A Low Carbon Pathway for the Cement Sector in the Republic of Türkiye

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Contents

Abbreviations and Acronyms

3D	Three Dimensional
AI	Artificial Intelligence
BAT	Best Available Technology
$Ca(OH)_2$	Calcium Hydroxide
$CaCO_3$	Calcium Carbonate - Limestone
CAGR	Compound Annual Growth Rate
CaO	Calcium Oxide
Capex	Capital Expenditure
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CEIS	Cement Industry Employers' Association
CEMBUREAU	European Cement Association
CO_2	Carbon Dioxide
Dr	Doctor
EBRD	European Bank for Reconstruction and Development
ECRA	European Cement Research Academy
ERMCO	European Ready Mixed Concrete Organization
ETS	Emission Trading System
EU	European Union
FTS	Frontier Technologies Scenario
GCCA	Global Cement and Concrete Association
GHG	Greenhouse Gas
Gt	Gigatonnes

GWh	Gigawatt Hour
H_2	Hydrogen
H_2O	Water
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
Kcal	Kilocalorie
kg	Kilogram
kWh	Kilowatt-hour
LCP	Low Carbon Pathway Scenario
LULUCF	Land Use, Land Use Change and Forestry
M&E	Monitoring and Evaluation
MBT	Mechanical-Biological Treatment
MJ	Megajoule
MoIT	Ministry of Industry and Trade
MPA	Mineral Products Association
MPP	Mission Possible Partnership
Mt	Million Tonnes
NPV	Net Present Value
OAIB	Central Anatolian Exporters Association
OIZ	Organized Industrial Zones
OpEx	Operational Expense
ORC	Organic Rankine Cycle
R&D	Research and Development
RDF	Refuse-Derived Fuel

RMC	Ready Mixed Concrete
SCM	Supplementary Cementitious Materials
SF_6	Sulphur Hexafluoride
SPP	Solar Power Plant
SPS	Stated Policy Scenario
SRF	Solid Recovered Fuel
SteerCo	Steering Committee
TEIAS	Turkish Electricity Transmission Corporation
TENMAK	Turkish Energy, Nuclear and Mineral Research Agency
THBB	Turkish Ready Mixed Concrete Association
TOBB	Union of Chambers and Commodity Exchanges of Türkiye
TR	Türkiye
TUBITAK	Scientific and Technological Research Council of Türkiye
Türkçimento	Turkish Cement Manufacturers' Association
TurkStat	Turkish Statistical Institute
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VDZ	German Cement Works Association
VÖZ	Austrian Cement Industry Association
WHR	Waste Heat Recovery
WoM	Without Measures
WPP	Wind Power Plant
YoY	Year-over-Year

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Introduction

Advances in the International Climate Regime have been fostered by the UN-backed, science-based emission reduction targets. Climate targets determined on a supranational level have been incorporated into binding policies through key international and regional initiatives such as the Paris Agreement and the European Green Deal. The Paris Agreement is a landmark example of international cooperation on the mitigation of climate change, binding parties to limit their GHG emissions. The Agreement calls on counties to work together to adapt to the impacts of climate change, and to strengthen their commitments over time. This project aims at supporting the deployment of low carbon options for the industry in line with Türkiye's 2053 net zero target.

The European Green Deal is the EU's ambitious and comprehensive plan to become the first climate-neutral continent and fundamentally transform the European Economy.[1] The Carbon Border Adjustment Mechanism, a key policy tool under the deal, aims to prevent carbon leakage by imposing a price on the carbon emitted during the production of carbon intensive goods entering the EU. Thereby, the mechanism aims to encourage cleaner industrial production in non-EU countries and drive global emissions down. Global efforts towards limiting the global warming to 1.5°C above preindustrial levels[2] have intensified and increasingly focused on hard-to-abate[3] (must abate) sectors, one of which is the cement sector.

Being the key ingredient of concrete –world's most used human-made material-, cement sector is of strategic importance to virtually all countries. Along with this strategic importance, cement sector is critical for global decarbonization and green transformation agenda accounting for approximately 7% of global CO_2 emissions.[4]

Türkiye's geographical location and rapidly growing population have led to a surge in construction activities including mega infrastructure projects, increasing the demand for cement. As a result, the cement industry has become a vital driver of the construction sector and a key player in supporting urbanization and economic development. At the time of writing this report, Türkiye's cement industry serves with 56 integrated cement plants and 21 grinding plants[5], manufacturing more than 77 million tonnes of cement (2022).[6]

Along with the global outlook, the Turkish cement sector also accounts for a significant share of national GHG emissions. According to Türkiye's Greenhouse Gas Inventory, as of 2021, energy related glass, cement and ceramic production emissions stood at 32.7 million tonnes of CO_2 while IPPU (Industrial Processes and Product Use) related cement emissions were 44.2 million tonnes of CO_2.[7] Due to the risks it may face in the near future, steps need to be taken at the technological and policy level to decarbonize the sector.

Türkiye ratified the Paris Agreement in 2021 to reach net zero by 2053, and the Carbon Border Adjustment Mechanism (CBAM), reporting for which starts in October 2023, will require Türkiye's exporters to take immediate action to report and reduce their direct and indirect CO_2 emissions. Due to that, high emitting cement is committed to reducing these emissions through ongoing decarbonization efforts.

[1] European Commission, Delivering the European Green Deal

[2] United Nations Climate Change, The Paris Agreement.

[3] The term "hard-to-abate" sectors generally refers to industries or activities that are particularly challenging to decarbonize or reduce their greenhouse gas emissions. These sectors tend to rely heavily on fossil fuels and often have limited alternatives available.

[4] Retrieved from: https://gccassociation.org/news/global-cement-and-concrete-industry-announces-roadmap-to-achieve-groundbreaking-net-zero-co$_2$-emissions-by-2050/

[5] Retrieved from: https://www.turkcimento.org.tr/tr/uye_fabrikalar

[6] TURKSTAT. Production values cover the total Türkiye's cement industry.

[7] Türkiye's Greenhouse Gas Inventory, 1990-2021. Retrieved from: https://enerji.gov.tr//Media/Dizin/EVCED/tr/%C3%87evreVe%C4%B0klim/%C4%B0klimDe%C4%9Fi%C5%9Fikli%C4%9Fi/UlusalSeraGaz%C4%B1EmisyonEnvanteri/Belgeler/Ek-1.pdf

This project, financed by EBRD, with the Ministry of Industry and Technology as the main beneficiary and carried out under the leadership of PwC Türkiye Consortium, aims to support and contribute to climate related policy actions in line with national and Türkiye's cement sector's decarbonization targets. The Steering Committee is formed in order to reflect the views of all sector stakeholders in the most accurate and complete way. The Ministry of Industry and Technology, The Ministry of Energy and Natural Resources, The Ministry of Environment, Urbanization and Climate Change, the Ministry of Trade, The Ministry of Labour and Social Security, and Scientific and Technological Research Council of Türkiye (TUBITAK) and related other public institutions as well as Turkish Cement Manufacturers Association and Cement, Glass, Ceramics and Soil Products Exporters' Association (under OAIB) are the members of the Steering Committee.

During the development of this roadmap for Türkiye's cement sector, three Steering Committee Meetings were organized to share the project outputs with the related stakeholders and collect their feedback effectively. In addition to the meetings mentioned, many other focused stakeholder discussion meetings were also held to discuss model results and policy recommendations.

Achieving significant reductions in emissions will require a combination of measures that are tailored to the specific circumstances of each cement producer. However, the roadmap set here will enable policymakers and industry actors to benchmark their activities against a data-backed transition scenario. Following the adoption of this roadmap, this report can serve as foundation to developing investment plan and platform that helps to accelerate implementation of actions recommended by bringing together relevant actors and sharing a common vision for the sector.

Executive Summary

Executive Summary

Industrial decarbonization policies will be playing a crucial role in Türkiye's emissions reduction performance in the coming decades. This study aims at supporting Türkiye's cement sector in development of near and long-term decarbonization roadmap and the corresponding investment requirements.

This project targets to set out comprehensive roadmap for the progressive decarbonization of Türkiye's cement sector, in line with Türkiye's Government's overall sustainable development and decarbonization goals. This study delves deeper into Türkiye's cement industry, understands and benchmarks current policies and initiatives, models GHG emissions under several scenarios and detects sectoral policies, technology and investments in the line with the Türkiye's Government's overall decarbonization strategy and international undertakings.

The final output of this project is the "Decarbonization Roadmap", consisting of a set of optimal recommendations on policies, technologies, legislative framework and regulations, institutional arrangements/capacity building and budget planning process to lead the decarbonization of the cement sector in Türkiye in line with scenarios and national targets.

Policy recommendations that make up the "Decarbonization Roadmap" are essentially derived from sector analysis, expert opinion, and modelling & scenario analysis. The set of recommendations generated have been opened to several rounds of feedback from the Steering Committee members and wider sector representatives.

Key Findings and Results:

Global Cement Production and Trade

The total volume of cement production worldwide amounted to **4.1 billion tonnes** in 2022. The upward trend in cement production since 2018 has been disrupted by a downward trend in 2022 mainly due to the contraction in China's cement production, the largest cement market in the world. As of 2022, China represents 51.1% of global cement production, while **Türkiye's share in total cement production is 1.9% (77 million tonnes).**[8]

Global cement export[9] volume amounted to **171.4 million tonnes,** demonstrating a decrease from 209.6 million tonnes in 2018, a 4.9% CAGR contraction in the respective period in 2022. While Vietnam was the leading cement exporter in 2019 and 2020, **Türkiye took the place of Vietnam as the leading exporter in 2022 with a share of 16.9% (29 million tonnes) in quantity terms.** In 2022, Vietnam ranks second with a share of 15.8% (27.0 million tonnes) and Japan ranks third with a share of 5.6% (9.6 million tonnes) in total global cement exports.[10]

Global cement exports valued **13.2 billion dollars in 2022.** Even though global cement exports contracted by 2% yoy in value terms last year, they grew at a CAGR of **3.34% in the period of 2018-2022.** According to country rankings, **Vietnam ranks first with a share of 13.8%, while Türkiye and Germany rank second and third respectively with a share of 12.6% and 4.5% in value terms.** Türkiye's 12.6% share corresponds to approximately 1.7 billion dollars in 2022.[11]

An Overview of Türkiye's Cement Sector: Production and Exports

Production and Capacity

In Türkiye, **72.4 million tonnes of clinker and 77.0 million** tonnes of cement were produced in 2022.[12] In the period of 2015-2022, cement production and clinker production in the country achieved growth at a CAGR of 0.8% and 2.3%, respectively.

Türkiye's cement sector meets domestic and foreign demand with **56 integrated cement factories** and **21 grinding plants** with a production capacity of 147.2 million tonnes of cement and 96.6 million tonnes of clinker in 2022.[13] Figures in 2022 show cement and clinker capacity utilization rates are 52.3% and 74.9%, respectively.[14]

Export

Türkiye's cement exports were 12.4 million tonnes in 2013 and reached **27.2 million tonnes in 2022.[15]** Although the cement sector exports have grown at a CAGR of 9.1% in total in the last decade, the main growth was achieved between 2015-2020 with a CAGR of 23.9%. In 2020, Türkiye's cement exports reached approximately 31.3 million tonnes, the highest level in the last 10 years (2013-2022).[16]

[8]CEMBUREAU. Activity Report 2022, 2021, 2020, Türkçimento, OAIB, PwC Analysis
[9]Global cement exports include product groups regarding cement industry covered by CBAM
[10]Trademap. Global cement exports are calculated based on the product groups of the cement sector covered by CBAM.
[11]Trademap. Global cement exports are calculated based on the product groups of the cement sector covered by CBAM.
[12]Türkçimento, TURKSTAT, PwC Analysis. Production values cover the total Türkiye's cement industry.
[13]Türkçimento, OAIB, PwC Analysis. Capacity values cover the total Türkiye's cement industry.
[14]Türkçimento, TURKSTAT, PwC Analysis
[15]Products covered by CBAM are instead based on national data.
[16]TURKSTAT

The United States of America (USA) is the leading country in Türkiye's cement exports in 2022 with a share of 36.0%, followed by Israel with a share of 11.7%. Syria ranks third with a share of 5.1% in the same year. The USA has maintained its leading position for Türkiye's cement exports in the last three years.[17]

Türkiye's exports to EU-27 countries have increased steadily, especially after 2018. **In the period between 2018 and 2022, Türkiye's exports to EU countries increased at a CAGR of 37.5% in terms of quantity.** Besides, the share of EU countries accounted for 16.6% of total cement exports (in tonnage) in Türkiye.[18]

Total cement products, covered by CBAM, imports of the European Union countries (EU-27) amounted to 23.2 million tonnes in 2022.[19] The volume of **Türkiye's exports to EU countries became 4.8 million tonnes in 2022 and the share of Türkiye's cement exports in EU cement imports was 20.8%.**

In addition, in value terms, the share of Türkiye cement exports in total EU cement imports accounted for 8.7% in 2022. This share corresponds to approximately 266 million dollars.[20]

Snapshot of the Emissions from the Global Cement Sector

Around the globe, CO_2 emissions from the cement sector have continued to rise, except for the slight decline in 2015, mainly due to a contraction in Chinese market in the respective year. Process emissions from cement production process, which was 1.25 gigatonnes of CO_2 in 2010, grew with a CAGR of 2.2% and **reached the 1.67 gigatonnes in 2021.**[21]

The highest source of process emissions from the cement production process is China, as the largest cement producer country in the world. China is responsible for 51% (853 million tonnes of CO_2) of cement process emissions worldwide in 2021. **Türkiye is the 5th highest emitter in the world industrial processes and product use (IPPU) related emissions caused by cement production with the share of 2.6% in 2021 (44.2 million tonnes of CO_2).**[22]

Potential for Decarbonization in Türkiye's Cement Industry

The use of alternative raw materials to reduce the clinker/cement ratio and low carbon alternative fuels will be vital to achieve the decarbonization targets of the industry. Ensuring the establishment of Mechanical-Biological Treatment (MBT) facilities will support the industry's emission reduction efforts. Besides, potential use of hydrogen as fuel in the cement industry in line with Türkiye's recent national hydrogen economy development strategy[23], will also help reduce the total industry emissions.

The most effective technological improvement for the sector to achieve the 2053 net zero target is the **development of carbon, capture and storage (CCUS) technology.** Reduction of process emissions in the cement sector is limited and CCUS technologies will play a major role in meeting the industry emissions reduction goal. Therefore, closely following R&D efforts and as well as studies conducted in other nations will be essential to meeting the emission targets outlined in the mitigation scenarios.

The project results that if no mitigation measures and technological transformation are considered **(WoM scenario),** emissions are expected to **reach a peak level of 89.4 million tonnes (Scope 1+ Scope 2) by 2053,** from the level of 76.6 million tonnes (Scope 1+ Scope 2) in 2021.

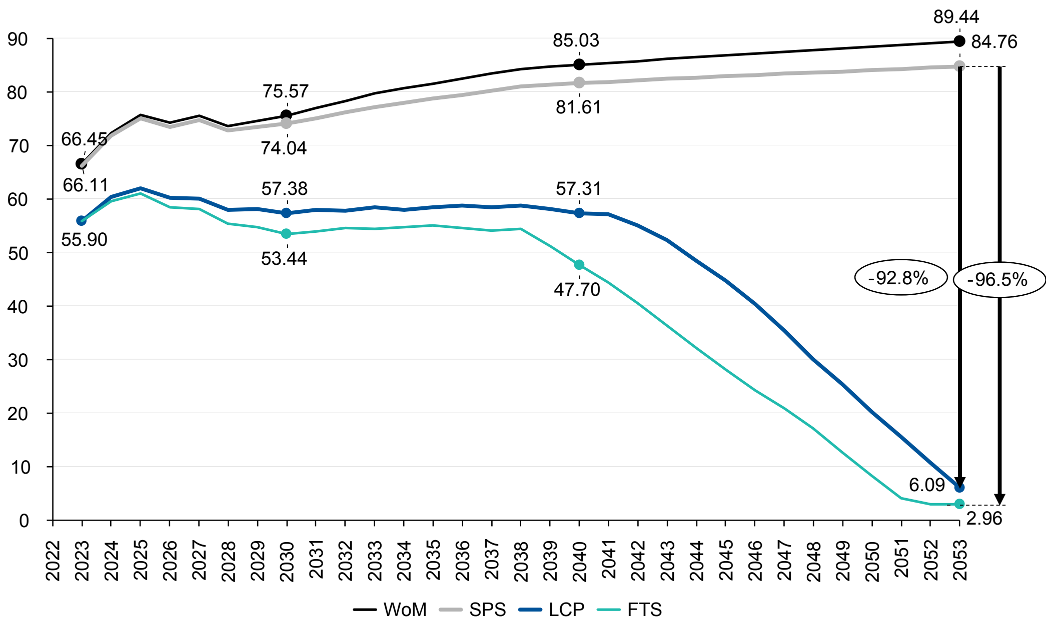
According to the Stated Policy Scenario (SPS), which assumes no additional new technology investment, **84.8 million tonnes of CO_2 emissions (Scope 1+ Scope 2) are expected to be produced in 2053** under the assumptions of the country's investment objectives in renewable energy, the reduction of the grid emission factor, and the announced climate policies.

The Low Carbon Pathway (LCP) scenario, which is the least-cost and optimal mitigation scenario in which all feasible low-carbon technologies as well as financial and regulatory policies are introduced, is projected to achieve **a 92.8% CO_2 emission reduction by 2053** compared to the SPS scenario and release **6.1 million tonnes** of emissions (Scope 1+ Scope 2).

[17]TURKSTAT
[18]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis
[19]Represents products (Aluminous cement, cement clinkers, white portland cement, whether or not artificially colored, other portland cement and other hydraulic cement products) within the scope of CBAM.
[20]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis
[21]Our World in Data, Türkiye's Greenhouse Gas Inventory, PwC Analysis
[22]Our World in Data, Türkiye's Greenhouse Gas Inventory, PwC Analysis
[23]Ministry of Energy and Natural Resources (2023). Türkiye Hydrogen Technologies Strategy and Roadmap Report

In the Frontier Technologies Scenario (FTS), which has more aggressive emission reduction targets compared to the LCP scenario, **3.0 million tonnes of emissions (Scope 1+ Scope 2) are emitted in 2053,** while **a reduction of 96.5%** is achieved compared to the SPS.

Figure 1. Türkiye Total Cement Sector Emission Projections by Years (Scope 1 and Scope 2, Million Tonnes CO_2)[24 25]



Key decarbonization levers such as **recarbonation, efficiency in concrete, materials and design, efficiency in the use of thermal energy and electricity, the use of new and alternative fuels and carbon capture and storage technology** are vital to reach the net zero target in the LCP scenario. The impact of concrete efficiency has been included in both fuel, electricity and process emissions in the mitigation scenarios based on the effect of the reduction in cement demand and the associated reduction in cement production.[26]

Figure 2 illustrates the sources of emission reductions. In 2053, an emission reduction of **5.2% is estimated to be achieved due to grid emission** improvements, followed by the **recarbonation leverage, which is reduced by 13.5%** from Business-as-Usual scenario. Subsequently, total emissions before technological improvements and fuel switch are projected to reach 84.8 million tonnes CO_2 in SPS in 2053. **23.7% of the additional emission reduction is attributable to thermal efficiency, electricity efficiency and the use of hydrogen and alternative fuels.**

The impact of **CCUS technology is only on Scope 1 emissions (50.4 million tonnes) and is projected to reduce 50.7%** of total emissions compared to the WoM scenario. This is equivalent to a projected reduction of 45.4 million tonnes of emissions with CCUS in the LCP scenario. As in the case of the other cement decarbonization roadmaps, **CCUS has also the highest share among the decarbonization levers** in Türkiye's LCP.

As a result, with the impact of all these levers and climate policies such as the emissions trading system, **6.1 million tonnes of CO_2 emissions (Scope 1+ Scope 2) are projected to occur after CCUS** in the LCP scenario, which corresponds to 93.2% reduction compared to the WoM scenario.

[24]PwC Analysis
[25]The impact of one of the emission reduction levers, the recarbonation lever, is taken into account in the mitigation scenarios. Therefore, in comparison to the reference scenario, differing emission amounts are anticipated in 2023.
[26]PwC Analysis. CCUS mitigation only covers Scope 1 emissions. Emissions from electricity use are not included.

Figure 2. Cement Decarbonization Roadmap for LCP Scenario in 2053 (Scope 1+Scope 2 Emissions, Million Tonnes)

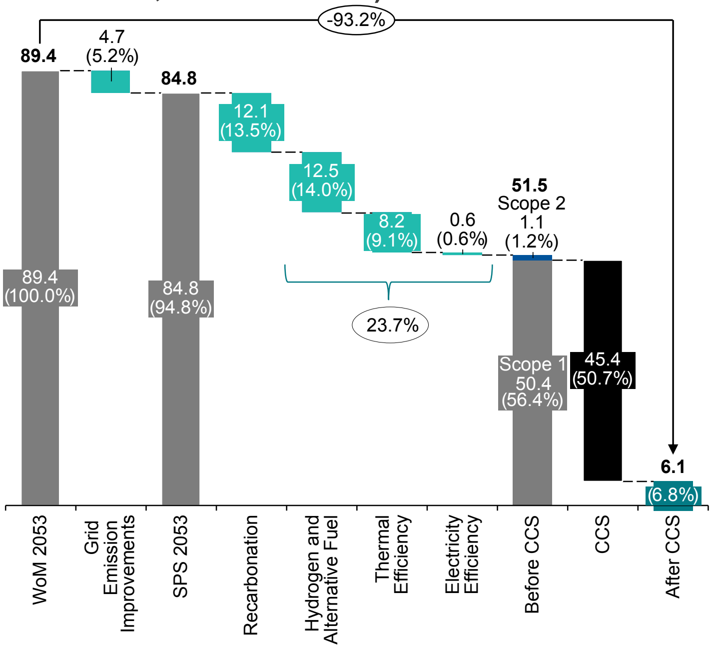
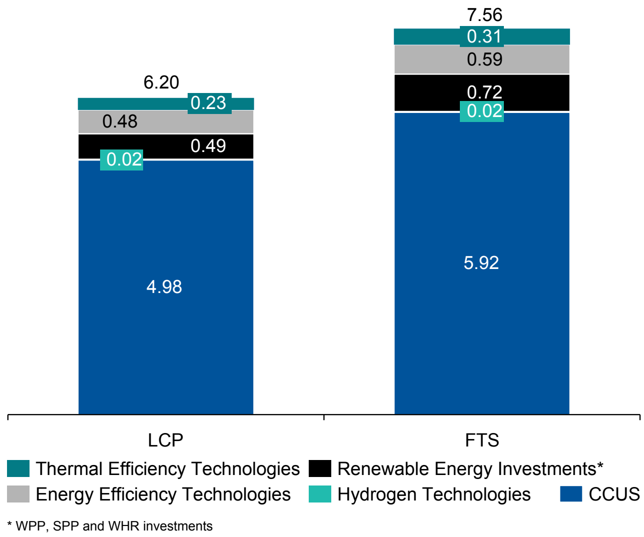


Figure 3. Net Present Value of Total Investments, 2023-2053 (Billion Dollars)



Investment Requirements for the Transition of the Industry

The modelling results suggest that Türkiye's cement sector should ensure **a shift to alternative raw materials and fuels as well as achieve technological transformation** in order to reach the ambitious emission reduction targets.

CCUS investments in particular are critical for the sector to reach the net zero emission target. The total nominal investment cost of the transition of Türkiye's cement industry is calculated as **29.8 billion dollars for LCP and 30.7 billion dollars for FTS scenarios** for the next 30 years.

