement sector relevance. It funded the EUR 60 million H2CEM project, which targeted production and use of hydrogen in Greek cement plants.[253] Cement and other industrial stakeholders have also called for an IPCEI on industrial carbon management, i.e. CCUS. [254]

German policies again build on those in place at the EU level. Germany has, for example, been an EU and world-leading proponent of renewable hydrogen for climate action. Its 2023-revised National Hydrogen Strategy has targeted industrial applications. Germany's System Development Strategy also plans for electricity and grid development to support a more robust renewable energy system capable of supporting energy-intensive industry, alongside households. A National Biomass Strategy is also currently in development. This could help establish a framework for continued feedstock availability, to aid the deeper decarbonisation of the cement fuel mix.[255]

Providing for the material needs of cement decarbonisation is a necessarily long-term challenge. Industry pathways to net zero are still evolving and more complicated than in sectors such as power generation. This ensures demands for infrastructure, workers, raw materials, and energy will evolve alongside. As well as meeting this ongoing challenge, European policymakers could pay more attention to revolving issues that preclude uptake of alternative building materials and practices. Attention to increasing the availability, and knowledge around lifecycle emissions, of timber and other bio-based materials could be beneficial in reducing cement demand, for example.

Advancing technological breakthroughs

Decarbonising cement depends on further technological breakthroughs. Development of alternative clinkers and cements, as well as electrification and renewables for kiln heat, are among the priorities. Development of new alternative building materials and practices could also be an asset on the demand reduction front.

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[252] European Commission, 'Trans-European Networks for Energy'.
[253] European Commission, 'Hydrogen Value Chain'.
[254] 'Open Letter of Support | Harnessing the Important Project of Common European Interest (IPCEI) Mechanism to Accelerate CCS Infrastructure in Europe'.
[255] BMWK, 'Lead Markets for Climate-Friendly Basic Materials'.

Horizon Europe is the EU's key instrument for R&D funding and promotion, including supporting commercial ventures that struggle to attract private finance. It aims to fight key global problems such as climate change, while enhancing EU social and economic resilience. Horizon Europe incorporates the European Innovation Council (EIC), which supports potential breakthrough technologies with high levels of potential to scale up but similarly high investment risk. Horizon Europe devotes 35% of its budget to climate solutions. The EUR 95.5 billion allocation for the 2021-27 period includes a dedicated Low-Carbon and Clean Industry program, which incorporates a cement focus.[256]

One promising Horizon Europe project, DETOCS – which brings together leading research institutes and industry – highlights the utility of continued investigation in currently non-commercial areas. It aims to use digital tools to predict and control the quality of cement and concrete blends using SCMs and anticipates helping to lower the EU's average clinker ratio from 0.7 to 0.4 by 2030 and 0.25 by 2050.[257] This would represent a considerable climate breakthrough, particularly if later applied globally.

Horizon Europe also issued a cement-noteworthy tender for proposals under the EIC Pathfinder program in 2024. This explores cement and concrete's carbon sink potential, by leveraging one or other of alternative binders, reduced clinker content and binder efficiency, energy and emissions reduction, or enabling technologies. The EIC noted conventional carbon capture technologies would add significant cost to cement, whereas novel carbon utilisation technologies would be cost-effective and potentially revenue-raising, offering negative emissions at scale.[258]

Germany has recognised the importance of also widely sharing knowledge derived from R&D. It operates several 'competence centres' in areas such as circular economy and resource efficiency. The work of the Competence Centre on Climate Change Mitigation in Energy-Intensive Industries (KEI) is most relevant to cement. As well as administering funding programs such as BIK, it serves as a platform for sharing knowledge among governments and research institutes, including through the Cluster Decarbonisation in Industries program.[259]

Germany's R&D-focused Future Building Program also supports development of sustainable building materials, as well as new calculation methods for assessing

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[256] European Commission, 'Horizon Europe - European Commission'.
[257] 'Data to Enable Transformation and Optimisation for Concrete Sustainability | DETOCS Project | Fact Sheet | HORIZON'.
[258] European Innovation Council, 'Pathfinder Challenge: Towards Cement and Concrete as a Carbon Sink'.
[259] Competence Centre on Climate Change Mitigation in Energy-Intensive Industries, 'Cluster Decarbonisation in Industries'.

sustainability performance in the built environment.[260] Helpfully, the program also addresses regulatory barriers to increased sustainability. Building industry standards can be a particular deterrent to uptake of disruptive, low emissions materials and practices.

Facilitating CCUS deployment

Europe leads on early-stage cement sector CCUS development. Deploying CCUS at sufficient scale faces considerable financial, technical, legislative, and social acceptability challenge. As this report has noted, it should also be a last resort option behind all viable options for elimination of emissions at source. Nonetheless, the EU and its member states have provided strong policy support to overcome sector challenges.

High carbon prices in the EU ETS – heading above EUR 100 per tonne during 2023 – have already been credited with improving the business case for CCUS. Cement producers have incentive to invest in means of avoiding future carbon price exposure.[261] The EU and member states such as Germany have also provided considerable additional financial and regulatory support to lowering various barriers to deployment.

