



The Cement Industry & Green Public Procurement

June 2026





Text

Stavros Gennitsaris, Industrial Policy Associate, The Green Tank
Nikos Mantzaris, Partner & Lead Policy Analyst, The Green Tank

Cite as:

The Green Tank (2026) “The Cement Industry & Green Public Procurement”
Copyright © The Green Tank, 2026

Layout design:

Design Nature

Contact Details:

📍 50, Vas. Sofias Avenue, 115 28 Athens
☎ 210 7233384
🌐 thegreentank.gr
✉ info@thegreentank.gr

Executive Summary

The cement industry constitutes a major source of greenhouse gas emissions, accounting for approximately 5-8% of global anthropogenic emissions; **if this sector were a country, it would rank third among global polluters.** Thus, the cement industry must deliver a significant reduction in emissions, as its contribution is vital to achieving the EU-27's climate targets for 2030 (at least 55% reduction in net emissions compared to 1990) and 2050 (climate neutrality).

Approximately 40% of the sector's emissions are related to the combustion of fossil fuels to produce the heat required for clinker manufacturing. In principle, these emissions can be significantly reduced by replacing fossil fuels with cleaner fuels or through energy efficiency improvement measures. However, the remaining 60% of emissions stem intrinsically from the calcination process and cannot be reduced through fuel substitution, thereby rendering the sector "hard to abate."

In recent years, carbon capture, utilization, and storage (CCUS) technologies have been promoted as the cornerstone of decarbonizing the cement industry. Nonetheless, these technologies are accompanied by increased energy consumption, high investment and operating costs, and complex technical and economic challenges that can significantly constrain their effectiveness. Moreover, their widespread deployment -even for emissions resulting from heat production processes- carries a risk: it may eliminate the incentive to implement alternative solutions that reduce emissions at the source, thereby ultimately delaying the industry's decarbonization process. Consequently, the application of CCUS technologies should be limited to emissions that cannot be reduced by other means. **Both energy efficiency improvements and Waste Heat Recovery** constitute mature, readily available, and economically viable solutions. Furthermore, in the medium term, the **use of green hydrogen as a fuel and the electrification** of the clinker production process can play a pivotal role in significantly reducing the sector's carbon footprint; however, implementing these types of investments requires significant resources.

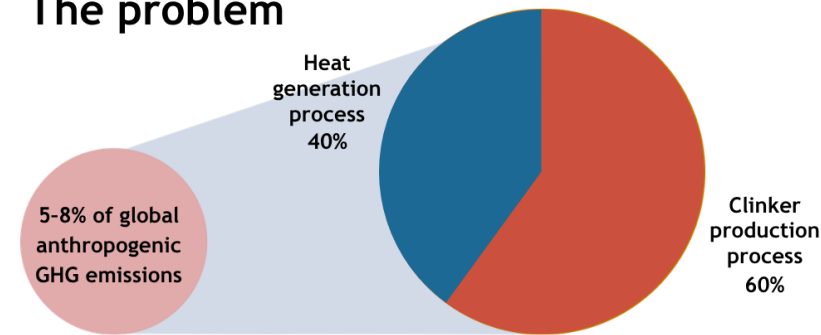
Public sector entities are among the primary purchasers of cement both in Greece and worldwide. In this context, **Green Public Procurement (GPP) can serve as a key instrument for the development of these technologies, by creating demand for low-carbon cement products.** However, Greece's current National Action Plan for GPP is limited to non-binding quantitative targets and does not provide sufficient incentives for the adoption and advancement of decarbonization technologies.

This policy paper recommends strengthening the National Action Plan through targeted measures; the latter aim to ensure the reliable measurement and certification of cement products' carbon footprint; the gradual incorporation of mandatory environmental criteria into public procurement; and the creation of incentives to support clean technologies for both cement producers and contracting authorities. Specific measures include the following:

1. **The development of a national certification framework for cement products** that meet specific environmental and energy criteria, to be integrated into public procurement and aligned with established European standards and eco-labels.
2. **The mandatory provision of an environmental product declaration for cement, to be introduced gradually.** Initially, it is recommended that at least 40% of public contracts regarding cement or concrete require that producers provide environmental footprint data, as a transitional step toward the development of reliable measurement systems. **In a subsequent phase, the submission of an environmental product declaration shall become mandatory** for participation in public tenders for the supply of cement.
3. **The gradual implementation of stricter CO₂ emission thresholds** for cement used in public works, aiming to incentivize investments for the decarbonization of the sector.
4. **The implementation of an evaluation system in public procurement that prioritizes cement products that exceed minimum environmental standards** and utilize less mature technologies, with the aim of decarbonizing the clinker production process.
5. **The establishment of a financial incentive mechanism for cement producers achieving lower CO₂ emission levels** relative to the industry; the awarded funds shall be used exclusively for existing or future investments in less mature decarbonization technologies applicable to the cement industry.
6. **The provision of additional funding or increased budgets to contracting authorities** exceeding national targets for the implementation of green public procurement.

Finally, it is recommended that **Greece join the Industrial Deep Decarbonization Initiative (IDDI)**, with the aim of strengthening the country's role in shaping decarbonization policies at a global level.

The problem



Institutional framework

- Legally binding targets under European and national climate law
- Increase in CO₂ emission costs due to the gradual phase-out of free allowances for industry in the EU ETS between 2026-2034

CCUS technologies are not a panacea

- An option for emissions that cannot be reduced by other means
- Diversion of financial resources from other decarbonization solutions
- High cost as well as technical challenges

Alternative options

- Energy efficiency improvements
- Waste heat recovery
- Alternative fuels
- Use of green hydrogen
- Electrification

Policy Measures

1. National certification system for cement products

- Integration into public procurement
- Alignment with European standards & ecolabels

2. Mandatory data provision targets

- Phase 1: 40% of public contracts involving cement
- Phase 2: Mandatory Environmental Product Declaration (EPD) for participation in public procurement

3. Mandatory environmental criteria

- Gradual implementation of stricter CO₂ emission limits for cement in public procurement

4. Incentivization of less mature technologies

- Notional reduction in the evaluation price of the financial tender for cement products produced using less mature technologies

5. Incentives for green cement producers

- Financial incentives to support investments in innovative decarbonization technologies
- Linking financial incentives to the CO₂ price in the EU ETS

6. Incentives for green contracting authorities

- Additional funding exclusively for projects that comply with environmental criteria

Participation of Greece to the Industrial Deep Decarbonization Initiative (IDDI)

- Provision of incentives for investments and the creation of green cement markets
- Strengthening the country's role in shaping global heavy industry decarbonization policies

Contents

INTRODUCTION	8
CARBON CAPTURE, UTILIZATION, AND STORAGE TECHNOLOGIES (CCUS)	10
ALTERNATIVE TECHNOLOGIES AIMED AT REDUCING EMISSIONS IN THE CEMENT INDUSTRY	12
Energy efficiency improvements	13
Waste Heat Recovery for Electricity Production	15
Replacement of fossil fuels with alternative fuels	17
Use of hydrogen as fuel.....	19
Electrification of the clinker production process.....	22
INCORPORATION OF MEASURES FOR THE DECARBONIZATION OF THE CEMENT INDUSTRY INTO THE GREEK ACTION PLAN FOR GREEN PUBLIC PROCUREMENT	26
International and European Policies on Green Public Procurement.....	26
National Action Plan for Green Public Procurement	29
Recommended Policy Measures for Greece’s GPP National Action Plan.....	30
Development of a national certification system for cement products.....	30
Gradual introduction of a requirement to submit an Environmental Product Declaration (EPD) for participation in cement-related public procurement	31
Gradual introduction of mandatory environmental criteria in public procurement in the cement sector.....	31
Establishment of a green cement incentive scheme aimed at advancing technologies with high emission reduction potential	33
Provision of financial incentives to cement producers achieving high environmental performance.....	34
Provision of financial support to contracting authorities achieving higher levels of green public procurement	34
CONCLUSIONS	35

Introduction

Second only to water in global use, cement underpins urbanization, infrastructure development, and large-scale construction, thereby constituting a key pillar of the economy¹. Nevertheless, cement production is among the most energy-intensive and highly polluting industrial sectors globally², estimated to account for approximately 5-8% of total global anthropogenic greenhouse gas (GHG) emissions². Considering that the sector's total global carbon dioxide (CO₂) emissions amounted to approximately 2.9 Gt in 2021, if the cement industry were a country, it would rank third among the world's polluters³.

On the other hand, the climate crisis highlights the urgency of reducing greenhouse gas emissions in the cement industry. In particular, the European Union (EU) has adopted a coherent climate policy framework, aimed at achieving climate neutrality by 2050, as reflected in the European Green Deal strategy⁴ and the European Climate Law⁵. In this context, the interim target for 2030 foresees a reduction of net greenhouse gas emissions in the EU-27 by at least 55% compared to 1990 levels, prompting the adoption of the "Fit for 55" legislative package⁶. With regard to Greece, the national climate law includes legally binding targets to reduce net anthropogenic GHG emissions by at least 55% by 2030 and 80% by 2040, compared to 1990 levels⁷. The Emissions Trading System (ETS), a cornerstone of European climate policy, stipulates that the free allowances under the ETS for industry as a whole will be gradually eliminated between 2026 and 2034⁸. However, as ETS mechanisms progressively increase the cost of CO₂ emissions and free allowances are phased out, industries are exposed to these additional costs; as a result, strong economic incentives arise for investment in low-emission cement production technologies⁹. At the same time, growing social and market pressures are acting as a catalyst, creating stronger demand for sustainable building materials¹⁰. In addition, sustainability criteria are increasingly being integrated into both public and private procurement frameworks, thereby promoting the adoption of green solutions.

