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Benchmark-analysis of current and targeted emissions´ reduction in the Saudi steel and cement industries towards full decarbonization

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Registered offices
Bonn and Eschborn

Köthener Str. 2-3
10963 Berlin

T +49 30 338424 186
E info@giz.de
I www.giz.de

Authors
Achim Schreider, Project Manager, Lahmeyer International

Hirak Al-Hammad, Deputy Project Manager, Lahmeyer International

Muhammad Qaiser Masood, Project Engineer, Lahmeyer International

Responsible
Dr. Louy Qoaider, Head of Hydrogen and Decarbonization Diplomacy Office in Riyadh

Reviewers
Dr. Mohamad Hejazi, Executive Director, Climate and Sustainability Department, King Abdullah Petroleum Studies and Research Center (KAPSARC)

Dr. Louy Qoaider, Head of Hydrogen and Decarbonization Diplomacy Office in Riyadh

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List of Abbreviations

ATR	Autothermal Reforming
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CAGR	Compound Annual Growth Rate
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
GCC	Gulf Cooperation Council
GCOM	Greenhouse Gas Crediting and Offsetting Mechanism
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H_2	Hydrogen
IEA	International Energy Agency
ITMOs	Internationally Transferred Mitigation Outcomes
KSA	Kingdom of Saudi Arabia
LEILAC	Low Emissions Intensity Lime and Cement
MSW	Municipal Solid Waste
Mt	Million Tonne
NEOM	New Enterprise Operating Model
PCB	Polychlorinated Biphenyls
PIF	Public Investment Fund
POX	Partial Oxidation
RDF	Refuse Derived Fuel
SAR	Saudi Riyal
SCM	Supplementary Cementitious Materials
SMR	Steam Methane Reforming
t	Tonne
TRL	Technology Readiness Level
US$	US Dollar
€	Euro

Exchange rate.

1 SAR = 0.27 US$; 1 € = 1.09 US$

Executive summary

Saudi Arabia is undergoing a profound economic and environmental transformation. Guided by Vision 2030, the Kingdom is pursuing an ambitious transformation that seeks to reduce economic dependence on hydrocarbons, develop new industrial sectors, and position itself as a regional and global hub for sustainability and innovation. This transformation is not only economic but also environmental. With the public commitment to reach net-zero greenhouse gas emissions by 2060, Saudi Arabia has joined the global community in acknowledging the urgency of climate action – while also recognizing the unique structural and resource challenges it faces as a major energy producer. Central to both the national development strategy and the climate transition are the steel and cement industries. These sectors form the industrial backbone of the Kingdom of Saudi Arabia (KSA), supplying essential materials for urban expansion, transportation networks, energy infrastructure, and giga-projects such as NEOM, the Red Sea Project, and Qiddiya. They are also among the most emissions-intensive industries globally. In Saudi Arabia, they play a dual role: as indispensable enablers of economic growth, and as hard-to-abate sectors that must find viable pathways to reduce emissions in line with long-term climate targets.

This report assesses the current state, economic contribution, emissions intensity, future growth outlook, and technological decarbonization options for the Saudi steel and cement sectors. It aims to inform national and sectoral-level dialogue on how to align industrial development with the Kingdom's net-zero commitment. The study is based on publicly available data, desk-based research, and modelling carried out by the authors. Methodological approaches include linear regression for steel and cement production forecasting, emissions intensity calculations, and technology uptake modelling, complemented by qualitative SWOT (strengths, weaknesses, opportunities, and threats) analysis. While formal stakeholder consultation was not within the scope of this work, the report was informed by informal exchanges with few industry leading experts who provided valuable insights into technology readiness and regional barriers to deployment.

Understanding the role of steel and cement sectors in Saudi Arabia

The report examines the industrial and economic significance of the steel and cement sectors in Saudi Arabia.

The steel sector has seen steady growth, with capacity doubling from 6.9 million tonnes (Mt) in 2012 to over 12 million tonnes in 2023. Announced expansions suggest capacity will exceed 26 million tonnes in the near future. Domestic consumption reached 13 million tonnes in 2023, while imports have declined by nearly 40% over the past decade, falling from 8 million tonnes in 2012 to 5 million tonnes in 2023. Steel production is heavily weighted toward electric arc furnaces and direct reduced iron (DRI) – technologies that are more amenable to future decarbonization through hydrogen and carbon capture integration.

Cement production capacity expanded from 56 million tonnes in 2012 to 92 million tonnes in 2023, reflecting expectations of long-term infrastructure growth. Although production peaked at 61 million tonnes in 2015, it has since stabilized at around 49.6 million tonnes in 2023. The Kingdom remains self-sufficient in clinker, and exports – largely to markets in Africa and Asia – hover between 8 and 9 million tonnes per year. There are 22 active cement plants in operation, with the top four firms holding 46% of capacity. However, overall utilization has declined from 95% in 2012 to just 54% in 2023, indicating both overcapacity and latent readiness to meet future demand spikes.

Quantifying the carbon footprint and economic profile

The steel and cement industries are responsible for an estimated 32.92 million tonnes of CO_2e annually, or 4.6% of Saudi Arabia’s 2021 national baseline emissions. In steel, the overall emission intensity is estimated at 0.59 tCO_2e per tonne of product – a weighted average based on the current production technology mix: 20% scrap- Electric Arc Furnace (EAF), 70% DRI-EAF, and 10% Blast Furnace-Basic Oxygen Furnace (BF-BOF), the latter used in just one plant in the Kingdom. Emission intensity in cement is estimated at 0.53 tCO_2e per tonne of product, driven largely by process emissions from calcination.

Together, the two sectors generated SAR 44.56 billion in direct economic value in 2023, accounting for approximately 0.5% of national GDP and 5.2% of manufacturing output. Economic value estimates were derived through volume and price analysis, with SAR 30.69 billion attributed to the steel sector and SAR 13.87 billion to the cement sector. Their impact is even broader through indirect linkages to construction, transport, and upstream supply chains. Employment estimates suggest 27,000–30,000 people are directly employed in both sectors, while total supply chain effects likely support an additional 60,000–70,000 jobs when multiplier effects (2.1x to 2.4x) are considered. These figures underscore the sectors' relevance not just to industrial production, but also to economic livelihoods and regional development.

Forecasting production growth and identifying technology pathways

To forecast steel and cement production through 2060, a linear regression analysis was conducted using historical production data and its relationship with two key economic sectors: construction and manufacturing. Vision 2030 is anticipated to significantly boost the construction and manufacturing sectors (excluding petroleum) between 2020 and 2030, with projected growth rates of 9.2% and 8.2%, respectively. However, long-term growth projections for these sectors between 2031 and 2060 are difficult to estimate. A recent study by KAPSARC indicates that Saudi Arabia’s overall GDP will grow at a CAGR of 3.3% through 2030, then moderate to 2.1% between 2030 and 2060, with non-oil GDP projected to grow at a higher CAGR of 2.6% over the same period. Aligned with this outlook, it was conservatively estimated that the economic contributions of both the construction and manufacturing sectors would grow at a CAGR of 2.4% beyond 2030.

Consistent with this broader trajectory, steel production is projected to grow at 3.52% annually through 2030, reflecting the intensity of ongoing economic activity, and at 1.23% annually thereafter, in line with the more moderate outlook through 2060. Cement production is expected to follow a similar pattern – growing at 4.49% annually through 2030 due to intensive infrastructure development, and at 1.59% per year beyond that. Steel production is expected to expand as announced capacity additions come into operation, enabling the sector to better meet rising domestic demand and further reduce reliance on imports, while additional cement capacity is not immediately needed.

To support the net-zero transition, the report identifies a set of decarbonization pathways for both sectors. In steel, these include Carbon Capture, Utilization, and Storage (CCUS) retrofits for the remaining BF-BOF plant, hydrogen and CCUS integration in DRI-EAF configurations, and hydrogen retrofitting for scrap-EAF furnaces. These pathways, taken together, could reduce direct emissions from the steel sector by up to 77% by 2060, with green hydrogen playing a dominant role in later decades - contributing to around 64% of the total emission reductions.

In cement, four technical strategies were assessed for their mitigation potential: CCUS, alternative fuel substitution, clinker reduction, and energy efficiency improvements. Of these, CCUS offers the largest abatement potential up to 25%, though it is also the most capital-intensive and operationally complex. Alternative fuels could reduce emissions by up to 11% but require infrastructure for waste collection and processing. Clinker substitution offers up to 17% abatement but is constrained by the availability of supplementary materials such as slag and fly ash. Energy efficiency can provide further reductions, though gains are incremental given the modern configuration of existing plants. In total, these combined measures could reduce direct emissions from the cement sector by 66% by 2060.

However, it is important to note that these emission trajectories are based entirely on long-term steel and cement production forecasts, which inherently carry uncertainty. There is no officially available long-term dataset on Saudi Arabia's future steel and cement production. Thus, while the projections used in this report are derived from modelling techniques such as linear regression and economic indicators, they represent plausible forecasts – not certainties. The entire decarbonization strategy outlined in this report – including technology deployment timelines and emission reduction potentials – is contingent upon these forecasted steel and cement production trajectories, which may or may not materialize as projected.

The role of offsetting and outward mitigation options

Given that full decarbonization may not be technically or economically feasible within the steel and cement industries by 2060, projections which are again contingent on production forecasts, the report also considers outward emission reduction mechanisms that could contribute steel and cement industries to achieve net-zero targets by 2060.

By 2060, decarbonization measures in the steel sector are projected to avoid 8.46 $MtCO_2e$, compared to projected emissions of 11.03 $MtCO_2e$ without any decarbonization measures. The remaining 2.57 $MtCO_2e$ – representing 23.3% of projected 2060 emissions with mitigation – remains unabated, reflecting residual emissions from low-carbon processes that cannot be fully eliminated.

In the cement sector, decarbonization measures could avoid 37.74 $MtCO_2e$ by 2060, compared to projected emissions of 57.2 $MtCO_2e$ without decarbonization. The remaining 19.44 $MtCO_2e$ or 34% of the projected emissions would remain unabated.

With the modelled technology pathways in place for the steel and cement sectors through a mix of CCUS, hydrogen, alternative fuels, clinker substitution, and energy efficiency, the remaining emissions – the balance between the no-decarbonization and with-decarbonization scenarios – represent the volume of outward or offset-based reductions, in which these sectors could participate to address their residual emissions. These include afforestation and nature-based solutions under the Saudi Green Initiative, voluntary market engagement via Public Investment Fund backed auctions, and potential future participation in Article 6 of the Paris Agreement. These instruments could offer a complementary pathway for managing residual emissions from energy intensive steel and cement industries.

Strategic challenges, market barriers, and policy gaps

While technical options exist, their implementation is conditioned by a range of structural, market, and policy challenges. A central barrier is the absence of steel and cement sector-specific regulatory or financial incentives. Neither the steel nor cement sectors are currently subject to compliance carbon pricing, emissions caps, or targeted clean technology mandates. Electricity and fuel pricing in Saudi Arabia continues to benefit from subsidies, supporting industrial competitiveness, while ongoing energy pricing reforms are expected to gradually enhance the economic incentives for energy efficiency measures and fuel switching. Programs like the Saudi Green Initiative, the Circular Carbon Economy platform, and the Greenhouse Gas Crediting & Offsetting Mechanism (GCOM) currently reflect high-level political commitment, they also offer promising foundations upon which targeted, enforceable policies for industrial emitters -such as the steel and cement sectors – could be developed and implemented.

Access to technology remains an important consideration for scaling industrial decarbonization. While Saudi Arabia benefits from advanced steelmaking capabilities and an established base in DRI–EAF operations, the limited number of global technology licensors – particularly for DRI – and the long lead times required for constructing new facilities could pose challenges for rapid deployment. In the cement sector, the potential deployment of CCUS and alternative fuel systems is not primarily constrained by technical know-how, as Saudi Arabia possesses relevant capabilities through its experience with gas infrastructure and industrial operations. Rather, further progress hinges on putting in place essential enabling conditions and institutional arrangements. These include functional waste management systems to support the use of alternative fuels, setting clear technical standards for blended cement needed to approve and promote blended cement products and providing a greater regulatory clarity to support technology adoption. Addressing these enabling conditions will be critical to unlocking the potential for large-scale technology deployment in the coming years.

Another significant challenge lies in the cost implications of deploying deep decarbonization technologies, particularly for options like CCUS, which can substantially increase both operational costs and the final price of steel and cement products. In the absence of targeted financial incentives or cost-sharing mechanisms, producers may face difficulty justifying such investments – especially in a market where price sensitivity is high and there is limited consumer or regulatory demand for low-carbon materials. This highlights the need for dedicated programs, such as the Greenhouse Gas Crediting & Offsetting Mechanism (GCOM) could play a stronger role in supporting the uptake of these technologies. By offering financial compensation for verified emission reductions or enabling participation in voluntary carbon markets, such platforms could help mitigate cost burdens and accelerate the industrial transition. Meanwhile, global market dynamics are shifting as major economies introduce carbon regulations on traded goods. Although Saudi Arabia's steel and cement exports are not currently directed toward regions implementing measures like the European Union's Carbon Border Adjustment Mechanism (CBAM), future export diversification or broader changes in international market expectations could expose domestic producers to competitiveness pressures, underscoring the need for proactive alignment with emerging carbon standards and supportive domestic frameworks.