The net present values (NPV) of investment costs estimated for the next 30 years are estimated to be around **6.2 billion dollars and 7.6 billion dollars in the LCP and FTS scenarios,** respectively.[27]

The NPV of CCUS's total investment is **4.98 billion dollars and 5.92 billion dollars** in the LCP and FTS scenarios, respectively also considering the capture, transportation and storage costs. Noting that, in the sectoral decarbonization cost projections, costs associated with processes such as establishment of waste and storage facilities are excluded in the modeling study.

It is crucial to underline the fact that before the implementation of CCUS, in cement, steps such as increasing the use of additives instead of clinker and increasing the use of alternative fuels to reduce emissions have an important position in the emission reduction of the sector.

While it is possible to reduce emissions with other methods before CCUS, the investment values differ between sectors depending on the changes in the usage rates of innovative decarbonization technologies. The most important issue for achieving emission targets is supply and availability of materials, and these issues are discussed in detail in the policy recommendations section.

Türkiye's cement sector decarbonization trajectories highlight the need for development of effective financing mechanisms and plans. Highlighting the volume of investment needs, the cement industry and policy makers should start developing large-scale investment schemes starting from early years. Therefore, measures to boost the mobilization of additional funds should be prioritized immediately to enable the cement sector to accomplish the necessary technological transformation in the medium to long term. Policymakers and financial institutions need to collaborate and develop financing mechanisms so Türkiye's cement sector can access scaled-up capital flows to foster decarbonization investments.

[27]Investment costs for the period 2023-2053 are calculated as NPV with a discount rate of 7%.

Proposed Policy Steps over the Next 30 Years for a Low Carbon Cement Sector

Decarbonization of the cement sector requires targeted work across intertwined policy areas. The holistic policy set devised in this project is based on:

- Sector specific information and assumptions shared by key project stakeholders (representing official organizational views).
- The project expert's opinion and academic research on the best applications for cement sector decarbonization.
- Model and scenario analysis results.

The resulting policy recommendations are mapped to two key policy themes: **A) Input & technology** and **B) Policy & market.** The policy areas (may also be referred to as decarbonization levers) mapped to these high-level themes are summarized as follows.

High - Level Policy Themes

Input & Technology	Policy & Market

Specific Policy Areas

Input & Technology:

1. Reducing Clinker Use in Cement Production
2. Carbon Capture, Utilization and Storage Technologies (CCUS)
3. Waste Heat Recovery
4. Alternative Fuel Use
5. Green Energy
6. Process Improvement
7. Inclusive Employment and Upskilling / Reskilling of Labor Force
8. Material Efficiency in Construction
9. Recarbonation

Policy & Market:

1. R&D
2. ETS
3. Trade Models
4. National Policy Documents
5. Green Transformation Finance
6. Collaborations
7. Industrial Symbiosis

Phases

- Phase 1 (2023 -2025)
- Phase 2 (2026 -2033)
- Phase 3 (2034 -2038)
- Phase 4 (2039 -2053)

Action Areas

- Regulation
- Investment
- Incentive & Finance
- Capacity Building

Stakeholders

- Responsible / Coordinating Institution
- Related Institutions

A) Input & Technology Related Policies

A.1) Reducing Clinker Use in Cement Production: These policies cover actions designed to increase and promote the use of alternative materials as cement additives to reduce clinker/cement ratio.

A.2) Carbon Capture, Utilization and Storage (CCUS) Technologies: These policies cover actions on the integration of CCUS into the production process, particularly when alternative decarbonization solutions prove inadequate. This section also outlines the necessary actions to enhance the legal, financial, and technical frameworks essential for integrating CCUS into cement production.

A.3) Waste Heat Energy Recovery: These policies cover the actions necessary to enhance existing incentive systems for the establishment of waste heat recovery systems to reduce energy consumption in cement plants.

A.4) Alternative Fuel Use: These policies cover scientific, technical, and financial actions as well as trade policies to ensure the availability of alternative fuels such as refuse derived fuel, solid recovered fuel, treatment sludges with lower emissions that can be used to reduce energy-related emissions in cement plants.

A.5) Green Energy: These policies cover actions necessary to explore the use of green energy sources and to prepare the necessary infrastructure for further penetration of renewable energy sources. Policies also involve the formulation of medium to long term strategies for the widespread deployment of green H_2 for commercial purposes.

A.6) Process Improvement: These policies cover actions on the utilization of best available techniques (BAT) in cement plants to increase energy and process, integrating technological transformation solutions and conducting studies to reduce electrical and thermal power consumption.

A.7) Inclusive Employment and Upskilling / Reskilling of Labor Force: These policies cover actions on conducting studies to train the workforce with new qualifications and skills within the scope of the green transformation process, as well as implementing training programs to ensure equal opportunities for all. The policies also provide options for awareness raising of sector stakeholders on green and digital transformation.

A.8) Material Efficiency in Construction: These policies cover actions regarding the utilization of low-carbon cement and promotion of material efficiency in ready-mixed concrete production and construction sites.

A.9) Recarbonation: These policies cover inclusion of recarbonation in the calculation and verification of GHG emissions from cement production to promote decarbonization.

B) Policy & Market Related Policies

B.1) Research & Development (R&D): These policies cover dissemination of R&D and innovation incentives for green transformation of the cement sector, particularly research of innovative binders for the production of low-carbon concrete and cement.

B.2) Emissions Trading System (ETS): These policies cover actions on establishment of a Türkiye's ETS, a major policy lever to lower CO_2 emissions. Policies also outline actions such as incentivizing green transformation for those operating in the cement sector and providing free allowances for selected sectors.

B.3) Trade Models: These policies cover actions on analyzing possible trade shifts and market changes and implementing necessary responses to protect the competitiveness of the cement sector.

B.4) National Policy Documents: These policies cover actions on harmonization of relevant legislation related to green transformation with the EU, and the enactment of regulations to promote the use of low-carbon cement by the public and private sectors.

B.5) Green Transformation Finance: These policies cover actions on conducting studies to ensure that the cement sector benefits from green transformation financing supports.

B.6) Collaborations: These policies cover actions on establishment of an ecosystem addressing the sectoral decarbonization targets, as well as enhancing collaboration between the sector stakeholders.

B.7) Industrial Symbiosis: These policy actions cover development of an industrial symbiosis network to increase the utilization of waste and by-products from different sectors in cement production and increase product circularity.

A more detailed discussion of these policy actions, including identification of the key stakeholders that can or should take responsibility for the policy actions may be found in *"Section 3. National Policy Landscape and Roadmap for Progressive Decarbonization of Türkiye's Cement Industry"* of this document.

1 Current Situation and Benchmark Analysis

1. Current Situation and Benchmark Analysis

1.1. Overview of the Cement Industry's Current Status

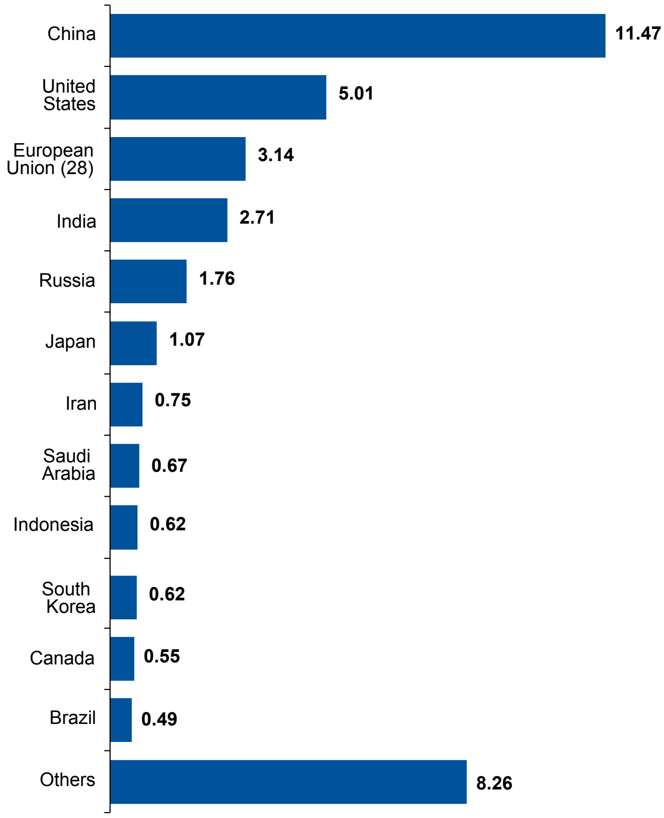
1.1.1. Global and National CO_2 Emissions

Global CO_2 Emissions by Countries

GHGs, or greenhouse gases, are gases that are present in the Earth's atmosphere and have the ability to trap heat.[28] This trapped heat leads to the greenhouse effect, which is a natural process that keeps the Earth's temperature within a certain range, allowing it to support life. However, human activities have significantly increased the concentrations of these greenhouse gases in the atmosphere, leading to an enhanced greenhouse effect and global warming. The most common human-caused greenhouse gas is carbon dioxide (CO_2). It is released primarily through the burning of fossil fuels (coal, oil, and natural gas) for energy, as well as through deforestation and some industrial processes. Global greenhouse gas emissions have followed an increasing trend since the beginning of the 21st century, mainly due to the increase in CO_2 emissions from China and other emerging economies. As a result, atmospheric concentrations of greenhouse gases have increased significantly, reinforcing the natural greenhouse effect, which can adversely affect life on earth.[29]

About 65% of CO_2 emissions come from 4 countries and the EU28. The Figure 4 illustrates fossil fuel and industry related emissions emitted by countries. The top 5 emitters are China, the US, the EU28, India and Russia, and global CO_2 emissions from fossil fuel and industry reached 37.1 Gt CO_2 in 2021. China remains the world's largest carbon emitter, responsible for 31% of all emissions. The second-rank USA responsible for 13% of the global CO_2 emissions while EU responsible for 8.5%. In 2021, Türkiye has caused 0.45 gigaton of CO_2 and responsible for 1.2% of the global CO_2 emissions.[30]

Figure 4. Most CO_2* Emitting Countries, 2021 (Gigatonnes CO_2)[31]



*Fossil fuel and industry emissions

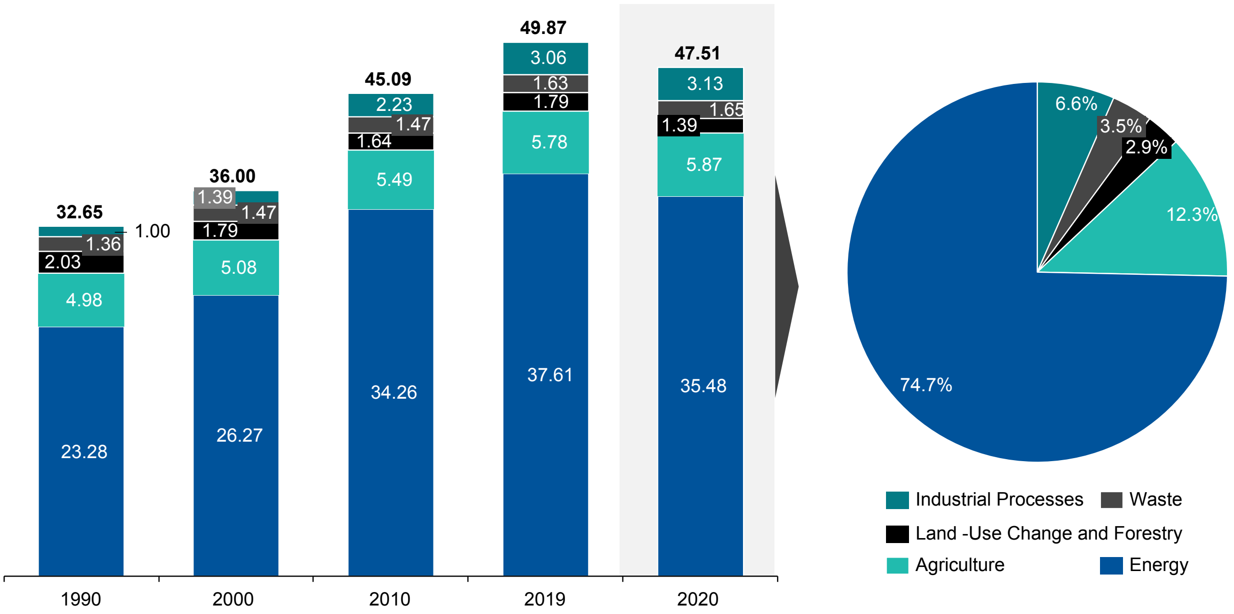
Global GHG Emissions by Sectors

Energy consumption is by far the largest source of anthropogenic greenhouse gas emissions. The sector makes up nearly three-quarters of global emissions (74.7%). Electricity and heat generation, followed by manufacturing and transportation, account for the majority of emissions in the energy sector. Agriculture accounts for 12.3% of greenhouse

[28]Retrieved from, https://www.europarl.europa.eu/news/en/headlines/society/20230316STO77629/climate-change-the-greenhouse-gases-causing-global-warming
[29]Retrieved from, https://www.un.org/en/climatechange/science/causes-effects-climate-change
[30]Our World in Data, PwC Analysis
[31]Our World in Data, PwC Analysis

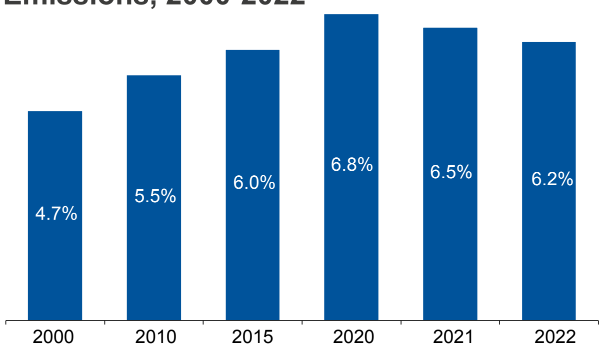
gas emissions. The primary sources of greenhouse gas emissions from industry are the burning of fossil fuels and chemical processes required for production processes. In 2020, industrial processes were responsible for 6.6% of the global GHG emissions.[32]

Figure 5. World Greenhouse Gas Emissions by Sectors, 1990-2020 (Gigatonnes CO_{2e}) (Left), Share of Sectors in World's GHG Emissions, 2020 (Right)[33]



After the year of 2000, the energy-related emissions rate of industrial processes increased, however this trend began to reverse after 2020. In 2000, the share of industrial process emissions in global energy-related greenhouse gas emissions was 4.7%. The share of industrial processes in total emissions reached 6.8% in 2020 and that declined to 6.2% in 2022.

Figure 6. Share of Industrial Processes in Global Energy-related Greenhouse Gas Emissions, 2000-2022[34]



[32]https://ourworldindata.org/ghg-emissions-by-sector
[33]World Resource Institute, PwC Analysis
[34]EIA (2023). Global energy-related greenhouse gas emissions, 2000-2022.

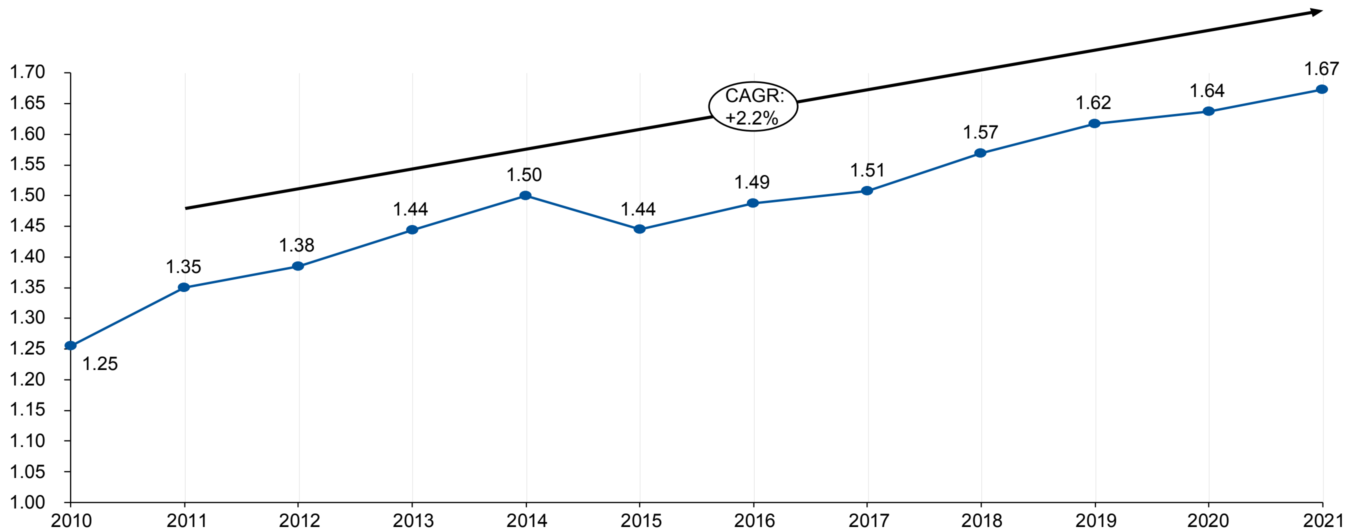
Since 1990, industrial processes stand out as the fastest-growing sources of greenhouse gas emissions. This emission source has almost tripled in the last 30 years. Industrial processes include mineral products (cement production, lime production, limestone use, soda ash prod. and use, asphalt roofing, road paving), chemical industry (ammonia, nitric acid, adipic acid, urea, carbides, caprolactam, petrochemicals), metal production (iron, steel and ferroalloys, aluminium, magnesium, other metals) and other (pulp and paper, food and drink production, production of halocarbons, use of halocarbons and SF_6).[35] Among these sectors, the cement, iron and steel, aluminum and chemical sectors have been identified as hard-to-abate sectors. The term "hard-to-abate sector" refers to industries or sectors of the economy that are particularly difficult to decarbonize or reduce greenhouse gas emissions for a variety of technical, economic, or structural reasons.[36]

Cement production is a significant source of greenhouse gas emissions, primarily due to the chemical processes and energy-intensive nature of cement manufacturing. Production of cement accounts for around 7% of global CO_2 emissions.[37] Compared to other hard-to-abate sectors, the steel sector is responsible for 7% and aluminum sector for 2%[38] and chemicals sector for 2%.[39]

CO_2 Emissions from Global and National Cement Production

The increase in cement production in recent years has been the main driver for the rise in cement related total emissions. Around the globe, process emissions have increased, except for the slight decline in 2015. The year-on-year decline is attributed to China's slowing economy and declining coal use. In addition, China's investment and rapid growth in renewables is also helping to reduce its emissions.[40] As seen in the Figure 7, process emissions from the cement production process, which was 1.25 gigatonnes of CO_2 in 2010, grew with a CAGR of 2.2% and reached the 1.67 gigatonnes in 2021.

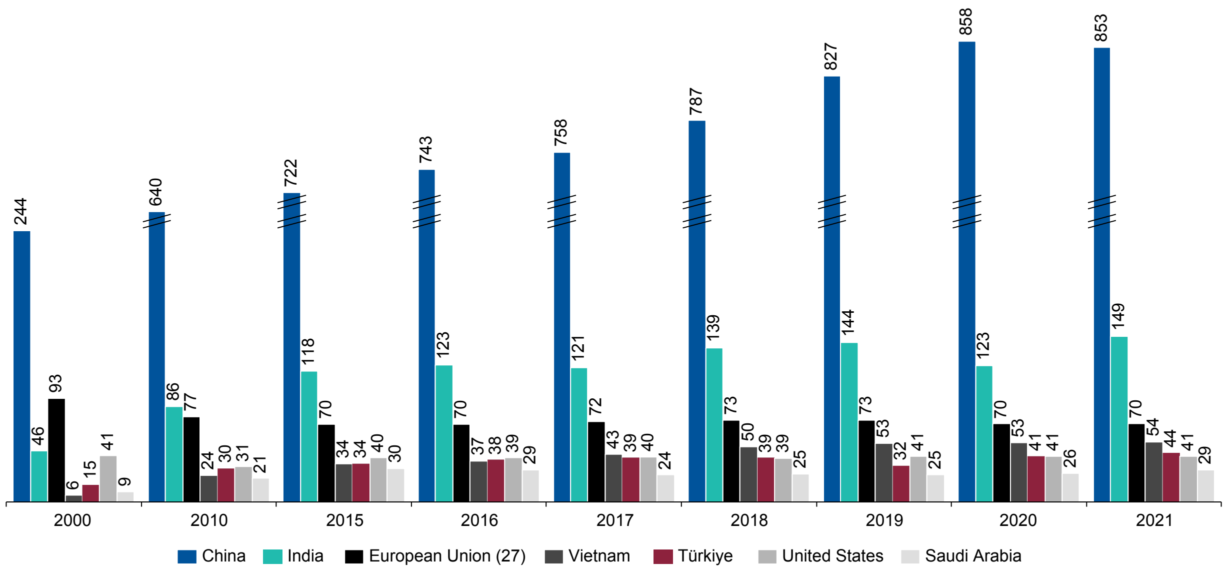
Figure 7. Annual Process Emissions from Cement, Global (Gigatonnes CO_2)[41]



[35] IPCC
[36] OECD (2020). Developing Sustainable Finance Definitions and Taxonomies, Green Finance and Investment. Retrieved from, https://read.oecd-ilibrary.org/finance-and-investment/developing-sustainable-finance-definitions-and-taxonomies_134a2dbe-en#page4
[37] GCCA
[38] MPP
[39] IEA
[40] https://www.nature.com/articles/nature.2015.18965 & https://www.nature.com/articles/nature.2015.18440
[41] Our World in Data. Annual CO_2 emissions from cement, PwC Analysis

China is the biggest emitter of process emissions, as the largest cement producer country in the world. China is responsible for 51% (853 million tonnes of CO_2) of cement process emissions worldwide in 2021. It is followed by India with 8.9% (149 million tonnes of CO_2), the European Union with 4.4% (74.21 million tonnes of CO_2) and Vietnam with 3.2% (54.12 million tonnes of CO_2). Cement industry in Türkiye is the 5th highest IPPU related emission emitter in the world with a 2.6% contribution (44.2 million tonnes of CO_2).

Figure 8. Cement Process Emissions by Countries (Million Tonnes of CO_2)[42]



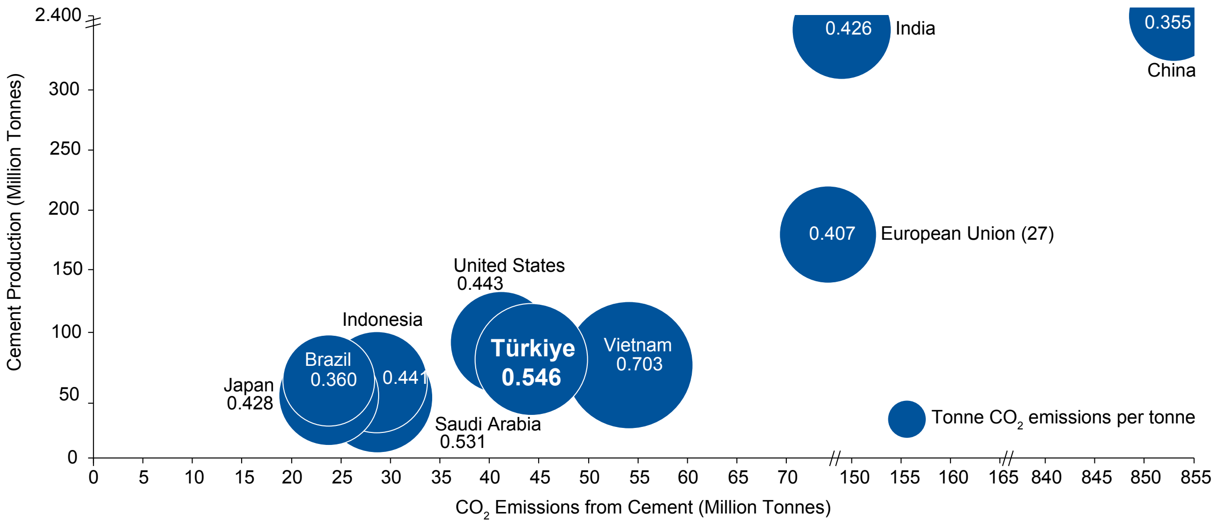
Over the last 20 years, all countries have increased their process emissions, except the EU. Since 2010, (2010 to 2021), India has increased its direct CO_2 emissions from the cement production process the most at a CAGR of 5.1%. The other countries that resulted in larger increase in process emissions from the cement sector were Türkiye, Saudi Arabia and China, respectively. Between 2010-2021, the cement producers in EU (27) managed to reduce their IPPU related total emissions by 0.8% CAGR and emitted 70 million tonnes of CO_2 as of 2021.