¹Gagg, C. R., Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis*, vol. 40, p. 114-140 (May 2014): <https://shorturl.at/Qkwe3>

²World Economic Forum, LOW-CARBON CONCRETE AND CONSTRUCTION: A REVIEW OF GREEN PUBLIC PROCUREMENT PROGRAMMES, (June 2022): <https://shorturl.at/gVpVK>

³Nehdi M. L., Marani A. & Zhang L., Is net-zero feasible: Systematic review of cement and concrete decarbonization technologies. *Renewable and Sustainable Energy Reviews*, vol. 191, p. 114169 (March 2024): <https://shorturl.at/cWB96>

⁴European Commission, The European Green Deal, (December 2019): <https://shorturl.at/MF1DX>

⁵Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ("European Climate Law"): <https://shorturl.at/pRcqQ>

⁶European Council - Council of the EU, Fit for 55 Package: <https://shorturl.at/oE580>

⁷Law no. 4936/2022: National Climate Law - Transition to climate neutrality and adaptation to climate change, urgent provisions to address the energy crisis and protect the environment - GG 105/A/May 27 (May 2022): <https://shorturl.at/QYnh2>

⁸European Council - Council of the EU, Fit for 55: Reform of the EU Emissions Trading System: <https://shorturl.at/eruvf>

⁹The Green Tank, Trends in the Emissions Trading System in the EU-27 and Greece 2005-2024, (July 2025): <https://shorturl.at/b7kLn>

¹⁰Firoozi A.A., Oyejobi D. O., Avudaiappan S. & Saavedra Flores E., Emerging trends in sustainable building materials: Technological innovations, enhanced performance, and future directions. *Results in Engineering*, vol. 2, p. 103521 (December 2024): <https://shorturl.at/MS956>

In response to this new reality, in May 2020, the European Cement Association (Cement Europe) announced the industry's commitment to reach net-zero emissions along the cement and concrete value chain by 2050¹¹. Achieving this goal, however, presents significant challenges. More specifically, the production of clinker -namely, the primary component of cement that is responsible for its binding and structural properties- requires the calcination of limestone (CaCO_3) at 1450°C. This process constitutes the main source of CO₂ emissions in the cement industry, accounting for approximately 60% of the sector's emissions¹². Nearly all remaining emissions (40%) are energy-related, resulting from fossil fuels being combusted to achieve the required high operating temperatures. Overall, the global average emission intensity of ordinary Portland cement production is estimated at approximately 673 kg of CO₂ per ton of cement¹³, while the cement industry's average electricity consumption amounts to approximately 100 kWh per ton of cement produced¹⁴. With regard to the Greek cement industry, in 2023, the clinker production process emitted 808 kg of CO₂ per ton of clinker¹⁵. While energy emissions can be reduced through fuel substitution and higher energy efficiency¹⁶, the emissions associated with the calcination of limestone are inherent to the chemical reaction of its decomposition; thus, the cement industry is undeniably among the most challenging sectors to decarbonize².

Significant technological solutions are available to the cement industry, in order for the latter to decarbonize its processes and achieve a net-zero carbon footprint by 2050. More specifically, Carbon Capture, Utilization, and Storage (CCUS) technologies have the potential to reduce CO₂ emissions from the cement production process¹⁷, and particularly those resulting from limestone calcination. However, the widespread employment of CCUS technologies, even for emissions resulting from heat production processes, carries the risk of eliminating the incentive to implement alternative solutions that reduce emissions at the source. Specifically, the continuous improvement and optimization of industrial processes' energy efficiency; the recovery of waste heat; the replacement of fossil fuels with alternative fuels; the use of green hydrogen as a fuel; and the electrification of energy-intensive processes are all viable and realistic alternatives for reducing the carbon footprint of thermal energy production.

¹¹ European Cement Association (CEMBUREAU), From Ambition to Deployment - our 2050 roadmap: The road travelled, pathways and levers to scale up our net zero ambition (2024): <https://shorturl.at/6FzVD>

¹² Andrew, R. M., Global CO₂ emissions from cement production. Earth System Science Data, vol. 10, is. 1, p. 195-217 (January 2018): <https://shorturl.at/OPoMs>

¹³ International Renewable Energy Agency, Decarbonising hard-to-abate sectors with renewables: Enablers and recommendations (2025): <https://shorturl.at/vGPol>

¹⁴ World Bank, Cement Sector: Energy Efficiency and Decarbonization (EE&D) Opportunities. Pakistan Sustainable Energy Series (August 2025): <https://shorturl.at/Di74i>

¹⁵ The data on clinker quantities were obtained from the UNFCCC annual emissions inventory report for Greece. The latest available report was published in April 2025 and includes data up to and including 2023. Data on CO₂ emissions were obtained from the EU Emissions Register.

¹⁶ International Energy Agency, Technology Roadmap: Low-Carbon Transition in the Cement Industry, (April 2018): <https://shorturl.at/FWN4P>

¹⁷ Intergovernmental Panel on Climate Change (IPCC), Section 4: Near-Term Responses in a Changing Climate. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2023): <https://shorturl.at/wzOef>

Nonetheless, the development and implementation of these technologies require significant investments for the retrofit of existing production facilities or the construction of new ones. Public entities represent the cement market's primary consumers, accounting for approximately 30-40% in the United States and Europe, respectively^{2,18}. Consequently, the State can play a catalytic role in enhancing, promoting, and implementing these technologies and ensuring the cement industry's smooth adaptation to climate policy requirements by leveraging Green Public Procurement (GPP).

In this context, this report initially describes the key technologies that can contribute to reducing GHG emissions from cement production processes, and particularly those related to thermal energy production, providing data on their technological maturity and costs. Acknowledging the GPP's role in promoting and supporting these technologies, the subsequent section reviews international and European policies that promote GPP as a distinctive tool within a broader strategy to decarbonize industry. The report concludes with recommendations on policies and measures that could be incorporated into the Greek Action Plan for Green Public Procurement, so as to promote and finance investments in the aforementioned technologies.

Carbon Capture, Utilization, and Storage Technologies (CCUS)

Acknowledging that a significant share of total CO₂ emissions from cement production is linked to the decomposition of calcium carbonate into calcium oxide in kilns (namely, to the clinker production process itself), as of 2009, the International Energy Agency has been recommending CCUS technologies as the most suitable solutions for reducing calcination emissions in the cement industry¹⁹. Considering that the latter accounts for a large part of the sector's total emissions, CCUS technologies are expected to play a decisive role in achieving the commitment adopted by Cement Europe in 2020, namely, to achieve net-zero emissions across the cement and concrete value chain by 2050. As projected, the implementation of CCUS technologies will have a significant positive impact even in the short term. Specifically, Cement Europe's climate neutrality roadmap estimates that, by 2030, these technologies could reduce CO₂ emissions by approximately 83 kg CO₂/ton of cement, which represents 28% of the sector's total emissions reduction to be achieved via all measures²⁰. CCUS contribution is estimated to approach a share of 47.5% or 300 kg CO₂/ton of cement by 2040 and 46.5% or 374 kg CO₂/ton of cement by the 2050 climate neutrality target¹¹.

However, the installation of CCUS systems significantly increases energy consumption at plant level (by 50-300%) due to consumables manufacturing, solvent pumping, the operation of high-efficiency separation devices, and the purification and compression of CO₂ so as to

¹⁸ NRDC, A design guide to state and local low-carbon concrete procurement (April 2022): <https://shorturl.at/DEqF9>

¹⁹ International Energy Agency (IEA), Cement Technology Roadmap: Carbon Emissions Reductions up to 2050 (October 2009): <https://shorturl.at/GF6cB>

²⁰ The European Cement Association aims to reduce emissions across the cement value chain from 804 kg CO₂/ton of cement in 1990 to 507 kg CO₂/ton of cement by 2030

meet downstream process specifications²¹. Furthermore, CCUS projects require high initial investments in the range of several hundred million euros for a cement plant, while their operating costs are substantial due to these installations' particularly high energy requirements¹³. Specifically, capturing approximately 90% of a cement kiln's CO₂ emissions can increase the plant's total energy consumption by approximately 25-40%. As a result, the implementation of CCS technologies may double or even triple clinker production costs²².

Despite their high financial requirements, CCUS technologies have been progressively considered economically viable in recent years due to the rise in carbon dioxide costs and the phasing out of free emission allowances by 2034, in accordance with the revised Directive 2023/ 959/EU on the Emissions Trading System (ETS) operation. The attractiveness of these investments has been further enhanced by the increase in available resources from the EU's Innovation Fund; the latter is financed by the auctioning of a distinct fraction of ETS emission allowances to support the decarbonization of industry, including CCUS projects²³.

In line with these policy guidelines and in accordance with their corporate plans to reduce their carbon footprint, the two major Greek cement manufacturers (TITAN and AGET Heracles) have prioritized the use of carbon capture and storage technologies as a key lever for reducing their emissions. Specifically, TITAN Greece has secured €234 million in funding from the Innovation Fund for the IFESTOS project, which aims to install a CCS system to capture carbon dioxide emitted from the rotary kilns at the company's Kamari plant²⁴. The captured CO₂ will then be liquefied and transported for geological storage, thus preventing a total of 1.9 million tons of CO₂ emissions per year; this quantity corresponds to approximately 15% of the company's Scope 1 emissions. The IFESTOS project was included in the strategic investment framework in June 2025, with the final investment decision expected by the end of 2026 and a target start of operations set for 2030²⁵. At the same time, AGET Heracles has secured approximately €124.27 million from the EU Innovation Fund²⁶ to launch the OLYMPUS project, which involves the installation of a CCS system at the company's plant in Milaki, Evia. The captured CO₂ will be liquefied and transported for storage, with the goal of avoiding 1 million tons of CO₂ per year. The total reduction in absolute GHG emissions is estimated at 6.8 million metric tons of carbon dioxide equivalent over the first ten years of the system's operation²⁷. The OLYMPUS project was included in

²¹ European Cement Research Academy (ECRA), The ECRA Technology Papers 2022: State of the Art Cement Manufacturing - Current technologies and their future development (2022): <https://shorturl.at/SDc2f>

²² Ige O.E. & Kabeya M., Decarbonizing the Cement Industry: Technological, Economic, and Policy Barriers to CO₂ Mitigation Adoption. Clean Technologies, vol. 7, is. 4, p. 85 (October 2025): <https://shorturl.at/e7bT0>

²³ The Green Tank, The Decarbonization of Greek Industry: Plans, Challenges and prospects: (January 2025): <https://shorturl.at/232jM>

²⁴ IFESTOS: TITAN's pioneering carbon capture project: <https://shorturl.at/kAaAK>

²⁵ TITAN Greece's IFESTOS project has been designated as a Strategic Investment by Enterprise Greece: <https://shorturl.at/HGYOn>

²⁶ Olympus HERACLES Group - HOLCIM's Carbon Capture project towards a Net Zero Future: <https://shorturl.at/R5Dwj>

²⁷ European Commission, Innovation Fund, OLYMPUS: Ascending to the top of CO₂ avoidance in the EU cement sector through the innovative OxyCalciner technology: <https://shorturl.at/oanGx>

the strategic investment framework in November 2025, with an operational start date set for 2029²⁸.

In addition to storage in suitable geological formations (CCS), captured CO₂ can be used in various applications (CCU). At the current stage of CCUS development, the captured CO₂ is predominantly employed -globally- in Enhanced Oil Recovery (EOR). Specifically, by the end of 2025, 63 CCUS projects were operational worldwide, of which 27 (approximately 43%) utilized part of the captured CO₂ (26.2 million tons, or 41% of the total CO₂ captured) for EOR²⁹. This type of captured CO₂ use is primarily implemented in North America, which hosts the vast majority of CCUS projects¹⁶. Consequently, even though the CO₂ injected into oil reservoirs remains stored after exploitation is complete, this technology is currently widely used to support hydrocarbon extraction.

Alternative technologies aimed at reducing emissions in the cement industry

Despite their potential to reduce emissions in the cement industry, CCS projects are not a “panacea.” According to a study by the Institute for Energy Economics and Financial Analysis (IEEFA), the total cost of planned CCS projects in the EU approximates €520 billion³⁰. Considering that their implementation depends heavily on public subsidies, the estimated cost to taxpayers may amount to €140 billion. Such a fiscal commitment carries the risk of diverting valuable public resources away from mature, readily available, and more cost-effective decarbonization solutions for the heat production process in the cement industry³¹. In addition to the high installation and operating costs of these projects, the actual CO₂ capture rate of existing projects is lower than expected. Specifically, the IEEFA examined 16 CCS projects and found that none had achieved CO₂ capture rates above 80%, while the average capture rate was approximately 49%³².