While Saudi Arabia is structurally well-positioned to lead in low-carbon industrial production – thanks to its DRI-EAF based steelmaking capacity, largely modern cement plants with dry-process kilns, hydrogen strategy, and infrastructure ambition – realizing this potential will require coordinated policy reform, strategic investment, and institutional capacity-building. Looking ahead, the findings of this report are intended to support meaningful next steps toward the decarbonization of Saudi Arabia's steel and cement sectors. By outlining technology options, highlighting structural challenges, and presenting sector-specific insights, the analysis provides a foundation for informed decision making. It invites policymakers, industrial actors, and supporting institutions to build on the Vision 2030 momentum by developing enabling regulations and mobilizing targeted investment. Accelerating progress in these hard-to-abate steel and cement sectors will be essential to aligning industrial growth with Saudi Arabia's net-zero target, while supporting a long-term development trajectory that is economically competitive and environmentally sustainable.

01. Introduction

Saudi Arabia is undergoing a major transformation, driven by an ambition to diversify its economy, reduce its reliance on hydrocarbons, and prepare for a low-carbon future. Central to this vision is Saudi Vision 2030, a comprehensive national strategy that seeks to unlock new economic sectors, stimulate industrial innovation, and position the Kingdom as a global hub for investment and sustainability. With massive investments flowing into giga projects such as NEOM, The Red Sea Project, and Qiddiya, and into the development of new cities and infrastructure, the demand for basic materials like steel and cement is expected to remain substantial over the coming decades.

In parallel, Saudi Arabia has committed to achieving net-zero greenhouse gas emissions by 2060, a pledge that aligns with global climate efforts while recognising the Kingdom's unique energy landscape. As part of this trajectory, the Saudi Green Initiative, the Circular Carbon Economy framework, the recently launched Saudi Arabia's Greenhouse Gas Crediting & Offsetting Mechanism (GCOM) have emerged as key national platforms to support carbon management, green technology deployment, and broader environmental stewardship. These initiatives also signal a growing policy focus on decarbonizing the industrial sector, particularly energy-intensive industries such as steel and cement.

Steel and cement are foundational to Saudi Arabia’s development ambitions. They are essential inputs for the construction of roads, housing, energy infrastructure, transport systems, and industrial facilities – making them integral to realizing the goals of Vision 2030. At the same time, both industries are also among the largest industrial contributors to greenhouse gas emissions, globally and domestically. Their reliance on high-temperature processes and fossil fuels presents complex challenges for emissions reduction. Yet, decarbonizing these sectors is not only critical for aligning with national climate targets – it also presents opportunities to modernize industrial production, attract clean investment, and develop export-ready green materials.

This report contributes to that broader effort by examining the current state and future potential of decarbonization in Saudi Arabia’s steel and cement industries. It assesses current emissions and production trends, explores potential technological pathways for emissions reduction, and evaluates how these sectors can contribute to the 2060 net-zero target. Drawing from production forecasts, economic significance, and projected emission reductions from the steel and cement industries, this report aims to inform the national dialogue on industrial decarbonization by analysing technology transition options, implementation barriers, and areas where further policy support or market development may be needed. In doing so, the report supports informed decision making for a low-carbon industrial future, aligned with both Saudi Arabia’s economic transformation and its climate commitments.

02. Methodological framework

Analytical approach and data sources

This report adopts a structured and multi-layered methodological approach to explore the decarbonization potential of Saudi Arabia’s steel and cement industries. The analysis relies primarily on desk-based research using publicly accessible data and technical literature, supplemented by the authors’ own modelling, calculations, and interpretation. Depending on the thematic focus, different analytical approaches were applied across the report’s main sections and was supported by an appropriate methodological framework.

In Section 4, which establishes the economic role of steel and cement in Saudi Arabia, the methodology draws extensively on secondary sources. Publicly available industry databases, national statistics, and international trade and production reports were used to map historical and current trends, providing a factual baseline for understanding the scale and structure of the two sectors. Estimates of direct economic contribution – such as steel and cement sector market size and GDP share – were derived from basic calculations using average prices and reported volumes. Broader economic linkages and employment figures were drawn from secondary sources, aiming to provide a general overview of the sectors' contribution to the national economy.

Section 5 assesses the current economic and environmental footprint of the steel and cement industries. Here, desk research remains the foundation, drawing from national sources, institutional reports, and international benchmarks. In addition, the authors conducted their own calculations to derive emission intensities, economic outputs, and other sector-specific metrics. These calculations involved combining published steel and cement production figures with pricing data and emissions factors to estimate market value and emission contributions, facilitating cross-regional comparisons.

In Section 6 and Section 7, the focus shifts toward long-term growth forecasting and emissions reduction pathways for steel and cement industries to achieve net-zero targets by 2060. A combination of statistical analysis and linear regression modelling was employed to estimate future production trends and assess potential decarbonization strategies. Linear regression models were developed to project growth in steel and cement industries based on macroeconomic indicators such as growth in the construction and manufacturing sectors. These projections were paired with technology-based emission reduction pathways, constructed using emission factors from literature and assumed technology penetration rates. While the input data originated from desk research, the modelling and assumptions applied reflect the authors’ analytical frameworks, shaped by both established knowledge and sectoral context.

Section 8 presents a qualitative strategic evaluation in the form of a SWOT analysis, conducted for the steel and cement sectors. This method was selected to assess the enabling conditions, structural barriers, and strategic levers associated with low-carbon transition in Saudi Arabia. The SWOT analysis draws on insights synthesized from earlier chapters and integrates interpretive judgement on issues such as technology readiness, regulatory support, economic feasibility, and market positioning. The strategic reflections in this section were also informed, at a high level, by exchanges with sector experts and practitioners.

During the preparation of the report, the authors benefited from informal discussions and exchanges with industry experts and stakeholders, including representatives from academic institutions. These interactions provided valuable perspectives on global technology developments, region-specific barriers to adoption, and the practical considerations surrounding implementation in the Saudi context. While formal stakeholder interviews and primary data collection was not part of the study's design, such expert insights helped authors shape the analytical direction and certain methodological assumptions used throughout the report.

Limitations and future analytical opportunities

Sectoral growth scenario modelling for steel and cement

In this study, future growth in the steel and cement sectors was estimated using a straightforward approach that combined statistical analysis with linear regression modelling. Growth projections in steel and cement industries were informed by macroeconomic indicators – specifically trends in the construction and manufacturing sectors – based on data gathered through desk research. While this method provides a practical and accessible starting point, it does not include broader macroeconomic scenario modelling, particularly in terms of how varying GDP growth trajectories could influence sectoral dynamics, due to limitations in available resources.

More advanced modelling approaches employ structured, scenario-based frameworks to explore how economic growth pathways shape demand across sectors. These typically rely on integrated analytical tools – such as macro-econometric models – that support the development of consistent high, baseline, and low growth scenarios across the economy. Applying a similar scenario-driven framework to the steel and cement sectors could improve the depth and reliability of the analysis by directly linking sectoral demand to evolving macroeconomic conditions. Building such scenarios – grounded in GDP forecasts and supported by detailed assumptions on construction and manufacturing growth – would offer a stronger foundation for long-term planning and policy formulation. This represents a logical next step for future work as more detailed data and analytical resources become available.

Technology transition scenarios: gaps in cost modelling

Another limitation of this study is the lack of cost forecast modelling in the assumptions underlying decarbonization technology uptake. The transition trajectories for technologies such as CCUS and hydrogen are primarily based on qualitative assessments of their technology readiness levels and their alignment with Saudi Arabia’s existing industrial infrastructure and resource conditions. While the anticipated influence of economic factors—such as the declining cost of green hydrogen by 2060—is qualitatively reflected in the long-term uptake patterns (e.g., increased hydrogen adoption toward 2060 in steel production), these aspects have not been quantitatively modelled in the technology transition pathways through pricing or cost-optimization models. Incorporating such elements—like hydrogen/CCUS cost decline forecasts, CO_2 price trajectories, regulatory incentives, or least-cost technology transition modelling – would provide a more quantitative and policy-relevant depiction of decarbonization pathways. Developing these layers of analysis represents further opportunity for future work, as more detailed cost data for technology transition and analytical resources become available.

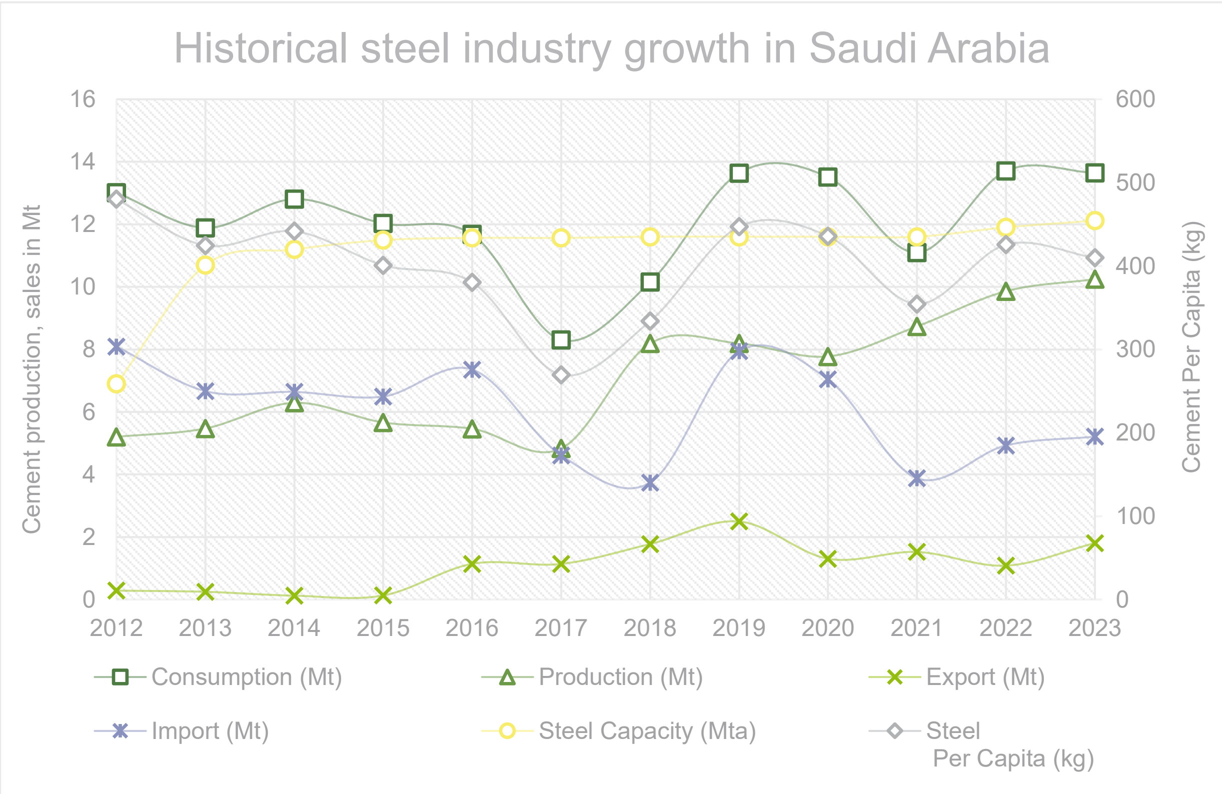
03. The role of steel and cement in Saudi Arabia´s economy

Steel and cement production, consumption, and trade

Steel Industry

The steel industry in Saudi Arabia has been a cornerstone of its industrial expansion and diversification, particularly under Vision 2030. Between 2012 and 2023, the installed steel production capacity in Saudi Arabia expanded significantly, rising from 6.9 Mt/year in 2012 to over 12 Mt/year in 2023 (World Steel Association, 2024), (KAPSARC, Global Steel Production, 2024), (OECD, 2023) . This represents a substantial increase in capacity, driven by the sustained domestic demand for steel products from infrastructure, construction, and industrial development projects.

Figure 03-1: Historical steel industry growth in Saudi Arabia



Source: Author's own analysis based on (World Steel Association, 2024), (KAPSARC, Global Steel Production, 2024), (OECD, 2023)

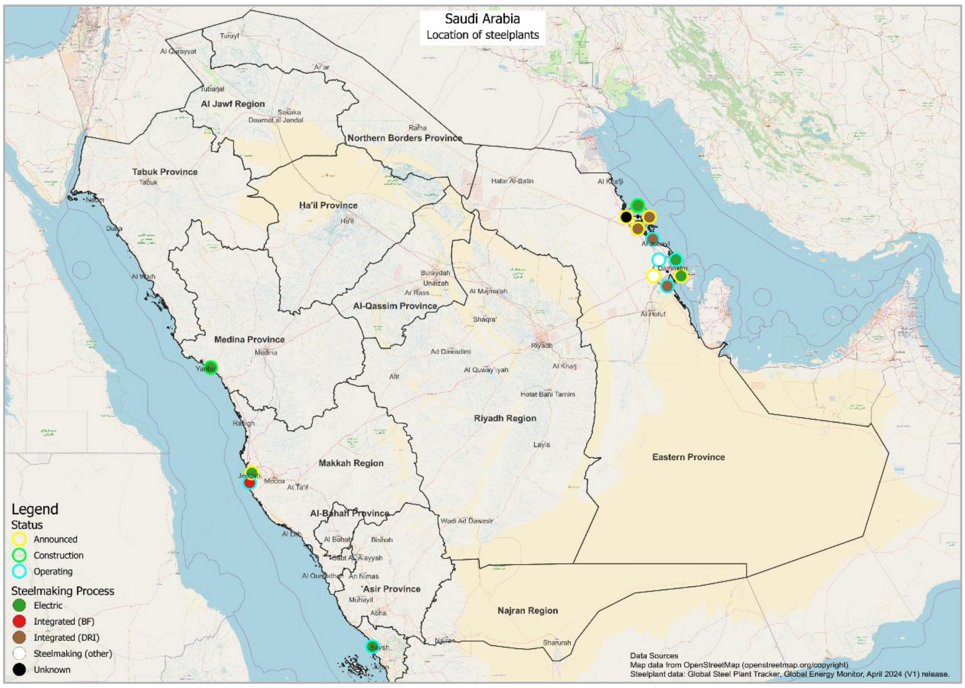
Despite this growth, imports continued to play a critical role in meeting demand, contributing to 50-70% of total consumption during most years, although imports have declined steadily. During the same period, steel consumption also grew, reaching at over 13 Mt in 2023. Imports peaked at 8 Mt in 2012 and gradually declined to 5 Mt by 2023 and net imports dropping to under 3.5 Mt in recent years, reflecting a shift towards self-reliance. Exports remained a small fraction of production, averaging below 1 Mt annually throughout the period, highlighting the industry's primary focus on domestic markets.