The EU Industrial Carbon Management Strategy (ICMS) of February 2024 seeks to develop technologies and regulatory and investment frameworks for managing CO_2 from cement and other industry sectors. The EU anticipates storing at least 50 $MtCO_2$/year by 2030, 280 $MtCO_2$/year by 2040, and 450 $MtCO_2$/year by 2050. The ICMS responds to the national energy and climate plans of many EU member states having identified cement as a priority carbon management sector. The EU anticipates needing up to 7300 km of CCS transport infrastructure and up to EUR 12.2 billion investment by 2030, rising to 19,000 km and EUR 16 billion by 2040.[262]

EU programmes noted above have already supported CCUS-related outcomes. Horizon Europe, for example, allocated a combined EUR 28 million funding to Heidelberg Material's well-advanced Leilac-1 and Leilac-2 projects. [263] The Innovation Fund and CEF are other prominent CCUS supporters. The ICMS envisions an increased role for these and other mechanisms.[264]

EU policymakers have also committed to further CCUS-linked legislative and regulatory reform. This seeks to ensure CCUS operates with high capture efficiency, achieves

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[260] 'Research Projects'.
[261] Gerrits and Blanchard, 'CCS in Europe Regional Overview'.
[262] European Commission, 'Industrial Carbon Management Strategy'.
[263] Leilac, 'Leilac-2'; Leilac, 'Leilac-1'.
[264] European Commission, 'Industrial Carbon Management Strategy'.

durable long-term storage, and employs low emissions energy sources.[265] The EU Taxonomy for Sustainable Activities also provides CCUS guidance. To class as climate change mitigating, CCUS technologies must use low-carbon electricity (with initial but declining 100 gCO_2e/kWh lifecycle emissions) and satisfy transport and storage technical screening criteria.[266]

The German government is formulating its own Carbon Management Strategy (CMS). This applies to economy-wide applications, though with a strong industrial focus once more. Draft CMS guidance argues that production of carbon neutral cement without CCUS "will not be realistically attainable, even assuming ambitious use of the circular economy, recycling and alternative construction materials".[267]

The CMS's most tangible and, given the broader context, instructive pledge was to amend Germany's Carbon Storage Act (CSA). This would allow for long-term CO_2 storage, which is currently restricted in Germany due to historical opposition to coal power-related CCUS. Policymaker promotion of the specific need for CCUS to help decarbonise cement and other emissions-intensive sectors appeared critical to making progress on legislative reform. Had there been consistent support to this limited role, passage of the changes might have been achieved by now. But tensions around CSA reform extending CCUS application to fossil gas-fired power led to it stagnating under Germany's new ruling coalition in early 2025.[268]

Germany's CCfD program for energy-intensive industries also extends financial support to cement-linked CCUS. A principles document for the CMS recognised that EU carbon price was unlikely to fully offset the cost of cement with CCUS in the short-to-medium term and additional public investment was required. [269]

Enhancing multi-stakeholder cooperation

Decarbonising cement depends on coordinating a wide range of interests and actors, from raw materials providers to building designers and end-of-life operation, taking in various financial, regulatory, community, and other intermediaries along the way.

The interaction between EU green industrial strategies and other policy tools is a valuable model for enhancing cooperation among numerous stakeholders. The GDIP

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[265] Climate Bonds Initiative, 'Concrete Policies to Underpin the Cement Transition'.
[266] European Commission, 'EU Taxonomy for Sustainable Activities'.
[267] Federal Ministry for Economic Affairs and Climate Action, Federal Government of Germany, 'Key Principles of the Federal Government for a Carbon Management Strategy'.
[268] 'Failed Law Reform Means Germany Loses One Year in Efforts to Establish CCS – Cement Industry'.
[269] Federal Ministry for Economic Affairs and Climate Action, Federal Government of Germany, 'Key Principles of the Federal Government for a Carbon Management Strategy'.

establishes the strategic direction for solving major challenges and delineates the roles and responsibilities – including around resource allocation – of various actors and institutions from industry, government, and civil society. The NZIA establishes some of the regulatory framework for delivering on commitments. The IPCEI model provides the necessary convening and coordinating power.

Germany's Cluster Decarbonisation in Industries (CDI) programme also responds to the need for multi-stakeholder cooperation. It works in concert with four German research institutions and brings together more than 60 stakeholders. Participants identify innovation potential and promote development and implementation of solutions for decarbonising cement and other sectors.[270]

It is difficult to quantify the concrete impacts of these mechanisms. But they certainly respond to an acute challenge which, left unaddressed, threatens the speed and scale of transformation the cement sector must undergo to meet climate goals.

Enhancing cross-border cooperation

European governments are also engaged in global level initiatives to enhance cement-related climate action. Germany is most prominent among them. It is a member of the International Deep Decarbonization Initiative – a global coalition of public and private organisations working to stimulate demand for low carbon cement and other materials.[271]

Germany also formed and leads the Climate Club, which brings together international governments focused on industrial decarbonisation, particularly for steel and cement. The Climate Club aims to raise ambition and foster cooperation among more than 40 members, accelerate creation of green markets, and "make decarbonised industrial production the default business case". As well as inter-government exchange, it engages stakeholders and experts from academia, think tanks, civil society, and industry.[272]

The Climate Club incorporates the Global Matchmaking Platform, which connects emerging markets and developing economies with international technical and financial assistance and private finance instruments. The Climate Club's Partnership for Net Zero Industry provides technical assistance to developing countries.[273]

These are valuable instruments. It is an established principle of international climate action that advanced economies will decarbonise their economies first. But cement

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[270] Competence Centre on Climate Change Mitigation in Energy-Intensive Industries, 'Cluster Decarbonisation in Industries'.
[271] UNIDO, 'Industrial Deep Decarbonisation Initiative'.
[272] Federal Government of Germany, 'The Climate Club'.
[273] Federal Government of Germany.

demand growth is heavily concentrated in lower income countries. These need considerable external support to invest in new low emissions solutions, alongside other capacity building, to ensure alignment with global decarbonisation goals.