Finally, an assessment by the Intergovernmental Panel on Climate Change (IPCC) suggests that measures such as switching to alternative fuels, electrification combined with the use of renewable energy sources (RES), and improving energy efficiency achieve better results in terms of both cost and effectiveness³³. Consequently, CCS should be viewed as a targeted and complementary tool to be employed in selected processes that are hard to abate, while public policies should prioritize alternative decarbonization solutions for the cement industry that reduce emissions at the source.

²⁸ HERACLES Group’s OLYMPUS Project Included in the National “Strategic Investments of Exceptional Importance” Framework (Νοέμβριος 2025): <https://shorturl.at/noBpq>

²⁹ Global CCS Institute, Global Status of CCS 2025 (2025): <https://shorturl.at/kHsTp>

³⁰ Institute for Energy Economic and Financial Analysis, Carbon capture and storage: Europe’s climate gamble (October 2024): <https://shorturl.at/8gsTg>

³¹ European Environmental Bureau, CCS reality check: Risks and Priorities (May 2025): <https://shorturl.at/tPcRb>

³² Institute for Energy Economic and Financial Analysis, Carbon Capture and Storage: An unproven technology that cannot meet planetary CO₂ mitigation needs: <https://shorturl.at/sV8KM>

³³ Intergovernmental Panel on Climate Change (IPCC), Climate Change 2022: Mitigation of Climate Change, Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2022): <https://shorturl.at/8lNgq>

For the reasons outlined above, it is important to focus on other effective, albeit often overlooked solutions, such as the continuous improvement of industrial processes' energy efficiency, which should be a priority of any decarbonization strategy for the cement industry; waste heat recovery; the replacement of fossil fuels with alternative fuels; the use of green hydrogen; and the electrification of energy-intensive processes.

Energy efficiency improvements

Improving energy efficiency is a fundamental strategy for reducing emissions and production costs in the cement industry, as every unit of energy saved directly translates to lower CO₂ emissions and lower energy costs. The available solutions for improving and optimizing energy consumption in this sector target the entire clinker production process and are classified as TRL 9³⁴, namely, they are fully mature, commercially available, and already implemented in numerous industrial plants.

Dry-process rotary kilns dominate globally, as they consume significantly less energy compared to wet processes, due to the reduced moisture content of the raw materials, which require less energy for drying. The state-of-the-art technology for clinker production includes dry-process kilns with a precalciner, multi-stage cyclone preheaters, and multi-channel burners; this configuration is recommended as an example of Best Available Technology (BAT), under European directives, and is implemented in all new plants worldwide¹¹.

Specifically, the integration of a precalciner and a multi-stage preheater in existing dry-process kilns enables the utilization of excess process heat for raw material drying and precalcination, thereby further reducing the process's energy consumption. Multi-stage cyclone preheaters allow for the progressive preheating and partial decarbonization of raw materials using exhaust heat, increasing energy efficiency by 30-40% compared to older processes¹⁶. Retrofitting plants with these technologies is estimated at €70-100 per ton of clinker. However, the cost may deviate significantly from this range depending on the initial condition of the plant and the level of retrofit required; in certain cases, building a new clinker production facility may be more cost-effective than modernizing an existing installation. Implementing these technologies can achieve an emissions reduction of 80-250 kg CO₂ per ton of clinker. Furthermore, this type of investment is expected to reduce operating costs by €2.81 - €9.07 per ton of cement²¹, with EU prices in the range of €150 - €200/ton of cement^{35,36}.

³⁴ TRL (Technology Readiness Level): A standardized nine-level scale assessing technological maturity. The scale ranges from TRL 1, which corresponds to the initial research stage (basic scientific principles are observed and reported), to TRL 9, which refers to technologies that are fully developed, tested, and proven to be operational in industrial and commercial environments.

³⁵ World Cement Association, Impact of EU ETS on the structure and profitability of the cement industry (2024): <https://shorturl.at/kwe39>

³⁶ Alexander Makhlay, European cement prices expected to rise in 2026 (February 2026): <https://shorturl.at/3zuv0>

Furthermore, **the conversion of mono-channel burners to multi-channel burners** constitutes an effective energy-saving measure for cement kilns. Multi-channel burners operate at a lower air supply rate (8-12% air ratio compared to 20-25% in mono-channel burners), thus achieving fuel savings of 50-80 MJ/ton of clinker in conventional kilns, and approximately half that amount in precalciner kilns. This improvement also translates into an emissions reduction of 2.2-3.3 kg CO₂/ton of clinker in conventional kilns. The required investment cost for the installation of a new burner and precalciner is estimated at €0.5-0.66 million, while the operational costs are projected to decrease by €0.07-0.11/ton of cement^{3,21}.

The stability of continuous production in the cement manufacturing process is a critical factor for energy efficiency, as fluctuations in the properties of raw materials or fuels affect thermal and electrical consumption. **The implementation of advanced control systems** using predictive models, artificial intelligence, and machine learning enables continuous monitoring and optimization of combustion and grinding processes, reducing energy losses and operational instability. The installation cost of advanced control systems ranges from €0.12 to €2.50 per ton of clinker; the expected net savings in operational costs are estimated at approximately €0.20 - €0.80 per ton of cement. The initial investment cost depends on the plant configuration and the desired level of automation and system management^{16,21}.

Furthermore, the electric motors running grinding mills, kilns, and fans consume vast amounts of electricity in the cement production process, whereas other motors have a lower capacity and operate at constant speeds. **The installation of frequency-controlled drives** can result in a significant reduction in operational costs, since the electricity consumption changes with the third power to the unit's speed. Specifically, frequency-controlled drives can reduce electricity consumption by 3% to 8%, while their implementation in fans corresponds to savings of approximately 5.5 kWh per ton of clinker. At the same time, **the installation of high-efficiency fans** can deliver an additional reduction of 1.1 kWh/ton of clinker, while **the replacement of electrically driven transmission systems with hydraulic ones** can yield energy savings in the range of 10% to 15%. Overall, the implementation of the aforementioned measures contributes to reducing emissions by 3 to 5 kg of CO₂ per ton of clinker. Beyond energy savings, frequency-controlled drives improve process control and flexibility, reducing mechanical stress and, consequently, maintenance costs. Installation costs are estimated at approximately €0.13-0.19 million for 1,000 kW systems, while the net reduction in operating costs can amount to €0.14 per ton of cement^{3,21}.

Table 1 summarizes the key technological solutions for improving energy efficiency in the clinker production process. The required capital expenditure (CAPEX), the expected benefits in operating costs (OPEX), and the corresponding energy and environmental benefits are indicated per technology. The range of cost estimates reflects variations in capacity, the plant's current technological status, and the level of retrofit required.

Table 1: Comparison of key energy efficiency improvement measures in the clinker production process

Measure	CAPEX	OPEX (savings)	Energy/Environmental benefit
Retrofit of dry process kiln with precalciner and multistage preheater	70-100 €/ton of clinker	2.81-9.07 €/ton of cement	+30-40% energy efficiency; avoidance of 80-250 kg CO ₂ /ton of clinker
Multi-channel burners	0.5-0.66 mil. €	0.07-0.11 €/ton of cement	Savings of 50-80 MJ/ton of clinker (25-40 MJ/ton of clinker in kilns with a precalciner); reduction of 2.2-3.3 kg CO ₂ /ton of clinker
Advanced control systems	0.12-2.5 €/ton of clinker	0.2-0.8 €/ton of cement	Reduction in thermal and electrical consumption; reduction of fluctuations
Frequency-controlled drives for motors	0.13-0.19 mil. € / 1,000 kW	up to 0.14 €/ton of cement	3-8% electricity savings, reduction of 3-5 kg CO ₂ /ton of clinker

Waste Heat Recovery for Electricity Production

Waste Heat Recovery (WHR) refers to the process of collecting and utilizing the maximum possible amount of heat from the production processes of an industrial facility, with the aim of reducing the thermal energy released into the environment and reusing it to produce electricity. In the cement industry, nearly 50% of the thermal energy introduced into the clinker production process is discharged primarily through combustion exhaust gases, hot air from the clinker cooling systems, and radiation from the equipment's hot surfaces. Particularly in dry-process plants, total heat losses can amount to 45.6% of the required thermal energy; this figure highlights the particularly high potential for applying waste heat recovery technologies in this sector³⁷.

The implementation of WHR systems in the cement industry constitutes a dual-benefit solution, as it reduces environmental impacts while lowering plant operational costs by decreasing primary energy consumption. The application of WHR technology in the cement industry began in Japan and subsequently spread to other continents, with Asia being the primary region of adoption. Particularly in China, heat recovery systems were promoted as a key driver of emission reductions in this sector; moreover, in 2011, their installation became mandatory for the licensing of new clinker production plants. As a result, waste heat recovery systems are installed in over 97% of new kilns in the country's cement industry³⁸.

In cement plants, the preheater tower and the clinker cooler exhaust represent the two primary locations to recover heat²¹. Technically, WHR systems in cement kilns operate based on the Rankine thermodynamic cycle. In this cycle, the heat recovered from the hot exhaust

³⁷ Marenco-Porto C.A., Fierro J.J., Nieto-Londoño C., Lopera L., Escudero-Atehortua A., Giraldo M. & Jouhara H., Potential savings in the cement industry using waste heat recovery technologies. *Energy*, vol. 279, p. 127810 (September 2023): <https://shorturl.at/Rhl7U>

³⁸ Ofosu-Adarkwa J., Xie N. & Javed S.A., Forecasting CO₂ emissions of China's cement industry using a hybrid Verhulst-GM(1,N) model and emissions' technical conversion. *Renewable and Sustainable Energy Reviews*, vol. 130, p. 109945 (September 2020): <https://shorturl.at/r3Fa4>

gases is transferred to a working fluid via a boiler, causing it to change from a liquid to a gaseous state. The steam produced is expanded into a turbine system connected to a generator, where thermal energy is converted first into mechanical and then into electrical energy. The exhaust steam is directed to a condenser, where it is cooled and reversed to a liquid state; finally, it is fed back to the boiler via a pump, thus completing the closed thermodynamic cycle³⁹.

Even though the electrical efficiency of WHR systems in the cement industry is typically limited to 20-25% due to the relatively low temperature of waste heat sources, the energy benefits remain significant²¹. The most common heat recovery applications in the cement industry are based on the Steam Rankine Cycle (SRC), while several plants employ the Organic Rankine Cycle (ORC). In the SRC, the recovered thermal load converts water into superheated steam, which is fed into a turbine to produce electricity, whereas the ORC uses an organic fluid with a lower boiling point, rendering this cycle more suitable for medium- or low-temperature sources⁴⁰. Specifically, ORC systems can utilize waste heat sources exceeding 150°C, while SRC systems are limited to those above 260°C³⁹.