Production and consumption trends in the Saudi steel industry have been closely aligned, with periodic fluctuations reflecting broader economic and market dynamics. However, external factors, such as the onset of the COVID-19 pandemic in 2020, led to a temporary slowdown in both production and consumption. The average consumption per capita during 2012-2023 reached at around 400 kg, well above global averages, highlighting the intensity of infrastructure, construction, and industrial development projects in the Kingdom.

Despite these challenges, the steel industry demonstrated resilience, with production stabilizing at around 9-11 Mt/year post-pandemic. This stability has been underpinned by Vision 2030 initiatives and significant investments in infrastructure and industrial development. While capacity utilization has fluctuated, in recent years the capacity utilization remained high reaching to around 84% in 2023, this reflects the industry's aim to meet future demand surges with additional investment.

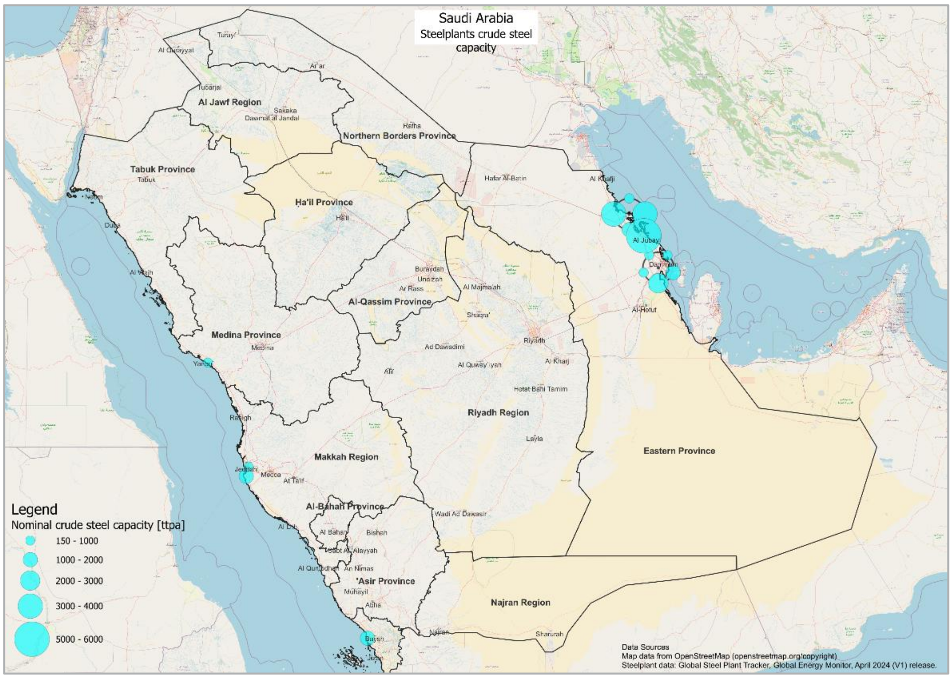
Saudi Arabia's steel sector is supported by modern production facilities. The geographic distribution of steel plants in Saudi Arabia shows clusters in key industrial and urban centres, such as the Eastern Province, Riyadh, and Jeddah. These regions host a mix of large-scale integrated steel plants and smaller electric arc furnace (EAF) facilities. Notable operators include the Saudi Iron and Steel Company (Hadeed) and other private and semi-government entities, which collectively account for the bulk of domestic production (Global Steel Plant Tracker, 2024).

Figure 03-2: Existing and planned steel plants, plant types in Saudi Arabia



Source: Author's own analysis based on (Global Steel Plant Tracker, 2024)

Figure 03-3: Existing and planned steel plant capacities in Saudi Arabia



Source: Author's own analysis based on (Global Steel Plant Tracker, 2024)

There have been a significant number of announced projects in Saudi Arabia, totalling over 12 Mt, which are expected to come into operation within the next 3-4 years. These projects aim to double the country's production capacity to over 26 Mt (Global Steel Plant Tracker, 2024), a move that may appear ambitious but aligns with recent trends – domestic steel production has been rising since

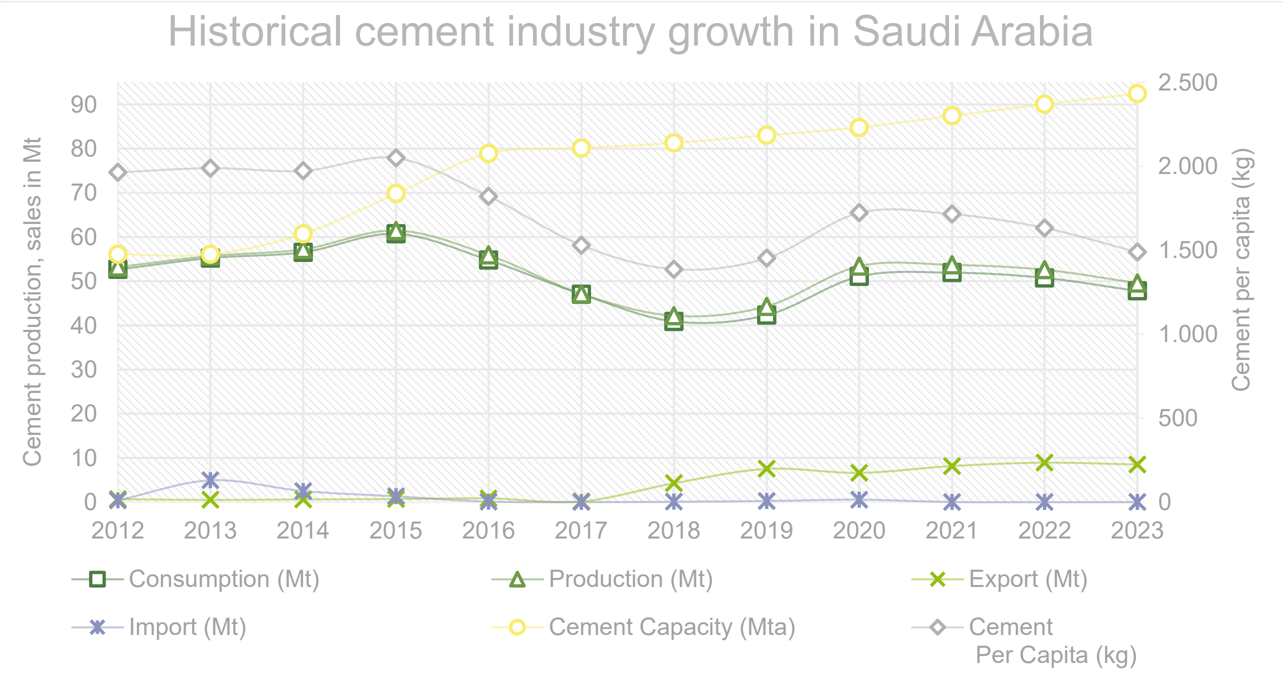
2020, while consumption continues to exceed output, with the shortfall met through imports. This planned expansion likely reflects market signals and anticipated demand from broader economic diversification activities.

Going forward, the focus of Saudi Arabia's steel industry will remain on meeting domestic demand, in construction, transportation, and industrial applications. With its modern production infrastructure and strategic investment in capacity expansion, the Kingdom's steel sector is poised to play a central role in realizing the ambitions of Vision 2030 and beyond.

Cement industry

The cement industry in Saudi Arabia has been integral to the nation's construction growth and economic diversification, particularly under Vision 2030. Historically, cement production grew steadily from 53 million tonnes (Mt) in 2012 to a peak of 61 Mt in 2015, driven by rapid urbanization and construction growth in Saudi Arabia. Saudi Arabia's cement industry experienced significant capacity growth between 2012 and 2023, although production and consumption remained cyclical during this period, with annual output aligning with demand trends. Installed capacity grew from 56 Mt/year in 2012 to 92 Mt/year in 2023, representing an increase of 65% over this period (CEMNET, 2023). This expansion reflects the anticipation of sustained demand from the construction of giga-projects and infrastructure development under Vision 2030.

Figure 03-4: Historical cement industry growth in Saudi Arabia

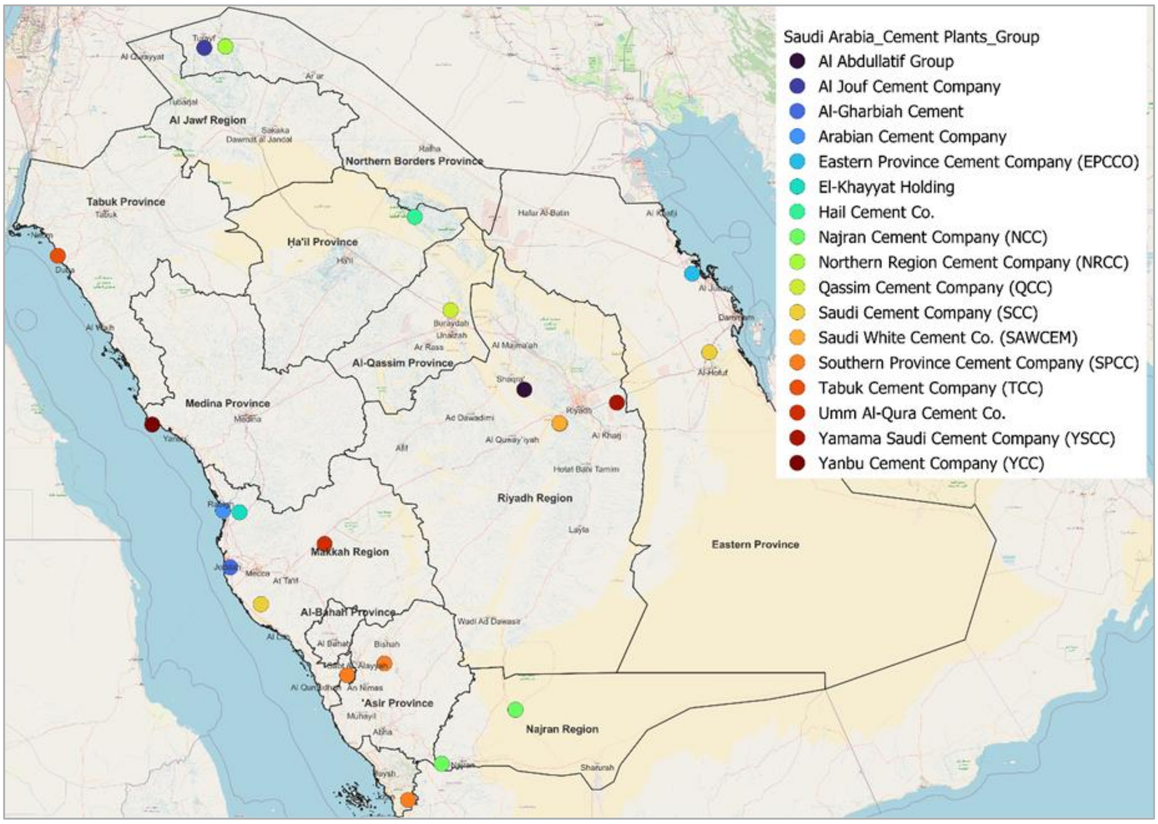


Source: Author's own analysis based on (CEMNET, 2023)

Both production and consumption has been cyclical during this period 2012-2023 while consumption trends mirror the production patterns. Saudi Arabia's cement production per capita reached its peak 2,050 kg in 2015, significantly surpassing global averages, demonstrating the country's increased construction activities. While this per capita production is high by global standards, this is in alignment within the Middle East. Between 2016 and 2019, both production and consumption slowed down from the 2015 level, which could be attributed to external economic or market factors such as reduced spending on infrastructure and construction projects or overcapacity leading to less cement production during this period. The COVID-19 pandemic in 2020 disrupted global economies, including Saudi Arabia, but the cement industry demonstrated resilience. Production remained stable at 53 Mt in 2020, supported by the Vision 2030 infrastructure development programs, such as NEOM and the Red Sea Project, which are integral to its economic diversification strategy. Although installed cement capacity utilization dropped from 95% in 2012 to 54% in 2023, signalling current overcapacity will be able to meet the increasing domestic demand to implement vision 2030. While current exports (clinkers and cements) are modest, ranging between 8-9 Mt/year mainly to countries in Africa and Asia, imports have almost ceased as domestic capacity expanded. The domestic cement industry in Saudi Arabia benefits from abundant local resources, modern infrastructure, and government subsidies for heavy fuel oil, which enhance its production cost competitiveness.