Policy recommendations to facilitate decarbonisation of China's cement sector

This chapter presents ways in which Chinese stakeholders might adapt their policy and regulatory responses to help decarbonise production of cement and its role in the broader economy. These recommendations are based on Chinese priorities and EU and German policy and regulatory experiences. Short-term priorities are those whose design and main implementation will be achieved by 2035; medium-term priorities have design and implementation schedules which stretch to 2045; longer-term priorities have schedules stretching to 2050, or ongoing to 2060 and beyond. Industry stakeholder actions taken in response to policies and regulations are not included in timelines. Table 10 summarises these recommendations and their main European reference cases.

Recommendations for decarbonising China's cement sector

Short-, medium-, and longer-term priorities, with reference to EU and German policies and regulations

Timeframe	Recommendation	Key European reference policy
Short-term	Optimise cement's ETS inclusion	EU ETS
	Ensure cement and building standards are fit-for-purpose	European standards, e.g. EN 197-1
	Improve alternative fuel availability and access	EU Landfill Directive, EU Waste Framework Directive (WFD); German Circular Economy Act
	Adopt innovative public funding mechanisms	EU Innovation Fund; German carbon contracts for difference for energy-intensive industry
	Improve industry access to green finance	EU Taxonomy for Sustainable Activities
Medium-term	Enhance national capacity for demand reduction	EU Circular Economy Action Plan, Construction Products and Ecodesign Regulations, WFD; German Circular Economy Strategy and Act,
	Create green lead markets through public procurement and labelling	German lead markets proposal for energy-intensive industries
	Ensure a smooth industry transition to a low demand, low emissions future	EU green industrial strategies, e.g. Green Deal Industrial Plan
Longer-term	Support continual technology breakthroughs through R&D	EU Horizon Europe
	Pursue limited CCUS development	EU Industrial Carbon Management Strategy; German Carbon Management Strategy
	Pursue cooperation on global cement decarbonisation	Germany's Climate Club and participation in Industrial Deep Decarbonization Initiative
	Build and maintain a supportive and integrated industrial ecosystem	EU green industrial strategies, Connecting Europe Facility, Important Projects of Common European Interest; German Cluster Decarbonisation in Industries program, national strategies for hydrogen, biomass, and power sector

Table 10. Recommendations for decarbonising China's cement sector

Short-term

Optimise cement's inclusion in ETS

Well-designed cement coverage by China's ETS could have a transformative emissions reduction effect. Carbon market design is an area in which the EU and Germany have considerable experience. The European ETS cement example shows the importance of ensuring that sector-specific regulations incentivise pursuit of deepest available decarbonisaiton. The EU has also used auctioning of emissions allowances as an important source of revenue for direct public investments in cleaner production.

Most European cement stakeholders appear concerned with reducing the threat of carbon leakage and general loss of competitiveness. Many Chinese cement stakeholders consulted in preparing this report expressed greater acceptance that considerable contraction in cement demand and associated supply will be a frontline driver of emissions reductions. This theoretically creates significant motivation to ensure that coverage of the cement sector in the Chinese ETS can drive deep emissions abatement.

Existing Chinese cement regulations set limits on energy use per unit of output and require the retirement of production capacity that exceeds these limits. This could have aggregate climate benefits, by reducing absolute emissions. Yet it might do little to further decrease the carbon intensity of Chinese cement. Chinese producers are already comparatively energy-efficient and, under current national cement standards, industry consolidation could see average clinker ratios and associated emissions intensity rise.

China's ongoing design and implementation of the regulations for cement's inclusion in the national ETS could adapt some generic benefits of the EU model, while addressing some of Europe's cement-specific shortcomings. Cement producers have not significantly contributed to economy-wide emissions abatement due to free allocation of emissions allowances. The phase-out of free allowances and phase-in of the CBAM regime will, however, start to drive more meaningful climate action later this decade.

The top-down approach of the EU ETS, with a progressively decreasing cap, provides a strong starting point for absolute emissions savings. China's ETS is currently designed to attract bottom-up carbon intensity improvements. This does not guarantee absolute emissions savings and might even create potential for best-performing operators to expand production. Eventual transition of the China ETS to a top-down cap and trade market, resembling the EU ETS, would be beneficial for emissions mitigation.

Using the European experience, China could seek to limit free allowances to cement producers from the start of their ETS inclusion. The EU example also highlights the importance of optimal product benchmarking. The ETS currently uses a clinker-based benchmark for assessing best-performing facilities. This again limits CO_2 pricing exposure, by confining ambition to an area in which there are few opportunities for deep decarbonisation at source. A clinker benchmark does incentivise CCUS development. Yet carbon markets should allow for technology neutral pursuit of lowest cost abatement options. Policies that limit CCUS overdependence are also valuable from the long-term, global perspective of meeting the Paris Agreement climate goals.