In addition to the above methods, the Kalina cycle represents an alternative WHR technology. It is a variation of the Rankine cycle that employs a mixture of water and ammonia as the working fluid, thus enabling a more efficient use of low- to medium-temperature heat sources. Specifically, the Kalina cycle can operate over a wide temperature range, from approximately 95°C to 535°C, achieving 15-25% higher electrical efficiency compared to the Organic Rankine Cycle³⁹.

The use of waste heat recovery systems in the European cement industry has grown significantly in recent years, with projects being implemented or at the testing stage in several countries. Indicatively, WHR installations are operational in Czechia, Germany, Italy, Portugal, Romania, Slovakia, and Sweden, spanning various stages of maturity, from pilot projects to fully operational units. Germany and Italy host most projects, while systems in Romania and Slovakia have been operating successfully for more than a decade, with installed capacities ranging between 2 and 8 MW_e³⁹.

From an economic standpoint, while WHR systems in the cement industry require a high initial investment, they are associated with low operating costs⁴⁰. Regarding energy efficiency, the Steam Rankine Cycle reduces net electricity consumption by 8-22 kWh per ton of clinker, while the Organic Rankine Cycle achieves slightly lower savings, between 8 and 15 kWh/ton of clinker. The Kalina cycle shows comparable or even higher performance, reducing consumption by 10-24 kWh per ton of clinker. The corresponding CO₂ emissions reductions are equally significant: the implementation of SRC and ORC systems results in the avoidance of 5-12 kg CO₂ and 5-8 kg CO₂ per ton of clinker, respectively, while the Kalina cycle cuts emissions by 6-14 kg CO₂/ton of clinker²¹.

With regard to investment costs, the installation of all three technologies is estimated to range between 15 and 30 million euros, with projections indicating relatively stable cost

³⁹ International Finance Corporation & Institute for Industrial Productivity, Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis (June 2014): <https://shorturl.at/bkM4Z>

⁴⁰ Joint Research Centre, Decarbonisation Options for the Cement Industry (2023): <https://shorturl.at/GuM7p>

levels for the period 2020-2050. The final cost is shaped by several parameters, such as the type of technology installed and the plant's size and geographical location. These factors account for the wide variation in specific capital costs, from approximately €6,500/kW of installed capacity for small 2 MW units (mainly ORC) to approximately €1,900/kW for larger 25 MW steam cycle plants. At the same time, all the aforementioned technologies are expected to reduce cement production costs by approximately €0.5-1.5 per ton^{39,40}.

Table 2 summarizes the key waste heat recovery technologies, focusing on Steam Rankine, Organic Rankine, and Kalina cycles. The main technical and operational characteristics are outlined per technology, along with their impact on the energy efficiency and environmental performance of cement production plants. At the same time, the economic data related to their implementation are indicated; cost and performance figures are presented as ranges, as they vary, mainly according to plant installed capacity.

Table 2. Comparative overview of waste heat recovery technologies for electricity production in the cement industry

Parameter	Steam Rankine Cycle (SRC)	Organic Rankine Cycle (ORC)	Kalina Cycle
Working fluid	Water/vapor	Organic fluid with a low boiling point	Water-ammonia mixture
Source temperature range	> 260 °C	> 150 °C	95-535 °C
Electricity savings	8-22 kWh/ton of clinker	8-15 kWh/ton of clinker	10-24 kWh/ton of clinker
CO ₂ emissions reduction	5-12 Kg CO ₂ /ton of clinker	5-8 Kg CO ₂ /ton of clinker	6-14 Kg CO ₂ /ton of clinker
Specific investment cost	1,900-6,500 €/kW	1,900-6,500 €/kW	1,900-6,500 €/kW
Total investment cost	15-30 mil. €	15-30 mil. €	15-30 mil. €
Impact on cement cost	0.5-1.5 €/ton reduction	0.5-1.5 €/ton reduction	0.5-1.5 €/ton reduction

Replacement of fossil fuels with alternative fuels

Co-processing waste as an alternative fuel constitutes an effective strategy for reducing CO₂ emissions in the cement industry; this method entails the partial or full replacement of traditional carbon-intensive fuels, such as petroleum coke, fuel oil, coal, or even fossil gas, with alternative fuels that have a low carbon footprint³. The latter mainly include biomass and treated waste, such as sewage sludge; municipal solid waste (MSW); refuse-derived fuel (RDF); solid recovered fuel produced from treated industrial and municipal waste (SRF); rubber tire-derived fuel (TDF); and plastics (PDF). A specific category of alternative fuels that has piqued the interest of the cement industry and the wind farm sector as a mutually beneficial cross-sectoral strategy is the utilization of decommissioned wind turbine blades for simultaneous energy production and material substitution. Indeed, the co-processing of

end-of-life composite materials -such as wind turbine blades made of glass or carbon fibers embedded in resins- in cement kilns provides a circular recycling solution¹¹Error! Bookmark not defined.,41

Fossil-based alternative fuels typically result in a reduction of 0.5-1 ton of CO₂ per ton of carbon-intensive fuel replaced; moreover, replacement with biomass can lead to reductions of up to 2.5 tons of CO₂⁴². Alternative fuels are often co-processed with fossil fuels, with the resulting ash being partially incorporated into the cement mortar, thereby reducing landfill waste and increasing energy recovery. The high kiln operating temperatures (approximately 1,450°C), in conjunction with material residence time of up to 10 seconds, ensure the complete destruction of all organic waste constituents, thus rendering co-processing a safe and effective method⁴³.

The replacement of fossil fuels with alternatives constitutes a fully mature technology on a commercial scale with widespread industrial applications (TRL 9). Nonetheless, the degree of utilization of alternative fuels varies significantly by region and remains low globally. Indeed, on average, approximately 6% of fossil fuels are currently replaced by alternative fuels worldwide; of these, roughly two-thirds are of fossil origin and one-third comes from biomass. The global use of alternative fuels is, however, projected to increase to an average of approximately 22% and 43% by 2030 and 2050, respectively⁴⁴. Progress in the European cement industry has outpaced the global average. Specifically, alternative fuels accounted for 53% of the energy mix in 2021, compared to 46% in 2017 and just 2% in 1990. Building on this momentum, the sector has set ambitious targets, aiming to increase the share of alternative fuels to 60% by 2030 and 95% by 2050, with biowaste contributing at 30% and 50%, respectively¹¹. Reportedly, there are no technical barriers to meeting over 90% of the thermal requirements for clinker production via alternative fuels; nevertheless, the practical application of this technology is influenced by a range of factors, such as alternative fuels' local availability; heavy metal, chlorine, sulfur, and PCB content; moisture content; particle size; and calorific value⁴⁵. Applications across Europe indicate that significantly higher substitution rates are possible, as average national rates exceeding 70% are being recorded; moreover, individual cement plants have achieved up to 100% substitution.^{3,21}

In Greece, the major cement manufacturers currently operate a number of production facilities that utilize alternative fuels. Specifically, the percentage of conventional solid fuels replaced by alternative fuels at TITAN's cement plants increased from 27% in 2020 to

⁴¹ Wind Europe, Decommissioning of Onshore Wind Turbines: Industry Guidance Document (November 2020): <https://shorturl.at/RbKCR>

⁴² Clark G., Davis M., Shibani, Kumar A., Assessment of fuel switching as a decarbonization strategy in the cement sector. Energy Conversion and Management, vol. 312, p. 118585 (July 2024): <https://shorturl.at/RUIC1>

⁴³ Beguedou E., Narra S., Armoo E.A., Agboka K. & Damgou M.K., Alternative Fuels Substitution in Cement Industries for Improved Energy Efficiency and Sustainability. Energies, vol. 16, is. 8, p. 3533 (April 2023): <https://shorturl.at/dgCLM>

⁴⁴ Global Cement and Concrete Association, Concrete Future: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete (2020): <https://shorturl.at/li0Km>

⁴⁵ Rahman A., Rasul M.G., Khan M.M.K., Sharma S., Recent development on the uses of alternative fuels in cement manufacturing process. Fuel, vol. 145, p. 84-99 (April 2015): <https://shorturl.at/ESrau>

39.3% in 2024^{46,47}. Moreover, the use of biomass rose significantly, reaching a thermal substitution rate of 18.4% against 7.7% in 2020. With regard to AGET Heracles, alternative fuels accounted for 45.4% of total thermal energy consumption in 2024, compared to 27.7% in 2020; moreover, the contribution of biomass to the fuel mix more than tripled, from 4.7% in 2020⁴⁸ to 16.8% in 2024⁴⁹.

With regard to clinker production plants with an annual production capacity of 2 million tons, investment costs for the installation and adaptation of co-processing infrastructure are estimated at €5-15 million, or between €2.5-7.5 per ton of clinker. The resulting net savings in operating costs approximate €3-4 per ton of cement²¹.

Despite its advantages, the strategy of replacing fossil fuels with alternative fuels has a modest impact on CO₂ emissions. Reductions range between 1-13%, depending on the composition of the fuel mix; the additional drying requirements of the alternative fuels; and the operational parameters of the kiln and other equipment of the clinker production facility^{42,50,51}. The greatest reduction in CO₂ emissions is achieved by replacing fossil fuels with biomass. However, with demand for biomass increasing and supply remaining constant, the anticipated deficit in available biomass is estimated at 50-150%¹³, thereby significantly hindering the long-term implementation of this strategy. Considering this solution's limited potential for decarbonizing the cement industry, more effective and efficient options need to be explored.

Use of hydrogen as fuel

Hydrogen constitutes one of the most promising clean fuels for heat production in industry, due to its high energy density, storage potential, versatility in use, and green profile - provided that it is produced via RES-powered electrolysis⁵². In the cement industry, hydrogen can be employed through two distinct approaches.

The first approach relates to **the utilization of hydrogen as a fuel to produce the thermal energy** required for clinker manufacturing⁵². Hydrogen combustion per se does not result in carbon dioxide emissions; nonetheless, hydrogen use may ultimately prove to have a substantial carbon footprint depending on the method of its production. For instance, the gasification of coal or lignite (brown hydrogen) can result in emissions of up to 19 kg CO₂/kg H₂. In contrast, if hydrogen is produced via electrolysis using electricity from RES (green hydrogen), the total carbon footprint is zero. Therefore, **green hydrogen** can fully or

⁴⁶ TITAN Greece, Sustainability Report 2024: <https://shorturl.at/BJlba>

⁴⁷ TITAN Greece, Sustainability Report 2020: <https://shorturl.at/2tHFN>

⁴⁸ Όμιλος ΗΡΑΚΛΗΣ, Sustainability Report 2020: <https://shorturl.at/ayOOJ>

⁴⁹ Όμιλος ΗΡΑΚΛΗΣ, Sustainability Report 2024: <https://shorturl.at/Uoqlp>

⁵⁰ Pitre V., La H. & Bergerson J.A., Impacts of alternative fuel combustion in cement manufacturing: Life cycle greenhouse gas, biogenic carbon, and criteria air contaminant emissions. Journal of Cleaner Production, vol. 475, p. 143717 (October 2024): <https://shorturl.at/LPDBc>

⁵¹ Global Efficiency Intelligence, Emissions Impacts of Alternative Fuels Combustion in the Cement Industry (June 2023): <https://shorturl.at/N3QQU>

⁵² Resources for the Future (RFF), Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions (December 2020): <https://shorturl.at/UVV8e>

partially replace fossil fuels, providing an effective method for decarbonizing the thermal energy production process in the cement industry⁵³.