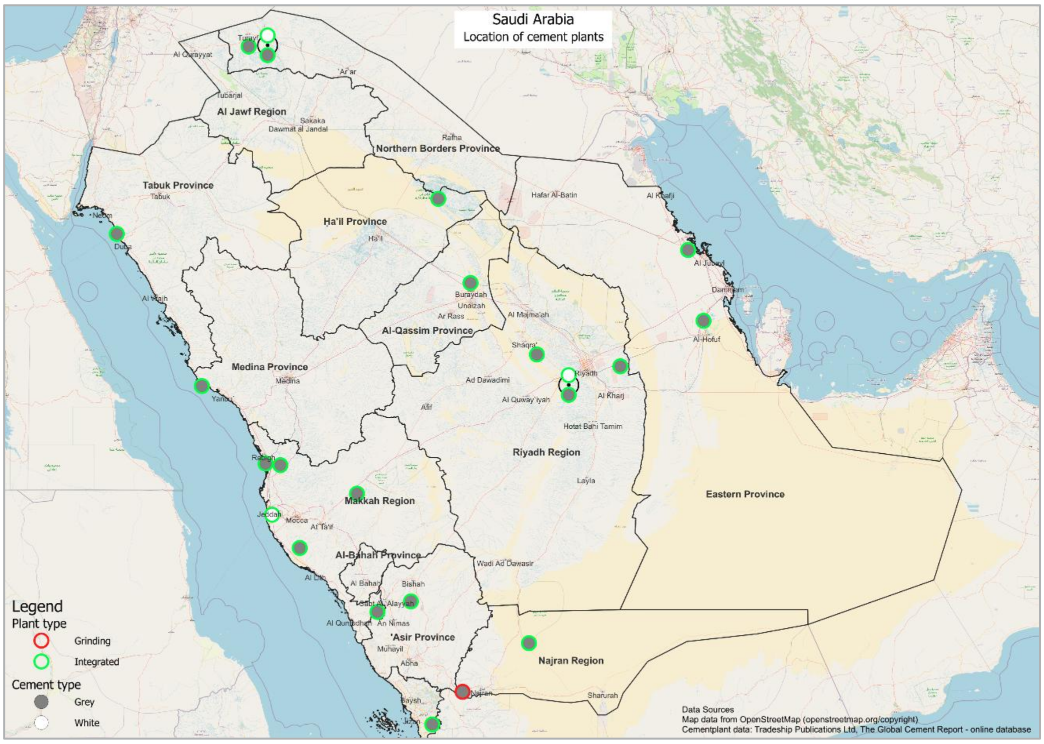
By 2023, Saudi Arabia maintained an installed capacity of 92 Mt/year with 17 operators managing 22 active plants. Saudi Arabia is fully self-sufficient in terms of clinker production and of its 22 plants, 21 plants have nitrated clinker production facilities, with the top four operators (Saudi Cement Company, Yamama Saudi Cement Company, Yanbu Cement Company and Southern Province Cement Company) contributing to the 46% of the market capacity (CEMNET, 2023).

Figure 03-5: Cement plant producers in Saudi Arabia



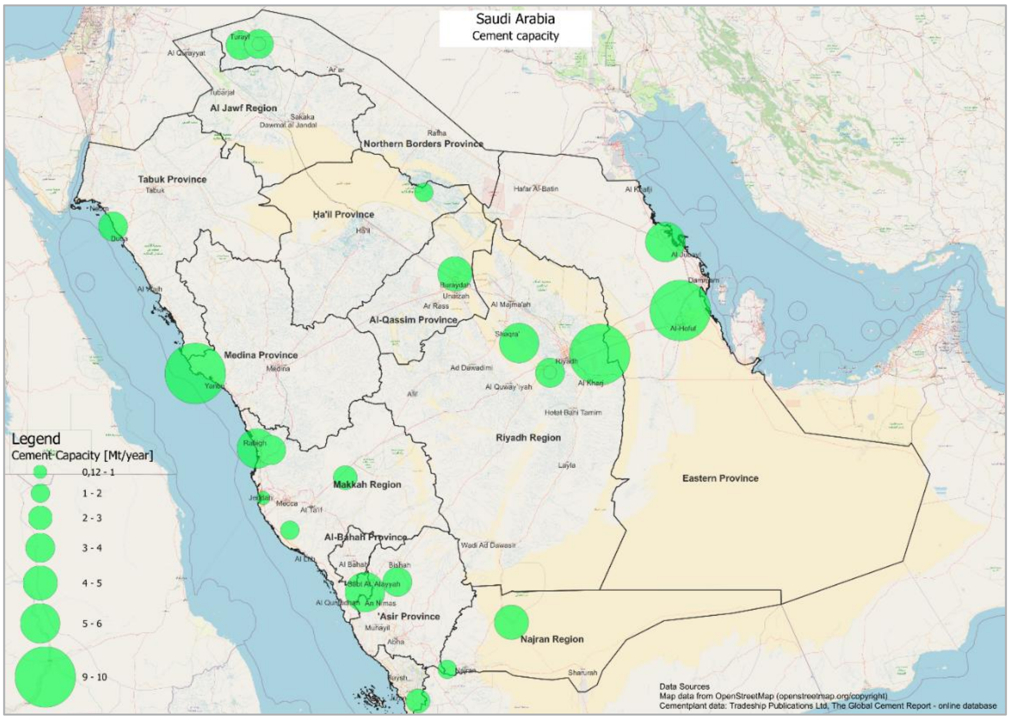
Source: Author's own analysis based on (CEMNET, 2023)

Figure 03-6: Cement plant types in Saudi Arabia



Source: Author's own analysis based on (CEMNET, 2023)

Figure 03-7: Cement plant capacities in Saudi Arabia



Source: Author's own analysis based on (CEMNET, 2023)

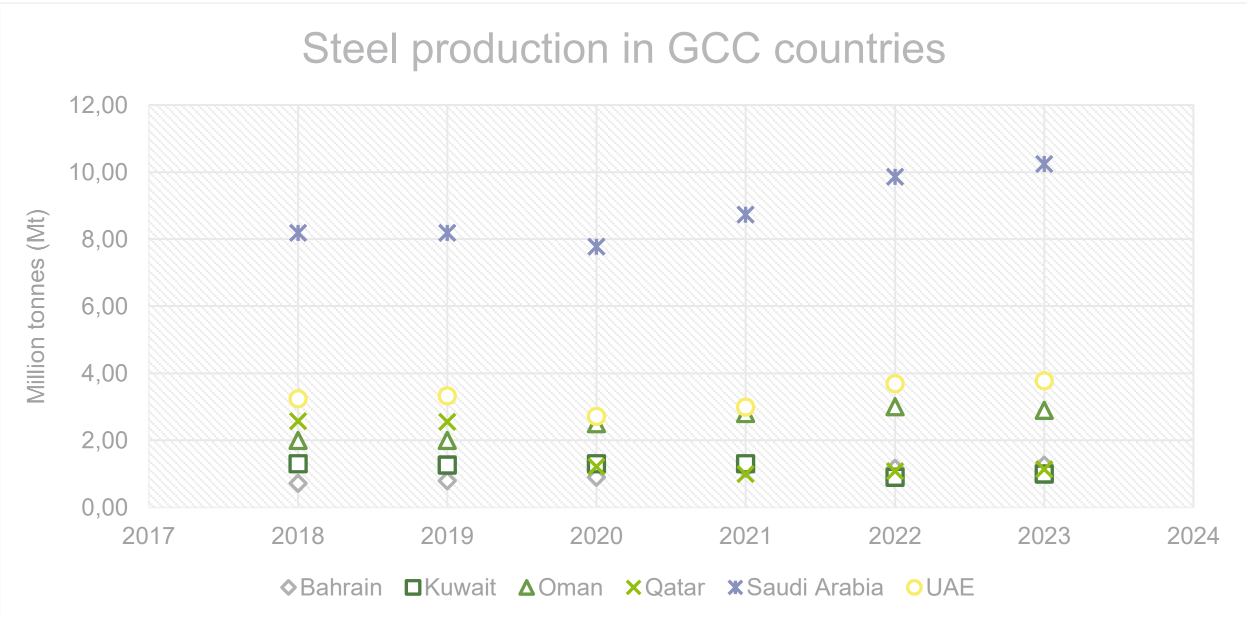
The graphs highlight the geographic distribution of plants and their operators. Notable large capacity clusters are visible in the central, eastern, western and southern regions including urban centres like Riyadh, Jeddah and Dammam. Plants with larger capacity (6-10Mt/yr) are clustered in these regions, whereas smaller plants (0.1-2Mt/yr) are spread across less industrialized areas, such as the northern region.

As Saudi Arabia continues to implement transformative projects under the Vision 2030, its cement sector will remain a key enabler of the nation's development and diversification efforts and it is envisioned that the main focus will remain on domestic consumption, rather than on exports (in case of any surplus production) supported by its self-sufficiency in clinker production.

Contribution to regional and global steel and cement output

As the largest steel producer in the Gulf Cooperation Council (GCC), Saudi Arabia contributes significantly to regional output, accounting for over 60% of the GCC's total steel production in 2023 (World Steel Association, 2024). While Saudi Arabia's global market share remains insignificant at below 1%, its strategic position in the Middle East and its alignment with Vision 2030 initiatives ensure that steel will remain a vital enabler of economic transformation.

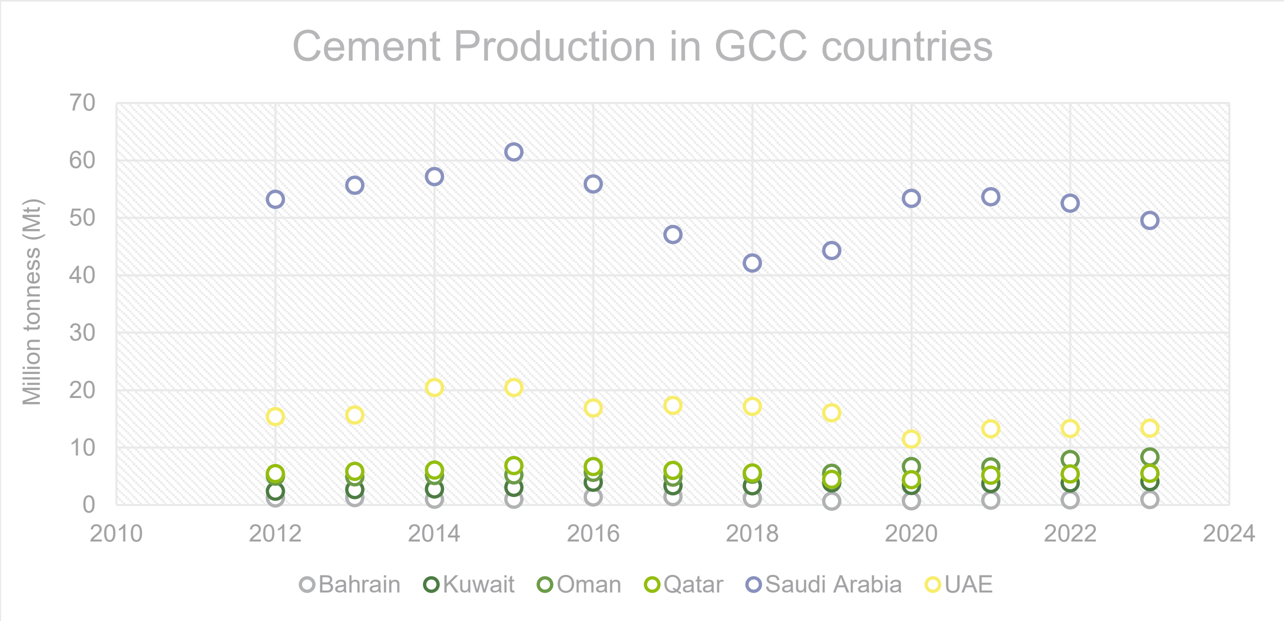
Figure 03-8: Steel production in GCC countries



Source: Author's own analysis based on (World Steel Association, 2024)

Saudi Arabia is the leading cement producer in the GCC, contributing significantly to the region's total output and accounting for over 60% of the GCC's total cement production in 2023. Globally, Saudi Arabia ranks as one of the top 15 producers with its current 50 Mt annual production. Though it remains far behind global leaders like China, India, US which dominate the cement market with over 2,500 Mt/year of cement production and 60% global shares, corresponding to just over 2% shares for Saudi Arabia with top three producers and 1.3% on the global level (CEMNET, 2023).