As in Europe, China's ETS would ideally adopt a cement rather than clinker-based benchmark for the sector. This would not impede efforts that significantly reduce emissions in clinker production, including alternative fuels, energy efficiency, or, in the longer term, CCUS. But it would also invite potentially far more significant – and, compared to CCUS, far less expensive and less complicated – options for at-source decarbonisation. This includes reduced clinker use via SCMs and pursuit of technological breakthroughs involving alternative binders and cements.

Exposing clinker production to cement-linked carbon pricing pressure could also accelerated demand reduction through rival building materials and practices. A cement-based benchmark would be additionally important in the context of China's traditionally low clinker ratio being likely to rise or remain static in future.

The EU example also shows how an ETS can be used to raise revenue to direct towards lowering cost and technical barriers to low emissions cement and cement alternatives. China could seek to emulate the European approach of auctioning emissions allowances to fund a body or process resembling the EU Innovation Fund, which has invested heavily in EU cement decarbonisation.

Ensure cement and building standards are fit-for-purpose

Industry standards governing patterns of cement production and consumption can also play a key role in the sector's emissions trajectory. The European example illustrates the importance of ensuring they are well-suited to the task of accelerating decarbonisation.

European cement and concrete standard have helped facilitate adoption of some emissions savings activities, such as alternative fuel co-processing. But they are prescriptive in nature, i.e. they set parameters around the physical characteristics of cement, including proportions of materials such as SCMs, water, and aggregates. This means they can limit uptake of disruptive technologies and practices. Performance-based standards target end results in areas such as strength and durability and allow for more variation in material use, subject to standardised testing regimes.

Benefitting from European experience and adopting more performance-based criteria in cement and building industry standards, such as the National Standard for General Silicate Cement, could be a major emissions breakthrough for China. Directly introducing more climate-conscious considerations into standards would be ideal. Removing criteria conducive to emissions-intensive outcomes, such as specification of higher-than-necessary clinker ratios in cement, and cement and concrete use in building projects, is also important.

Improve alternative fuel availability and access

Regarding the cement production process, increasing alternative fuel deployment is an area in which China has most room to make up on international peers. It is also one of the clearest areas where Europe, and Germany within it, leads. Greater alternative fuels adoption lacks deep decarbonisation potential. It could, however, be a relatively quick and cost-effective source of Chinese emissions reductions, while longer-term technological breakthroughs are pursued. It could have broader climate and sustainability benefits, by increasing circularity and reducing landfill emissions.

Commercial incentives played the decisive initial role in sparking European and German cement producers to switch to alternative fuels. This implies Chinese policymakers may need to pay more attention to removing the cost-competitiveness of coal, through stronger carbon pricing or changes to relevant energy subsidisation and taxation. Fiscal considerations do not appear to have played a major role in Europe's alternative fuel journey, though suggested reform of the EU Energy Taxation Directive, to incentivise fuel and electricity switching, could offer instruction to China in this respect.

The other major enabling factor in European alternative fuel deployment has been availability of sufficient supplies of suitable raw materials. This has been facilitated by circular economy-facilitating actions, such as restrictions on waste entering landfills and legislated ability of waste to be diverted to cement co-processing applications.

EU member states such as Germany have pursued these practices in accordance with, and often in advance of, requirements under the EU Landfill Directive and EU Waste Framework Directive (WFD). European adoption of principles such as 'polluter pays' and 'extended producer responsibility' have given extra momentum to the creation of value chains and supportive market structures. High levels of European public acceptance of co-processing – facilitated by strong industry dissemination of sustainability information – and accommodating cement product standards have also aided uptake.

Competition with other, better financially supported, users is the major concern facing China's cement sector on sourcing raw materials for co-processing. But a further enhanced diversion of waste streams from landfill could still give rise to surplus feedstocks in need of new markets. As with eroding coal's cost advantage, changes to fiscal regimes that favour cement producer access to affordable raw materials may also be required to replicate European conditions.

Chinese regulatory changes that allow co-processing to be treated as fuel replacement would also be beneficial and replicate European conditions under the WFD. China could potentially also benefit from greater industry attention – likely working in concert with government – on increasing public knowledge and acceptance of alternative fuels where they have clear climate benefits. Longer-term use of higher biofuel content will have the most direct emissions impacts.

Adopt innovative public funding mechanisms

Considerable new financial support will be required to help producers of cement – and potentially cement alternatives – meet new capital and operational expenditure needs. This is a universal challenge. European policymakers have responded with valuable support measures that could appeal to China's circumstances.

Chinese cement producers face declining profitability. Current regulation mostly focuses on reducing inefficient capacity, rather than directly helping industry decarbonise. Cement's inclusion in China's ETS could see market forces close the price gap between conventional cement and alternatives. But, as noted above, China could further increase ETS utility by adapting the European model of auctioning emissions allowances and using the proceeds to fund investment in low carbon solutions. The EU Innovation Fund's largest cement-specific support has gone to CCUS. But it has also channelled funding towards technologies for reducing emissions in the cement production process and demand-reducing alternative materials. China could use additional public investment in all these areas.

Germany's carbon contracts for differences (CCfD) model for energy-intensive industries could also serve as reference for China. CCfDs aim to build on EU ETS and Innovation Fund impacts, by requiring greater emissions abatement from successful recipients. The CCfD model also limits unproductive spending, by requiring industry to return public funds if changes in carbon pricing relative to production costs render low emissions output more competitive. China could similarly gain from supporting industry in ways that incentivise high ambition, while reducing public risk.