Thermo-dynamic analyses indicate that the integration of hydrogen combustion systems can cut emissions up to 44% compared to a plant operating exclusively on fossil fuels⁵⁴. When hydrogen is used partially as a supplementary fuel in the mixture, emission reductions range between 15% and 19.6%, while the thermal efficiency and operation of the furnace are maintained stable⁵⁵. Tests at large industrial plants have demonstrated that the partial replacement of fossil fuels with hydrogen is technically feasible and operationally stable, albeit requiring further optimization of the burner and combustion conditions¹¹. In 2022, a net-zero-carbon fuel blend was tested for heat production at the Hanson cement plant in the United Kingdom. Hydrogen accounted for approximately 40% of the kiln's thermal energy input, thereby illustrating that high rates of hydrogen substitution in cement kiln fuel mixes are technically feasible⁵⁶.

When hydrogen is not produced on-site at the cement plant, its supply requires special transportation and handling methods. Small quantities can be transported by truck or train under extremely high pressure (500-1,000 bar), due to its low calorific value relative to its volume (10.8 MJ/m³). Larger volumes require the development of permanent infrastructure, and particularly transmission pipelines and pressure-regulating valves, as hydrogen is injected into industrial facilities at near-atmospheric pressure. In contrast, when hydrogen is produced via electrolysis, the contribution of decompression systems to total energy consumption is minimal, while the electrolysis process itself accounts for the majority of total energy demand (44 MWh/ton of H₂ for electrolysis at 75% efficiency²¹).

The second approach relates to **the production of hydrogen through heat recovery from the clinker production process**. The large amounts of heat discharged from kilns and associated heat exchangers can be utilized for hydrogen production. Moreover, hybrid systems can be developed to combine waste gasification with hydrogen production within a single cement production facility. This approach offers multiple benefits: reduced production costs; replacement of primary fuels with gasification products; and utilization of the resulting ash as a raw material for clinker¹¹.

Hydrogen combustion in clinker production constitutes a promising decarbonization pathway for the cement industry; nonetheless, its implementation requires significant technical and operational adjustments. Hydrogen is highly flammable, with a flame that is scarcely visible

⁵³ Nhuchhen D.R., Sit S.P. & Layzell D.B., Decarbonization of cement production in a hydrogen economy. Applied Energy, vol. 317, p. 119180 (July 2022): <https://shorturl.at/dUvsS>

⁵⁴ Juangsa, F.B., Cezeliano A.S., Darmanto P.S. & Aziz M., Thermodynamic analysis of hydrogen utilization as alternative fuel in cement production. South African Journal of Chemical Engineering, vol. 42, p. 23-31 (October 2022): <https://shorturl.at/gAYQm>

⁵⁵ El-Emam R. S. & Gabriel K. S., Synergizing hydrogen and cement industries for Canada's climate plan - case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 43, p. 3151-3165 (June 2021): <https://shorturl.at/Yxjj7>

⁵⁶ Mineral Products Association, VDZ gGmbH, Cinar Ltd, Hanson & Tarmac, State of the art fuel mix for UK cement production to test the path for 'Net Zero': a technical, environmental and safety demonstration (August 2022): <https://shorturl.at/Ktrbn>

and may propagate rapidly, thus requiring robust safety measures⁵⁷. In addition, the relatively high autoignition temperature of hydrogen hinders the initiation of combustion without the use of an auxiliary ignition source. Furthermore, while hydrogen combustion completely eliminates CO₂ emissions, the high thermal load may promote the formation of nitrogen oxides (NO_x), requiring careful temperature management and dilution techniques. In particular, the dilution of hydrogen with steam or inert gases can improve flame stability and mitigate NO_x emissions⁵⁸.

Consequently, the successful utilization of hydrogen in the cement industry entails retrofitting burners, fuel supply and control systems, as well as assessing refractory material resistance under the new operating conditions. Key factors influencing the progress and viability of this technology include the cost and availability of hydrogen, as well as technical parameters, namely, the velocity, rate, and position of its injection within the burner, all of which determine flame morphology and thermal radiation efficiency. In addition, the installation of adequate storage and piping infrastructure is crucial to ensuring reliable process operation. In this context, the use of hydrogen as a fuel in clinker production is currently at TRL 6. Its widespread industrial adoption is expected once the TRL exceeds Level 8, which is anticipated by approximately 2040²¹.

The H2CEM project of the TITAN Group in Greece constitutes a representative case study on the use of green hydrogen as a zero-carbon fuel in cement production. The project aims to produce hydrogen via electrolysis, utilizing RES at the Group's plants in Kamari, Drepano, and Efkarpia. The industrial use of hydrogen is expected to reduce CO₂ emissions by approximately 160,000 tons per year, corresponding to at least an 8% decrease per ton of cement produced. At the same time, the company plans to construct a pilot rotary kiln designed to operate with hydrogen as primary fuel, in order to experimentally investigate flame behavior and combustion conditions^{11,59}.

The retrofit of production plants with a capacity of 6,000 tons of clinker per day to replace 10% of fuels with hydrogen requires an investment of 2.3 to 4.5 million euros. This cost refers to the adaptation of an existing installation to enable hydrogen handling and combustion, excluding the installation of electrolysis systems. However, the economic viability of hydrogen use as a fuel in cement production is largely determined by operating costs, which are directly linked to fuel price. Based on current estimates, the price of hydrogen is expected to drop from approximately €3.2/kg in 2020 to €2.2/kg in 2030 and €1.5/kg by 2050; this decline stems from the anticipated decrease in the cost of green hydrogen production via electrolysis and the growing availability of renewable energy. As a result, this technology is expected to become increasingly competitive compared to conventional fuels²¹.

⁵⁷ Mineral Products Association, Cinar Ltd & VDZ gGmbH, Options for switching UK cement production sites to near zero CO₂ emission fuel: Technical and financial feasibility (October 2019): <https://shorturl.at/Sjeli>

⁵⁸ Schneider M., Hoenig V., Ruppert J. & Rickert J., The cement plant of tomorrow. Cement and Concrete Research, vol. 173, p. 107290 (November 2023): <https://shorturl.at/1sjad>

⁵⁹ TITAN: Net Zero Innovation: <https://shorturl.at/k493h>

Electrification of the clinker production process

Among the most innovative approaches to decarbonizing the cement industry, the electrification of clinker production entails the replacement of fossil fuel combustion with electricity to provide heat to the kiln. This technology is at an early stage of development, as meeting the substantial thermal requirements of the calcination process constitutes a key technical constraint. Despite the challenges, certain cement manufacturers have already launched pilot research and development initiatives¹¹. Two main approaches exist: **partial electrification** entails using electricity primarily to preheat raw materials (up to ~900 °C) via plasma burners or electric resistance heaters, whereas **full electrification** employs electricity throughout the process, thus achieving the required final temperatures exclusively via high-temperature technologies, such as plasma burners; inductive heating; microwave heating; and resistive electrical heating systems⁴⁰.

Beyond plasma systems, heat production technologies using electricity for clinker manufacturing -although of research interest- remain at an early stage of development; moreover, their industrial application is hindered by significant technical and operational challenges. Specifically, while induction heating is highly efficient in conductive and magnetic materials, it is not readily applicable in the cement industry, as the relevant raw materials have very low electrical conductivity and no magnetic response. As a result, heat transfer requires the use of intermediate conductive elements; this configuration significantly reduces energy efficiency while increasing the system's thermal inertia, thereby rendering the method impractical for industrial-scale applications at this stage. Comparable difficulties are observed in microwave heating, which relies on the absorption of electromagnetic radiation by the material. Even though this method allows for rapid and direct heating without physical contact, the raw materials' low absorption rate, combined with reflection issues and uneven heating, result in low energy efficiency and substandard process stability. Finally, resistive electrical heating -notwithstanding its simplicity and the controllability of heat input- presents significant limitations: this technology requires the use of materials with exceptionally high resistance to thermal and oxidative conditions, while resistors are subject to severe degradation due to dust exposure and kiln thermal stresses. Overall, although early applications exist, these technologies remain largely at a laboratory or conceptual stage; the cement industry's high thermal conditions and reliability requirements significantly impede their direct implementation at their current maturity level³.

Among available technologies, plasma burners are currently regarded as the most promising, as they combine high temperatures, rapid response, and technical flexibility. Plasma is formed via the ionization of a working gas via electrical discharge or a high-frequency field, resulting in the generation of a high-temperature plasma jet. Heat is transferred to the material primarily via convection, with the type and flow of the gas (O₂, N₂, CO, air, or steam) determining process efficiency. The temperatures that can be achieved range from 1,500 °C to over 7,000 °C, rendering the technology theoretically capable of meeting the temperature requirements for clinker production.

Plasma heating has been the subject of major research projects, such as CemZero in Sweden, which was conducted by Vattenfall and Cemita. The project investigated various scenarios for the full electrification of cement production based on plasma burners,

confirming implementation feasibility on a pilot scale⁶⁰. Furthermore, project simulations suggested that a future electricity-operated Cementa plant could operate in synergy with a wind farm, improving the overall energy balance while simultaneously mitigating surplus electricity peaks arising from increased wind production.

Meanwhile, the British Mineral Products Association (MPA) conducted simulations and experimental studies in an industrial cement kiln, demonstrating that a plasma kiln can operate reliably in the highly demanding environment of the clinker production process. Although the duration of the tests was limited, the results confirmed the viability of the technology at an early stage, laying the groundwork for further development on a larger scale^{61,62}.

A relatively mature technology for the electrification of heat production processes in the cement industry is the RotoDynamic Heater (RDH™); developed by the Finnish company Coolbrook, it aims to provide high-temperature heat ranging from 700°C to 1,700°C⁶³. This technology has yielded successful results in a 1 MW pilot application -achieving temperatures above 1,000°C- and can be readily integrated into existing plants⁶⁴. In late 2025, the first industrial application of RDH was announced at Adani Cement's Boyareddypalli plant in the Andhra Pradesh region of India; the expected annual emissions reduction is projected at approximately 60,000 tons of CO₂⁶⁵.