While IPPU related cement emissions grew with a CAGR of 7.0% between 2000 and 2010, this increase has slowed down to 3.6% between 2010 and 2021. As in Figure 8, Türkiye, which had 15.2 million tonnes of CO_2 emissions in 2000, almost doubled its emissions in 2010 and reached 30 million tonnes of CO_2 emissions. By 2021, Türkiye's IPPU related emission from cement was realized as 44.2 million tonnes of CO_2.[43]

The global process emission intensity for the cement sector is calculated as 0.38 t CO_2 / t cement for 2021.[44] Vietnam stands out as the country with the highest emission intensity by far. Türkiye, which ranks second, is above the global average. Although China is by far the leader in total emissions from cement, the country has achieved to reduce its emission intensity significantly due to improvements in clinker-to-cement ratio, recent abolishment of low-grade cement and expanding production of higher-grade cement.[45]

[42]Our World in Data, Türkiye's Greenhouse Gas Inventory, PwC Analysis
[43]Our World in Data
[44]Our World in Data, CEMBUREAU, Emissions from Cement Production Process, PwC Analysis,
[45]Wu, T., Ng, S. T., & Chen, J. (2022). Deciphering the CO_2 emissions and emission intensity of cement sector in China through decomposition analysis. Journal of Cleaner Production, 352, 131627.

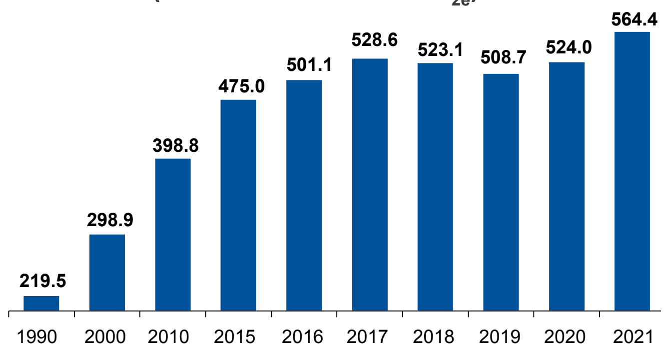
Figure 9. Process Emissions per Tonne Cement Production by Countries, 2021 (Million Tonnes of CO_2/Million Tonnes Cement)[46]



Emissions in Türkiye

Türkiye's emission data is derived from Türkiye's Greenhouse Gas Inventory prepared for the United Nations Framework Convention on Climate Change (UNFCCC). From 1990, the year the reporting period started, to 2021, Türkiye's emissions have increased nearly 2.5 times. Total GHG emissions increased from 398.8 million tonnes of CO_2 to 564.4 million tonnes of CO_2 with a CAGR of 3.2% between 2010 to 2021. As seen in the Figure 10, in 2021, total greenhouse gas emissions increased by 7.7% compared to the previous year. Total greenhouse gas emission per capita is calculated at 6.7 tonnes CO_{2e} in 2021, up from 3.9 tonnes CO_{2e} in 1990.[47]

Figure 10. Türkiye's Total Greenhouse Gas Emissions (Million Tonnes of CO_{2e})[48]



Türkiye's Greenhouse Gas Inventory assesses country's emissions under 5 sectors.

- Energy
- Industrial Processes and Product Use (IPPU)
- Agriculture
- Waste
- Land Use, Land Use Change and Forestry (LULUCF)

The energy sector includes emissions from the combustion of fossil fuels (energy, manufacturing and construction, transport and other sectors) as well as fugitive emissions from fossil fuels and CO_2 transportation and storage.[49] Greenhouse gas emissions from industrial processes and product use (IPPU) represents the emissions released from production processes. IPPU category covers only emissions from processes. Emissions from combustion of fuel used to provide energy to run processes is not included.

[46]CEMBUREAU, Our World in Data, Türkiye's Greenhouse Gas Inventory, PwC Analysis
[47]TURKSTAT, Greenhouse Gas Emissions Statistics, 1990-2021
[48]TURKSTAT, PwC Analysis
[49]Türkiye's Greenhouse Gas Inventory, 1990-2021. PwC Analysis

As seen in the Figure 11, among the total greenhouse gas emissions, the highest share is taken by energy-related emissions with 71.3%, followed by IPPU usage with 13.3%, agriculture with 12.8%, and the waste sector with 2.6%. Energy sector emissions increased by 3.1% (CAGR) compared to 2010 (287.9 million tonnes CO_{2e}), reaching 402.5 million tonnes CO_{2e} until 2021. IPPU were calculated as 75.1 million tonnes CO_{2e}, up 3.9% (CAGR) from 2010 (49.1 million tonnes CO_{2e}).[50]

Energy related emissions from cement sector is calculated together with glass and ceramics under non-metallic minerals. Since cement is an energy-intensive sector, energy-related emissions have increased over the years with increasing demand and production (excluding pandemic effect). Energy related emissions from non-metallic minerals sector grew with the CAGR of 4.0% between 2010 and 2021. In 2010, energy related emissions from non-metallic minerals sector were 21.36 million tonnes CO_2 and the share of these emissions in the total energy sector was 7.42%, whereas these figures increased to 32.7 million tonnes and 8.12% respectively in 2021. Compared to other CBAM sectors, the share of energy related emissions in non-metallic minerals sector within the total energy sector is much higher than that of iron and steel (1.45%) and aluminium (0.22%).[52]

Figure 11. Türkiye's Greenhouse Gas Emissions by Sectors, 2021 (Million Tonnes of CO_{2e})[51]

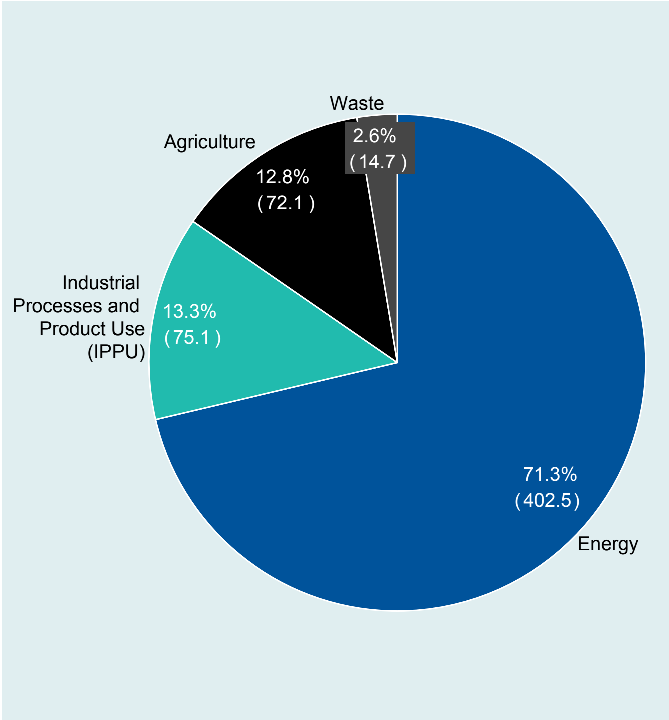
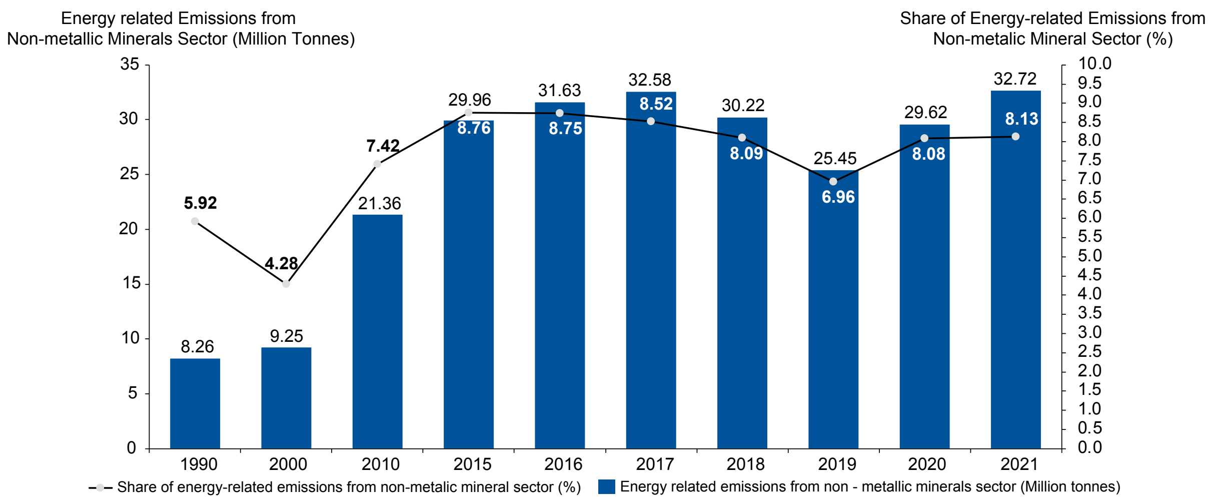


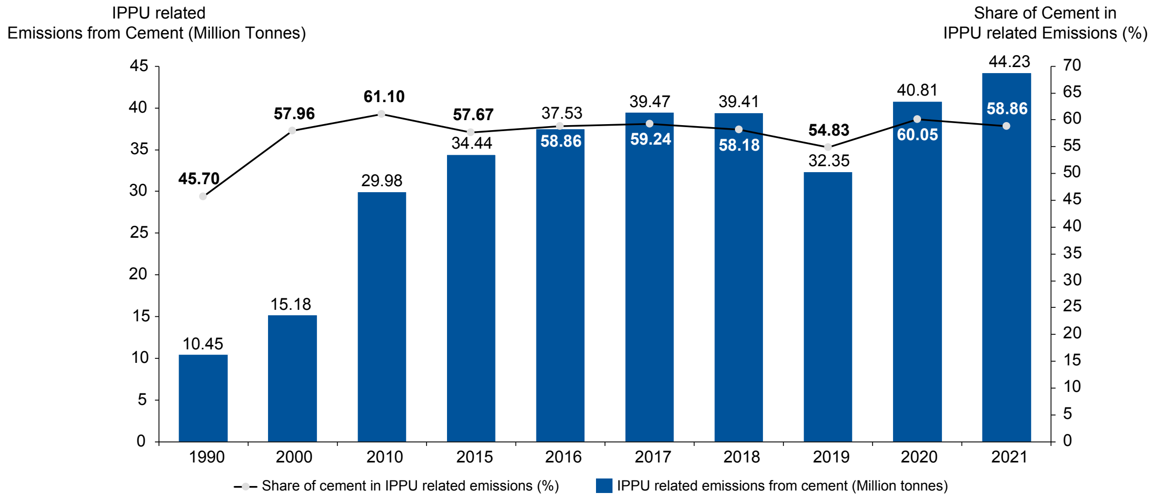
Figure 12. Türkiye's Energy Related Emissions from Non-Metallic Minerals Sector[53]



[50]Türkiye's Greenhouse Gas Inventory, 1990-2021. PwC Analysis
[51]Türkiye's Greenhouse Gas Inventory, 1990-2021. PwC Analysis
[52]Türkiye's Greenhouse Gas Inventory, PwC Analysis
[53]Türkiye's Greenhouse Gas Inventory, PwC Analysis

The CO_2 emissions of the cement sector (IPPU related[54]) have increased by 4.8% (CAGR) between 1990 and 2021. In 2021, clinker production was 84 million tonnes and cement production were 81 million tonnes. Accordingly, the cement sector caused 44.2 million tonnes of industrial processes and product use (IPPU) related CO_2 emissions. The share of cement sector within the total IPPU accounts for 58.9%. The share of total Scope 1 emissions from cement production in total scope 1 emission from industrial activities was 22.8% in Türkiye as of 2020.[55] At the same year, other hard-to-abate CBAM sectors have significantly lower shares compared to the cement sector. In 2021, the share of iron and steel sector within the total IPPU was 15.8% while the share of aluminium in that was 1.57%.

Figure 13. IPPU Emissions from Cement Sector[56]

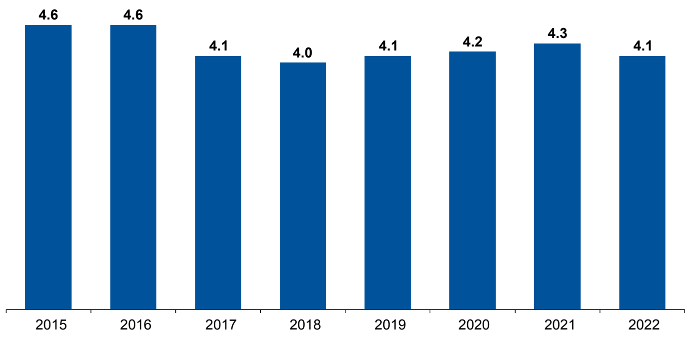


1.1.2. Global and National Cement Production

Global Cement Production

Global cement production was approximately 4.1 billion tonnes in 2022.[57] The upward trend in cement production since 2018 was disrupted by the 4.7% contraction in 2022. The main driver of the contraction is the change in Chinese cement production. China represents more than half (51.1%) of all cement production in the world in 2022.[58] In 2022, China's cement production decreased by 12.5% compared to the previous year. The decline is largely attributed to China's completion of major infrastructure projects and the construction of many of its largest cities, resulting in lower demand for cement.[59]

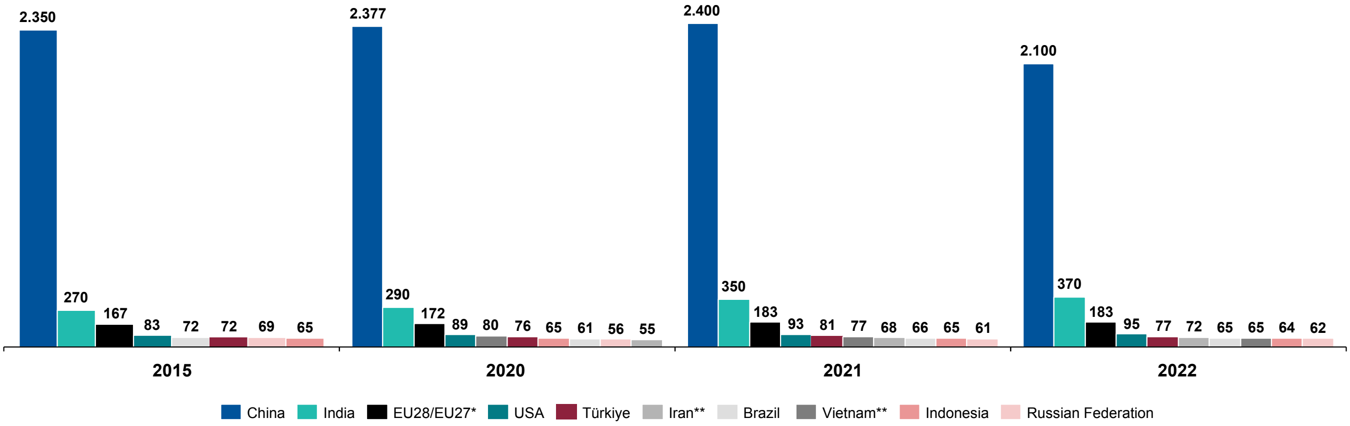
Figure 14. Global Cement Production, 2013-2022 (Billion Tonnes)[60]



[54]Among IPPU, cement production is considered under mineral industry.
[55]Expert View, PwC Analysis
[56]Türkiye's Greenhouse Gas Inventory, PwC Analysis
[57]CEMBUREAU (2023). Activity Report 2022.
[58]CEMBUREAU (2023). Activity Report 2022.
[59]Worldcement (2023). Retrieved from, https://www.worldcement.com/asia-pacific-rim/24052023/the-future-of-chinese-cement-production/
[60]CEMBUREAU. Activity Reports, PwC Analysis

China is followed by India in second place with a share of 9%. India produced 370 million tonnes of cement in 2022 with a CAGR of 4.6% in the last 8 years. EU countries are responsible for 4.5% of the total cement production. EU countries increased their cement production by 1.3% (CAGR) in the period 2015-2022. Türkiye has achieved a growth of 0.8% in the last 8 years and produced 77 million tonnes of cement in 2022. Thus, Türkiye took 1.8% share from the global production in 2015 and reached 1.9% share in 2022.

Figure 15. Cement Production by Country, 2015-2022 (Million Tonnes)[61]

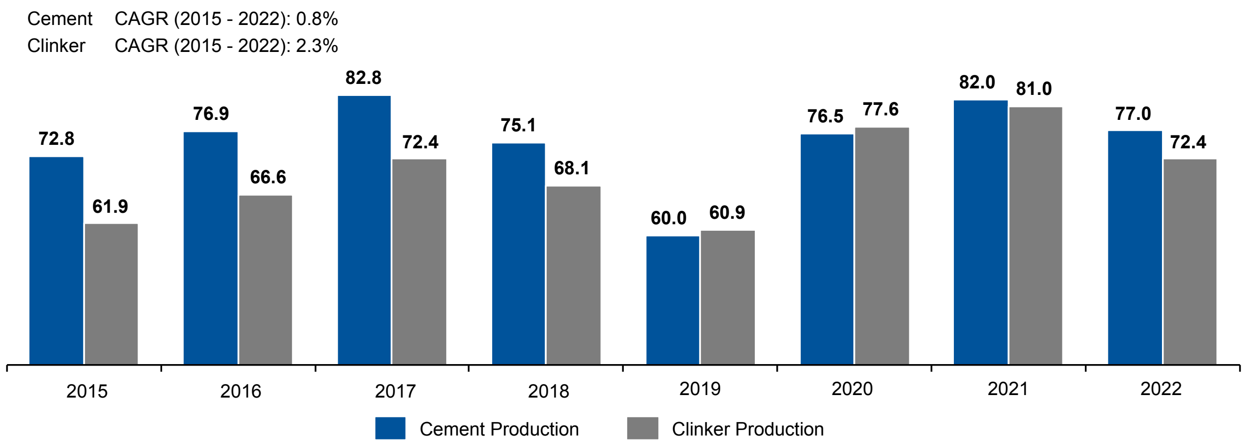


* EU28 until 2019 / EU27 as of 2020 reporting year
** The cement production amount can be obtained for Vietnam and Iran as of 2020

National Cement Production

Over the last eight years, cement production in the country increased by a CAGR of 0.8% to 77.0 million tonnes, while clinker production increased by a CAGR of 2.3% to 72.4 million tonnes over the same period.[62] Türkiye's construction sector has been contracting consecutively for the last 5 years thereby curtailing cement demand. On the other hand, the increase in clinker and cement exports in the same period also led to growth in production amounts. In addition, future projections foresee that the recent earthquakes will have an impact on cement demand and that the cement demand will mainly be met by the factories nearly located.

Figure 16. Türkiye's Cement and Clinker Production, 2015-2022 (Million Tonnes)[63]



[61]CEMBUREAU. Activity Report 2022, 2021, 2020, PwC Analysis
[62]Production values cover the total Türkiye's cement industry.
[63]TURKSTAT, PwC Analysis

As of 2022, Türkiye's cement sector comprises of 56 integrated cement plants and 21 grinding plants.[64] Over the past decade, cement production capacity in the country increased by 37.1% reaching 147.2 million tonnes, while clinker production capacity increased by 41.2% totaling 96.6 million tonnes. In spite of nominal increase, capacity growth in both cement and clinker production have been slowing down. This reduced growth is largely driven by mainly characterized by high energy costs and increase in production costs.

Figure 17. Cement and Clinker Production Capacities in Türkiye, 2015-2022 (Million Tonnes)[65]

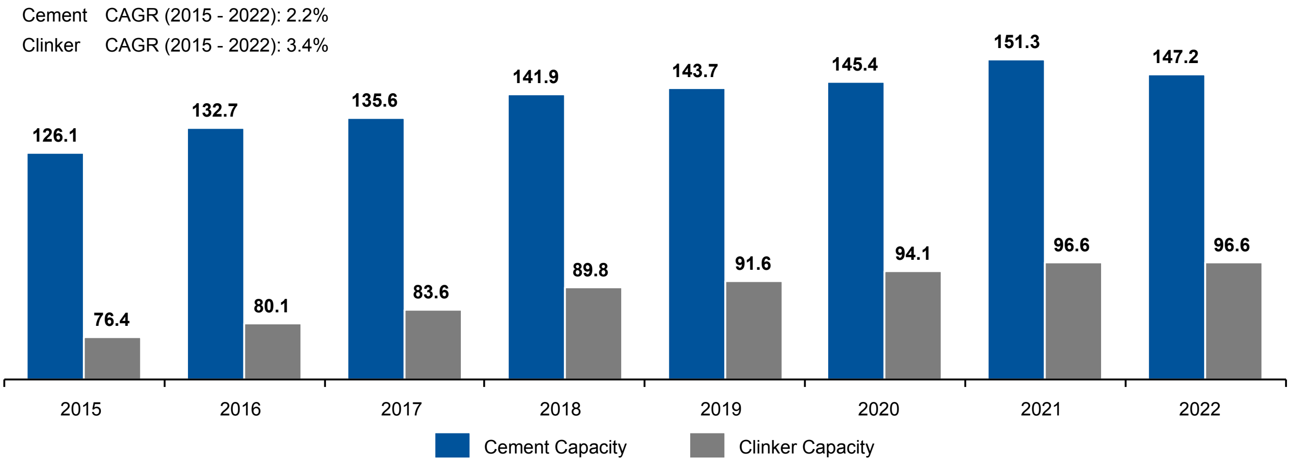
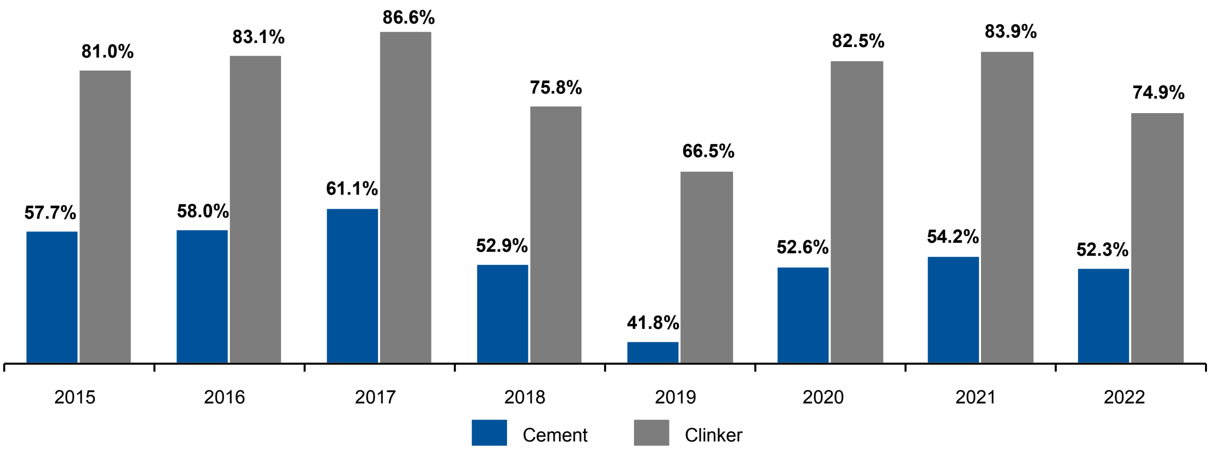


Figure 18 provides clinker and cement capacity utilization rates for the 2015-2022 period. Over the last decade annual capacity utilization rates in cement production have fallen and declined to around 52-53% in recent years, while annual clinker capacity utilization rates have decreased at a relatively smaller scale. Clinker's comparatively higher capacity utilization rate is backed by significant amount of clinker exports of the country.