Improve industry access to green finance

Producers of low emissions cement and alternatives could also need increased traditional finance. The Guidance on Further Strengthening Financial Support for Green and Low-Carbon Development of March 2024 suggested more support from financial institutions to low emissions Chinese production may be forthcoming, though there is a lack of clarity as to the nature and level of assistance this might provide. China has seen significant growth in green finance markets in recent years, though less progress in 'transitional' finance for highly emitting industries, such as cement.

European frameworks for channelling finance to cement decarbonisation are also relatively underdeveloped. The EU Taxonomy for Sustainable Activities is, however, a promising tool for addressing this deficit. Its technical screening criteria for cement incentivises relatively high abatement ambition. Its success may, however, depend on broader transformational change, including higher cement carbon pricing. The EU Taxonomy could be improved by stronger TSR in its building sector coverage. Successful sustainable finance raising also depends on industry developing credible and well-communicated transition plans. China could implement an ambitious sustainable finance taxonomy for cement, and work with industry members and investors to develop and promote credible industry transition pathways aligned with this.

Medium-term

Enhance national capacity for cement demand reduction
China's world-leading cement demand is already falling and existing regulations are likely to lead to a significant reduction in production capacity. This will help move supply and demand closer towards equilibrium. Yet meeting China's and the world's climate goals will require significant additional demand reduction, beginning now and reaching in to mid-century.

China's structural adjustment to a less cement-intensive economy in aggregate would ideally be accompanied by cement's share of building and construction activity significantly falling. This is particularly important due to China's average clinker ratio's expected flatlining or increase. This could lead to a corresponding rise in carbon intensity that will offset some climate benefits of falling demand.

China could avoid significant cement use through measures such as optimised concrete production, extending average building lives, using cement alternatives, and recycling concrete and construction waste. European economies are already far less cement-intensive than China. This partly results from differences in stages of development, other demographic and consumer characteristics, and alternative materials availability. But European governments, led by Germany, have also played an important role in constraining cement demand relative to where it could be.

In future, China could consider increased promotion of and compliance with principles and targets such as those established under the EU Circular Economy Action Plan and German Circular Economy Strategy, and their related legislation. As part of these efforts, China could adopt a clearly communicated waste hierarchy resembling that in the EU Waste Framework Directive and German Circular Economy Act and ensure strong compliance with this. This could also benefit its alternative fuel pursuits and potentially provide alternative materials and SCMs to reduce clinker content.

China could also go further than Europe, by mandating lifecycle emissions assessments and disclosures for cement and alternative building materials and practices. The EU continues to exempt cement from these requirements under its Construction Products and Ecodesign for Sustainable Products Regulations. The greater demand reduction imperative suggests their introduction could be beneficial in the China context.

Create green lead markets through public procurement and labelling

Lack of demand for low emissions cement is another universal concern. China has signposted growing interest in deploying green public procurement (GPP) in the building materials sector. It is not clear how much this process has advanced or will in future. Yet China's application of GPP to cement could be a powerful force for change. It should ideally be accompanied by a clear and ambitious definition and labelling regime for what constitutes low emissions cement and other building materials.

GPP is not well-developed at the EU level, though new mandatory commitments are forthcoming. Germany, however, has made a strong statement of near-term intent with its green lead market proposal for cement and other low emissions goods, developed through 2024. Germany has promised to introduce new mandatory GPP requirements – ideally at the EU level – and has already settled on a tiered classification system for identifying low emissions cement, which has been taken up by industry.

China could investigate the suitability of directly applying the German cement classification system to its own GPP processes. The tiered system is valuable, in that it allows for both achievable and ambitious outcomes. Global standardisation of product definitions and labelling between China, Europe, and elsewhere would be ideal for global climate action and potentially advanced by this outcome. China might also consider regulating application of a shadow carbon price in major procurement decisions, in line with the system Germany applies under the AVV Klima regulation.

Ensure a smooth industry transition to a low demand, low emissions future

Government policies and regulations must also consider the needs of workers and communities affected by industrial transitions. Europe's cement circumstances are vastly different to China's. European policies such as CBAM seek to protect cement-linked economic and employment opportunities while meeting climate goals. China's cement sector, by contrast, faces little external competition, and industry stakeholders are mostly seeking to adapt to a sharp contraction in demand and subsequent supply.

Structural change in China's cement sector will bring significant economic and social dislocation. This process could also have more complicated impacts on climate than is initially apparent. Falling production will lower absolute emissions. Industry consolidation could aid technology and knowledge diffusion and cost reductions. But it will also reduce industry profitability and some appetite for emissions reduction. Complex interactions with clinker ratios have also already been noted.

China could see value in outlining key goals, roles and responsibilities, and resource and regulatory responses to advance climate action in the cement sector in conjunction with transitioning industry members. This could include consideration of specific EU actions, such as Green Deal Industrial Plan/Net Zero Industry Act-aligned net zero worker training academies and approvals reform for expediting new industrial opportunities. Many Chinese cement workers and communities could adapt to a low emission production future. A well-resourced and coordinated strategic approach could explore further transition opportunities, including in alternative building material sectors.