Despite the encouraging results, the electrification of the cement industry is still transitioning from an experimental stage to industrial-scale application; the process's energy efficiency, operational stability, and high investment costs represent the main challenges hindering its advancement. This technology thus remains at a low level of technological maturity (TRL 4), as applications are limited to pilot projects and experimental studies, with no implementation on an industrial scale. Progress is expected to accelerate over the next decade, and electrification solutions are projected to exceed a TRL 8 between 2030 and 2040²¹. Nonetheless, the technical challenges associated with modifying existing equipment, as well as the high cost of retrofitting compared to building new units, constitute significant obstacles⁶⁶. Furthermore, industrial processes' high energy consumption requires an adequate and stable supply of low-carbon electricity, which, in turn, depends directly on RES development, electricity transmission grid efficiency, and the expansion of storage systems. Consequently, several cement manufacturers are already

⁶⁰ Cementa, & Vattenfall, CemZero: A Feasibility Study Evaluating Ways to Reach Sustainable Cement Production via the Use of Electricity (December 2018): <https://shorturl.at/eBidL>

⁶¹ Mineral Products Association (MPA), Development of State of the art fuel mix for UK cement production to test the path for 'Net Zero: <https://shorturl.at/kNPfY>

⁶² Volaity S.S., Aylas-Paredes B.K., Han T., Huang J., Sridhar S., Sant G., Kumar A. & Neithalath N., Towards decarbonization of cement industry: a critical review of electrification technologies for sustainable cement production. *Materials Sustainability*, vol. 3 (July 2025): <https://shorturl.at/M0gMg>

⁶³ Coolbrook, Electrifying high-temperature industrial heat with RotoDynamic Technology (November 2024): <https://shorturl.at/HSB9K>

⁶⁴ Coolbrook successfully completes first phase of pilot tests to demonstrate its RotoDynamic Technology and its potential to reduce global industrial CO₂ emissions by 30% (September 2023): <https://shorturl.at/IAEYI>

⁶⁵ Adani Cement and Coolbrook to deploy world's first commercial RotoDynamic Heater to advance cement decarbonisation (November 2025): <https://shorturl.at/KLjXt>

considering the installation of photovoltaics or wind farms near their plants, in order to ensure an adequate and economically viable supply of carbon-free electricity⁴⁰. RES penetration for self-produced electricity in the cement industry is currently limited worldwide; nonetheless, recent years have seen promising developments^{12,16}. Furthermore, as cement plants operate continuously, they could provide demand flexibility services, absorbing surplus energy from RES in high-RES penetration scenarios, thereby improving grid stability⁶².

The electrification of heat production in the cement industry can reduce related CO₂ emissions by 95-100%; nonetheless, it also increases the cost of clinker production by 95-113%, mainly due to the cost of electricity. At the same time, CO₂ avoidance costs, which reflect the supplementary investment and operating expenditures required to abate one additional unit of emissions, range from €63 to €86 per ton of CO₂. The capital investment associated with the installation of electrically powered units is substantial, with estimates varying widely according to plant capacity, geographical region, and baseline assumptions. Specifically for resistive electrical heating systems, installation costs range between €46-198 million, while operating costs amount to approximately €92 per ton of cement, exceeding by 30-40% those of fossil-fueled systems for heat production. With regard to inductive heating systems, installation costs for a cement plant with an annual capacity of one million tons of cement are approximately 40% higher, falling within the range of €175-276 million. In this case, nevertheless, operating costs are reduced by 15-20%, resulting in comparable clinker production and CO₂ emissions avoidance costs. Microwave heating systems have moderate installation costs ranging from €179 million to €230 million for a plant with a capacity of 3 million tons of cement per year; however, clinker production costs are elevated due to the materials' low thermal efficiency, with the cost of CO₂ emissions avoidance being competitive only in regions with affordable electricity produced by RES⁶². According to estimates by the CemZero project, the installation of plasma heating for a plant with an annual capacity of 1.3 million tons of cement costs 294 million euros, while operating expenses range between 92-120 euros per ton of cement, with 75% of the cost attributable to electricity consumption. Moreover, clinker production costs are elevated by 70-93% relative to fossil fuel-based heat production systems. However, the cost of CO₂ emissions avoidance is particularly competitive, amounting to approximately €75/ton of CO₂, when carbon dioxide is employed as a carrier gas and electricity is supplied by low-cost RES⁶⁰.

It has been suggested that financial investment estimates for the electrification of heating systems in the cement industry should also take into account opportunity costs arising from downtime needed for maintenance or equipment replacement, estimated at €93-190 per ton of cement⁶². Other studies suggest that the investment required for retrofitting existing plants approximates €88 per ton of cement, with non-energy-related operating costs ranging between €4-4.5 per ton of cement⁴²; total operating costs are estimated at €57-205, €62-221, and €49-180 per ton of cement for 2020, 2030, and 2050, respectively²¹.

In summary, the aforementioned solutions face technical and economic challenges related to investment costs, green electricity availability, and the retrofit of existing plants; nonetheless, the potential to reduce CO₂ emissions by up to 35% through the replacement of fossil fuels with green electricity renders electrification a strategic pillar for the decarbonization of the cement industry²¹.

Table 3 provides an overview of the main technologies for electricity-based heat production in the clinker production process. The required capital expenditure (CAPEX), the expected operating costs (OPEX), the estimated cost increase compared to fossil fuel-based heat production systems, as well as the cost of carbon dioxide emissions avoidance is presented for each technology. Cost figures are presented as ranges, as they depend significantly on the cost and source of electricity.

Table 3. Comparative presentation of electricity-based heat production technologies for the clinker production process

Technology	CAPEX	OPEX	Cost Increase	CO ₂ Avoidance Cost
General Estimates	88 €/ton of cement (retrofitting existing installations)	57-205 €/ton of cement (2020) 62-221 €/ton of cement (2030) 49-180 €/ton of cement (2050)	95-113% compared to fossil-fueled heat production	63-86 €/ton of CO ₂
Resistive Electrical Heating	46-198 mil.€	92 €/ton of cement	30-40% compared to fossil-fueled heat production	-
Conductive Heating	175-276 mil.€ (capacity: 1 Mt/year)	78-83 €/ton of cement	comparable to fossil-fueled heat production	-
Microwave Heating	179-230 mil.€ (capacity: 3 Mt/year)	Higher compared to other technologies		Competitive when electricity is supplied by low-cost RES
Plasma Heating (CemZero)	294 mil.€ (capacity: 1.3 Mt/year)	92-120 €/ton of cement		75 €/ton of CO ₂ when electricity is supplied by low-cost RES

Incorporation of Measures for the Decarbonization of the Cement Industry into the Greek Action Plan for Green Public Procurement

As indicated by the preceding section, significant funds are required for the implementation of technologies that will decarbonize cement industrial processes. The “greening” of public procurement represents a promising pathway for addressing this challenge.

In particular, the potential to use public procurement as a policy instrument to strengthen the market for low-carbon cement is confirmed by the fact that, in 2019, public procurement accounted for approximately 31% (47 Mt) of the total EU cement market (154 Mt). This share corresponds to an estimated €5.15 billion, within a total market size of approximately €17 billion⁶⁷. In Greece, public procurement for infrastructure and construction projects accounts for approximately 25-35% of total construction activity⁶⁸; thus, a significant share of domestic cement consumption is tied to projects funded or commissioned by the public sector.

In this context, the Greek Action Plan for Green Public Procurement can have a powerful impact as a policy tool that will steer public demand toward low-carbon cement products, while providing incentives for investment in cleaner production technologies. At the same time, Green Public Procurement (GPP) can serve as a catalyst, strengthening the competitiveness of the domestic cement industry by promoting innovation, research, and development, as well as linking the decarbonization of the cement industry to European funding mechanisms⁶⁹.

International and European Policies on Green Public Procurement

The 17 Sustainable Development Goals (SDGs) included in the UN 2030 Agenda for Sustainable Development have placed sustainability at the center of global policy. States that have adopted the SDGs have committed to ensuring “*sustainable consumption and production patterns*” (SDG 12) and to promoting “*sustainable public procurement practices*” (target 12.7)⁷⁰, with GPP being a key component of Sustainable Public Procurement (SPP).

⁶⁷ Research Centre on the Environment, Economy and Energy (3E) of the Brussels School of Governance, Public procurement of cement and steel for construction: Assessing the potential of lead markets for green steel and cement in the EU (July 2024): <https://shorturl.at/COYO8>

⁶⁸ Foundation for Economic and Industrial Research (IOBE), Trends, Challenges and Prospects of Construction in Greece (March 2024): <https://shorturl.at/ysGt5>

⁶⁹ Stokke R., Kristoffersen F.S., Stamland M., Holmen E., Hamdan H. & De Boer L., The role of green public procurement in enabling low-carbon cement with CCS: An innovation ecosystem perspective. *Journal of Cleaner Production*, vol. 363, p. 132451 (August 2022): <https://shorturl.at/nlWWp>

⁷⁰ United Nations, *Transforming our world: the 2030 Agenda for Sustainable Development* (October 2015): <https://shorturl.at/NOS4u>

In 2008, the European Commission defined GPP as “a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured”⁷¹.

Furthermore, as of 2014, the EU Directive on Public Procurement has provided a clear, albeit non-binding, framework for promoting GPP. In particular, Article 67 of the Directive strongly recommends that Member States incorporate environmental and social considerations into the assessment of the “most economically advantageous tender”⁷². Consequently, the 2014 Directive explicitly recognizes the possibility of incorporating environmental criteria into all key stages of a procurement process, namely, the technical specifications, the award criteria, and the contract performance clauses. A critical restriction is that environmental and social requirements must be directly related to the subject matter of the contract, rather than to the supplier⁷³.

However, the inclusion of these criteria remains at the discretion of national authorities and contracting entities. The requirement to apply best price-quality ratio criteria is not mandatory; as a result, the lowest price constitutes the primary award criterion in most EU tenders or, in certain cases, the only criterion at both the tendering and the contract award stages of public procurement⁷⁴. The European Court of Auditors’ special report on public procurement in the EU (2023) indicates that the frequency of using the lowest price as the award criterion increased in most Member States over the period 2011-2021. Particularly in 2021, the contracts awarded based on the lowest bid exceeded 80% of total procurement in 8 Member States (Slovakia, Cyprus, Romania, Lithuania, Greece, Bulgaria, Czechia, and Malta)⁷⁵. Moreover, in 2023, more than 50% of public tenders were awarded on the basis of the lowest price in 20 Member States, with this share exceeding 80% in 10⁷⁴.

As part of the revision of the EU Public Procurement Directive, the European Parliament’s resolution recommends strengthening GPP, emphasizing that “public procurement procedures should encourage and reward innovative and sustainable solutions that can stimulate economic development”⁷⁴. In the same vein, the Letta Report recommends a shift from the lowest price as the sole criterion for awarding public procurement to a holistic approach seeking the best price-quality ratio; this approach aims to incorporate quality, innovation, life-cycle costs, and social and environmental sustainability into bid evaluation⁷⁶. For instance, the European Commission generally applies a weighted approach

⁷¹ European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Public procurement for a better environment (July 2008): <https://shorturl.at/Qel4V>

⁷² European Parliament and Council of the EU, Directive 2014/24/EU of the European Parliament and of the Council of 26 February 2014 on public procurement and repealing Directive 2004/18/EC (2014): <https://shorturl.at/YsJJY>

⁷³ ICLEI - Local Governments for Sustainability, European Secretariat, The Procura+ Manual: A Guide to Implementing Sustainable Procurement, 3rd Edition (2016): <https://shorturl.at/lu6FV>

⁷⁴ European Parliament resolution of September 9, 2025 on public procurement (September 2025): <https://shorturl.at/9VQHd>

⁷⁵ European Court of Auditors, Special Report No. 28/2023: Public Procurement in the EU - Less Competition for Contracts Awarded for Works, Goods, and Services in the 20 Years Up to 2021 (December 2023): <https://shorturl.at/FNlBX>

⁷⁶ Letta Enrico, Much More Than a Market (April 2024): <https://shorturl.at/MT2db>

in the award of public procurement, allocating 30% to cost and 70% to the quality criteria, thereby integrating all the aspects outlined above.