Figure 18. Cement & Clinker Capacity Utilization Rates, 2015-2022[66]



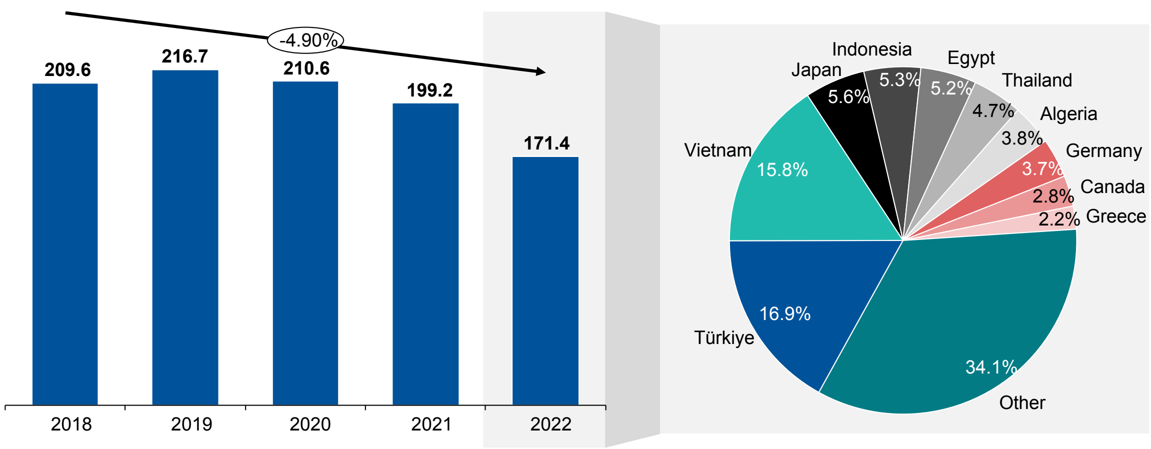
[64] Türkçimento.
[65] Türkçimento, 2015-2022 Cement Statistics of Türkiye, PwC Analysis. Capacity values cover the total Türkiye's cement industry.
[66] TURKSTAT, Türkçimento, PwC Analysis

1.1.3. Global and National Cement Export

Global Cement Export

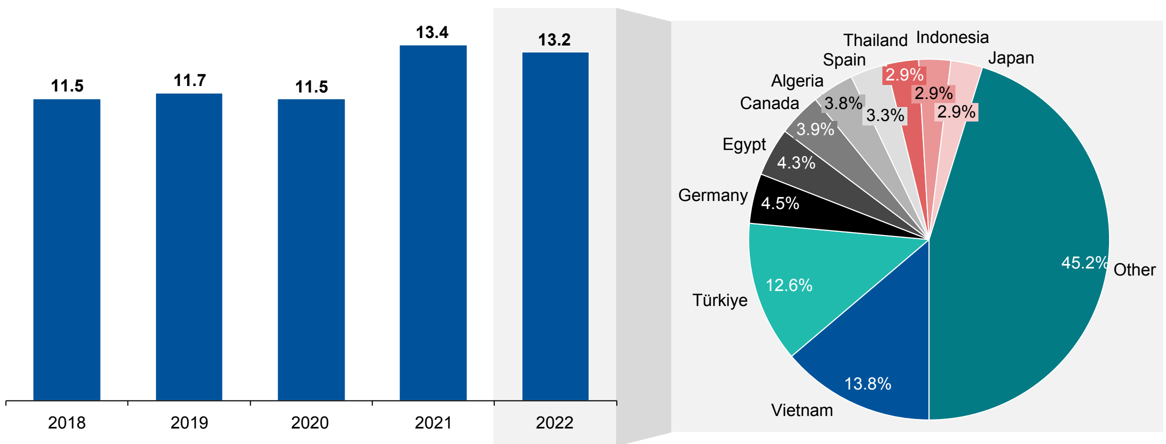
Aluminous cement, cement clinkers, white portland cement, other portland cement and other hydraulic cement products are in scope of CBAM regarding cement industry.[67] Global cement export in the world (including cement product groups covered by CBAM) decreased from 209.6 million tonnes in 2018 to 171.4 million tonnes in 2022, meaning a 4.9% CAGR contraction in the 2018-2022 period. While Vietnam was the leading cement exporter in 2019 and 2020, Türkiye took the place of Vietnam as the leading exporter in 2022 with a share of 16.9% (29 million tonnes). Vietnam ranks second with a share of 15.8% (27.0 million tonnes) and Japan ranks third with a share of 5.6% (9.6 million tonnes).[68]

Figure 19. Global Total Cement Exports (Million Tonnes) and Share of Countries in Cement Exports (%)[69]



Global cement exports have reached 13.2 billion dollars in 2022. Even though global cement exports contracted by 2% year over year last year, they grew at a CAGR of 3.34% in the period of 2018-2022. In value terms, Vietnam ranks first with a share of 13.8% of world cement exports in 2022, while Türkiye and Germany rank second and third respectively with a share of 12.6% and 4.5%.

Figure 20. Global Total Cement Exports (Billion Dollars) and Share of Countries in Cement Exports (%)[70]



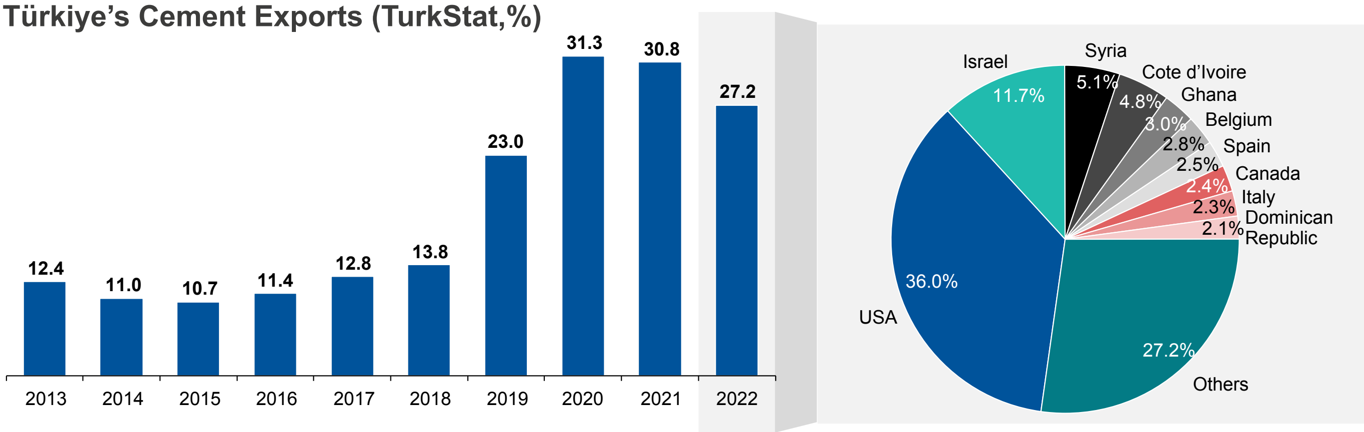
[67]European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf
[68]Trademap. Global cement exports are calculated based on the product groups of the cement sector covered by CBAM.
[69]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis
[70]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis

National Cement Export

According to TurkStat, Türkiye's cement exports were 12.4 million tonnes in 2013 and reached 27.2 million tonnes in 2022.[71] Although the cement sector exports have grown at a CAGR of 9.1% in total in the decade, the main growth was achieved between 2015-2020 with a CAGR of 23.9%. In 2020, Türkiye's cement exports reached approximately 31.3 million tonnes, the highest level in the last 10 years (2013-2022).[72] After 2020, there was a 6.8% CAGR contraction in exports in tonnage terms until 2022. The main reasons for the contraction are increase in energy prices and production costs, decrease in global cement imports and the Russia-Ukraine tension.

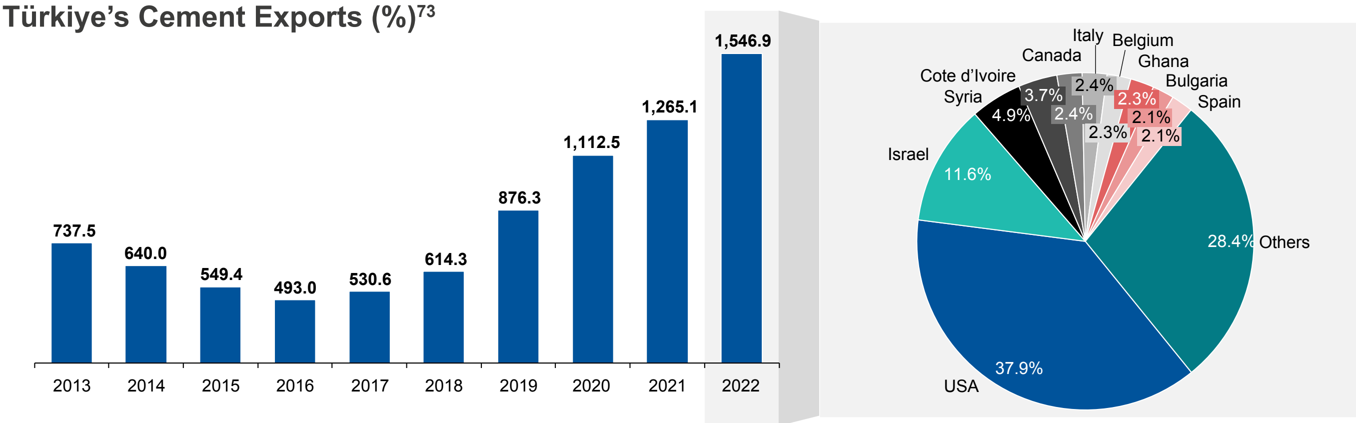
In the recent years, the United States of America has been the top export destination for Türkiye's cement products. In 2022, the USA is the leading market for Türkiye's cement exports in terms of tonnage with a share of 36.0%. Other important markets are Israel and Syria with 11.7% and 5.1% shares, respectively.

Figure 21. Türkiye's Cement Exports (Million Tonnes) and Share of Countries in Türkiye's Cement Exports (TurkStat,%)



Türkiye's cement exports reached approximately 1.55 billion dollars in 2022. Türkiye's cement exports grew at a CAGR of 8.6% in value terms between 2013-2022. This growth has accelerated after the year of 2017, with a CAGR of 23.9% by 2022. By country ranking, USA takes the first place with 37.9% share, followed by Israel and Syria with 11.6% and 4.9% shares, respectively.

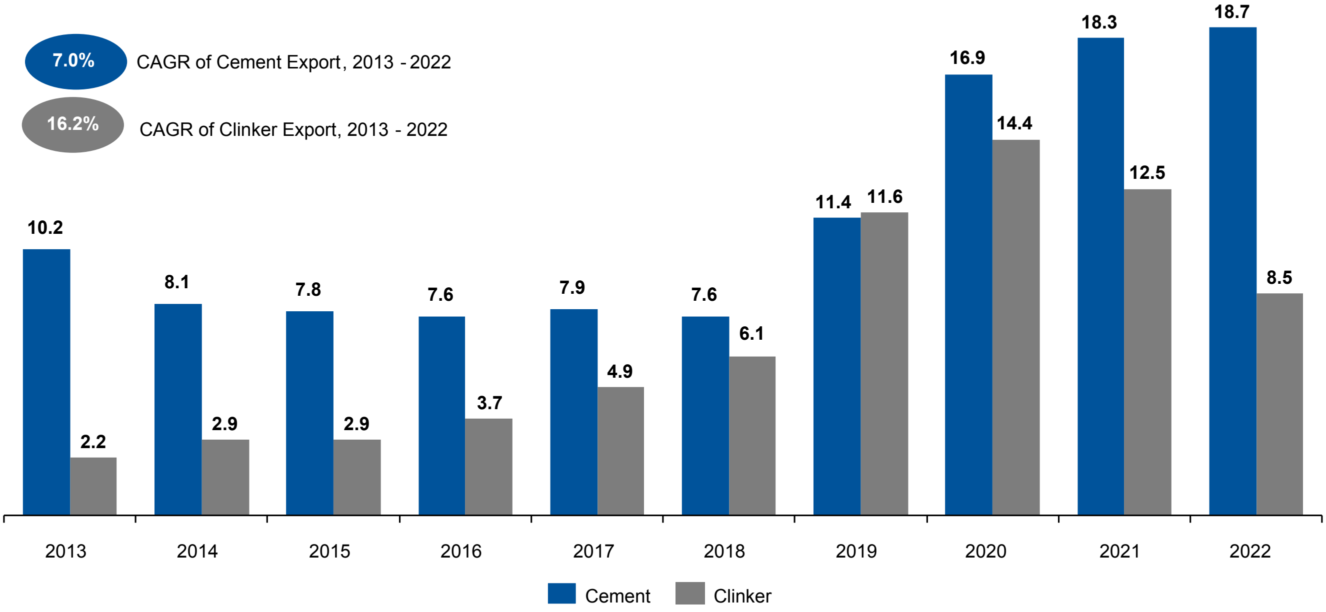
Figure 22. Türkiye's Cement Exports (Million Dollars) and Share of Countries in Türkiye's Cement Exports (%)[73]



[71]TurkStat
[72]TurkStat
[73]TURKSTAT, PwC Analysis

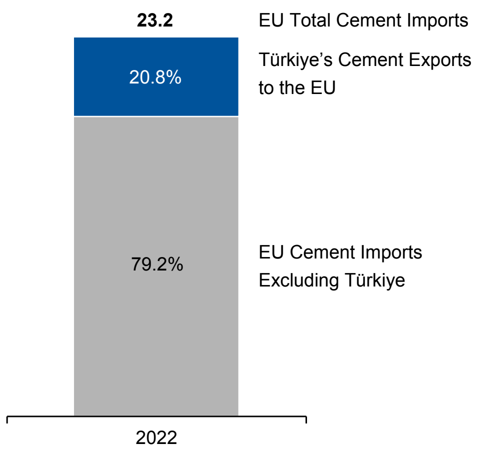
Detailed analysis of cement products and clinker was also carried out within the scope of the project. In this regard, clinker growth in exports between 2013 and 2022 is relatively higher than cement export growth. In 2013, clinker exports were 2.2 million tonnes, which grew by 16.2% in CAGR terms and reached 8.5 million tonnes in 2022. Similarly, cement exports, which were 10.2 million tonnes in 2013, grew by 7.0% in CAGR terms and reached 18.7 million tonnes in 2022. This strong growth performance is expected to continue in the upcoming years.

Figure 23. Türkiye's Cement and Clinker Exports (Million Tonnes)[74]



Total cement imports of the European Union countries (EU-27) amounted to 23.2 million tonnes in 2022.[76] The volume of Türkiye's exports to EU countries was 4.8 million tonnes in 2022 and the share of Türkiye's cement exports in EU cement imports was 20.8%. In addition, in value terms, the share of Türkiye cement exports in total EU cement imports accounted for 8.7% in 2022. This share corresponds to approximately 266 million dollars.[77]

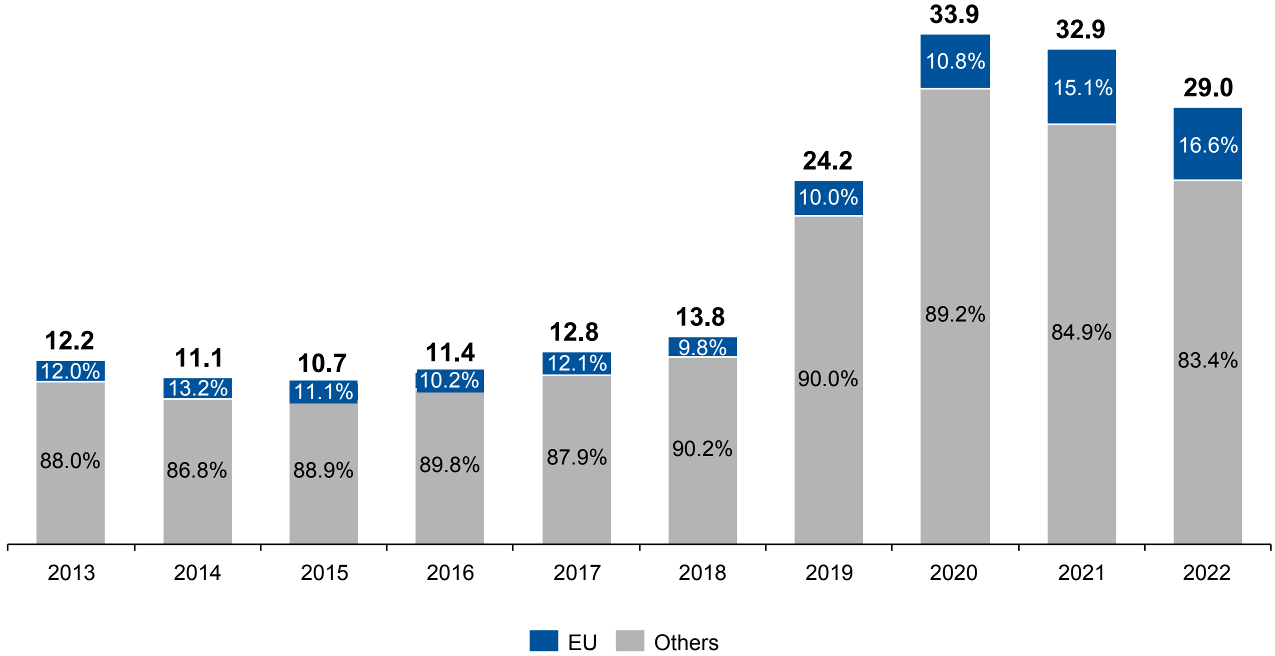
Figure 24. Share of Türkiye's Cement Exports in EU-27 Cement Imports (Million Tonnes)[75]



[74]TURKSTAT, PwC Analysis
[75]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis
[76]Represents products (Aluminous cement, cement clinkers, white portland cement, whether or not artificially colored, other portland cement and other hydraulic cement products) within the scope of CBAM.
[77]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis

Türkiye's exports to EU-27 countries have increased steadily, especially after 2018. In the period between 2018 and 2022, Türkiye's exports to EU countries increased at a CAGR of 37.5% in terms of quantity. Besides, in 2022, the share of EU countries accounted for 16.6% of total cement exports (in tonnage) in Türkiye.[78]

Figure 25. Share of EU-27 Countries in Türkiye's Total Cement Exports (Trademap, Million Tonnes)[79]



[78]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis
[79]Trademap, European Parliament. Retrieved from, https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.pdf, PwC Analysis

2 Modelling and Scenario Analysis of Cement Sector Decarbonization

2. Modelling and Scenario Analysis of Cement Sector Decarbonization

A key element of this project is the modelling and scenario analysis work, that forecasts and quantifies the impact of different combinations of policies and technologies on the future emissions of the cement sector. To be able to carry out the modelling work, demand and supply projections of Türkiye's Cement Sector have been developed under different assumptions up until 2053, and key decarbonization levers and technologies that will achieve decarbonization in the sector have been identified and modelled. The model generates the possible pathways for decarbonization of cement sector in Türkiye under 2 reference scenarios and 2 mitigation scenarios in order to estimate and benchmark the future emissions of the sector over the period of 2024-2053.

Reference scenarios generated as "reference" or "counter" points against which the mitigation scenario's performance is evaluated in terms of emission results. Under the reference scenario umbrella, two scenarios have been generated **i) Without Measures and ii) Stated Policy. The Without Measures (WoM) scenario,** assumes a "no policy" baseline where no explicit mitigative action is taken and no technological transformation takes place. Another reference scenario, **the Stated Policy Scenario (SPS),** is generated as a reference scenario to explore the potential effects of the stated policies – declared as of writing of this report- including process efficiency improvements, electricity grid decarbonization, EU CBAM constraints and introduction of a national ETS. In essence, SPS is generated to project the emissions where stated policy steps are taken but no technological transformation is estimated.

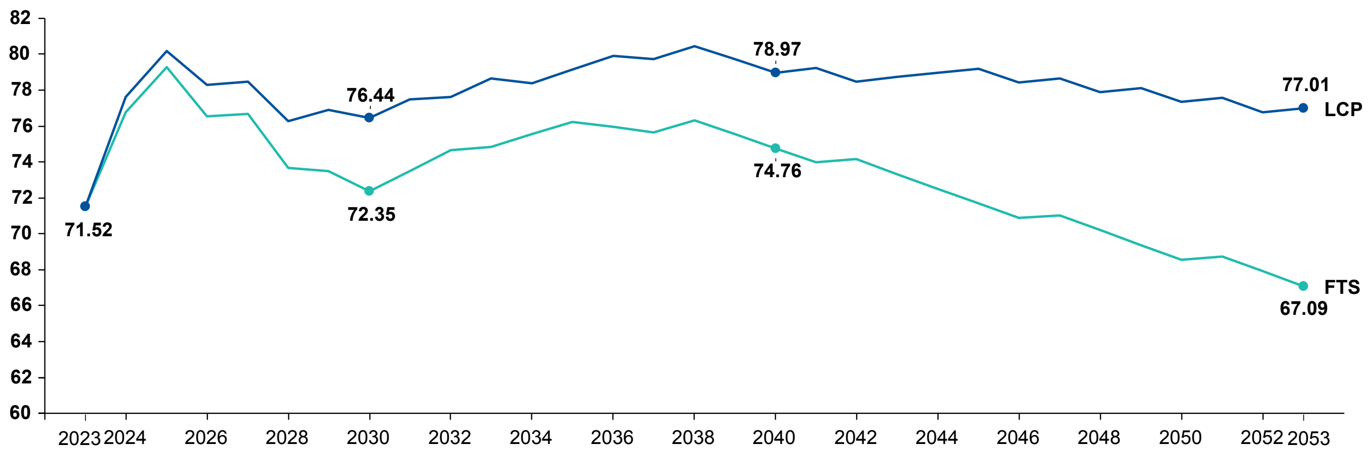
Mitigation scenarios are generated to forecast the impact of radical policy action and investment in technology on the emission levels of the sector. The two mitigation scenarios used in this project are **i) Low Carbon Pathway (LCP)** and **ii) Frontier Technologies (FTS).** Low Carbon Pathway and Frontier Technologies assume varying levels of mitigative policy actions and adoption of low carbon technologies towards a net zero emission target in 2053. **The LCP scenario** is designed to be the (cost-effective) optimal scenario for decarbonization of Türkiye's cement sector. The FTS scenario assuming more aggressive targets, is differentiated from the LCP Scenario by earlier introduction of frontier technologies. In addition, recarbonation and efficiency in concrete, design and construction levers are included in both mitigation scenarios.

The cement sector model prepared within the scope of the project is a long-term scenario analysis and optimization model developed to assess various decarbonization scenarios for Türkiye's cement sector. It is a large-scale linear multi-objective optimization model developed in IBM CPLEX software that aims to minimize the total discounted cost under technological and economic constraints while achieving a given emission target.