Longer-term

Support continual technology breakthroughs through R&D

Aligning the cement sector with climate goals requires continued technological progress. China has achieved world-leading performance in energy efficiency and has considerable room to improve in alternative fuels. But there is not potential for deep decarbonisation in either route. Most Chinese cement industry attention on technological breakthroughs focuses on CCUS. However, progress in areas such as renewably generated kiln heat or alternative binders – as well as options for more climate-friendly alternative building materials and practices – could usher in lower cost elimination of emissions at source.

The EU's Horizon Europe program has committed valuable resources to investigating options for deep decarbonisation. This includes funding projects looking to dramatically decrease clinker ratios and enhancing cement and concrete's carbon sink potential.

Cement-linked R&D programs in China could greatly advance breakthrough technology development. Outcomes that could help China considerably reduce its clinker ratios and develop low emission building material alternatives suited to its needs are logical priorities. China could potentially also replicate its leadership in development and deployment of renewables and electrification technologies in power and transportation, by advancing low to zero emissions kiln heating options. The greatest achievement would be significant advancement of alternative binders and carbon negative cements.

Foster limited CCUS development

CCUS is a leading priority for cement sector decarbonisation in China and elsewhere. Yet realising its indicated potential would mean overcoming significant cost, technical, and regulatory challenges, including around transportation and storage. CCUS overdependence also poses long-term risks to achieving the Paris Agreement climate goal. While Europe is yet to boast an operational cement-linked CCUS project, it has the most in development. The rollout of CCUS in the continent has been aided by a highly supportive policy ecosystem.

The EU and Germany have both formed dedicated CCUS strategies. These establish key targets and policy and financing commitments. Facilitating CCUS has also been a focus of many policy instruments outlined in this report. Most notably, the EU Innovation Fund has provided considerable public investment and the Connecting Europe Facility has aided coordination and financing of cross-border infrastructure. Policymakers are also seeking to amend necessary legislation and regulations. This process has not been without challenges. Germany's overhaul of its CO_2 storage legislation has stalled due to concerns it would sustain fossil power generation, in addition to aiding industrial decarbonisation.

China's cement-linked CCUS rollout has not attracted considerable policy support thus far. Existing challenges with balancing industry contraction with commitments to decarbonisation – and the caveats around CCUS noted in this report – suggest it is better placed focusing on lower cost, lower risk solutions in the short term. Broad Chinese industry consensus on the long-term importance of CCUS does, however, invite some targeted support for limited future deployment, including management of regulatory and infrastructure concerns.

Pursue cooperation on global cement decarbonisation

Decarbonisation of China's cement sector is a national and global priority. But it will still be insufficient to ensure global level cement alignment with climate goals. Emerging market and developing economies are poised to be new centres of demand growth. International support could help them avoid an unnecessarily high emissions pathway.

Germany has taken a particular lead in Europe on promoting international cooperation on cement and broader industrial decarbonisation. It participates in the International Deep Decarbonization Initiative (IDDI), a global public-private coalition that works to stimulate demand for cement and other low carbon materials. Germany has also formed and leads the Climate Club, which has similar aims to the IDDI, but focuses more on developing and emerging market economies.

China will logically prioritise its own cement sector decarbonisation. Yet its established sector leadership, and its ongoing decarbonisation journey, provide valuable authority and knowledge that it could progressively leverage in the international sphere.

Build and maintain a supportive and integrated industrial ecosystem

Chinese cement producers will also require considerable and continuous support to meet their needs for infrastructure, workers, energy, and raw materials for decarbonisation. They must also overcome structural barriers, such as low centralisation and integration with other economic sectors, which hamper efforts to share assets and effectively disseminate technologies and knowledge, including on demand reduction.

European support on solving these challenges is comparatively well-advanced. Circular economy and waste management regulations have provided alternative fuel access and future capacity for cement and concrete recycling. Individual EU regulations, such as the Renewable Energy Directive, mandate the uptake of key inputs to clean industrial production and provide regulatory support to overcoming barriers. Green industrial strategies closely assess opportunities and challenges in decarbonising sectors and outline and help instigate appropriate responses to them.

Mechanisms such as the Connecting Europe Facility, Trans-European Networks for Energy, and Important Projects of Common European Interest (IPCEI) also help mobilise and coordinate various resources and stakeholders in pursuit of common goals. These EU processes have taken a particular interest in CCUS development in recent years. National-level support, such as Germany's strategies and regulations on circular economy, hydrogen, biomass, renewable power, and CCUS, complement EU efforts.

China might benefit from creating a decarbonisation-ready industrial ecosystem for cement. Priorities identified by Chinese stakeholders range from the short-term provision of alternative fuel feedstocks to long-term development of CO_2 transportation and storage infrastructure. Requirements for renewable energy and decarbonised alternatives to traditional clinker will also grow in line with technological breakthroughs and exhaustion of materials such as fossil SCMs. New and existing workers may also need training to adapt to new technologies and processes.

European approaches and mechanisms are also relevant to China's challenges around low industry centralisation and integration. The IPCEI provides a good model for enhancing multi-stakeholder cooperation on key challenges. Germany's Cluster Decarbonisation in Industries program also brings together actors from industry, government, and R&D, to advance knowledge and technology transfer.