Figure 03-9: Cement production in GCC countries



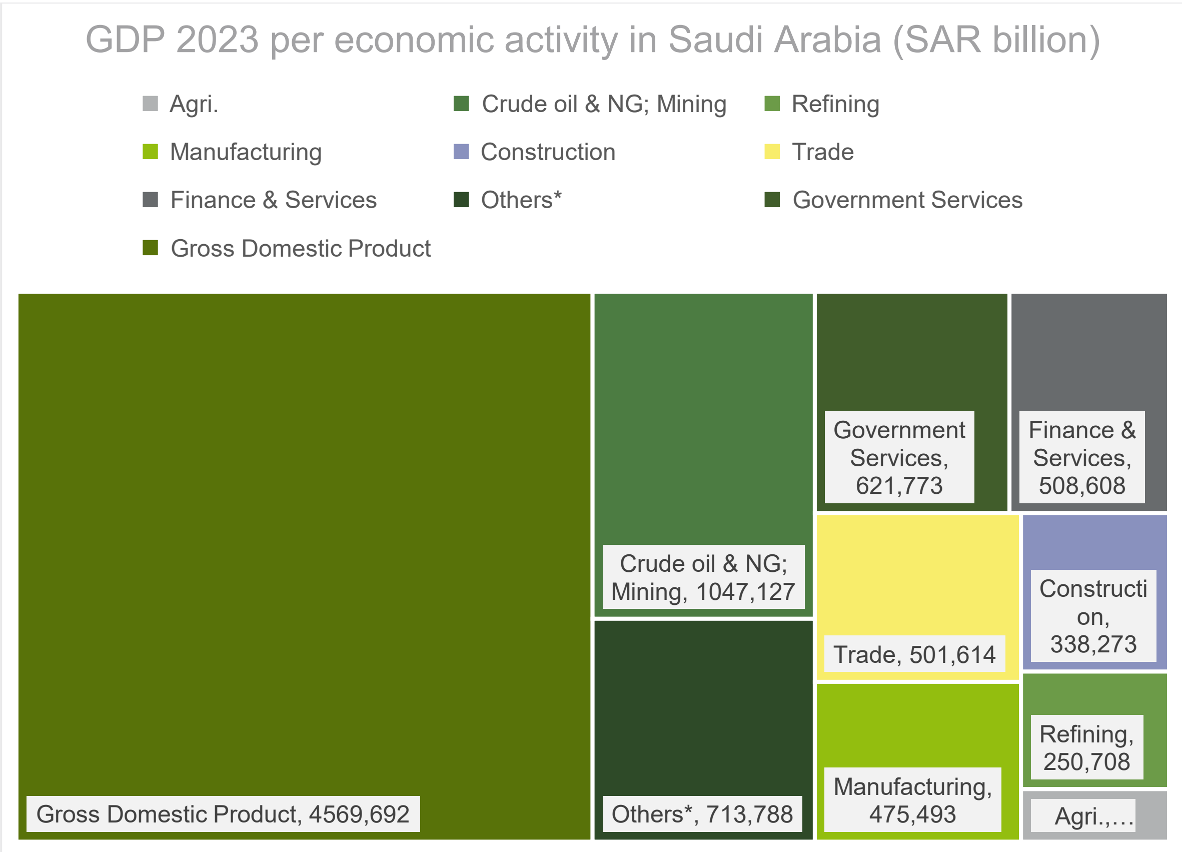
Source: Author's own analysis based on (CEMNET, 2023)

04. Current state of affairs of steel and cement industries

Current economic contribution of steel and cement industries

Saudi Arabia's GDP in 2023 reflects a diversified economic structure, balancing its traditional reliance on oil and gas with growing contributions from non-oil sectors. With a total GDP of SAR 4,570 billion in 2023, the country is advancing toward economic diversification in line with Vision 2030. The oil and gas sector, driven primarily by crude oil and natural gas activities, contributed SAR 1,279 billion, accounting for 28% of GDP. However, the non-oil economy now makes up 53.2% of GDP[1], signalling the diversification efforts. Key non-oil sectors, such as manufacturing, construction, and services, highlight Saudi Arabia's transformation into a more diversified economy (General Authority for Statistics, 2024)

Figure 04-1: GDP 2023 per economic activity in Saudi Arabia



**Others: Other Mining & Quarrying; Electricity, Gas and Water; Transport, Storage & Communication; Community, Social & Personal Services; Net Taxes on Products*

Source: Author's own analysis based on (General Authority for Statistics, 2024)

The steel and cement industries encompassed Saudi Arabia's industrial output under the manufacturing sector. Together these two industries had a direct economic output (i.e. market size)

[1] Government services and net taxes account for the remaining 18.8% share of GDP

of SAR 44.56 billion (USD 12 billion) in 2023 considering an average price of SAR 2,996 per tonne steel products (Arab Iron and Steel Union, 2024) and an average price of SAR 13.99 per 50 kg cement bag (KAPSARC, 2024) in Saudi Arabia in 2023 . This value reflects the gross revenue generated by steel and cement production.

Table 04-1: Direct economic output, Steel and Cement, KSA

2023	Production (Mt)	Per unit value (SAR/tonne)	Total Economic Output (SAR billion)
Steel	10.2	2,996	30.69
Cement	49.58	280	13.87
			44.56

Source: Author's own analysis based on (KAPSARC, 2024) and (Arab Iron and Steel Union, 2024)

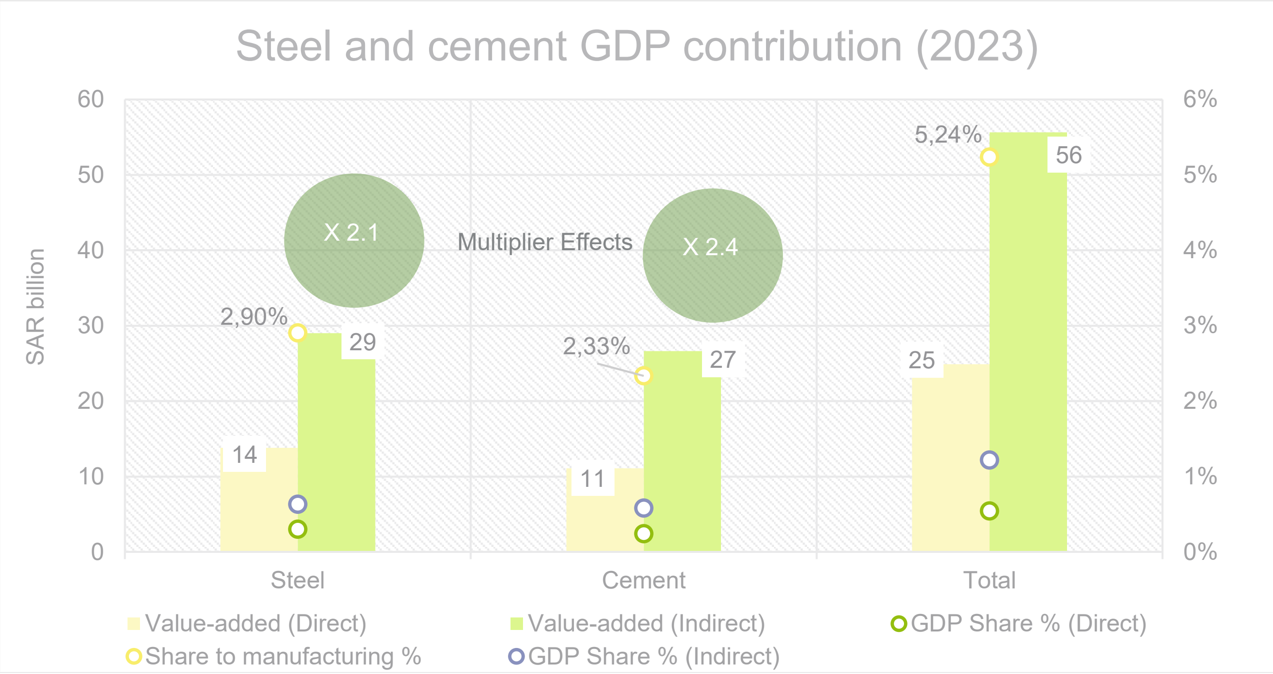
In 2023, the steel industry generated a total market value of SAR 30.69 billion (USD 8.3 billion) in 2023, with an estimated 45%[2] (SAR 13.8 billion) attributed to the industry's value-added processes, which include wages, depreciation, and other operating expenses such as general and administrative costs, utility services, and distribution expenses.

Similarly, the cement industry generated a total market value (i.e., total annual sales revenue) of SAR 13.87 billion (USD 3.7 billion) in 2023. Of this amount, approximately 80%[3] (SAR 11.10 billion) is attributed to the industry's value-added processes.

Figure 04-2: Economic output of steel and cement industries in Saudi Arabia

[2] The estimation is derived from the cost of sales (SAR 142 billion) and sales revenue (SAR 183 billion) of the SABIC-Hadeed company operating the Hadeed Steel Plant in Saudi Arabia, assuming that intermediate input costs account for 70% of the cost of sales for steel industry (SABIC Annual Report, 2022)

[3] The estimation is derived from the cost of sales (SAR 974 million) and sales revenue (SAR 1,653 million) of the Southern Province Cement Company in Saudi Arabia, assuming that intermediate input costs account for 30% of the cost of sales for cement industry (Southen Province Cement , 2020)



Source: Author's own analysis based on (General Authority for Statistics, 2024)

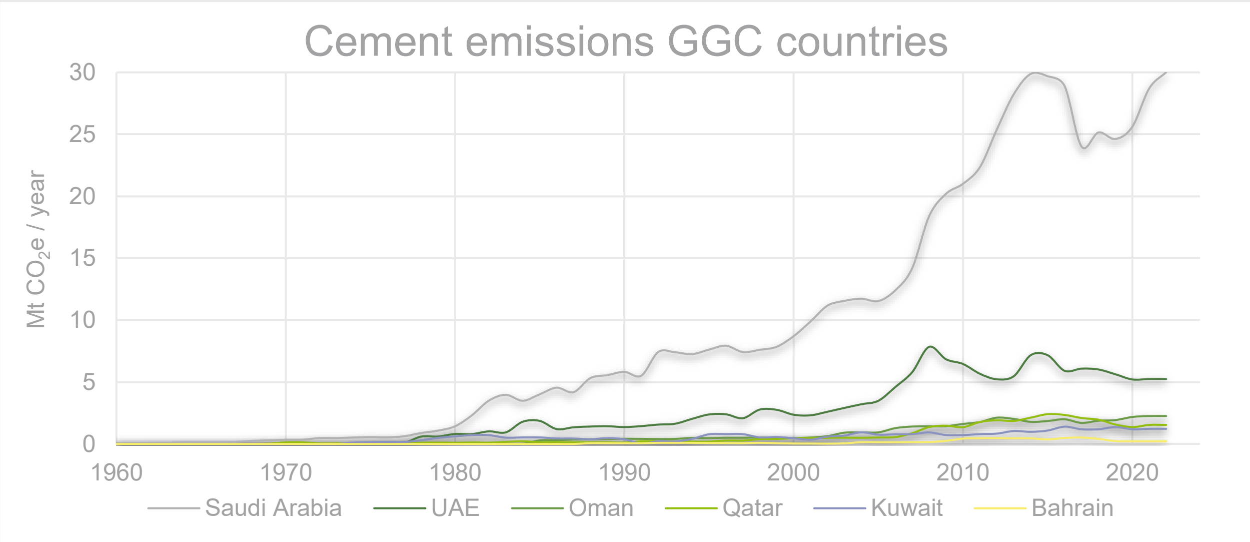
The steel and cement industries made up 5.2% share in the country's economic output within the manufacturing sector (excluding petroleum refining) that contributed SAR 475 billion (10.4% share in the GDP) to the economy in 2023. In the overall GDP, these two industries had a direct share of 0.5%.

The importance of steel and cement industries extends beyond its direct economic output. Steel is used in downstream industries, machinery, and manufacturing in addition to infrastructure projects. Besides direct employment, these industries also support indirect employment and stimulates demand for allied upstream industries like mining (e.g. raw materials supply such as iron ore) and downstream industries such as transport/logistics (e.g. transport of steel and cements). The cement industry primarily serves the construction sector with significant demand arising from giga projects and public infrastructure projects, indirectly contributed to the SAR 338 billion construction sector (7.4% share in the GDP). According to KAPSARC, the multiplier effects - both direct and indirect economic value-added - of basic and advanced metal production (which includes the steel industry) and non-metallic mineral products (which includes the cement industry) and on the economy in 2020 were 2.1 times and 2.4 times, respectively (KAPSARC, 2021). This means, for every SAR of value added generated in the steel and cement industries, an additional 2.1 and 2.4 SARs, respectively, are generated in the broader Saudi economy.

The steel and cement sectors in Saudi Arabia are estimated to directly employ approximately 12,000-15,000 workers (Saudi Exchange, 2024) (Company Pitchbook, 2024) and 15,000 workers (Arab News, 2024), respectively. These jobs span plant operations, maintenance, logistics, quality control, and other related functions. When considering the wider supply chain—including mining, transportation, equipment manufacturing, and ancillary services—the total employment impact is estimated to range between 60,000 and 70,000 jobs, considering the multiplier effect of steel and cement sectors.

Steel and cement emissions: Saudi Arabia and GCC

Figure 04-3: CO_2e emissions from cement in GCC countries



Source: Author's own analysis based on (Friedlingstein, 2023b)

The emissions from cement production for GCC countries depicts the rapid industrialization in the region since the turn of the 21st century. The Kingdom of Saudi Arabia is the leading country in cement production as well as the county with most CO_2e emissions. United Arab Emirates is the country with second most emissions but still lags behind KSA by producing 1/6th of the emissions (Friedlingstein, 2023b). The remaining Gulf countries only contribute very less to the overall emissions.

Notably, while historical annual CO_2e emission data for the steel industry is available for Saudi Arabia, publicly available data for other GCC countries remains limited or generalized within broader industrial categories. Saudi Arabia's First Biennial Transparency Report (BTR) 2024 (published in March 2025) reports that, in 2021, the cement and steel sectors emitted 28.373 and 4.544 million tonnes of CO_2e, respectively (Kingdom of Saudi Arabia, 2024). As the report does not disclose production data or technology mix—particularly for the steel sector—the baseline emission factors for the steel and cement industries are estimated at 0.52 tonnes CO_2e per tonne of steel and 0.53 tonnes CO_2e per tonne of cement, respectively, based on 2021 production data (see annex).