2.1. Sector Projections

Total cement production is predicted for 30-year horizon based on per capita cement consumption and population projection, also taking export expectations into account. Total clinker production is modeled by separately projecting domestic clinker consumption, clinker exports and clinker contribution to cement exports. As one of the key strategies to reduce carbon emissions in cement production to decrease the clinker to cement ratio, different assumptions are made regarding that ratio to forecast clinker consumption under two mitigation scenarios. The clinker to cement ratio has led to a differentiation of clinker domestic production and accordingly, two different results have been reached in total clinker production. **In 2053, 77 million tonnes and 67.1 million tonnes of clinker production are projected in the LCP and FTS, respectively.**

Figure 26. Total Clinker Production Forecast (Million Tonnes)



Necessary meetings were organized with sector experts, government agencies, representatives of Türkçimento and OAIB to discuss and comment on the projections and assumptions. Previous studies on the global and local cement sector were also reviewed and the comments of the representatives from the Steering Committee members were considered as well. The Ministry of Industry and Technology was consulted to evaluate the final projection. A more detailed methodology and results of sector projections were provided in the long version of this report.

2.2. Low-Carbon Cement Production

There is no single pathway for low-carbon cement production, and transformation requires a broad portfolio of technological options to be deployed individually or in combination, depending on a country's or a specific company's conditions.

Cement producers will lower their emissions by saving electricity and thermal energy, adopting new technologies and switching to lower emission inputs. One method to significantly reduce emissions is to swiftly integrate new technology into production operations. While some low-carbon cement technologies are commercially available today, others are in the pilot/demo phase or still in R&D stage. Hydrogen and carbon capture are breakthrough technologies that will nearly eliminate emissions, but these technologies are not expected to be deployed in the near term.

Based on a review of the literature, recommendations from industry stakeholders, and expertise from industry experts, the decarbonization levers in the cement sector have been thoroughly examined. There are 7 main levers that provide decarbonization in cement sector: **thermal efficiency, use of new and alternative fuels, clinker/cement ratio, electricity decarbonization, concrete, design and construction efficiency, recarbonation and carbon capture, storage, and utilization**. Based on their potential to save electrical and thermal energy, their development status and technological maturity, and their Capex and Opex (as determined by literature), the technologies examined under the levers mapped.

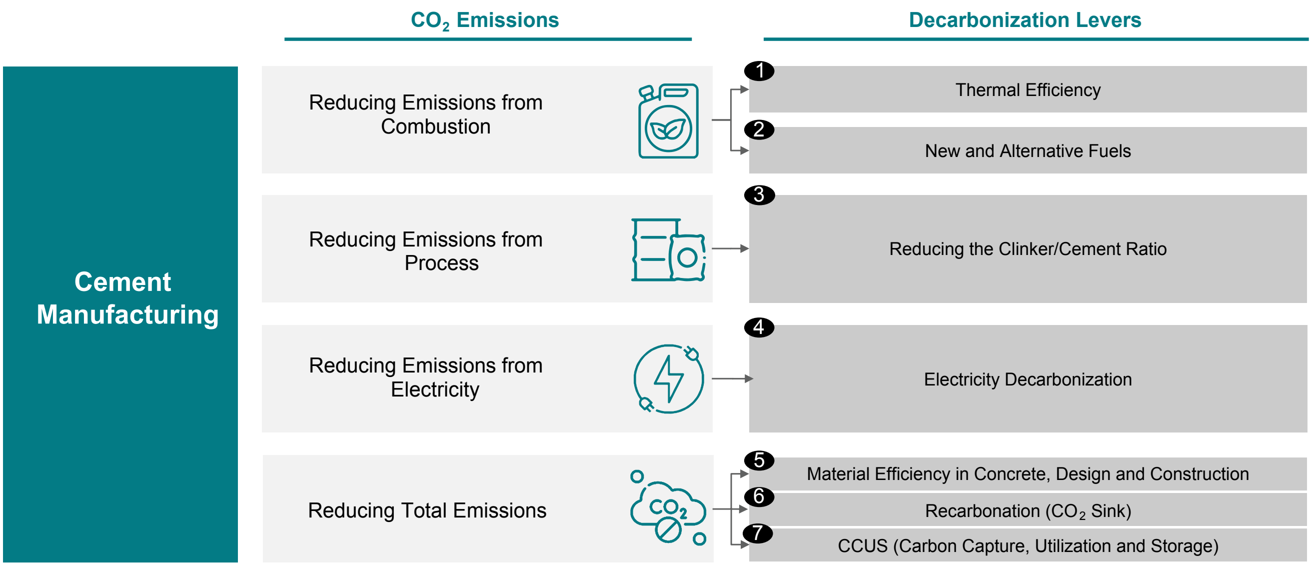
The commercialization years of decarbonization technologies for the cement sector were estimated reviewing the most up to date international resources and revised (when necessary) in line with the opinions of industry stakeholders and project experts, revealing a set of assumptions on possible timeframes for their market entry. The years of technology introduction and their shares in future production, as well as the rates of decarbonization levers such as alternative fuel use, recarbonation, efficiency in construction and materials, were discussed both in steering committee meetings and in focus group meetings with sector umbrella organizations (Türkçimento and OAIB) and incorporated into the modelling assumptions accordingly.

Cement Sector Decarbonization Levers

Technology archetypes under the decarbonization levers, which define combinations of inputs for various processes, were assessed using the European Cement Research Academy (ECRA) study[809] framework as a reference. This report outlines the current situation and the technologies that can contribute to improving energy efficiency and reducing greenhouse gas emissions in global cement production in the medium and long term. In this study, the impact of a total of 55 technologies on reducing energy consumption and CO_2 emissions was examined in detail under the headings of raw material inputs and cost parameters. In addition, technology readiness levels were provided for each technology.[81]

The main emission sources in the cement sector are combustion, process and electricity. Within the scope of the project, decarbonization levers were defined to reduce emissions both in specific emission areas and in the whole total system emissions.

Figure 27. Decarbonization Levers of Cement Sector



[80]European Cement Research Academy. The ECRA Technology Papers 2022
[81]The 2022 update of the ECRA Technology Papers was commissioned by the Mission Possible Partnership (MPP) and the Global Cement and Concrete Association (GCCA).

The introduction years of the selected technologies for Türkiye's cement sector and their penetration rates in production were determined under different scenarios. Extensive data such as emission reduction effects of the technologies, projected investment and operational cost (Capex, OpEx) values, input requirements and net calorific values were compiled and used in the modeling.

Thermal Efficiency

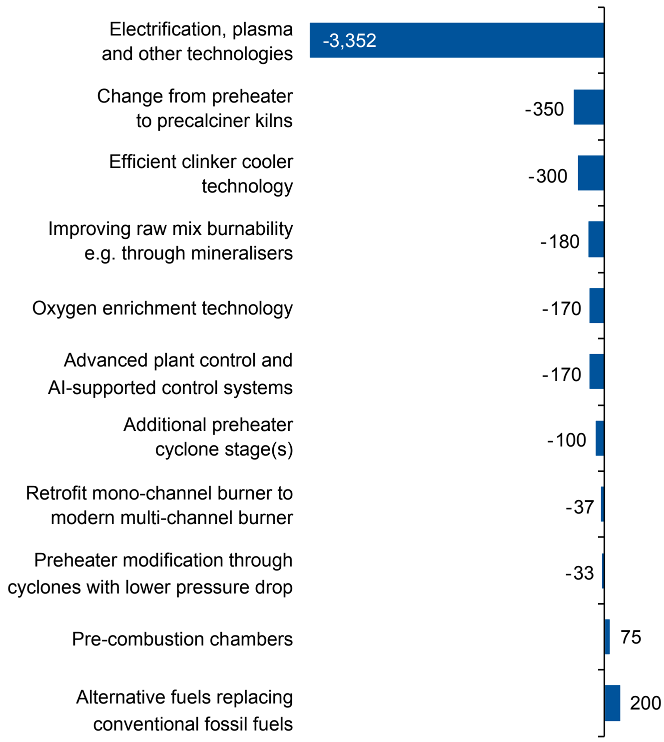
Thermal energy efficiency plays an important role in reducing emissions from combustion. Emissions from the combustion of fossil fuels account for about 40% of total emissions from cement production.[82] Combustion emissions can vary depending on the fuel mix used and can potentially be reduced to zero in the future. Combustion emissions, predominantly generated by using fuels to provide the thermal energy needed in the kiln and pre-calciner for the chemical reactions in the clinker production stage. Thermal energy consumption is influenced by factors such as the average capacity of cement plants, moisture content and burnability of raw materials, available kiln types, kiln ages, alternate fuel utilization rate and cement standards.[83]

Within the scope of thermal energy efficiency leverage, improving raw mix burnability (e.g. through mineralizers), change from preheater to precalciner kilns, preheater modification through cyclones with lower pressure drop, additional preheater cyclone stage(s), retrofit mono-channel burner to modern multi-channel burner, oxygen enrichment technology, efficient clinker cooler technology, alternative fuels replacing conventional fossil fuels, pre-combustion chambers, advanced plant control and AI-supported control systems and electrification, plasma and other technologies are examined in detail.

The thermal energy savings potentials of the technologies examined under the thermal efficiency decarbonization lever mentioned above are given in Figure 28. As shown in Figure 28, which is based on the ECRA report, technologies with negative values represent efficiency in thermal energy use. Conversely, technologies with positive values indicate thermal energy use increase per tonne of clinker. These technologies are used in the optimization model with their respective penetration years, input use and Capex and Opex figures to find the low-cost scenario options for Türkiye's cement sector in the planning period which spans the next 30 years.

Scenario-based technology entry years and penetration caps for these technologies were defined. Most of the technologies are existing technologies already in use by Türkiye's cement sector. In the aggressive FTS scenario, maximum technology penetration rates are higher and closer to global projections, while in the more realistic LCP scenario, technology maximum penetration rates are based on Türkiye's conditions. Electrification, plasma, and other technologies, which have the highest thermal efficiency impact, is not considered in the model as it is predicted to be commissioned in 2055 and later in both mitigation scenarios based on sector experts and Türkiye's conditions.

Figure 28. Impact of Technologies on Thermal Energy (MJ/t Clinker)[84]

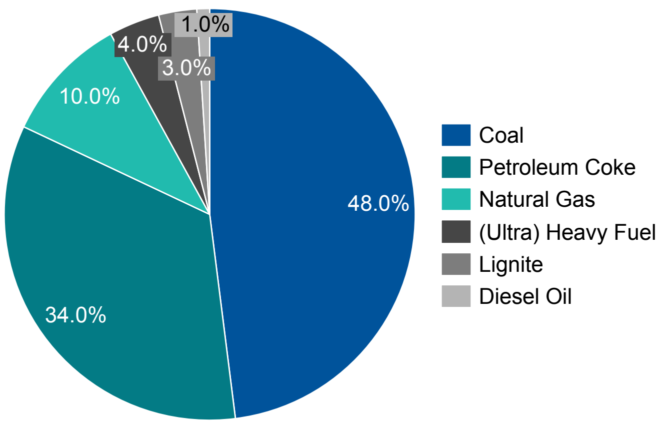


[82]Lehne, J., & Preston, F. (2018). Making Concrete Change: Innovation in Low-carbon Cement and Concrete. Chatham House.
[83]CSI&IEA (2018). Technology Roadmap Low-Carbon Transition in the Cement Industry
[84]European Cement Research Academy. The ECRA Technology Papers 2022 & Sector Expert View

New and Alternative Fuels

Cement producers prefer to use alternative fuels although there are various restrictions when factors such as energy costs and environmental standards are considered. The fuels mostly used in cement plants can be classified into five main categories: waste used as alternative fuels, municipal waste, biomass, non-hazardous industrial and commercial waste, and other unclassified alternative fuels. In the light of research and international experience, it is estimated that none of the alternative fuels alone can meet the entire thermal demand of cement production. On the other hand, with the goal of decarbonization, it is assumed that the demand can be met with alternative fuel mixtures.[85]

Figure 29. Utilization Rate Distribution of Conventional Fossil Fuels-Global[86]



Approximately 35% of total emissions originating from cement factories in Türkiye stem from kiln fuels and 5% originate from electricity consumption.[87] Reducing the need for thermal and electrical energy is undoubtably the most necessary step needed to reduce emissions caused by fuel and energy consumption. However, fuel switch should not be interpreted as a mere proportional replacement of conventional fuels; to reduce GHG emissions, the proportion of fuels containing biomass should be increased.

It is certain that use of alternative fuels and biomass will be insufficient at some point considering the current thermal energy needs, and more innovative solutions will be needed. Therefore, the use of green hydrogen as furnace fuel is one of the most critical steps towards decarbonization. Green hydrogen is produced from renewable energy sources, and it is very advantageous since it provides a great deal of energy and its GHG emission factor can become zero. However, currently, hydrogen production, temporary storage, using hydrogen as fuel, etc. present many technological and financial difficulties.

The use of green energy to meet the thermal energy needs of rotary kilns will greatly reduce emissions caused by combustion. Although hydrogen is seen as the most prominent green energy source for the sector in the future, plasma and microwave technologies are other sources and technologies that should be considered.

Within the scope of the modeling, the net calorific values, emission factors and biomass ratios of new and alternative fuel sources are examined in detail and the necessary inputs for the fuel switching of the model are provided.

[85]IFC (2017). Increasing The Use of Alternative Fuels at Cement Plants: International Best Practice. Retrieved from, https://www.ifc.org/wps/wcm/connect/33180042-b8c1-4797-ac82-cd5167689d39/Alternative_Fuels_08+04.pdf?MOD=AJPERES&CVID=lT3Bm3Z
[86]Retrieved from https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/
[87]Project experts' calculation using the data provided from the Ministry of Energy and Natural Resources.

Table 1. Fuel Characteristics[88 89]

Fuels	Net Calorific Value (NCV) (TJ/Gg)				Emission Factor ($t\ CO_2/TJ$)	Biomass ratio (%)
	2023 - 2029	2030 - 2039	2040 - 2049	2050 - 2053		2024 - 2053
Petroleum Coke	32.2	32.2	32.2	32.2	97.4	0%
Domestic Lignite	8.3	8.3	8.3	8.3	96.1	0%
Import Coal	23.8	23.8	23.8	23.8	94.5	0%
Domestic Coal	23.8	23.8	23.8	23.8	94.5	0%
Fuel Oil	39.4	39.4	39.4	39.4	77.0	0%
Natural Gas	0.03	0.03	0.03	0.03	53.7	0%
Hazardous Refuse- derived Fuel	13.6	14.7	15.9	16.7	85.0	0%
Domestic Refuse-derived Fuel (SRF)	15.7	15.7	16.3	16.7	75.0	40%
Other Alternative Fuels	15.1	16.7	17.8	18.8	80.0	0%
Used Tyres	25.7	27.2	27.2	27.2	85.0	27%
Domestic Sewage Sludge	8.3	11.2	11.2	11.2	111.8	100%
Hydrogen	120.7	120.7	120.7	120.7	0.0	0%

Reducing Clinker/Cement Ratio

In the clinker production stage, the raw meal is pre-calcined before entering the rotary kiln. During calcination a chemical reaction occurs so that limestone ($CaCO_3$) decomposes into calcium oxide (CaO) and carbon dioxide (CO_2). The emissions from this process are defined as process emissions.

$$CaCO_3 \rightarrow CaO + CO_2$$

For every tonne of clinker produced, approximately 0.5 tonnes of CO_2 are produced. Process emissions are emissions that are expected to occur as long as the raw material is not changed. In this context, reducing the clinker ratio has been included as a key lever in many decarbonization maps.[90]

The main action to lower clinker usage is the alternative use of cement additives, known also as cementitious materials. Well-known cement additives include natural and artificial materials such as natural pozzolanic materials and artificial cementitious materials (e.g., blast furnace slag).

Within the scope of the model, the clinker/cement ratio was modelled by taking into account the availability of cement additives in Türkiye. In this context, **it is projected that the clinker/cement ratio will reach 0.70 in 2053 in the moderate LCP scenario and 0.6 in the more aggressive FTS scenario.**

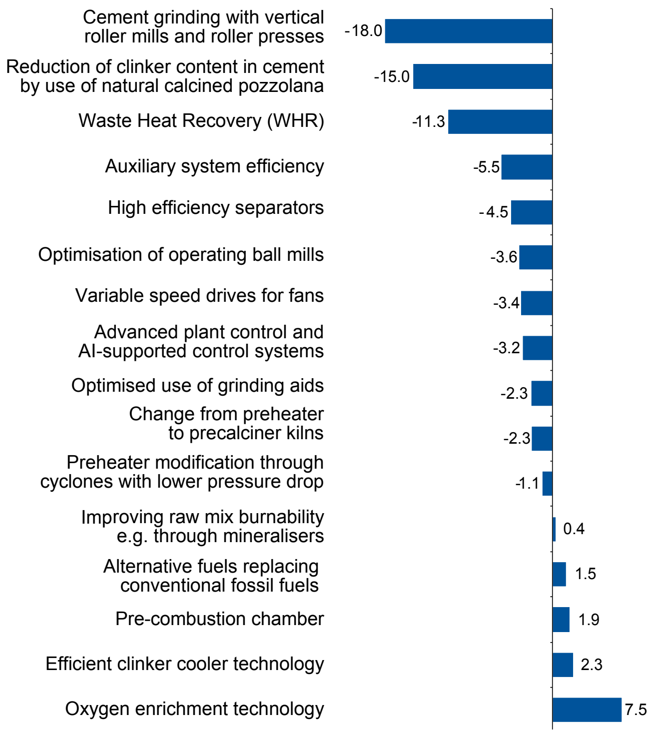
[88] MENR, NIR 2020, Expert Opinion
[89] Other alternative fuels include, bilge oil, liquid wastes etc.
[90] Dhas, S. (2021). Decarbonization pathways for the cement industry.

Electricity Decarbonization

According to CEMBUREAU[91] that, as an energy-intensive industry, about 12% of cement's energy composition is supplied by electricity, while the rest is met by various fuels. Considering a dry process, the total electricity consumption is in raw material preparation with 25% share, clinker production with 25% share and then cement grinding with 43% share.[92] The remaining share is used in raw material extraction, fuel grinding and packaging and loading.[93] Through research and development studies, it is expected that fuel combination ratios and percentages of energy use per process will change, and less CO_2 will be emitted out of cement production.Within the scope of electricity decarbonization leverage, improving raw mix burnability e.g. through mineralizers, change from preheater to precalciner kilns, preheater modification through cyclones with lower pressure drop, oxygen enrichment technology, efficient clinker cooler technology, waste heat recovery: ORC, alternative fuels replacing conventional fossil fuels, pre-combustion chambers, advanced plant control and AI-supported control systems, variable speed drives for fans, auxiliary system efficiency, cement grinding with vertical roller mills and roller presses, high efficiency separators, optimization of operating ball mills, optimized use of grinding aids, reduction of clinker content in cement by use of natural calcined pozzolana are examined in detail.

The electricity savings potentials per tonne cement of the technologies examined under the electricity decarbonization lever mentioned above are given in Figure 30. The electricity saving potential of these technologies is taken into account in the long-term optimization model scenarios. Technologies with negative values represent efficiency in electricity use, whereas technologies with positive values indicate electricity use increase.

Figure 30. Impacts of Technologies on Electricity Utilization (kWh/t Cement)[94]



Material Efficiency in Concrete, Design and Construction

One of the key decarbonization levers for the cement sector is material efficiency in concrete, design, and construction. This lever indirectly affects cement decarbonization. Efficiency in concrete, materials and construction is expected to reduce the demand for cement, which in turn will reduce emissions depending on the scenarios.

[91]CEMBUREAU (2020). Powering The Cement Industry. Retrieved from, https://cembureau.eu/media/ckkpgrg1/cembureau-view-cement-sector-electricity-use-in-the-european-cement-industry.pdf
[92]Percentages may vary depending on the factories and inputs.
[93]Türkçimento (2019). Çimento Endüstrisine Elektrik Enerjisi Temini.
[94]European Cement Research Academy. The ECRA Technology Papers 2022 & Sector Expert View

Approximately 60% of the cement used in the domestic market in Türkiye is used in the production of ready mixed concrete (RMC).[95] Almost all of the cement producers also produce RMC. Türkiye ranks first in Europe and among the top 5 in the world with 105 million m^3 of RMC production in 2022, according to European Ready Mixed Concrete Organization (ERMCO)[96] data.

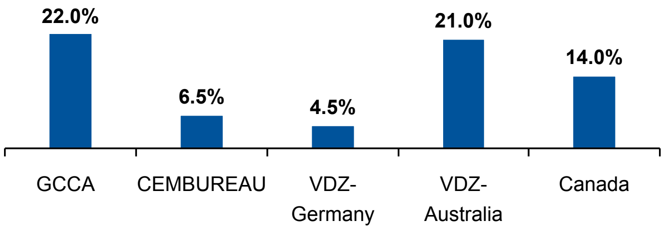
Cement is mixed with materials such as water, aggregate, sand and chemical additives in mortar and concrete production. Concrete admixtures are natural or manufactured chemicals added during concrete mixing to improve certain properties of ready-mixed concrete such as workability, durability, initial and final strength. Research on optimizing the cement consumption per unit volume of concrete and optimizing admixtures and concrete composition is critical for decarbonization of concrete. In many applications, supplementary cementitious materials (SCM) such as fly ash, blast furnace slag or silica fume can be used to replace some of the cement needed to make concrete, resulting in significant reductions in greenhouse gas emissions. However, the amount of substitutes (mineral additives) that can be used instead of cement is limited by standards. In addition, the effects of these materials on the rate of strength gain and setting time cause the usage rates to vary significantly depending on the application.

As a result of actions such as the use of artificial intelligence (machine learning)-based predictive methods in the production of ready-mixed concrete, the use of digital tools (sensors, IoT, etc.) in quality control and concrete mix design processes, the use of mineral additives such as natural pozzolan, calcined clay and bottom ash (other than fly ash and blast furnace slag) and the use of more effective chemical admixtures; an efficiency gain in cement demand should be considered.

Research is currently being conducted on how to reduce the carbon footprint of building materials. Within this context, it is important to ensure the prevention of premature structural failure and to ensure the durability and longevity of the structure. Early studies show that the use of efficient building design can reduce carbon output by up to 30% in certain building types.[97] Improvements to building structures can also be achieved with 3D printing. Recent studies have shown that more efficient use of concrete in buildings and other construction projects can reduce the consumption of concrete in these structures.

The mitigation potential of material efficiency in design and construction and efficiency in concrete has been taken into account in the project as in many roadmaps. In this context, net cement demand after efficiency improvements is projected to decrease gradually by 3%, 5% and 7% in 2030, 2040 and 2053 in the LCP scenario. In the more aggressive FTS scenario, these rates are estimated as 3%, 6% and 10% for the same years, respectively.