Appendix I: Cement net zero roadmaps

IEA NZE scenario cement milestones (global level)

Milestones	Current (2022)	2030	2035	2050
Cement production (Mt)	4160	4260	4140	3930
Clinker-to-cement ratio (tonne per tonne)	0.71	0.65	0.61	0.57
Kiln thermal energy intensity (GJ per tonne of clinker)	3.6	3.4	3.3	2.9
Share of near zero emissions clinker production	0%	8%	27%	93%
CO2 captured (Mt CO2)	0	170	480	1310
Share of low emissions fuel in thermal energy use, of which:	5%	30%	49%	86%
• Bioenergy without CCUS	5%	15%	17%	19%
• Bioenergy with CCUS	0%	2%	8%	19%
• Fossil fuels and non-renewable waste with CCUS	0%	10%	22%	31%
• Hydrogen	0%	1%	3%	9%
• Electricity	0%	0%	0%	8%

Table 11. IEA NZE Scenario cement milestones (global level)

[274] IEA, 'Net Zero Roadmap'.
[275] IEA.

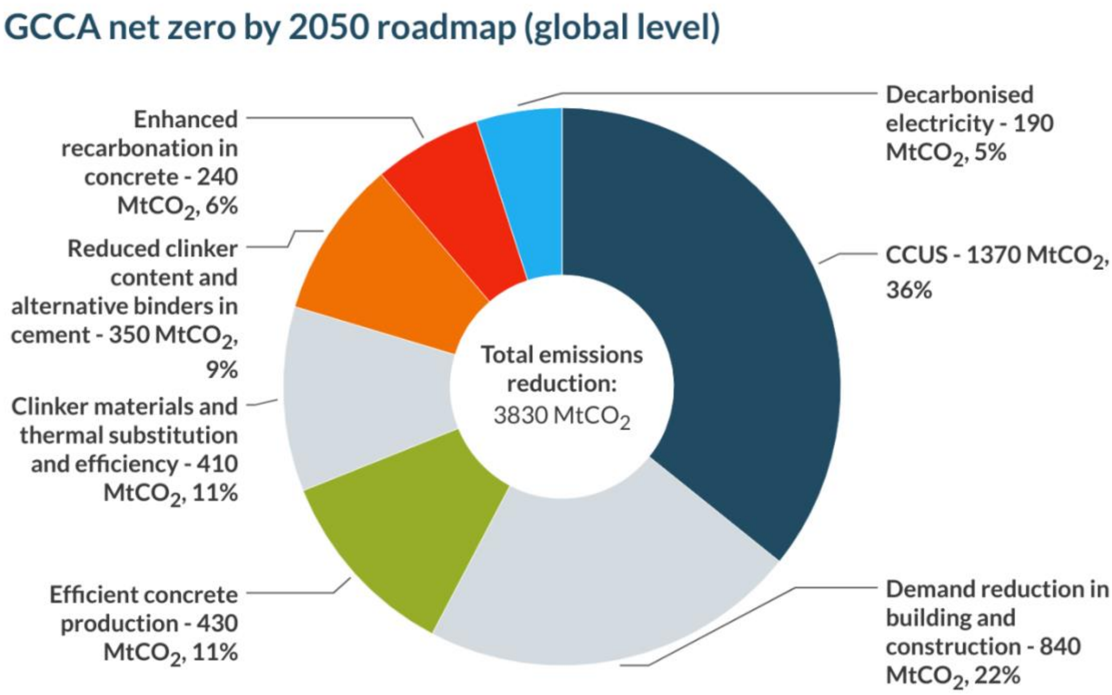


Figure 16. GCCA net zero by 2050 roadmap (global level)

[276] Global Cement and Concrete Association, 'Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete'.