Table 04-2: Carbon intensity of steel and cement production 2021

	Year	Production (Mt)	CO2 Emission (MtCO2e)	Carbon Intensity (tCO2e/tonne)
Steel	2021	8.74	4.54	0.52
Cement	2021	53.70	28.37	0.53

Source: Author's own analysis based on (Kingdom of Saudi Arabia, 2024), (CEMNET, 2023), (World Steel Association, 2024)

In the report, the carbon intensity from 2023 onward – assuming no decarbonization measures – is used as the baseline for projecting emission reductions through 2060 (Chapter 7). For steel production, the current carbon intensity is estimated based on 2023 production data, technology mix and its associated emission footprints, which closely align with the carbon intensity estimations (0.52 tonnes CO_2e per tonne of steel in 2021) derived from the Saudi Arabia's First Biennial Transparency Report 2024. Based on 2023 production data, the current carbon intensity of cement production in Saudi Arabia is estimated using emission data from the (Kingdom of Saudi Arabia, 2024).

Table 04-3: Current carbon intensity of steel and cement production

Production type	Year	Production (Mt)	Carbon Intensity (tCO2e/tonne)	CO2 Emission (MtCO2e)
Steel (with technology mix)	**2023**	**10.21**	**0.59**	**6.0**
BF-BOF:10%	*2023*		*1.6*	
Scarp-EAF: 20%	*2023*		*0.04*	
DRI-EAF (natural gas): 70%	*2023*		*0.6*	
Cement	**2023**	**49.58**	**0.53**	**26.2**

Source: Author's own analysis based on (Kingdom of Saudi Arabia, 2024) (Armijo, 2025), (CEMNET, 2023), (World Steel Association, 2024)

Notably, Saudi Arabia aims to reduce emissions by 278 MtCO_2e annually by 2030, using 2019 as the base year. As per the First Biennial Transparency Report 2024, in 2021, the total emissions in Saudi Arabia were 717.2 MtCO_2e [4]. Together, the steel and cement industries contributed 4.6% (32.92 MtCO_2e) to the 2021 emission level (Kingdom of Saudi Arabia, 2024).

[4] The value 717.2 MtCO_2e in 2021 is derived from the sum of sectoral totals excluding net sink of emissions from the Land Use, Land-Use Change and Forestry (LULUCF) sector, which is typically reported separately in accordance with IPCC practices.

05. Contributions of steel and cement industries in achieving net-zero by 2060

Growth potential for steel and cement to 2060

Vision 2030 is anticipated to significantly boost the construction and manufacturing sectors (excluding petroleum) between 2020 and 2030, with projected growth rates of 9.2% and 8.2%, respectively. By 2030, these sectors are expected to contribute 6.1% and 11.6% to GDP, respectively (KAPSARC, 2021). To forecast steel and cement demand through 2060, a linear regression analysis was conducted using historical production data and its relationship with two key economic sectors: construction and manufacturing. Long-term growth projections for the construction and manufacturing sectors between 2031 and 2060 are challenging to estimate. KAPSARC indicates that Saudi Arabia's overall GDP will grow at a CAGR of 3.3% through 2030, and at a CAGR of 2.1% between 2030 and 2060, with non-oil GDP projected to grow at a higher CAGR of 2.6% over the same period (KAPSARC, November 2023). As a simplified assumption aligned with this outlook, it was assumed that the economic contributions of both construction and manufacturing sectors would double from their 2030 levels by 2060, implying a CAGR of 2.4%, consistent with the broader non-oil GDP trajectory.

The following table shows linear regression results, with the linear regression formula $y=\beta_0+\beta_1.x$, where

y: The dependent variable (steel growth and cement growth in relation to construction and manufacturing growth respectively)

x: The independent variable (construction growth and manufacturing growth).

β_0: The y-intercept of the regression line (the value of y when x=0).

β_1:The slope of the regression line (indicates the rate of change in y for a unit change in x).

The CAGR (Compound Annual Growth Rate) was integrated into the regression framework, forecasting y (steel and cement production) as a function of time t for two different periods (till 2030, and 2031-2060):

$y_t = y_0 . (1+g)^t$,

where:

y_t: Steel and cement production at time t.

y_0: Initial production (at t=0).

g: growth rate of steel and cement sectors

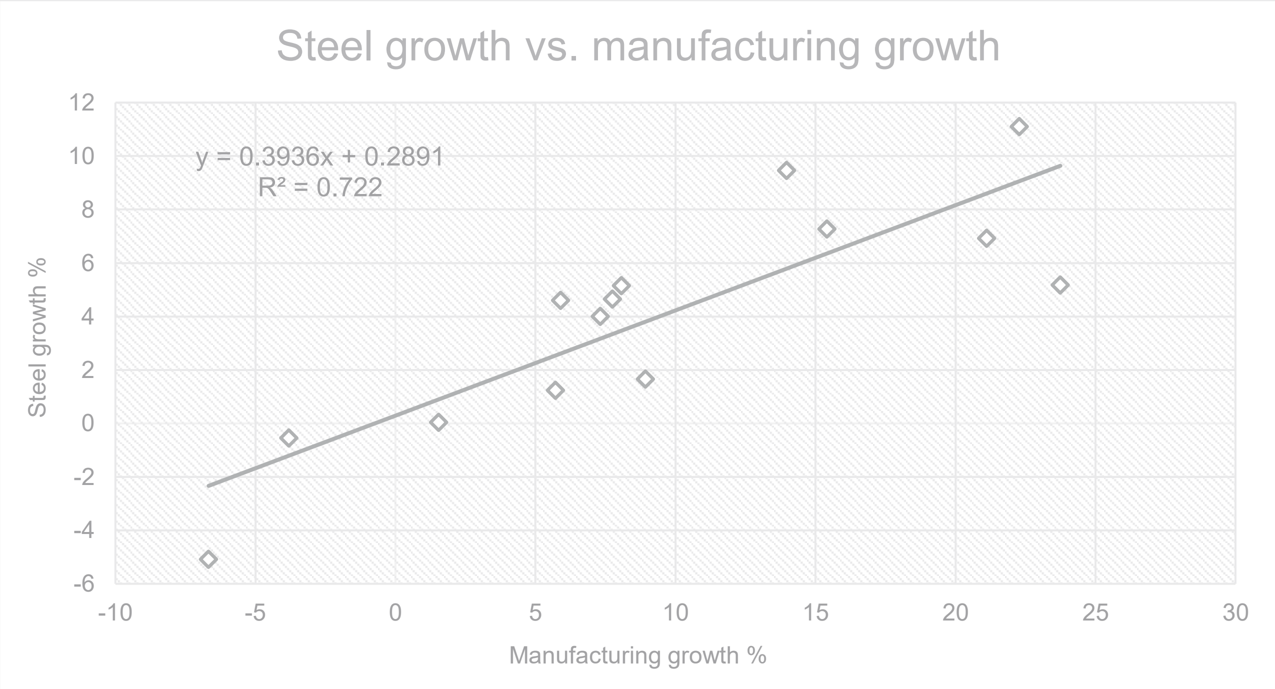
t: Time in years.

Table 05-1: Linear regression analysis results for steel and cement industries

Parameters	Steel (in relation to manufacturing)	Cement (in relation to Construction)	Remarks
R^2 value	0.72	0.81	strong corelation ($R^2 > 0.7$) between the variable
P-value	0.000119529	1.28421E-07	statistically significant relationship ($P < 0.05$) between the variable
β_0	0.2891	0.5652	
β_1	0.3936	0.4267	
CAGR (till 2030)	3.52%	4.49%	
CAGR (2031-2060)	1.23%	1.59%	

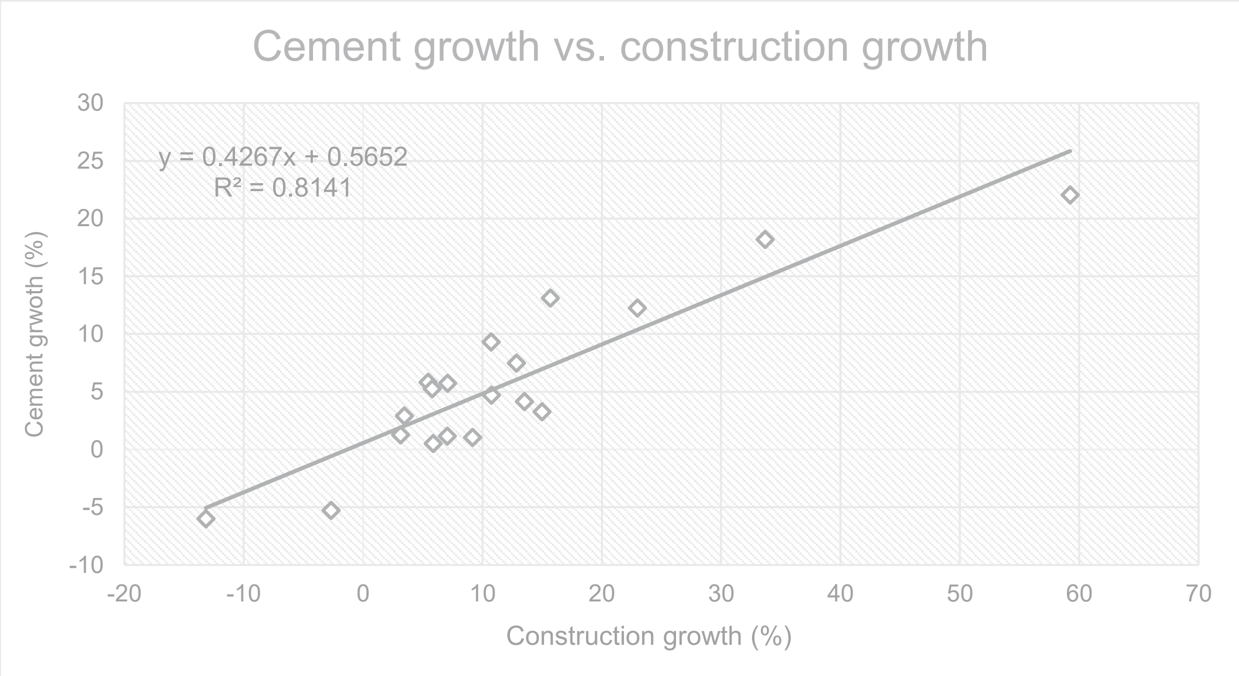
Source: Author's own analysis

Figure 05-1: Linear regression analysis between steel and manufacturing sectors growth



Source: Author's own analysis based on Table 6-1

Figure 05-2: Linear regression analysis between cement and construction sectors growth

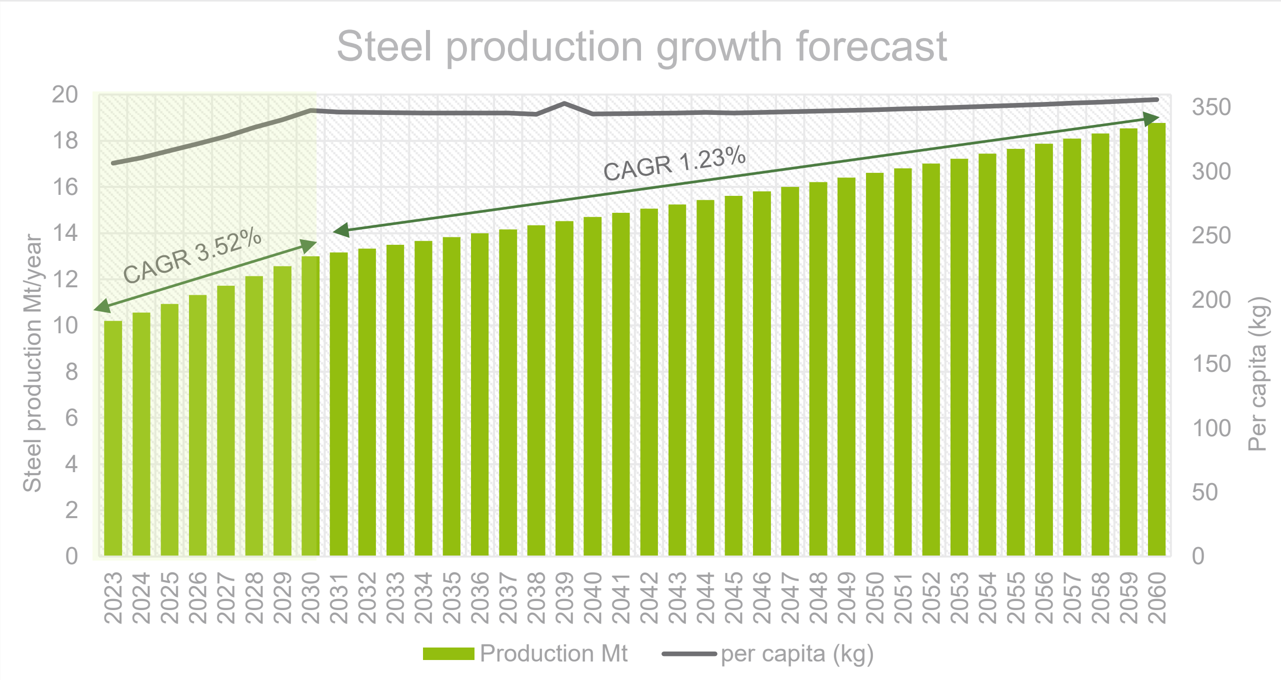


Source: Author's own analysis based on Table 6-1

The steel and cement production forecast till 2060 assumes that full production will be consumed domestically, eliminating the need for imports due to sufficient capacity utilization (existing and planned). This ensures that the country can fully rely on its own production to meet growing demand while maintaining optimal utilization rates.