The Draghi report on the future of European competitiveness -published a few months after the Letta Report- incorporates climate policy as a tool of industrial strategy, with the aim of strengthening competitiveness, resilience, energy security, and resource sufficiency. In this context, public procurement policies are employed as both an instrument for achieving the EU's climate goals and a means of creating demand for innovative, low-carbon products manufactured in Europe⁷⁷. More specifically, in the section on energy-intensive industries, the report recommends boosting demand for green products by promoting transparency and introducing standardized environmental criteria in public procurement. To this end, the report further recommends the adoption of a common definition of “green products” across the EU Single Market to avoid conflicting standards, as well as the development of a common methodology for products' carbon footprint assessment.

In March 2026, the European Commission integrated these recommendations into the Industrial Accelerator Act, aimed at accelerating the growth of European industry and increasing demand for low-carbon products manufactured in Europe, including cement⁷⁸. Particularly with regard to the latter, the Act stipulates that at least 5% of the total volume in public procurement must meet low-carbon criteria. These measures are expected to take effect on 1 January 2029, boosting demand for low-carbon cement and promoting investments in decarbonization technologies for the cement industry.

At the same time, a number of recent European policies are establishing a favorable environment for the gradual adoption of GPP in sectors such as construction and industry-related products. In particular, the revised EU Directive on the energy performance of buildings introduces the requirement to calculate and disclose GHG emissions throughout the entire life cycle of new buildings, through Energy Performance Certificates, starting in 2030⁷⁹. Furthermore, Member States are required to adopt national roadmaps and targets for reducing these emissions. The directive does not directly establish binding GPP criteria; nonetheless, the introduced framework provides fertile ground for incorporating carbon footprint criteria into public procurement of construction works, including cement use⁶⁷.

The revised Regulation on the marketing of construction products complements this framework by establishing harmonized rules for the marketing and assessment of construction products in the EU⁸⁰. Although the Regulation does not directly impose strict thresholds, it encourages the development of harmonized standards regarding environmental performance and minimum threshold levels of products such as cement through delegated acts. At the same time, the Regulation on establishing ecodesign

⁷⁷ Draghi Mario, The future of European competitiveness (Part A): A competitiveness strategy for Europe (September 2024): <https://shorturl.at/kbFa6>

⁷⁸ European Commission, Proposal for a regulation of the European Parliament and of the Council establishing a framework of measures for the acceleration of industrial capacity and decarbonisation in strategic sectors and amending Regulations (EU) 2018/1724, (EU) 2024/1735 and (EU) 2024/3110 (March 2026): <https://shorturl.at/5mnDJ>

⁷⁹ Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast), (May 2024): <https://shorturl.at/AJtR2>

⁸⁰ Regulation (EU) 2024/3110 of the European Parliament and of the Council of 27 November 2024 laying down harmonised rules for the marketing of construction products and repealing Regulation (EU) No 305/2011 (December 2024): <https://shorturl.at/l4mOh>

requirements for sustainable products introduces a horizontal framework for numerous categories of products placed on the EU market. These requirements may address, inter alia, the carbon and environmental footprint of products, fostering transparency through tools such as the Digital Product Passport⁸¹. Furthermore, this Regulation provides that, in the event that environmental requirements for cement are not established in a timely manner following the adoption of the Regulation on construction products, the Commission shall adopt delegated acts to set ecodesign requirements for cement no earlier than 31 December 2028 and no later than 1 January 2030. Consequently, this Regulation paves the way for instituting mandatory environmental sustainability requirements into public procurement, thereby strengthening the promotion of low-carbon cement through GPP.

In summary, while the Directive on public procurement allows Member States to integrate environmental criteria, the implementation of GPP remains largely optional. By contrast, both the Regulation on the marketing of construction products and the Regulation on setting ecodesign requirements for sustainable products are more targeted, signaling a gradual shift towards a progressively mandatory and systematic integration of environmental sustainability considerations into public procurement, particularly regarding carbon-intensive sectors such as cement production. The existing EU policy framework thus provides a significant opportunity to stimulate stable demand for low-carbon cement and to support the sector's transition towards a more competitive and climate-neutral model through green public procurement.

National Action Plan for Green Public Procurement

In 2021, Greece adopted its first National Action Plan for Green Public Procurement (GPP NAP), covering the period 2021-2023 and stipulating that it be revised every three years, or earlier if deemed necessary⁸². The Plan provides the institutional framework for the integration of environmental criteria into public procurement and is aligned with the corresponding EU policies. It also includes a monitoring and evaluation mechanism, as contracting authorities are required to record annual quantitative indicators collected via a standardized questionnaire. Authorities are required to report the number and type of public procurement incorporating green criteria, as well as provide feedback on their capacity-building in GPP management⁸³.

Specifically, the first NAP set out both mandatory requirements and quantitative targets for specific categories of procurement, which apply to all contracting authorities, across all levels of government. GPP implementation targets vary by category, ranging from 15% to 80%, with the majority of categories set at 50%. The obligation to apply green criteria is being introduced gradually: initially for central government, subsequently for local authorities, and finally for all contracting entities. The revised NAP, published in 2024, updated the GPP application targets, by lowering overly ambitious binding targets and

⁸¹ Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC (June 2024): <https://shorturl.at/S5v2y>

⁸² Joint Ministerial Decision 14900/2021 - GG 466/B/08.02.2021

⁸³ OECD, Harnessing Public Procurement for the Green Transition: Good Practices in OECD Countries (June 2024): <https://shorturl.at/57kWv>

adjusting upward those set at lower levels in the initial plan. The national targets for 2024 thus fall between 20% and 60%, with most clustering around 50%⁸⁴.

With regard to cement industry products, and cement in particular, the national non-binding targets for GPP application are set at 40% for the “Planning, road infrastructure, construction, and maintenance” and “Planning, office buildings, construction, and management” categories. As these constitute the main categories of public works with high cement consumption, GPP can serve as a powerful policy tool to drive demand for low carbon products in the Greek market.

Recommended Policy Measures for Greece’s GPP National Action Plan

Although the National Action Plan for the promotion of Green Public Procurement is moving in a positive direction, it does not provide sufficient incentives for the adoption and development of decarbonization technologies in the heat production process within the cement industry. Therefore, following the non-binding targets set for construction and infrastructure, the next revision of the Greek GPP plan should incorporate targeted and binding criteria for cement. In this context, GPP could evolve from a horizontal compliance mechanism into a strategic policy instrument for supporting decarbonization technologies in the Greek cement industry while enhancing its competitiveness. This section outlines policy measures and recommendations to support and enable the implementation of the decarbonization technologies described in the preceding chapter.

Development of a national certification system for cement products

The establishment of common, reliable, and widely accepted tools and methodologies for certifying the environmental footprint of cement constitutes a prerequisite for GPP effectiveness. The need for harmonized methodologies and standards is also highlighted in European reports and regulatory texts, such as, inter alia, the Draghi Report and the Regulation on setting ecodesign requirements for sustainable products^{77,81}. These tools ensure the accurate quantification and monitoring of emissions, energy efficiency, and resource use, rendering environmental performance targets clear, measurable, and verifiable. Agreement on common standards enhances transparency, comparability among producers, as well as public procurement reliability, thereby fostering the industry’s green transition. To this end, **a national certification scheme should be established for cement products that meet specific CO₂ emission thresholds per ton of product and specific targets regarding the use of RES-based electricity and thermal energy.** Subsequently, this certification could be introduced as a prerequisite for participation in public procurement tenders, thus, ensuring that only products meeting specific characteristics and emission thresholds are considered for public procurement. The national certification framework can build on existing European or international standards and align with established ecolabels,

⁸⁴ Joint Ministerial Decision 54862/2024 - GG 4102/B/12.07.2024

such as the EU Ecolabel, by incorporating or adopting selected criteria^{85,86}. At present, the EU Ecolabel framework does not provide for a specific product group covering cement as a material. However, the European Commission's decision establishing the criteria for awarding the EU Ecolabel to hard-covering products does include the precast concrete category, stipulating specific emission limits for the cement used in these products, together with methods for quantifying these emissions⁸⁷. The national certification system for cement products is expected to be more effective and fit-for-purpose through alignment with corresponding European initiatives; thus, it should be designed on the basis of the existing framework and periodically revised to reflect changes in the EU Ecolabel criteria for cement products.

Gradual introduction of a requirement to submit an Environmental Product Declaration (EPD) for participation in cement-related public procurement

The non-binding nature of the national target for GPP adoption in the two construction-related categories should be revised, in order to encourage the gradual integration of environmental criteria across all public works tenders. Initially, the non-binding target should be made mandatory and further specified, so as to ensure that **at least 40% of public procurement involving cement or concrete require bidders to provide environmental footprint data** (such as CO₂ emissions per ton of product; embodied energy from non-renewable sources; resource use), without the assessment being required at this stage. **At a subsequent stage, the submission of an Environmental Product Declaration (EPD) should become mandatory for participation in cement-related public procurement.** This measure does not directly contribute to the financing of the proposed technologies; nonetheless, this transitional phase is expected to enable industry and contracting authorities to develop the necessary certification and quantification systems, while improving transparency and comparability across products. At the same time, the data collected through this process will facilitate the development of a national register of environmental characteristics for cement products.

Gradual introduction of mandatory environmental criteria in public procurement in the cement sector

At a subsequent stage, **the aforementioned environmental criteria should become binding, thereby ensuring that procurement for construction materials -and cement in particular- meets specific upper thresholds regarding CO₂ emissions and energy and resource use**, in line with national and European decarbonization targets. Specifically,

⁸⁵ Donatello S., Perez Camacho M.N. & Wolf O., Practical guide for the use of the EU Ecolabel in the green public procurement of hard covering products (September 2024): <https://shorturl.at/Wm84p>

⁸⁶ One Planet network, Good practices on ecolabelling and sustainable public procurement (January 2026): <https://shorturl.at/Hkbn7>

⁸⁷ European Commission, Commission Decision (EU) 2021/476 of 16 March 2021 establishing the EU Ecolabel criteria for hard covering products (March 2021): <https://shorturl.at/FuwaP>

participation in relevant tenders should thus require the mandatory submission of an EPD based on established European or international frameworks, such as EN 15804⁸⁸ or ISO 21930⁸⁹. In the initial implementation phase, minimum thresholds should only apply to the “Global Warming Potential (GWP)” indicator, which measures the embodied CO₂ emissions per ton of product. However, the provision of a complete EPD should be encouraged to promote the development and further enrichment of a national register of environmental performance characteristics for cement products.

The establishment of mandatory environmental criteria can be based on Regulation 2020/852, which establishes the EU framework to facilitate sustainable investments (EU taxonomy)⁹⁰. The EU Taxonomy Regulation establishes six environmental objectives: climate change mitigation, climate change adaptation, the sustainable use and protection of water and marine resources, the transition to a circular economy, pollution prevention and control, and the protection and restoration of biodiversity and ecosystems. For an activity to be classified as sustainable, it must simultaneously fulfill three conditions. Specifically, it must contribute substantially to at least one of the six objectives (Substantial Contribution), do no significant harm to any of the remaining five (Do No Significant Harm principle - DNSH), and comply with minimum safeguards regarding human and labor rights.