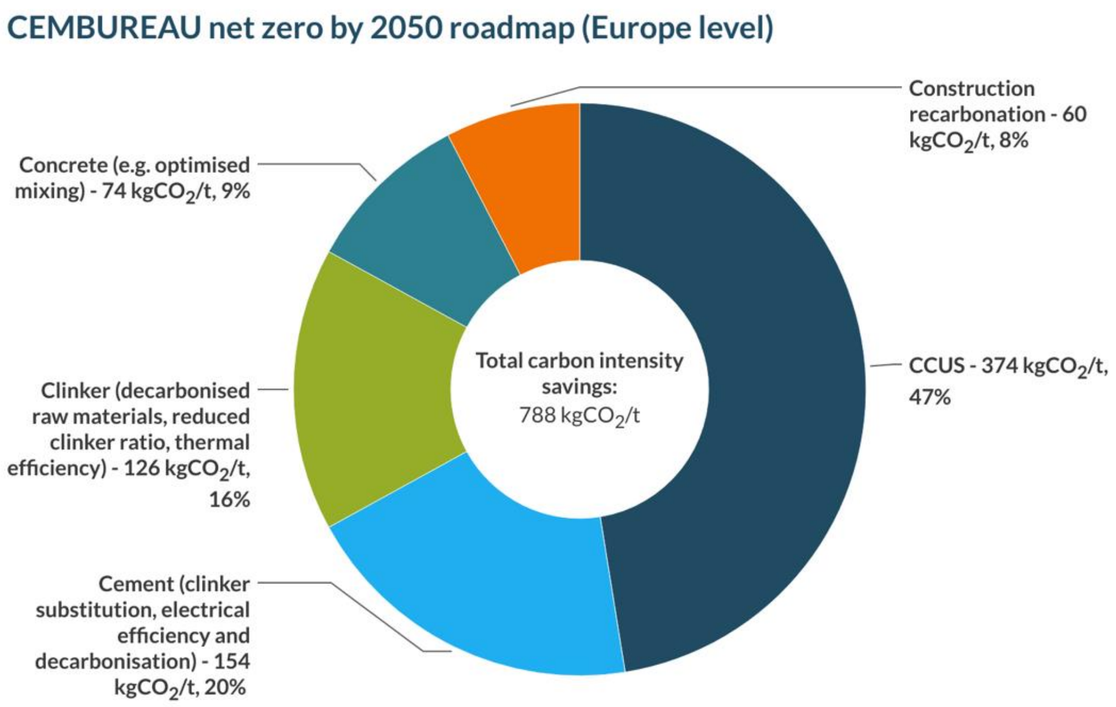
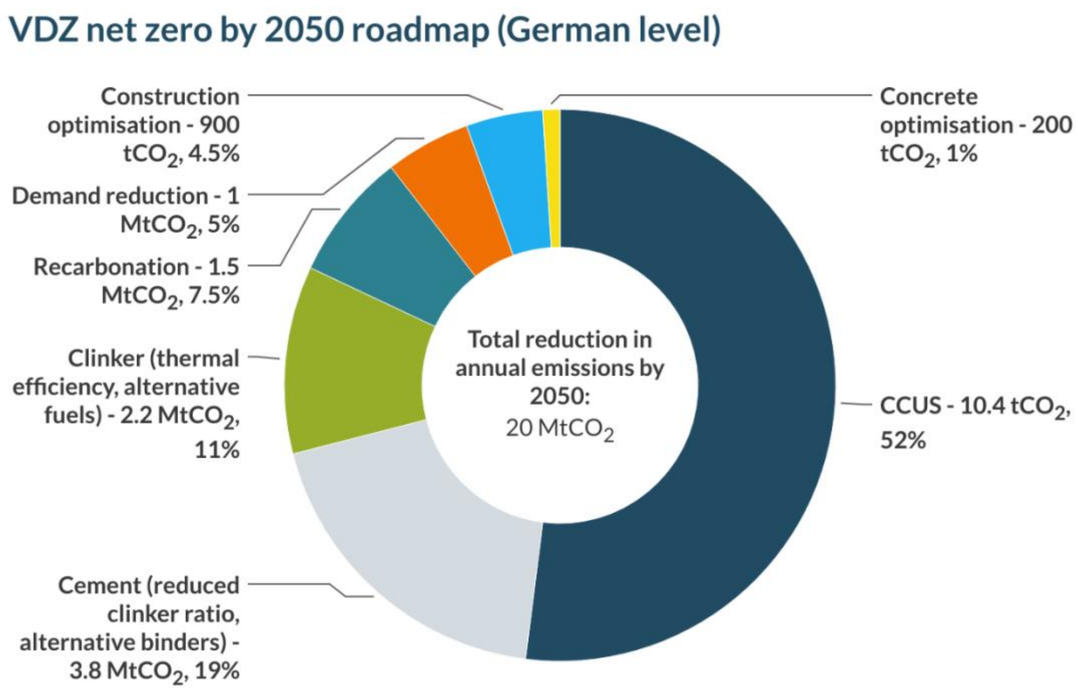


Figure 17. CEMBUREAU net zero by 2050 roadmap (Europe level)



[277] CEMBUREAU, 'CEMBUREAU's Net Zero Roadmap'.

Figure 18. VDZ net zero by 2050 roadmap (German level)

[278] VDZ, 'Decarbonising Cement and Concrete'.

APPENDIX II:

Chinese stakeholder insights on cement sector decarbonisation priorities, challenges, and opportunities

There is broad industry acceptance that cement demand is in decline. The main priority is to adapt to this reality with the least disruption. There is a short-term need to manage the retirement and replacement of assets, to avoid adding to already significant excess capacity. There is a longer-term need to adapt business models to a less cement-intensive future
Some, mainly larger producers, will be able to manage the changes relatively well, but many smaller operators will struggle and are likely to exit the sector
Lowering the carbon intensity of cement production must be achieved simultaneous to managing industry contraction
Many producers and stakeholders support efforts to enhance demand reduction beyond naturally anticipated rates
On lowering cement's carbon intensity, there is most industry support for improving alternative fuel deployment. The primary barrier to this is not a lack of will or the cost advantages of coal, but barriers to accessing affordable raw materials
There is widespread industry support for increased CCUS deployment. The main identified priorities are lowering costs of deployment and developing shared infrastructure, supportive regulations, and utilisation business cases
The potential for further breakthroughs in proven mitigation routes, primarily energy efficiency, are diminishing
Dramatic breakthroughs in areas such as alternative binders and cements and electrification/renewable-powered kilns are not anticipated in the medium-term
Current industry standards create challenges around lowering clinker ratios
Cost is the overriding challenge for sector mitigation, particularly as many companies are already struggling with diminished profitability due to falling demand
Poor access to public and private financial support exacerbates cost challenges
Poor integration between the Chinese cement sector and sectors such as building and construction creates decarbonisation barriers, particularly for demand reduction
Cement's incorporation into China's ETS presents the biggest policy opportunity for emissions mitigation

Table 12. Chinese stakeholder insights on cement sector decarbonisation priorities, challenges, and opportunities

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