Steel production in Saudi Arabia is projected to grow steadily, mainly driven by increased industrial demand. Based on the economic growth forecasts (KAPSARC, 2021), the regression analysis results (Table 6-1) indicate that steel production in Saudi Arabia is forecasted to grow with a 3.52% CAGR from 2023 to 2030, followed by more moderate growth of 1.23% CAGR from 2031 to 2060. This trajectory aligns with the expected 2.4% CAGR of the construction and manufacturing sector's GDP from 2031 onward, as discussed earlier. Current steel production levels are approximately 10.2 million tonnes/year (2023), operating at a capacity utilization of ~84%, with an existing capacity of 12.1 million tonnes/year (World Steel Association, 2024), (KAPSARC, Global Steel Production, 2024), (OECD, 2023). According to the Global Steel Plant Tracker, planned capacity additions are expected to double within the next 3–4 years, increasing to 26.02 million tonnes (Global Steel Plant Tracker, 2024), thereby providing greater flexibility to produce steel as demand rises till 2060. Per capita steel consumption is currently ~307 kg/person and is expected to be ~356 kg/person by 2060 with the expanding economic growth.

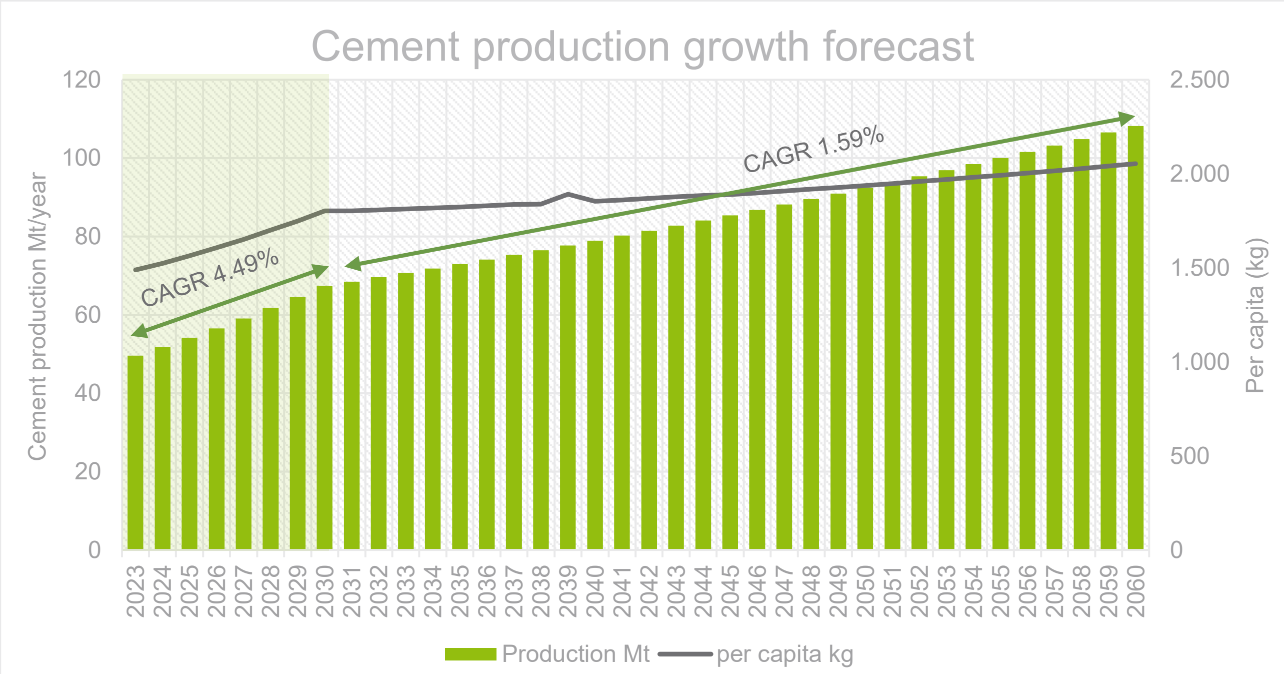
Figure 05-3: Steel production growth forecast in Saudi Arabia



Source: Author's own analysis

Similarly, based on the economic growth forecasts ((KAPSARC, 2021) and 2023 production data (CEMNET, 2023), the regression analysis results (Table 6-1) indicate that cement production in Saudi Arabia is forecasted to grow with a 4.49% CAGR from 2023 to 2030, followed by more moderate growth of 1.59% CAGR from 2031 to 2060. Per capita consumption is expected to rise from 1,489 kg in 2023 to over 2,000 kg by 2060, driven by increased construction activity. The current cement production capacity of 92.45 million tonnes/year, with a utilization rate of ~54% in 2023, will gradually increase toward 73% utilization by 2030 (CEMNET, 2023). To meet the projected cement demand, new capacity will need to be added, especially as older plants would also require replacement. Utilization rates could approach ~100% by 2050 under this growth trajectory. Efficient maintenance and upgrading of existing plants will ensure production keeps pace with demand, supporting the Vision 2030 goals and long-term economic growth.

Figure 05-4: Cement production growth forecast in Saudi Arabia



Source: Author’s own analysis

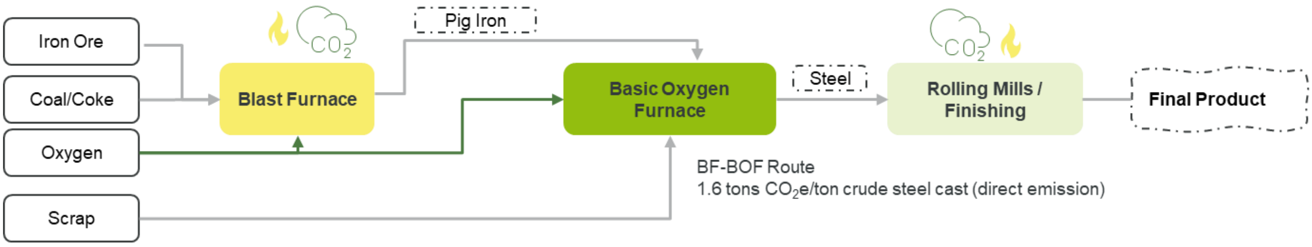
06. Pathways to decarbonization in Saudi steel and cement: transition options, production forecasts, and emission reduction projections

Steel decarbonization pathways

Steel production globally can now be divided into two main paths:

1. **Primary steel[5]:** Produced using iron ore as the raw material with two primary routes: 1) blast Furnace (BF) - Basic Oxygen Furnace (BOF) route, 2) Direct Reduced Iron (DRI) - Electric Arc Furnace (EAF) route
   - **Blast Furnace (BF) - Basic Oxygen Furnace (BOF) Route:** This method relies on coal as the primary energy source, with an average carbon footprint of 1.6 tonnes of CO_2e per tonne of steel as direct emission (Armijo, 2025). It accounts for approximately 70% of global steel production.

Figure 06-1: Primary steel production using BF-BOF

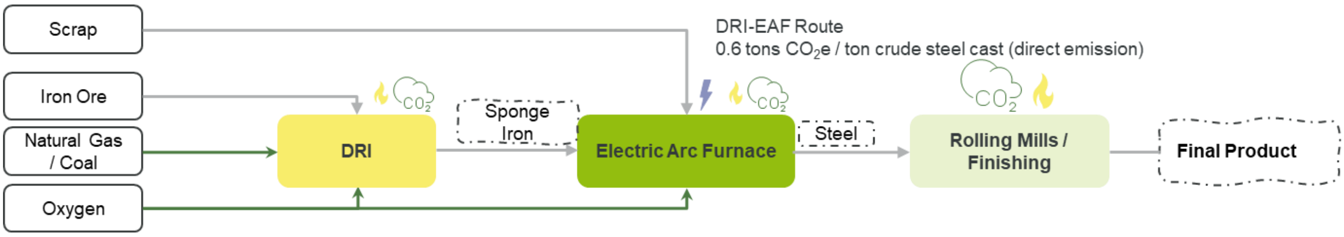


Source: Own analysis

   - **Direct Reduced Iron (DRI) - Electric Arc Furnace (EAF) Route:** This method uses a gaseous reactant, typically produced from natural gas, as the reducing agent. It accounts for 7% of global steel production and has a significantly lower carbon footprint of 0.6 tonnes of CO_2e per tonne of steel as direct emission (Armijo, 2025).

[5] Primary steel production involves producing steel for the first time from iron ore. However, scrap is also used in the BOF. After the blast furnace stage, the product, known as pig iron, has a carbon content too high to be classified as steel. The pig iron is then processed in the BOF, where oxygen is introduced to reduce the carbon content. Scrap is added during this process to help control the reaction temperature and enhance sustainability.

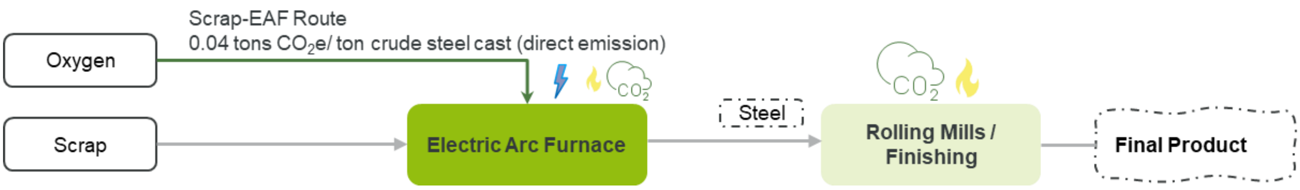
Figure 06-2: Primary steel production using DRI-EAF



Source: Own analysis

2. **Scrap-EAF/Secondary steel:** Produced using steel scrap as the raw material, which is melted in EAF. Currently, less than 30% of global steel production follows this process. EAF is also the method with the smallest carbon footprint, emitting approximately 0.04 tonnes of CO_2e per tonne of steel produced as direct emission (Armijo, 2025).

Figure 06-3: Secondary Steel production using scrap-EAF



Source: Own analysis

To analyse the carbon footprint of the steel sector in Saudi Arabia, the first step is to assess the production mix and the technologies currently in use. Of the 12.2 Mt steel production capacity installed in Saudi Arabia, approximately 70% is produced using the DRI-EAF route, 20% through recycling scrap in EAF, and only 10% via the BF-BOF route, primarily at the Rajhi Al Assemah Steel plant in Jeddah (Global Steel Plant Tracker, 2024). This positions Saudi Arabia's steel production landscape competitively for producing cleaner steel.

Building on the foundation of specific steel production facilities, the exploration of suitable decarbonization pathways toward more sustainable and carbon-neutral production presents significant opportunities for advancement in Saudi Arabia. In this regard, to explore potential decarbonization pathways for KSA's steel industry, IEA offers a useful reference. The IEA identifies 23 decarbonization technologies, ranging in Technology Readiness Levels (TRL) from 2 (concept stage) to 9 (market uptake stage). To ensure a pragmatic and actionable approach, this analysis will focus only on successfully demonstrated and commercially available technologies with a viable chance of implementation in the coming years.

Table 06-1: Steel decarbonization pathways and uptake potential for Saudi Arabia

Steel production options #	Decarbonization pathways	IEA TRL[6]	Contexts in Saudi Arabia	Uptake Potential
BF-BOF based steel production	1.BF-BOF production to DRI technology (powered by natural gas; a natural gas-hydrogen blend; 100% hydrogen)	6 to 8	The Rajhi Al Assemah Steel plant in Jeddah, the only facility in Saudi Arabia utilizing the BF-BOF production route, accounts for 10% of the country's steel production capacity. In operation since 1984, the plant is approaching a point where significant investments will be required to extend its operational life. Given its reliance on Blast Furnace technology, a potential course of action would be to completely transition to DRI based steel production. Adopting this pathway would involve gradually phasing out the existing plant while constructing the new facility in parallel. This transition could present challenges, such as space constraints and the need for meticulous coordination between ongoing operations and construction activities.	Low/ not considered for Saudi Arabia
	2.BF-BOF production coupled with CCUS technology	7 to 8	An alternative transition pathway for the existing BF-BOF plant is to partially reduce CO_2 emissions by adopting CCUS technologies for flue gases and minimizing coke[7] usage through alternative energy sources. CCUS technologies are widely used and technologically mature. An example is the Carbon2Chem project, which demonstrates the dual benefits of this technology. It not only reduces the CO_2 footprint by up to 80% of BF emissions, but also gives captured CO_2 a second life by converting it into chemical products. (thyssenkrupp, 2024)	Limited uptake potential in the short-term (till the production process is completely phased-out)
	3.Alternative fuel (hydrogen or biomass) injection for BF-BOF production	8 to 9	Another potential pathway, which can be combined with CCUS, is the partial replacement of fossil fuels used in the blast furnace with alternative fuels such as hydrogen or biomass. These can be used as combustion fuels in the furnace; however, due to the operational constraints of the blast furnace, coal cannot be entirely replaced with hydrogen. Biomass injection is a mature technology and has delivered promising results in plants in Brazil and Canada. However, for Saudi Arabia, this approach may not be ideal due to challenges in biomass availability. Hydrogen injection potential in the blast furnace can be excluded for Saudi Arabia, as only one plant in Saudi Arabia utilizes this technology, and it is expected to be phased out and replaced with DRI.	Low/not considered for Saudi Arabia due to challenges in biomass availability.
DRI-EAF based steel production	4.Gradual increase of hydrogen concentration in syngas together with CCUS (blue hydrogen)	8 to 9	Focusing on the majority of current steel production in Saudi Arabia, which follows the DRI-EAF route, and currently accounts for 70% of steel production in Saudi Arabia DRI technology relies on natural gas to produce syngas—a mixture of hydrogen and carbon monoxide—used both as a chemical reductant and an energy source, resulting in CO_2 emissions.	Good potential in the medium to long term.