At the initial stage of mandatory application of environmental criteria, CO₂ emission thresholds could be set in accordance with the technical screening criteria for Doing No Significant Harm to climate change mitigation, as specified in Annex II of Delegated Regulation (EU) 2021/2139, supplementing the Sustainable Investments Regulation. This threshold corresponds to the median emissions value of existing EU installations, calculated at 0.816 tons CO₂/ton of clinker or 0.530 tons CO₂/ton of cement⁹¹. It is noted that the Greek cement industry already satisfies this limit as the average carbon intensity of its products is 0.808 tons CO₂/ton of clinker, thereby enabling a smooth and gradual adaptation to the requirements of the proposed GPP framework. **In a second stage, emission thresholds should be aligned with the stricter criteria for substantial contribution to climate change mitigation**, which, according to Annex I of Delegated Regulation (EU) 2021/2139, set the minimum eligibility threshold at the average value of the most efficient decile of EU installations, calculated at 0.722 tons CO₂/ton of clinker or 0.469 tons CO₂/ton of cement.

This approach ensures the gradual alignment of public procurement in Greece with the EU’s advanced technical requirements, as well as the acceleration of investments in innovative decarbonization technologies for the cement industry. Nonetheless, the data collected through the implementation of the previous measure may indicate that the participating

⁸⁸ EN 15804 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products - 3rd Edition (2013): <https://shorturl.at/vcUvW>

⁸⁹ ISO 21930 - 2nd Edition (2017): <https://shorturl.at/PF2ys>

⁹⁰ European Parliament & EU Council, Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (June 2020): <https://shorturl.at/NNDFc>

⁹¹ European Parliament & EU Council, Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives (December 2021): <https://shorturl.at/rPwL3>

cement manufacturers are unable to meet the emission threshold criteria set out in Delegated Regulation (EU) 2021/2139. In this case, thresholds should be adjusted every three years to match 90% of the Greek cement industry's performance level, so as to remain ambitious yet realistic. The introduction of minimum thresholds seeks to achieve a gradual yet purposeful reduction in maximum CO₂ emissions per ton of product, with a view to aligning the Greek market with the net-zero emissions targets for 2050. In particular, the implementation of this measure is expected to encourage the immediate adoption of readily available and mature technologies for the decarbonization of the clinker production process.

Establishment of a green cement incentive scheme aimed at advancing technologies with high emission reduction potential

An incentive mechanism should be developed for cement products that outperform the minimum environmental thresholds described in the previous measure via the implementation of innovative technologies to reduce cement production environmental impacts, with the aim of achieving a greater reduction in emissions from this sector. In this context, **a percentage target should be set for cement- or concrete-related GPP that -in addition to meeting the minimum CO₂ emission threshold- is also based on more innovative technologies, such as green hydrogen or green electricity for heat production; energy efficiency optimization solutions; and heat recovery systems.** Under this scheme, and in line with the policy principles outlined in the section on European policies promoting GPP, the awarding of contracts will be based on the criterion of the most economically advantageous tender on the basis of the best price-quality ratio. The environmental and technological performance of products shall be assigned significant weighting relative to cost, thereby ensuring that innovation constitutes a decisive criterion in supplier selection. Specifically, suppliers shall submit detailed environmental product declarations, as well as documentation on clinker production practices. Contracting entities shall apply an evaluation system that rewards bids introducing technological solutions promoting the decarbonization of cement production. This mechanism can be based on an inversely proportional correlation between the Technology Readiness Level of each technology and a relative (fictional) reduction in the tender's financial offer, solely for the purposes of comparative evaluation and ranking. For instance, as reported in the previous section, electrification via plasma heating constitutes the least mature solution (TRL 4) among the technologies under consideration. Under this policy, the financial bid of a supplier utilizing such a technology may be awarded the maximum designated premium during the evaluation of their bid, which will result in a notional reduction of around 8-10% on their bid price for the formulation of the comparative evaluation price. The proposed measure bears similarities to the successful CO₂ Performance Ladder implemented in the Netherlands, as it employs an award mechanism within public procurement procedures to promote environmental and technological performance beyond minimum compliance requirements. While based on a similar rationale, the CO₂ Performance Ladder focuses on the environmental performance of the organization as a whole, whereas the proposed measure aims to incentivize and advance technologies with high emission reduction potential through public procurement. In both cases, environmental performance does not function as an exclusive award criterion; instead, it is integrated as a competitive advantage factor through a notional financial discount for the formulation of the tender's comparative

evaluation price, which increases in correlation to the ambition of emission reduction practices⁸³. This mechanism could contribute to accelerating the maturation and adoption of low-emission technologies in the Greek cement industry, while indirectly fostering technological innovation and competitiveness.

Provision of financial incentives to cement producers achieving high environmental performance

A mechanism should be established to provide financial incentives for the supply of cement products that significantly exceed minimum GPP requirements. As previously mentioned, within the framework of GPP, environmental footprint data for each type of cement should be recorded and compiled into a national register of environmental characteristics for cement products. Based on this data, **manufacturers offering cement products with CO₂ emissions below the average CO₂ emissions of the previous year's products should receive a one-off financial incentive.** The latter shall exclusively finance existing or future investments in innovative technologies with high emission reduction potential for the cement industry. This aid shall be calculated based on the price of CO₂ in the European Emissions Trading System (EU ETS) for each ton of CO₂ reduction achieved below the average of the previous year. This policy measure provides a transparent and measurable incentive for reducing emissions beyond minimum requirements, thereby both promoting and rewarding suppliers' continuous improvement. At the same time, it may constitute an indirect subsidy for the installation and operating costs of the most complex and innovative technologies aimed at cement decarbonization.

Provision of financial support to contracting authorities achieving higher levels of green public procurement

Under the proposed measure, contracting authorities that successfully implement GPP may receive additional funding or an increased budget for projects that comply with environmental criteria. The targets already set for each authority under the national GPP strategy shall serve as a reference point and basis for the implementation mechanism. Specifically, **contracting authorities should be assessed annually against these targets, and additional funding should be provided to those exceeding established benchmarks.** This approach is aligned with successful international examples. For instance, the performance-based reward system applied in the Republic of Korea provides for the annual evaluation of public organizations based on performance indicators; the latter include the degree of GPP implementation, measured as the share of green procurement in total public procurement. The higher an organization's GPP performance, the greater the financial reward it receives, either in the form of ad hoc annual funding or through targeted environmental grants to consistently high-performing authorities⁸³. The proposed measure rewards the full integration of environmental standards into public contracts through positive financial incentives for contracting authorities, thus, in turn, promoting the systematic application of GPP in cement procurement.

Conclusions

The cement industry constitutes a major source of industrial carbon dioxide emissions worldwide; therefore, this sector is key to achieving the legally binding target of climate neutrality by 2050, as set out in the Climate Laws of both the EU and Greece. Achieving this target requires a radical shift in both the energy mix and the operating model of the cement industry. At the same time, the latter is undeniably among the most challenging sectors to decarbonize, due to its high energy footprint and the emissions inherent to the clinker production process. The gradual elimination of free carbon dioxide emission allowances by 2034, combined with the sector's heavy reliance on coal and its derivatives, renders the cement industry particularly vulnerable to environmental and regulatory pressures. Measures to decarbonize the energy mix and improve the sector's energy efficiency have been implemented in recent years; nonetheless, progress toward reducing emissions from cement products has been modest.

The gradual transition to a clinker production process with a low carbon footprint requires a combination of short-term and long-term measures. In this context, carbon capture, utilization, and storage technologies are identified as an important tool for reducing calcination emissions, which cannot be eliminated through interventions in the production energy mix. However, these technologies are not a panacea. Firstly, they aim to capture emissions after they are produced rather than reduce emissions at the source. Moreover, they are associated with particularly high energy and economic costs. Finally, their implementation is associated with a series of technical and economic challenges, casting doubt on their success in reducing the carbon footprint of heavy industry. Due to these factors, their potential as the sector's primary decarbonization strategy is limited.

Decarbonization policies should prioritize interventions that directly reduce emissions at the source. Energy efficiency improvements, as well as waste heat recovery, are technically mature and economically viable solutions yielding immediate results. Technologies aimed at replacing fossil fuels with alternative, comparatively low-emission fuels derived from processed waste or biomass have emerged as the most mature and financially viable option. Nonetheless, these alternatives offer relatively small environmental benefits, while also failing to address the structural issue of the carbon-intensive heat production inherent in clinker manufacturing.

In the medium-term horizon, the use of green hydrogen as a fuel and the electrification of the production process can significantly contribute to the successful and sustainable decarbonization of the sector. These technologies are currently at an early stage of maturity; however, they can deliver substantial emission reductions, particularly when the supplied hydrogen and electricity are produced by RES.

Consequently, the successful transition of the cement industry to a low-carbon model requires a coherent policy framework that links technological advancements with the country's industrial strategy. In this context, Green Public Procurement can serve as an important policy instrument for promoting and indirectly supporting investments in CO₂-reduction technologies. Targeted GPP implementation can boost domestic demand for low-carbon cement in public procurement, which accounts for more than 30% of total cement demand. The cement industry can thus be transformed from a high-emission sector into a

field for the deployment of innovative solutions, thereby contributing to both improved economic competitiveness and the achievement of national and European climate targets. The establishment of stable and sufficient demand for low-emission products is key to mobilizing investment and ensuring the economically viable decarbonization of the sector.

The Green Tank's policy recommendations address the aforementioned requirements and challenges through a gradual yet coherent approach, which includes the following measures:

- the **establishment of a national certification system** for cement products
- the mandatory **submission and assessment of environmental data**
- the introduction of **mandatory minimum environmental specifications** for cement products in public procurement
- the **prioritization of environmental and technological performance** over low economic cost alone,
- the **provision of financial incentives for cement product manufacturers** that achieve significant emission reductions, and
- the **provision of financial rewards for contracting authorities** that exceed the targets set out in the GPP national action plan.

The implementation of these policy measures can have a multiplier effect, accelerating the adoption of innovative low-emission technologies, such as the use of green hydrogen as a fuel and the electrification of the clinker production process; this development, in turn, shall enable economies of scale for green cement products while enhancing the international competitiveness of the Greek cement industry. At national level, beyond being a climate policy instrument, the systematic application of Green Public Procurement is key to a comprehensive industrial strategy for the transition towards a climate-neutral economy.

Finally, the Industrial Deep Decarbonization Initiative (IDDI) is an international platform that brings together governments, businesses and organizations in collaborative efforts aimed, inter alia, at setting targets for green public procurement, providing incentives for investment in low-emission products, and developing markets for low- and near-zero-emission materials, such as cement. Within the framework of a coherent national strategy for the abatement of the cement sector, **Greece's participation in the IDDI** would represent a key milestone, while also strengthening the country's role in shaping global decarbonization policies for heavy industry.