Figure 31. Reduction Potential of Material Efficiency in Design and Construction in 2050[98]



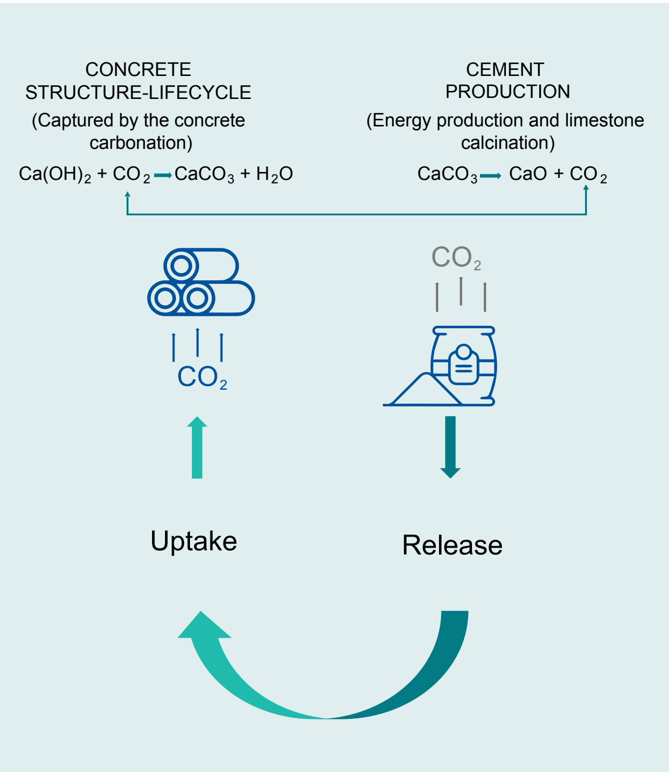
Recarbonation (CO_2 Sink)

Recarbonation is the process whereby some of the CO2 emitted in cement production is chemically re-bound by cement-containing materials through carbonation, thus reducing overall CO_2 emissions. How fast recarbonation takes place depends on various parameters, e.g. type of cement, humidity, permeability of concrete, etc. The recarbonation lever is included in all decarbonization roadmaps as it is a scientific phenomenon in the literature that some of the carbon dioxide produced by the chemical breakdown (decomposition) of limestone at high temperature during cement production is permanently captured by plasters, reinforced concrete buildings, concrete roads, cement-based building products and even concrete waste. Therefore, the recarbonation lever is also included in this project.[99]

[95] A sectoral estimation was carried out based on expert opinion and THBB and Türkçimento data.
[96] ERMCO (n.d.) Retrieved from, https://ermco.eu/
[97] Erten (2011). Yeşil Binalar. Sürdürülebilir Üretim ve Tüketim Yayınları – V, Ministry of Environment, Urbanization and Climate Change, Ankara. & Expert View
[98] GCCA (2021). The GCCA 2050 Cement and Concrete Industry Roadmap for Cement and Concrete. Cembureau, 2050 Carbon Neutrality Roadmap. VDZ, Decarbonising Cement and Concrete: A CO_2 Roadmap for the German cement industry. VDZ, Decarbonisation Pathways for the Australian Cement and Concrete Sector. Cement Association of Canada, Concrete Zero.
[99] CEMBUREAU. Retrieved from, https://cembureau.eu/media/kvlbxuuz/cembureau-view-cement-sector-recarbonation.pdf

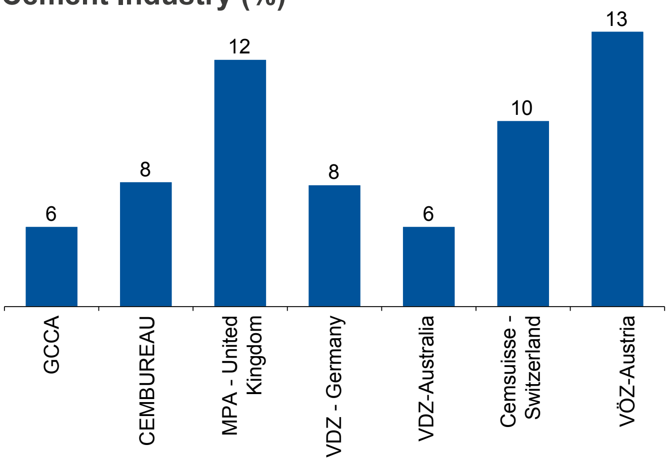
The calcination reaction can be naturally reversed in concrete through hydrated cement products. The process called re-carbonation occurs in all reinforced concrete structures (buildings, pavements, tunnels, dams, bridges) throughout their lifetime. Carbonation also occurs in mortar and plaster made by mixing sand with cement and water. When carbon dioxide in the atmosphere penetrates the concrete, it dissolves in the water in the voids in the concrete and reacts with hydrated products, mainly calcium hydroxide ($Ca(OH)_2$), to form limestone and water. For a concrete product or structure, more than half of the carbon dioxide emitted by the calcination reaction is eventually rebounded by the carbonation mechanism, but the timescale over which this occurs can vary from a few months or years to hundreds of years.

Figure 32. Recarbonation Process[100]



Different organization have assumed between 6-13% contribution of recarbonation to achieve Net Zero Emission targets by 2050. Although re-carbonation is not yet included in National Greenhouse Gas Inventory Reports, it has been included in the carbon footprint calculation standards of concrete buildings, structures and products, decarbonization roadmaps and IPCC reports.

Figure 33. Contribution of Recarbonation to Achieve Net Zero Emission Target in 2050 for Cement Industry (%)[101]



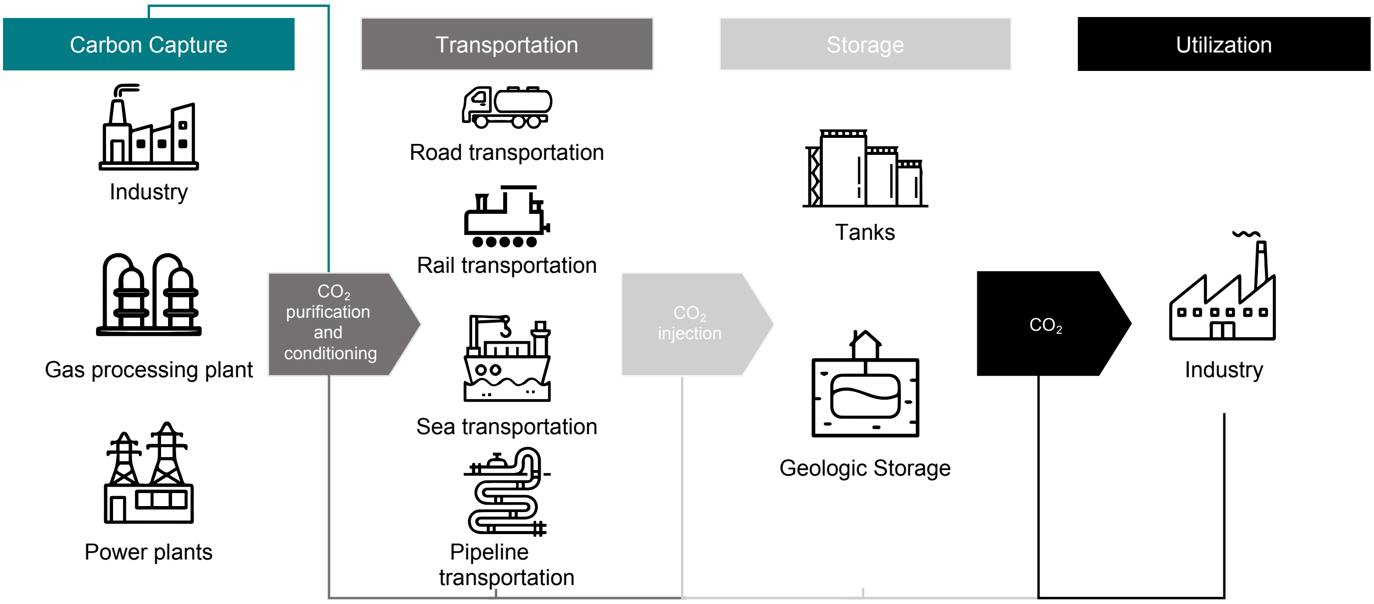
Within the scope of the project, recarbonation leverage was taken into account in the light of international road maps and expert opinions, and it was predicted that total emissions would decrease by 13% after implementing this lever.

CCUS (Carbon Capture, Utilization and Storage)

CCUS is one of the key technologies for zero emissions (especially process emissions from calcination, which account for 60-65% of total emissions). Initially, CCUS facilities are designed to capture carbon dioxide directly from power generation, industrial and gas processing facilities with nearby CO_2 storage sites. More recently, CO_2 has been transported and stored in underground geological formations. In addition, captured CO_2 can be used as a raw material, for example, CO_2 captured from cement plants can be used in the production of chemicals.[102]

[100] Felix, E. F., & Possan, E. (2018). Balance emissions and CO_2 uptake in concrete structures: simulation based on the cement content and type. Revista ibracon de estruturas e materiais, 11, 135-162.
[101] GCCA (2021). The GCCA 2050 Cement and Concrete Industry Roadmap for Cement and Concrete. Cembureau, 2050 Carbon Neutrality Roadmap. UK (2020). UK Concrete and Cement Industry Roadmap to Beyond Net Zero. VDZ, Decarbonising Cement and Concrete: A CO_2 Roadmap for the German cement industry. VDZ, Decarbonisation Pathways for the Australian Cement and Concrete Sector. Cemsuisse, Roadmap 2050 Klimaneutraler Zement als Ziel, Cemsuisse, 2021. VÖZ (2022). Roadmap zur CO_2-Neutralität der österreichischen Zementindustrie bis 2050.
[102] CEMBUREAU. Retrieved from, https://cembureau.eu/policy-focus/climate-energy/ccus/

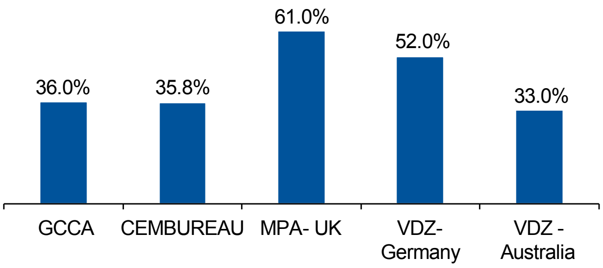
Figure 34. Concept of Carbon Capture, Storage and Utilization[103]



CCUS is a cornerstone of the net zero carbon roadmaps for the cement industry. The technology has been shown as applicable and technically proven, but an industry-wide roll out of CCUS will require close cooperation between the industry, policymakers and the investment community. The widespread use of CCUS will play a key role in the decarbonization process of the cement sector, but it seems that more research and investments are needed in this field.

Figure 35 indicates the CO_2 emission reduction potential of CCUS technology currently in some representative technology roadmaps. In the light of the road maps, it can be seen that CCUS has the largest share in CO_2 reduction in the cement sector. According to the roadmaps, the contribution of CCUS to the net zero cement target varies between 33% and 61%.

Figure 35. CCUS Emission Reduction in Selected Cement Decarbonization Roadmaps[104]



After adopting all available technology options, it is assumed that there will be a potential to reduce total remaining emissions by 90% in the LCP scenario and 95% in the more aggressive FTS scenario by implementing CCUS technologies.

2.3. Low-Carbon Scenarios Through 2053

This study employs two sets of scenarios, reference and mitigation, that represent different aspects of technology investments and policy actions required to reduce emissions in the cement sector, whereby:

Reference scenarios function as a point of comparison for the alternative scenarios. One of the reference scenarios, the WoM scenario, represents a no policy baseline where no explicit mitigative action is taken. The other reference scenario, the Stated Policy Scenario (SPS), is generated as a reference scenario to explore the potential effects of stated policies, efficiency improvements in facilities, electricity grid decarbonization, EU Carbon Border Adjustment Mechanism constraints and introduction of the planned national ETS in the near future.

[103] Türkçimento (2022). Karbon Yakalama, Kullanma ve Depolama. Retrieved from, https://www.turkcimento.org.tr/uploads/pdf/karbon_yakalama_ve_depolama.pdf
[104] GCCA (2021). The GCCA 2050 Cement and Concrete Industry Roadmap for Cement and Concrete. Cembureau, 2050 Carbon Neutrality Roadmap. UK (2020). UK Concrete and Cement Industry Roadmap to Beyond Net Zero. VDZ, Decarbonising Cement and Concrete: A CO2 Roadmap for the German cement industry. VDZ, Decarbonisation Pathways for the Australian Cement and Concrete Sector.

Mitigation scenarios consider a more radical policy and technology change to transition to a low carbon pathway. In line with Türkiye's 2053 net zero emissions target, two different net-zero scenarios are devised for Türkiye's cement sector. The LCP scenario, which considers an ETS price lower than EU ETS and technological transformation, is considered as the optimal scenario for the transition of Türkiye's cement sector. The more aggressive Frontier Technologies Scenario (FTS) is differentiated from the LCP Scenario by the early introduction of disruptive technologies and higher penetration rate assumptions, with an ETS price equal to the indicative EU ETS carbon price. In both mitigation scenarios, recarbonation and efficiency in concrete, design and construction decarbonization levers are also included in the model, with different impacts depending on the scenarios.

Figure 36. Cement Sector Scenarios

Cement Sector Scenarios		ETS	Transformation	Emission Target	Policies
Reference Scenarios	Without Measures Scenario (WoM)	No ETS	No Technological Transformation	No emission reduction target	No emission reduction policies
Reference Scenarios	Stated Policy Scenario (SPS)	Türkiye ETS < EU ETS	No Technological Transformation	No emission reduction target	Implementation of emission reduction policies
Mitigation Scenarios	Low -Carbon Pathway Scenario (LCP)	Türkiye ETS < EU ETS	Optimal Technological Transformation Emission Reduction Through Recarbonation	Cost -effective emission reduction targeting net zero by 2053	Implementation of emission reduction policies
Mitigation Scenarios	Frontier Technologies Scenario (FTS)	Türkiye ETS = EU ETS	Aggressive Technological Transformation Emission Reduction Through Recarbonation	Cost -effective emission reduction targeting net zero by 2053	Implementation of emission reduction policies

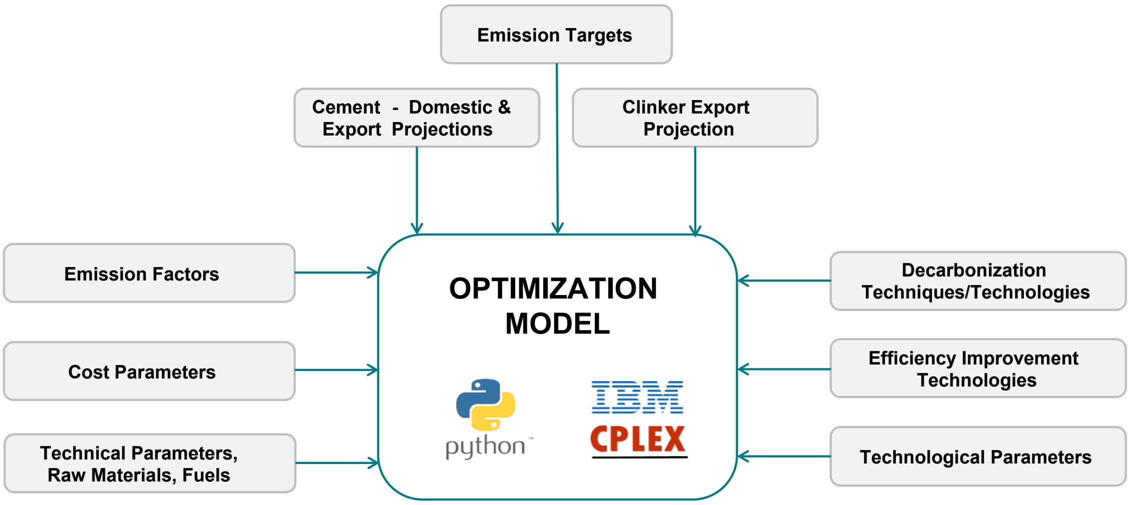
2.4. Greenhouse Gases (GHG) and Policy Interaction Model

2.4.1. The Model Approach

The cement sector model used as part of this project is a multi-objective, long-term scenario analysis and optimization model developed to analyze various scenarios for Türkiye's cement sector. The model uses large-scale linear programming with the objective of minimizing discounted total costs under technological and economic constraints while achieving a certain emission target. Finally, the model calculates the optimal solution set for various emission reduction levers for the period of 2023-2053.

The general framework of the optimization model is illustrated in Figure 37. As seen in this figure, the optimization model developed on IBM CPLEX, requires several sets of inputs, i.e., cement domestic demand & export projections, clinker export projections, emission targets, current and future technological options, their costs, and technical features along with emission parameters, fuel consumption distribution and their costs. Set-up as such, the optimization model runs specific scenarios generated. The solution produced by model compares the projected demand, production by technology type, total emissions and lays out the share of each technology in production, fuel change, utilization and investment need for the given time period.

Figure 37. General Framework of the Optimization Model



2.4.2. Model Results

Within the aforementioned scope, the modelling work aims to forecast; emission levels, costs, technology transformation, investment requirements and the impact of climate policy initiatives on these under different scenarios, for the next 30-years.

In the next sections, the model results will be discussed in detail through the lenses of emissions. In the emission section, scenario-based emission reduction assumptions are analyzed in detail. Alternative fuels consumption and renewable energy consumption in the cement sector are also discussed. The investment needs required to achieve decarbonization based on the scenarios are provided under section 2.5.

According to the model results, CCUS technology is one of the key levers to reduce cement sector emissions. In addition to the technologies, the use of new and alternative fuels and clinker substitutes as inputs has led to a decrease in emission levels. Investment costs are expected to increase with the introduction of CCUS technology in the LCP and FTS scenarios that aim to achieve net zero emissions towards the end of the planning period.

Selected Decarbonization Roadmaps for Cement Industry

There are multiple levers to be applied at different stages of cement production to reduce emissions and achieve net zero emissions. Various research and development projects are being carried out to reduce CO_2 emissions in cement production. These efforts focus on the use of clinker substitute materials to reduce the clinker/cement ratio, the use of alternative fuels with high biomass content, the use of carbon capture, utilization and storage (CCUS) technologies and the increase in the use of electricity generated from renewable energy.

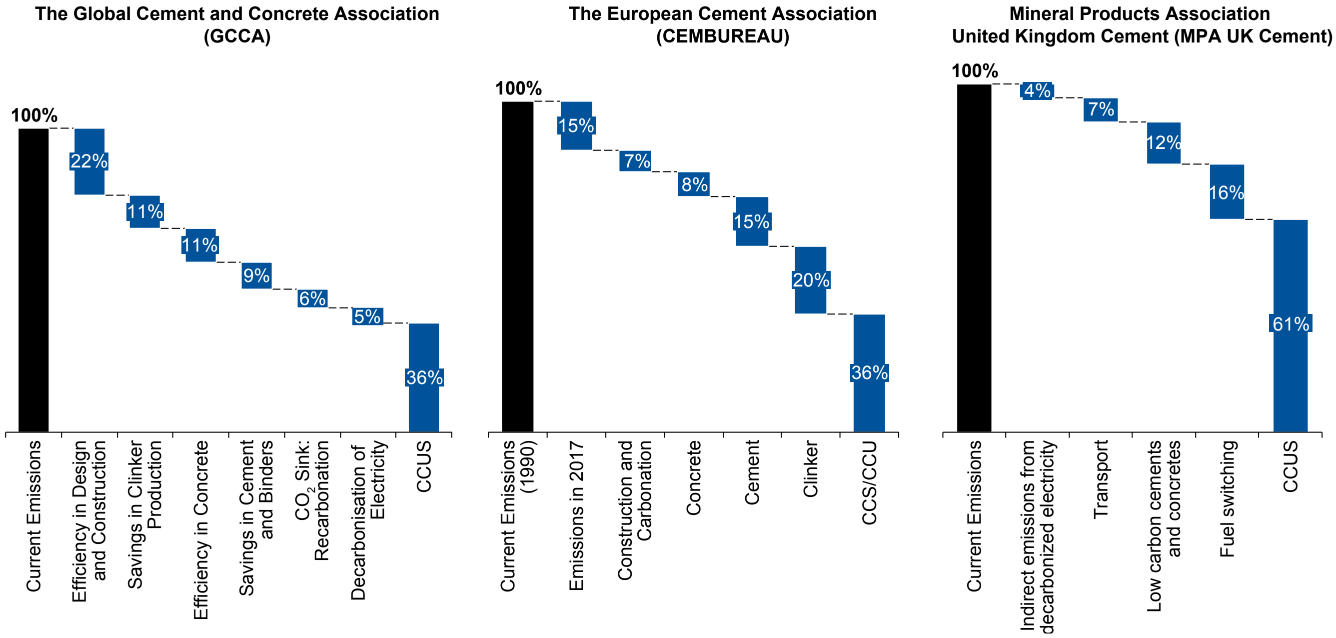
For benchmarking purposes, this report will refer to three key international cement decarbonization roadmap studies prepared by Global Cement and Concrete Association (GCCA), European Cement Association (CEMBUREAU) and United Kingdom Mineral Products Association Concrete and Cement (MPA). Within the scope of the project, the decarbonization levers of the relevant reports were examined in detail and their applicability to Türkiye was discussed with industry stakeholders and industry experts.

According to GCCA data, total global CO_2 emissions from the cement sector in 2021 exceed 2.5 Gt. Moreover, 3.8 Gt of CO_2 emissions are expected to be emitted in 2050, if no decarbonization goals are followed and no measures are taken by the sector. In this context, GCCA has defined 7 vital levers for the decarbonization of the cement sector and created a roadmap to achieve a net zero target in 2050. The largest share for emission reduction in the roadmap belongs to carbon storage and utilization technology with 36% share. Following this lever, efficiency action in buildings and design ranks second with 22%. In addition, the report highlights savings in clinker production and emphasizes thermal efficiency, the use of hydrogen as fuel, decarbonization of raw materials and the use of alternative fuels to reduce emissions within the scope of the related decarbonization levers. The report also envisages achieving the 2050 net zero target through various steps to be taken in the areas of efficiency in concrete production, recarbonation, decarbonization of electricity and savings from cement and binders.[105]

CEMBUREAU cement industry roadmap aims to achieve net zero emissions along the cement and concrete value chain by 2050. In this context, CEMBUREAU recognized the need for interim targets and set a target to reduce gross CO_2 emissions by 30% for cement and 40% for the value chain by 2030, in line with the Paris Agreement's two-degree Scenario. According to the CEMBUREAU scenario, 5 main levers are emphasized to achieve the net zero target in 2050: efficiency in construction and recarbonation, efficiency in concrete, efficiency in cement, efficiency in clinker and CCUS. As in the GCCA roadmap, CCUS technologies have the largest share in decarbonization of cement sector.[106]

The UK concrete and cement industry has developed a roadmap to go beyond the net zero target. According to the roadmap, it aims to remove more carbon dioxide from the atmosphere than it emits each year. In this context, it focuses on 5 main production-related levers. Among these levers, CCUS is the key decarbonization lever with the largest share in reducing emissions and achieving the net zero target. Aiming for a roadmap beyond net zero, MPA UK Cement targets 44% and 12% reductions through thermal mass and recarbonation, respectively.[107]

Figure 38. Global Cement Decarbonization Roadmaps to Beyond Net Zero in 2050[108]



[105]GCCA (2021). The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete
[106]CEMBUREAU (2020). Reaching Climate Neutrality Along the Cement and Concrete Value Chain by 2050
[107]MPA UK Cement (2020). UK Concrete and Cement Industry Roadmap to Beyond Net Zero
[108]GCCA, CEMBUREAU, MPA UK Cement, PwC Analysis

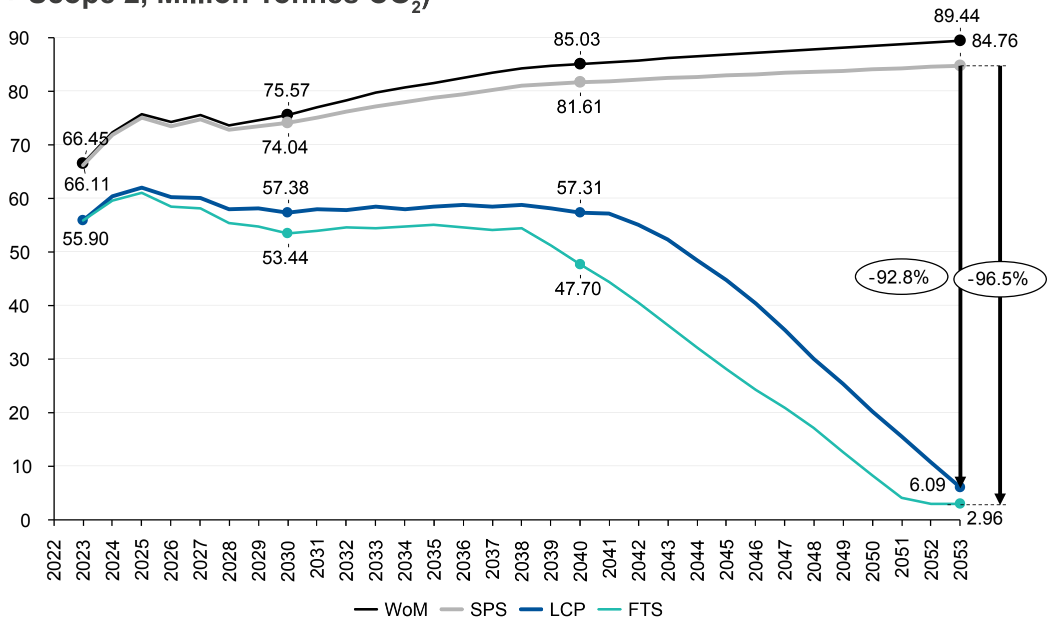
Emission Projections for Türkiye's Total Cement Industry

Emission forecasts by scenarios provide an insight into the emission reduction potential of Türkiye's cement sector under different technological transformation pathways. **In the WoM scenario,** where no mitigation action and technological transformation is assessed, emissions are expected to increase significantly reaching **the highest level, 89.44 million tonnes by 2053,** as seen in Figure 39. In the SPS scenario, no new technology investment is assumed, while grid emissions reduction and the lower domestic carbon price projections are introduced. In the light of all these assumptions, **under the SPS scenario 84.76 million tonnes of CO_2 emissions are expected to be produced in 2053.**

In the optimal scenario, named LCP scenario, assuming lower carbon prices than the projected EU carbon prices, **6.09 million tonnes of CO_2 are emitted in 2053, which means a reduction of 92.8% in total emissions in 2053** compared to the SPS scenario. In the FTS, the most aggressive scenario, with carbon prices equal to EU carbon prices and more aggressive reduction targets, **2.96 million tonnes of CO_2 emissions are produced in the same year.** Thus, **96.5% emission reduction is achieved in the FTS scenario** compared to the SPS scenario. In addition, it is noted that both LCP and FTS scenario emissions are different from the reference scenarios (WoM and SPS) due to the effect of recarbonation and concrete, material and design efficiency.

The cement industry has a limited capacity to reduce emissions due to most of the emissions (around 60%) are generated in the calcination process. The crucial point in mitigation scenarios is most of the emission reductions are projected to be obtained after the commissioning of CCUS to achieve the net zero target. **CCUS is projected to become deployed in 2042 for the LCP and in 2039 for the FTS,** gradually increasing its impact on emission reductions, but in both scenarios, total emissions do not reach net zero by 2053.

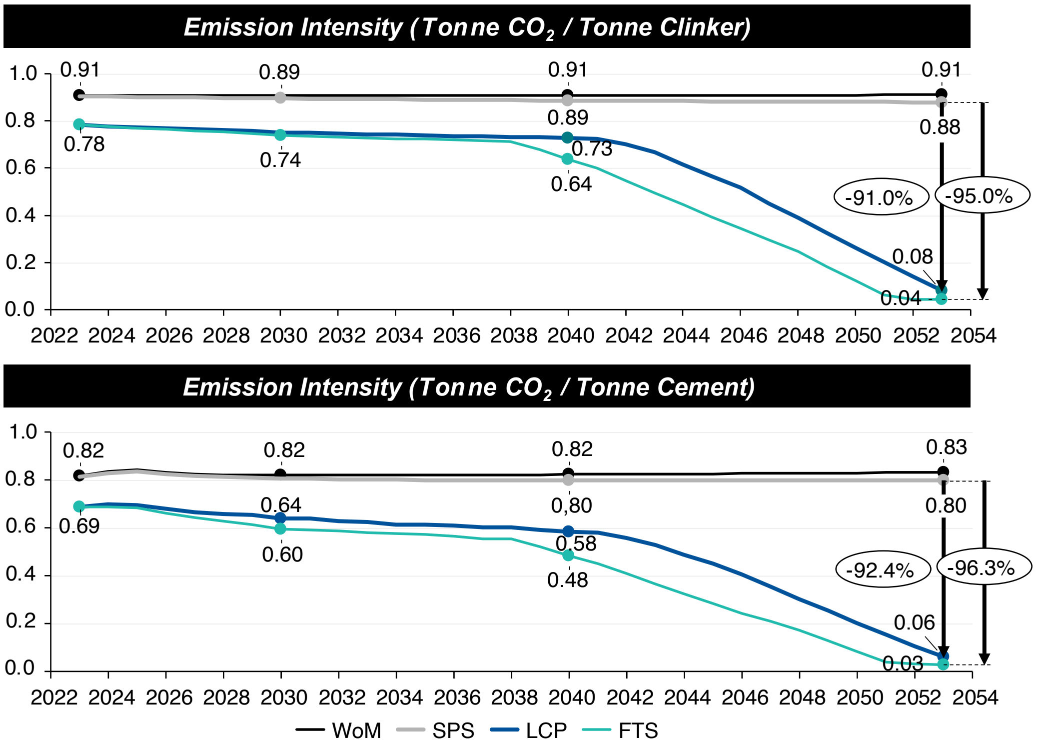
Figure 39. Türkiye Total Cement Sector Emission Projections by Years (Scope 1 + Scope 2, Million Tonnes CO_2)[109 110]



[109] PwC Analysis
[110] Recarbonation, concrete, material and design efficiency are included in the LCP and FTS scenarios but are not included in the WoM and SPS scenarios.

Significant reductions in emissions intensity can ,be achieved by implementing decarbonization investments. Both Scope 1 and Scope 2 emissions are considered together when calculating intensity. Emission intensity for clinker can be reduced by 91.0% and 95.0% for LCP and FTS scenarios compared to the SPS in 2053. On the other hand, emission intensity for cement is projected to decrease to 0.06-tonne CO_2 /tonne cement in LCP and 0.03-tonne CO_2 /tonne cement in FTS in 2053, achieving a reduction of 92.4% and 96.3%, respectively, compared to the SPS scenario.

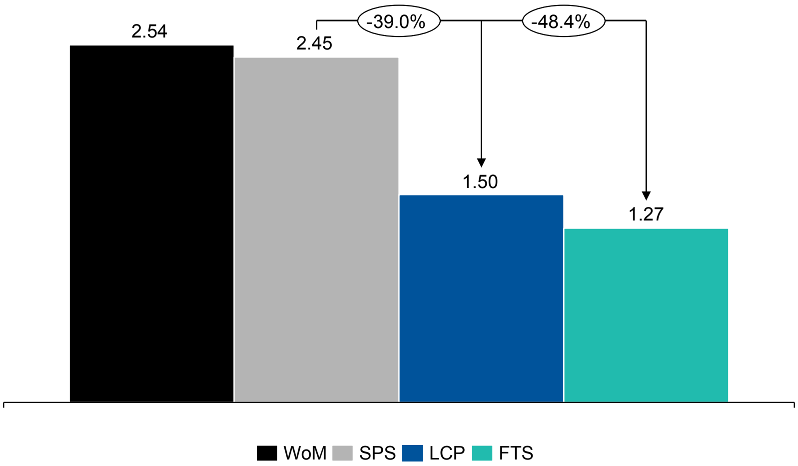
Figure 40. Emission Intensities (Scope 1+Scope 2 Emissions /Tonne Clinker), (Scope 1+Scope 2 Emissions /Tonne Cement)[111 112 113]



The WoM scenario is projected to generate the highest total emissions in the next 30 years and emit 2.54 billion tonnes CO_2, whereas SPS scenario generates a total of 2.45 billion tonnes CO_2 in the same period, illustrated in Figure 41. The LCP scenario, which provides 39.0% reduction compared to the SPS scenario, is expected to emit 1.50 billion tonnes CO_2 cumulatively over the period 2023-2053. In the FTS scenario, which assumes more aggressive use of new technologies, new and alternative fuels, cement additives and a higher national carbon price, total CO_2 emissions are projected to decline more than in the other scenarios over the next 30 years. FTS scenario concludes an additional 229 million tonnes of emission reduction compared to the LCP.

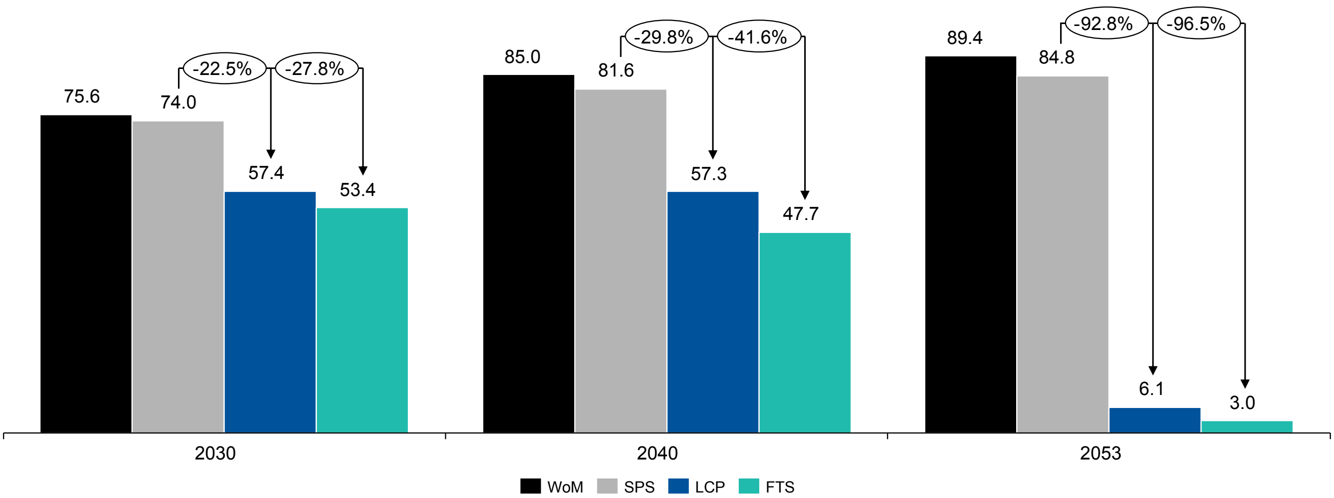
[111]PwC Analysis
[112]Recarbonation, concrete, material and design efficiency are included in the LCP and FTS scenarios but are not included in the WoM and SPS scenarios.
[113]Both Scope 1 and Scope 2 emissions are considered together when calculating intensity.

Figure 41. Cumulative CO_2 Emissions of Türkiye's Cement Sector 2023-2053 (Scope 1+Scope 2 Emissions, Billion Tonnes CO_2)[114]



Emissions are also reviewed for different periods and emission reduction rates in 2030, 2040, 2053 are projected and illustrated in Figure 42. Since radical technologies and fuels have yet to be deployed or are utilized in limited quantities, the least reduction is achieved in 2030. Regarding the scenario-based emissions by years, in 2030, 22.5% and 27.8% emission reductions are achieved in LCP and FTS, respectively, compared to the SPS scenario. In 2040, 29.8% emission reduction is achieved in LCP and 41.6% in FTS compared to SPS. After 2040, emission reductions are closely associated to the introduction of CCUS technology until 2053. In 2053, 92.8% in LCP and 96.5% emission reductions are obtained in FTS compared to the SPS scenario.

Figure 42. Emissions Levels for Selected Years (Scope 1+Scope 2 Emissions, Million Tonne CO_2)[115 116]

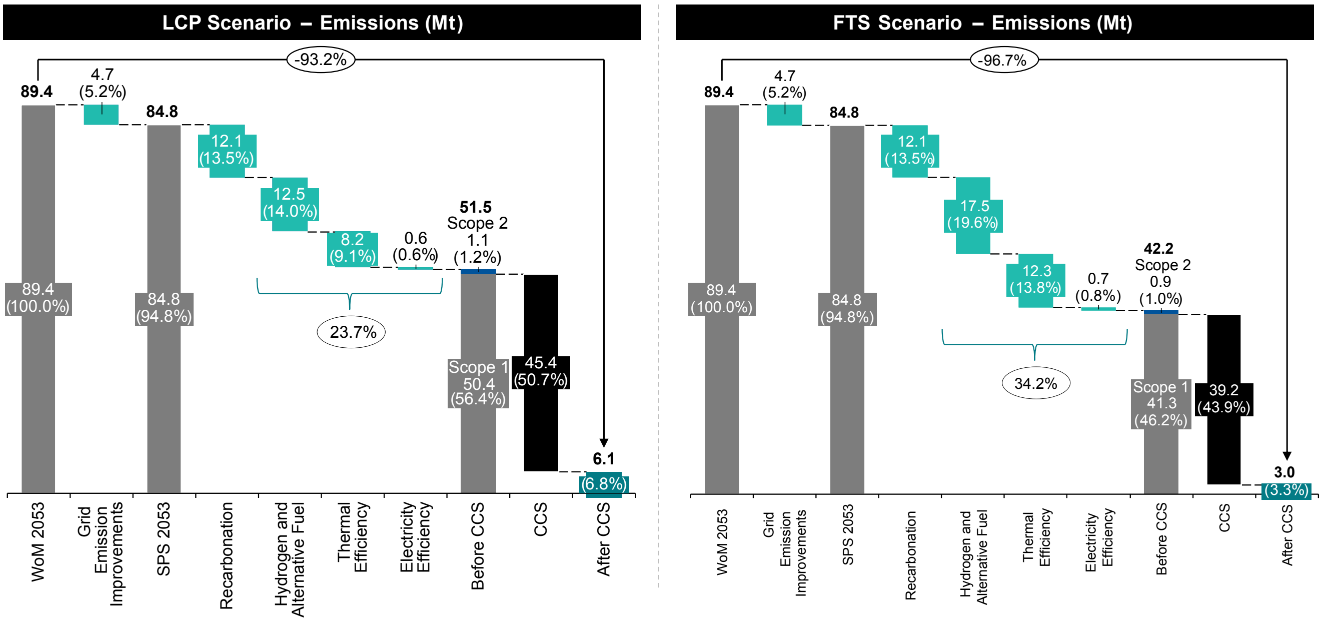


[114]Both Scope 1 and Scope 2 emissions are considered together when calculating intensity.
[115]PwC Analysis
[116]Recarbonation, concrete, material and design efficiency are included in the LCP and FTS scenarios but are not included in the WoM and SPS scenarios.

The end of the forecasting period, 2053, emission levels are compared among the reference and mitigation scenarios in Figure 43. It can be concluded from this figure that emissions in the WoM scenario are expected to be reduced by 4.7 million tonnes of CO2 in the SPS scenario mainly due to the impact of grid emission improvements based on a reduction in the emission factor. One of the key levers, the recarbonation lever, is expected to reduce emissions by 12.1 million tonnes (13.5%) compared to WoM, reducing total emissions to 72.7 million CO_2. Subsequently, in the LCP scenario, 23.7% of emissions can be reduced (compared to the WoM scenario) through electricity efficiency, fuel switching and thermal efficiency, reaching 51.5 million tonnes of emissions (Scope 1+Scope 2) before CCUS technology is implemented. The impact of CCUS technology is only on Scope 1 emissions (50.4 million tonnes). In the LCP scenario, CCUS technology is expected to achieve 45.4 million tonnes (50.7%) of emission reductions compared to WoM. As a result, 6.1 million tonnes of final CO_2 emissions (Scope 1+ Scope 2) are projected in the LCP scenario by 2053. In total, 93.2% reduction is ensured in the LCP scenario with respect to the WoM scenario in 2053.

Similarly, the FTS scenario envisages 4.7 million tonnes emission reductions through grid electricity improvements. Then, 12.1 million tonnes of emission reductions are projected through recarbonation. Thereafter, 17.5 million tonnes of emission reductions have been achieved through the use of alternative fuels and hydrogen, 12.3 million tonnes through electricity efficiency and 0.7 million tonnes through thermal energy efficiency. Thus, the FTS scenario emissions for 2053 before CCUS technology implementation reaches 42.2 million tonnes (Scope 1+Scope 2) emissions. With the deployment of the CCUS technology, 39.2 million tonnes (43.9%) additional emission reduction (only on scope 1 emissions) is achieved compared to the WoM scenario, resulting in 3.0 million tonnes of final emissions in 2053. Overall, 96.7% reduction is obtained in the FTS scenario is achieved compared to the WoM scenario in 2053.

Figure 43. Cement Decarbonization Roadmaps of Mitigation Scenarios in 2053 (Scope 1+Scope 2 Emissions)[117 118]



[117] PwC Analysis
[118] CCUS mitigation only covers Scope 1 emissions. Emissions from electricity use are not included.

Alternative Fuels and Renewable Energy Requirement Projections

One of the major focus areas for the cement industry to reduce emissions is to increase the use of alternative and new fuels replacing conventional fossil fuels. All available and emerging fuel types are introduced to the model and in mitigation scenarios, the share of alternative fuels (hazardous waste, SRF, used tires, municipal sewage sludge and other alternative fuels) in tonnage is assumed to rise over the years. The LCP scenario suggests that the share of alternative fuels will increase from 10.6% (1.2 million tonnes) in 2023 to 49.4% (5.6 million tonnes) by 2053. In the more aggressive FTS scenario, the share of alternative fuels is forecasted to increase more, exceeding 34.3% (4.4 million tonnes) in 2030 and 64.8% (6.6 million tonnes) in 2053. Likewise, the energy provided by renewable wind energy (WPP) and solar energy (SPP) is expected to surge over the plan period. On the other hand, among renewable energy sources, waste heat recovery (WHR) stands out as the technology with the highest potential under this scope. In 2053, WHR is expected to meet part of the electricity demand of 1165.8 GWh in the LCP and 1419.3 GWh in the FTS scenarios.

Figure 44. Total Alternative Fuels Requirement Projections by Scenarios (Million Tonnes)[118]

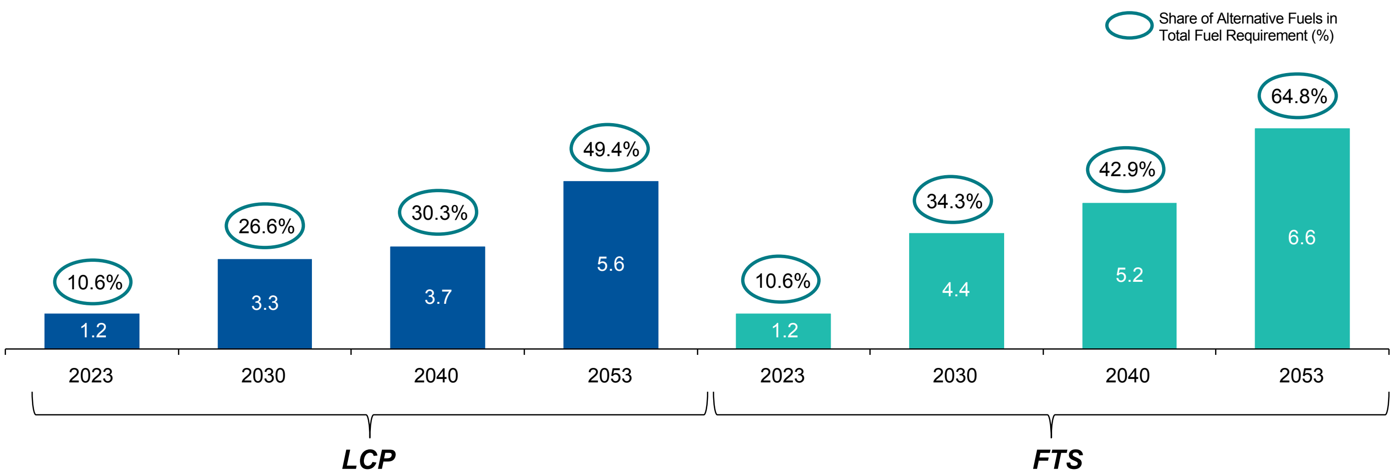
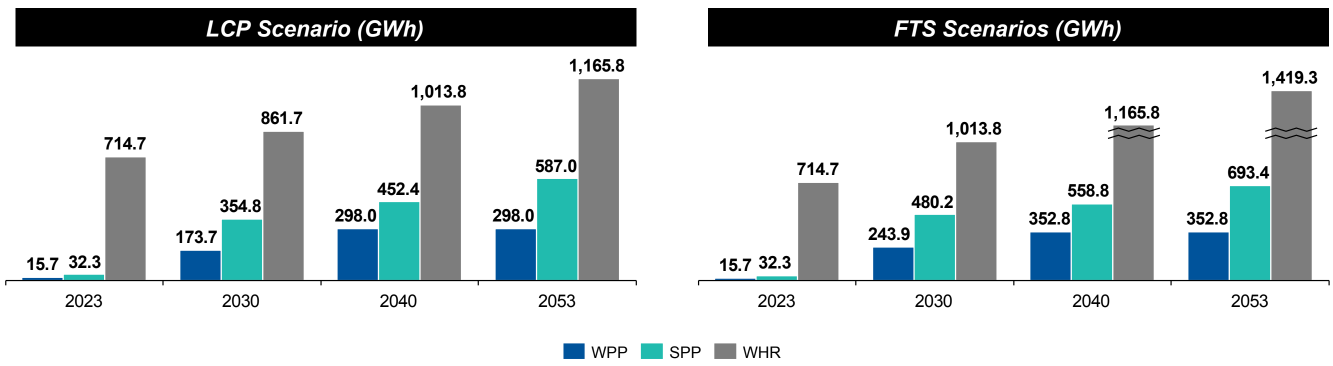


Figure 45. Renewable Energy Requirement Projections by Scenarios (GWh)[119]



[119]PwC Analysis
[120]PwC Analysis

2.5. Investment Requirements to Achieve Decarbonization

2.5.1. Scenario Based Investment Projections

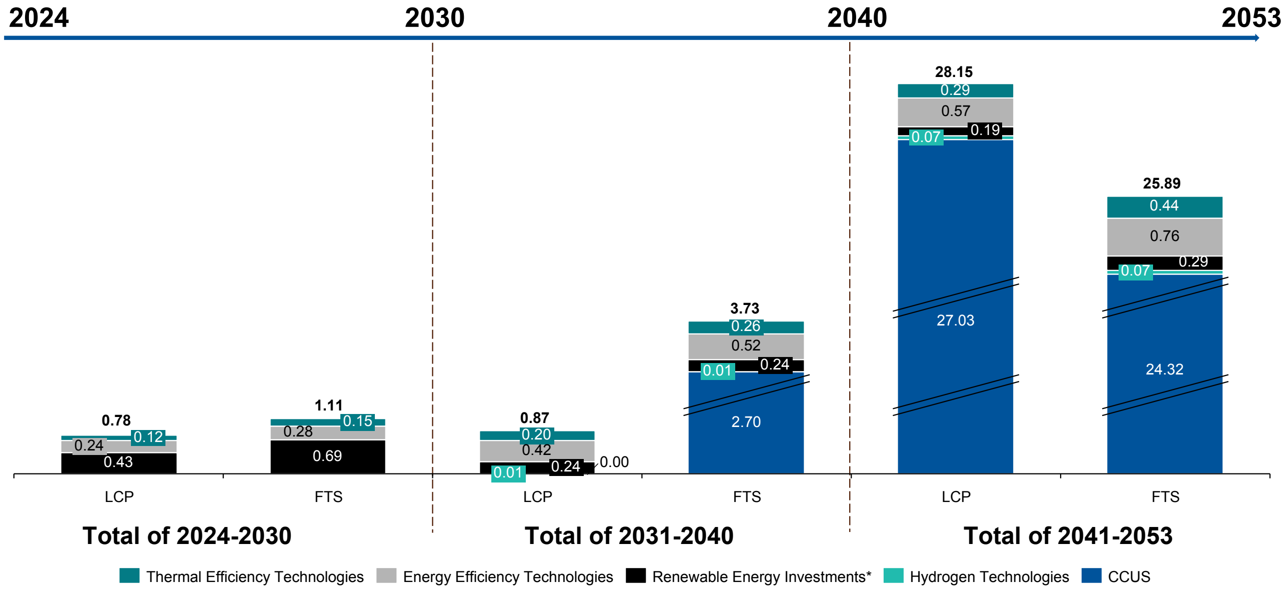
Türkiye's cement sector needs new technologies to be developed and implemented through effective investments to achieve the national emission reduction levels committed in line with the Paris Agreement and to transition to a low-carbon economy. Investments are evaluated based on the technologies, alternative raw materials and fuels selected for different cement sector transition scenarios.

Each scenario indicates different pathways towards decarbonization with different technology diffusion rates (most technologies are currently available), production shares and alternative fuel consumption rates. The objective of the optimization model, which uses input and technology-based data sets, is to minimize cost by considering the emission targets defined in the scenarios. Therefore, different cost and investment needs for different mitigation scenarios are estimated.

Investment requirements are directly related to technology introduction years, technology-related CAPEX costs and alternative raw material costs. The costs of the identified technologies have been adapted to Türkiye-specific conditions considering the meetings with technical experts, interviews with cement companies in the field, and the national cost targets announced by Türkiye. According to the model results, investments costs increase significantly especially with the introduction of CCUS technology to achieve the low carbon production target. In the cost projections, capture, transportation and storage cost is included for CCUS. Noting that, in the sectoral decarbonization cost projections, costs associated with processes such as establishment of waste and storage facilities are not considered as well.

In the model, the investment requirements of the decarbonization technologies are assessed under 5 categories: **Thermal efficiency, energy efficiency, renewable energy, hydrogen, and CCUS investments.** The total investment requirement of technological transformation 2024-2030 is expected to be 0.8 billion dollars and 1.1 billion dollars for the LCP and FTS scenarios, respectively. In respective years, the highest amount of investment is required for renewable energy in both mitigation scenarios. For the following decade (2031-2040), the total investment requirement for the LCP scenario is projected to reach 0.9 billion dollars. In the FTS scenario, the introduction of radical technologies is assumed to start earlier. Therefore, the FTS scenario requires 3.7 billion dollars total investment cost in the same period with the introduction of CCUS technology having relatively higher cost in 2040. 2041-2053 is the period when the highest investment requirement emerges for both mitigation scenarios. In the period, the investment requirements for the LCP and FTS scenarios are 28.2 and 25.9 billion dollars, respectively. The main source of investment cost for both mitigation scenario is CCUS technology. Since the FTS scenario assumes more aggressive targets, CCUS technology investments is expected to occur earlier in the FTS compared to the LCP. As the deployment of CCUS investments is projected to begin in 2039 for the FTS, the total CCUS investment cost is forecasted to be higher in LCP for the 2041-2053.

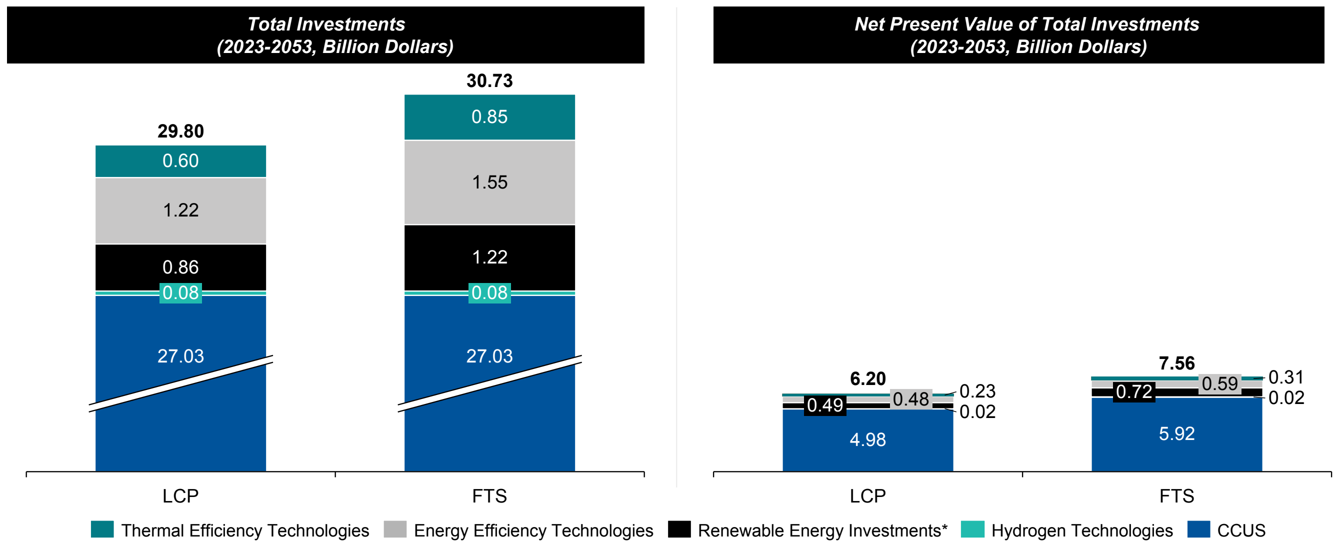
Figure 46. Total Investment Requirement for Selected Periods by Scenarios (Billion Dollars)[121 122]



* WPP, SPP and WHR investments

The total investment requirement in the 2023-2053 period is calculated as 29.8 billion dollars in the LCP scenario and 30.7 billion dollars in the FTS scenario. Based on the NPV of the total investment calculated using a discount rate of 7%, in the 2023-2053 period, total investments required to reach net zero is projected approximately to be 6.2 billion dollars for LCP, while that is around 7.6 billion dollars for FTS. The NPV of CCUS's total investment in the LCP scenario is 5.0 billion dollars and 5.9 billion dollars in the LCP and FTS scenarios, respectively. The annualized NPV requirement is 499 million dollars for LCP scenario and 609 million dollars for FTS scenario for the years 2023 to 2053.

Figure 47. Total Investments and Net Present Value of Total Investments (2023-2053, Billion Dollars)[123 124]



* WPP, SPP and WHR investments

[121]PwC Analysis
[122]The CCUS investment includes Carbon Capture, Transportation and Storage.
[123]PwC Analysis
[124]The CCUS investment includes Carbon Capture, Transportation and Storage.

3 The Roadmap for Progressive Decarbonization of Türkiye's Cement Sector

3. The Roadmap for Decarbonization of the Turkish Cement Sector

The final output of this project is the "Decarbonization Roadmap", consisting of a set of optimal recommendations on policies, technologies, legislative framework and regulations, institutional arrangements/capacity building and budget planning process to lead the decarbonization of the cement sector in Türkiye in line with scenarios and national targets.

Policy recommendations that make up the "Decarbonization Roadmap" are essentially derived from sector analysis, expert opinion, and modelling & scenario analysis. The set of recommendations generated have been opened to several rounds of feedback from the SteerCo members and wider sector representatives.

Special note on recommended technologies:

The set of technologies and techniques recommended as part of the roadmap has been fortified with the Scientific and Technological Research Council of Türkiye - TUBITAK's "Green Growth Technology Roadmap for Cement Industry"[125] work, which was carried out in parallel to the project work and has been co-created with sector experts, academia and TUBITAK's own experts.

Special note on the planned national emissions trading system (ETS) and free allowances:

The EU Emissions Trading System (EU ETS) has been the primary tool used by the continent to decarbonize the economy since 2005. ETS is a cap-and-trade system that limits the total emissions caused by the industries by setting a cap on maximum emissions emitted. The main objective of this system is to reward carbon-efficiency and design incentive programs to foster new and innovative approaches and investments to reduce emissions. In order to keep the hard-to-abate sectors, like the cement industry, competitive, this approach distributes free allowances to industrial sectors based on sectoral risk of carbon leakage and emission efficiency targets.

The government of Türkiye has embarked on a comprehensive climate policy agenda to achieve ambitious emission targets and this year is set to be a milestone in the development of a national emission trading system aimed at contributing to the effective control and gradual reduction of carbon emissions. When designing policies and mechanisms, Türkiye can take into account the general guidelines for the creation and operation of the ETS, which will particularly be vital for the early stages of the system's development. The rules for the allocation of emission allowances will be a fundamental component of the system. Therefore, it is so critical to provide a certain amount of free emissions allowances for heavy industries, including cement industry, in the first years of the system not to harm its competitive power with the countries who fall under less stringent climate legislation.

In the EU, manufacturing received 80% of emissions allowances free of charge in 2013, but this proportion has gradually declined, falling to 30% in 2020.[126] The EU is now further tightening the ETS as part of the "Fit for 55" package, result in a much lower supply of free carbon allowances to cement companies. Moreover, the free distribution of EU ETS allowances will be gradually discontinued under the CBAM phase-in plan, and its phase-out will start slowly before picking up speed toward the conclusion of the time. In the upcoming years, the withdrawal of free allowances will be necessary to proceed towards decarbonizing the cement industry, even though manufacturers will probably receive free allowances covering a major portion of their carbon emissions during the national ETS's introduction period. Managing this transition period will play a crucial role to give the cement producers certainty and help them prepare for the new era in the short and medium term.

[125] TUBITAK (2022). Green Growth Technology Roadmap for Cement Industry.
[126] European Commission, Allocation to industrial installations

Within an overarching methodology, policy recommendations are grouped under **Input and Technology** and **Policy and Market** high level policy themes, and under these two policy themes **16 main policy areas** have been generated.

A) Input and Technology

A.1) Reducing Clinker Use in Cement Production

A.2) Carbon Capture, Utilization and Storage (CCUS) Technologies

A.3) Waste Heat Energy Recovery

A.4) Alternative Fuel Use

A.5) Green Energy

A.6) Process Improvement

A.7) Inclusive Employment and Upskilling / Reskilling of Labor Force

A.8) Material Efficiency in Construction

A.9) Recarbonation

B) Policy & Market

B.1) Research & Development

B.2) Emissions Trading System

B.3) Trade Models

B.4) National Policy Documents

B.5) Green Transformation Finance

B.6) Cooperation

B.7) Industrial Symbiosis

3.1. Input and Technology

Decarbonization policy areas related to input and technology are detailed below.

● **Phase 1** (2023-2025) ● **Phase 2** (2026-2033) ● **Phase 3** (2034-2038) ● **Phase 4** (2039-2053)

	Application Time/Interval			
A.1) Reducing Clinker Use in Cement Production	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out studies to promote the use of blast furnace slag and fly ash in cement plants throughout Türkiye.	●	●	●	●
Carry out studies on possible calcined clay investments and utilization in Türkiye and further elaborate on the potential sources of calcined clay alongside these initiatives.	●	●	●	●
Expand the use of alternative materials as cement additives.	●	●	●	●
Conduct resource mapping studies across Türkiye to identify natural (pozzolana), by-product (blast furnace slag and ash) and waste material resources that can be utilized as cementitious alternatives to clinker.	●	●	●	●

	Application Time/Interval			
A.2) Carbon Capture, Utilization and Storage (CCUS) Technologies	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out activities to increase the carbon capture and utilization capacity in Türkiye’s cement sector.	●	●	●	●
Establish a public and/or private regional carbon transport and storage network open for use of cement sector.		●	●	●
Investigate methods and develop technologies for utilization of carbon through carbon curing or injection in cementitious materials.		●	●	●

	Application Time/Interval			
A.3) Waste Heat Energy Recovery	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Enhance existing incentive systems for the establishment of new waste heat recovery (WHR) facilities.	●	●	●	

	Application Time/Interval			
A.4) Alternative Fuel Use	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out studies to increase the supply of Industrial Refuse-Derived Fuel (RDF).	●	●	●	●
Evaluate the establishment of Mechanical-Biological Treatment (MBT) facilities, including the biological drying process, in metropolitan municipality/municipality solid waste landfills for the production of solid recovered fuel (SRF) from municipal solid waste.	●	●	●	●
Ensure the utilization of dried treatment sludge from the wastewater treatment plants of metropolitan municipalities, OIZs and industrial facilities in the cement sector.	●	●	●	●
Expand the use of liquid wastes such as bilge and sludge from ships in the cement sector by dewatering at ports.	●	●	●	●
Ensure the establishment of authorized laboratories for biomass analyses of alternative fuels.	●	●	●	●
Carry out activities to increase the utilization rate of alternative fuels within the scope of mandatory energy audits and benchmarking studies through financial or fiscal supports.	●	●	●	●
Invest in closed alternative fuel stock areas and feeding systems to increase the utilization rates of alternative fuels.	●	●	●	●

	Application Time/Interval			
A.5) Green Energy	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Extend studies to explore the use of green energy sources (such as hydrogen, plasma, microwaves, etc.) and technologies for thermal energy.	●	●	●	●
Conduct studies to identify existing and appropriate technologies to make green hydrogen commercially available and cost-effective for the cement sector.	●	●	●	●
Ensure that renewable energy investments increase by conducting assessment studies specific to the cement sector.	●	●	●	

	Application Time/Interval			
A.6) Process Improvement	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Continue benchmarking studies to increase the adaptation of cement plants to the best available technologies (BAT) for CO_2 mitigation.	●	●		
Continue benchmarking and auditing studies to reduce cement rotary kiln thermal power consumption (kcal/kg clinker).	●	●	●	●
Develop technological transformation solutions to minimize carbon emissions in cement production processes.	●	●	●	
Continue benchmarking and auditing studies to reduce electrical energy consumption (kWh/tonne cement) in the cement sector.	●	●	●	●

	Application Time/Interval			
A.7) Inclusive Employment and Upskilling / Reskilling of Labor Force	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Increase employment opportunities for women and other underrepresented groups requiring special policies in the cement sector, ensuring equal opportunities for all.	●	●	●	●
Carry out studies to train the workforce with new qualifications and skills within the scope of the green transformation process in the cement sector.	●	●	●	●
Prepare and implement development programmes regarding carbon reduction to raise the awareness of sector stakeholders on green and digital transformation.	●	●	●	●
Prepare and implement necessary training programs in line with the workforce needs required by the green transformation process.	●	●	●	●

	Application Time/Interval			
A.8) Material Efficiency in Construction	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Promote the utilization of low-carbon cement in ready-mixed concrete production and construction sites.	●	●	●	●

	Application Time/Interval			
A.9) Recarbonation	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out studies to include recarbonation in the calculation and verification of GHG emissions from cement production.	●			

3.2. Policy & Market

Decarbonization policy areas related to policy and market are detailed below.

● **Phase 1** (2023-2025) ● **Phase 2** (2026-2033) ● **Phase 3** (2034-2038) ● **Phase 4** (2039-2053)

	Application Time/Interval			
B.1) Research and Development	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Research innovative binders for low carbon concrete and cement production and support implementation projects.	●	●	●	●
Carry out studies to disseminate R&D and innovation incentives for green transformation of the cement sector.	●	●	●	●

	Application Time/Interval			
B.2) Emissions Trading System	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Support those operating in the cement sector for green transformation in line with ETS compliance.		●	●	
When the principles of emission measurement and reporting within the scope of EU CBAM are determined, implement initiatives to ensure our practices are recognized by the EU.	●	●		

	Application Time/Interval			
B.3) Trade Models	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Take measures to protect the international competitiveness of the sector by analyzing the market changes arising from increasing trade between countries that have not taken decarbonization steps.	●	●	●	●

	Application Time/Interval			
B.4) National Policy Documents	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out studies to determine where the relevant legislation (e.g., emissions trading system, waste management, raw materials, circular economy, etc.) differs from EU legislation and achieve full compliance to secure the right to free movement of goods obtained through the Customs Union and harmonization of technical legislation.	●	●	●	
Implement regulations to encourage the use of low-carbon cement by the public and private sector.	●	●	●	●

	Application Time/Interval			
B.5) Green Transformation Finance	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Carry out studies to ensure that the cement sector benefits from green transformation financing supports.	●	●	●	

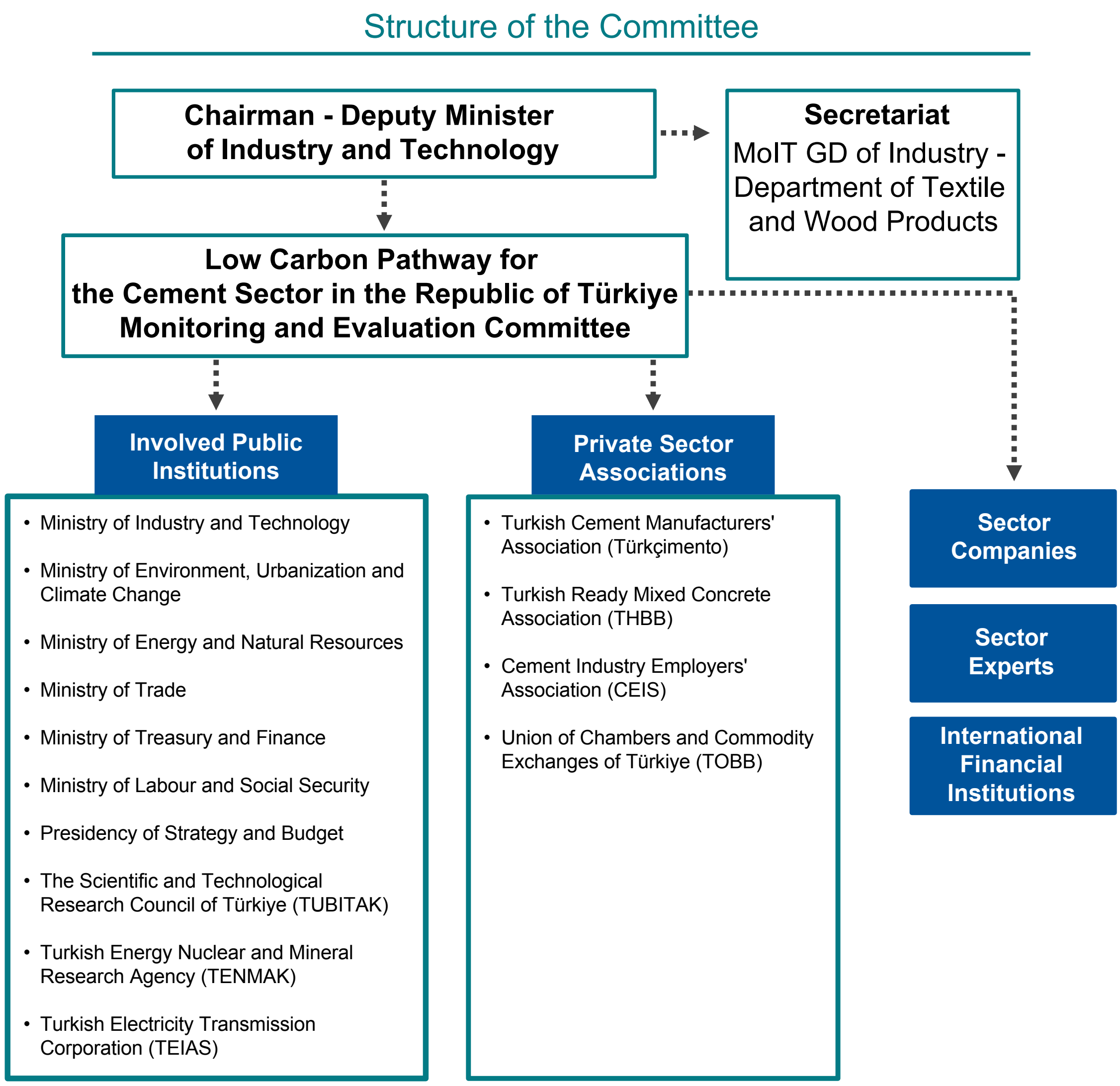
	Application Time/Interval			
B.6) Collaborations	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Create an ecosystem that includes initiatives addressing the low-carbon targets of the cement sector.	●	●	●	●
Carry out studies to enhance collaboration between the relevant public institutions, affiliated organizations, universities and cement factories.	●	●	●	●

	Application Time/Interval			
B.7) Industrial Symbiosis	**Phase 1** (2023-2025)	**Phase 2** (2026-2033)	**Phase 3** (2034-2038)	**Phase 4** (2039-2053)
Establish an industrial symbiosis network to analyze the utilization potential of waste and by-products from different industries in cement production and identify those suitable for use.	●	●	●	●

Monitoring and Evaluation Mechanism

Along with stakeholder mapping, monitoring the implementation of policy recommendations and their impact on the national cement sector is also of crucial importance. Therefore, to ensure that the high standards set for the delivery of the established roadmap are consistently met, a monitoring and evaluation mechanism that tracks and assesses the implementation process and results on a regular basis is a must. To this end, **a Monitoring and Evaluation (M&E) Committee is proposed.**

Figure 48. Structure of the Proposed M&E Committee



4 Conclusions

4. Conclusions

Türkiye, having ratified the Paris Agreement in October 2021 and embark upon the holistic Green Deal, which has significant implications for future bilateral trade, must have a strategy in place for decarbonization of its energy intensive industries. The country has taken major steps to ensure the smooth adaptation of key industries, including cement, to low-carbon manufacturing. This report aims to complement and anchor other regulatory work and analyses carried out to ensure Türkiye's cement sector decarbonization is on track and will support the country's decarbonization targets.

While the cement sector is of high strategic importance for Türkiye, it has also been a sector successfully serving domestic and international markets with high-quality products. The project members and other key stakeholders involved in the delivery of this report are very much aware of the heavy responsibility of ensuring this flagship sector hold harmless while also fostering its decarbonization in parallel with Türkiye's emission reduction targets. With these goals in mind, this report details the data-driven mitigation targets and complementary policy actions that will set the groundwork for decarbonizing the cement sector in Türkiye. The assumed responsibility and continued support of key stakeholders is necessary to turn this strategy into reality.

Reaching carbon neutrality in Türkiye's cement industry will require significant advances in technology as well as dedicated and strong policy implementation. The cement industry's commitment to achieving net-zero will rely on a number of levers that include increasing thermal efficiencies, reducing the clinker to cement ratio, increasing the biomass fuel substitution rates, using alternative and new fuels and reducing fossil fuel use, and decarbonization in electricity in the short-to-medium term. To be part of the low-carbon future, the use of hydrogen and carbon capture, utilization, and storage (CCUS) is expected to be heavily relied upon as a key component of the long-term net zero strategy for the cement industry. Efficiency in concrete production and use also vital factors for the route for decarbonization the industry.

Türkiye's cement sector's decarbonization trajectories highlight the need for development of effective financing mechanisms and plans. Therefore, measures for boosting the mobilization of additional funds should be prioritized in the short term to enable the cement sector to make the necessary technological transformation in the medium to long term. Policymakers and financial institutions need to collaborate and develop new and innovative financing mechanisms, so Türkiye's cement sector has access to scaled-up capital flows to foster decarbonization investments along the pathway.

Implementation of this roadmap will require the continuous support and effective coordination of all related stakeholders. The proposed monitoring and evaluation mechanism should play a leading role in following the developments affecting the cement sector, whereas, forecasts and policy framework should be upgraded when needed and all stakeholders should be guided effectively in implementing the related policies under their control and ownership.

This project has required extensive efforts from the project team under the supervision of the Ministry of Industry and Technology and EBRD, with huge support from related stakeholders including the industry players themselves. Our expectation is that this work will pave the optimal pathway for the decarbonization of Türkiye's cement sector, increase support and financing from relevant parties, and ensure effective implementation of policies in identified areas. The transition of Türkiye's cement sector to a low carbon structure will not only support the country's overall decarbonization goals but also ensure the competitiveness of the domestic industry in global markets amidst increasing sustainability and environmental concerns.