[6] TRL sources: (IEA, 2024)
[7] Within the BF process, coke is used as a fuel and reducing agent where it helps convert iron ore. Within the BOF process coke or coal can be used in small amounts to adjust the carbon content of steel.

Steel production options #	Decarbonization pathways	IEA TRL[6]	Contexts in Saudi Arabia	Uptake Potential
			In the medium term, reducing the carbon footprint can be achieved by installing carbon capture systems. Typically, natural gas is converted into syngas in a reactor, which then feeds into the DRI process. CCUS technology can be installed either before the DRI process, capturing CO_2 directly from the reactor, or after the DRI process, capturing CO_2 from flue gases. A commercially available solution from Tenova[8] even allows for the extraction of food-grade CO_2. For the specific case of Saudi Arabian plants, which utilize Midrex technology[9], a more suitable approach would be to install CCUS immediately after the reactor that produces the syngas. This strategy provides flexibility to gradually increase the hydrogen concentration and retrofit the DRI plant to operate on blue hydrogen, paving the way for a more sustainable and decarbonized production process.	
	5.DRI-EAF route with green hydrogen	6	The earlier DRI-EAF production processes together with CCUS will help adapt the DRI processes to eventually operate with 100% hydrogen, enabling the seamless integration of green hydrogen technology in the long term and achieving fully decarbonized steel production. Green hydrogen, supported by the country's significant potential for renewable energy production, represents a promising alternative. It offers the potential to reduce emissions by up to 98% compared to a standard DRI plant, making it an important step toward achieving fully decarbonized steel production through DRI in the long-term.	Good potential in the long-term
Scrap-EAF route: Scrap recycling-based steel production	6.Electrification (green electricity) of scrap recycling and high-temperature furnaces	7 to 8	The steel production that relies on scrap recycling, as well as for all processes involving furnaces for high-temperature operations, an approach to decarbonization is full electrification. This would involve using green electricity to power EAF and only applies to low-temperature furnaces, where applicable. While green electrification can play an important role in the decarbonization, particularly in downstream processes responsible for 10-20% of total emissions, most of these emissions require hydrogen (e.g. rolling mills) to address the high temperature demands of these processes.	Low/not considered for Saudi Arabia
	7. Hydrogen retrofitting for high-temperature furnaces in scrap recycling process	7 to 8	The energy intensity of high-temperature applications and furnaces, such as rolling mills, are too high to be met through electrification. Several burners[10] manufacturers already offer commercially available hydrogen burners. These burners can be deployed as part of a transition strategy. This implies that such	Good potential in the mid to long term.

[8] Tenova, a steel technology provider, specializes in developing and commercializing DRI technology under the HyL brand. Recently, Tenova formed a joint venture with Danieli and is now commercializing the DRI technology under the brand name Energiron (https://www.energiron.com/).
[9] Midrex: A US-based DRI technology company and a global leader in the commercialization of these plants. In the EMEA region, their technology is provided by two official licensors: Primetals and Paul Wurth (https://www.midrex.com/).
[10] Burners are a critical component of the furnace, responsible for generating the flame and providing the energy input. To transition from burning CH_4 (methane) to H_2 (hydrogen), the burners must be adapted to accommodate hydrogen combustion. Since the temperature distribution and combustion byproducts differ between CH_4 and H_2, the furnace may also require retrofitting. This could include modifications to refractory materials, burner distribution, and other design elements to ensure optimal performance and durability.

Steel production options #	Decarbonization pathways	IEA TRL[6]	Contexts in Saudi Arabia	Uptake Potential
			furnaces will require refurbishment and retrofitting in the mid-term to enable the use of clean hydrogen as a replacement for natural gas once sufficient supplies become available.	
	8. EAF with CCUS	7 to 8	CCUS technology is not viable for EAF processes, as the CO_2 concentration in the output stream is too low for efficient capture.	Low/not considered for Saudi Arabia

Source: Own analysis
IEA based TRL label: 1-3: Concept; 4: Early prototype proven in test conditions, 5-6: Full prototype proven at scale; 7-8: Technology demonstration; 9-10: Market uptake (solution is commercial and competitive but needs further integration; 11: Mature technology with predictable growth

Of the eight decarbonization options discussed above within the three main routes of conventional steel production, four options show technically and contextually suitable uptake potential for Saudi Arabia, and will be considered further to estimate emission reduction potential. These measures include:

1. BF-BOF based steel production → BF-BOF production coupled with CCUS technology
2. DRI-EAF based steel production → Gradual increase of hydrogen concentration in syngas together with CCUS (blue hydrogen) → DRI-EAF route with green hydrogen
3. Scrap-EAF route: Scrap recycling-based steel production → Hydrogen retrofitting for high-temperature furnaces in scrap recycling process

These three options were selected for further consideration based on their TRL advancement from pilot-scale demonstration to commercial deployment, as well as their compatibility with Saudi Arabia's existing production infrastructure and resource conditions.

As discussed above, in the BF-BOF based steel production, uptake potential due to hydrogen injection in the blast furnace or combining CCUS with hydrogen injection is excluded, as only one plant in Saudi Arabia utilizes this technology, and it is expected to be phased out and replaced with DRI (with CCUS and green hydrogen measures). Additionally, hydrogen injection in the BF-BOF process would reduce CO_2 concentration in flue gases, lowering the efficiency of CCUS and making the approach counterproductive. Hydrogen is better utilized in other applications, such as high-temperature furnaces in scrap recycling-based steel production.

For the EAF route using scrap recycling-based steel production, both the green electrification route and installing CCUS technology are not technically feasible. The CO_2 concentration in the output stream is too low for efficient carbon capture. Similarly, green electrification is impractical due to the high-temperature requirements of this process, which could potentially be met with hydrogen injection in the long term. Although a combination of electrification and hydrogen implementation can improve overall process efficiency, the impact on CO_2 reduction is minimal or negligible. Electrification potential in low-temperature furnace applications is also excluded from uptake potential.

Therefore, considering the planned additional capacity using the DRI-EAF and scrap-EAF routes in Saudi Arabia, both demonstrate good potential for CO_2-free steel production in the long term. A key consideration in developing such projects is to account for emerging hydrogen-based technologies and design the facilities to be hydrogen-ready, enabling a seamless transition from natural gas to hydrogen. Currently, the two major technology providers, MIDREX and ENERGIRON (Tenova/Danieli), offer solutions for producing fully decarbonized steel using DRI. Hydrogen-based DRI is showing promising results, and pilot projects such as HyBrit [11] suggest that commercial-scale plants will become available in the near future.

Emission reduction projections from production of steel

The table below summarizes the impacts of each of the three technological pathways employed in the Kingdom. The "No Abatement" row represents the CO_2e emissions of the current state-of-the-art technologies, reflecting the status quo. The "With CCUS" row illustrates the emissions reductions achievable with the implementation of carbon capture technologies, while the "With H_2 Injection" row shows the potential emissions reductions from replacing fossil fuels with green hydrogen.

Table 06-2: CO_2e Footprint (tonne CO2e/tonne steel) as direct emission

	CO2e Footprint (tonne CO2e/tonne steel) – direct emission		
	BF+BOF	Scrap-EAF	DRI-EAF
No Abatement	1.6	0.04	0.6
With CCUS	0.51	N/A	0.35
With H2 Injection	N/A	0.01	0.01

Source: based on (Armijo, 2025)

To track the uptake of select steel decarbonization technologies, penetration rates of steel decarbonization technologies are forecasted in the short-, medium- and long-terms as follows:

Table 06-3: Timeframes for progression of steel decarbonization technologies

Current Technology mix	Technology transition mix	2030	2040	2050	2060	Comments
BF-BOF :10%	BF-BOF with CCUS	2%	6%	2%	0%	• Only 10% of current production → Can apply CCUS early (2030), but most BFs will retire or remain marginal in Saudi Arabia. • Phased-out by 2050.
Scrap-based EAF: 20%	EAF with H2 injection	1%	6%	12%	20%	• Maintains a modest role in overall emission reductions and reflects retrofitting of Saudi's ~20% scrap-based EAF shares. • Gradual uptake aligns with maturing H_2 blending technologies
DRI-EAF : 70%	DRI-EAF with CCUS	4%	18%	30%	30%	• Saudi Arabia has the largest established based on DRI • CCUS serves as an effective short-term decarbonization lever using existing infrastructure. • CCUS reaches 30% by 2050 and then stabilizes in the long-term as a

[11] https://www.hybritdevelopment.se/en/

Current Technology mix	Technology transition mix	2030	2040	2050	2060	Comments
						complementary solution alongside the transition to green hydrogen.
	DRI-EAF with H_2.	3%	10%	30%	50%	• As green hydrogen becomes more cost-competitive, DRI production can switch from gas to H_2. • Saudi Arabia is heavily investing in green hydrogen (e.g., NEOM City). • By 2050–2060, DRI-EAF with H_2 becomes dominant.
	Total	10%	40%	74%	100%	

Source: Own assumptions (based on TRL advancement from pilot-scale demonstration to commercial deployment, Saudi Arabia's existing production infrastructure and resource conditions)

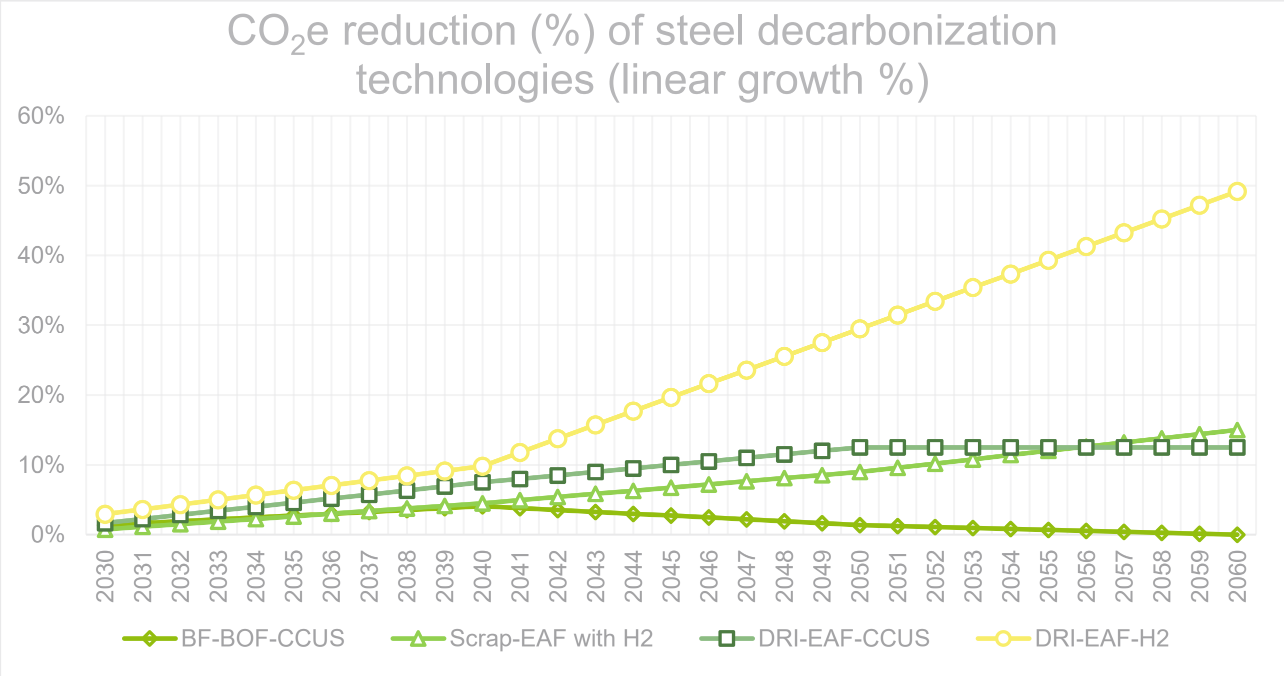
The following table represents the near- to long-term steel CO_2e reduction mixes, which are used along with the penetration rates of individual steel decarbonization technologies and their respective CO_2e footprint (tonne CO_2e /tonne steel) to estimate their CO_2e reduction volumes (in million tonnes/year) as follows:

Table 06-4: CO_2e reduction measures mix in steel decarbonization technologies

CO_2e reduction measures mix	2030	2040	2050	2060
BF-BOF with CCUS	1.4%	4.1%	1.4%	0.0%
Scrap-EAF with H2 injection	0.8%	4.5%	9.0%	15.0%
DRI-EAF with CCUS	1.7%	7.5%	12.5%	12.5%
DR-EAF with H2	3.0%	9.8%	29.5%	49.2%
Total	6.7%	25.9%	52.4%	76.7%

Source: Own analysis derived from CO_2e footprint of decarbonization technologies (Table 07-2) decarbonization technology transition mix (Table 07-3)

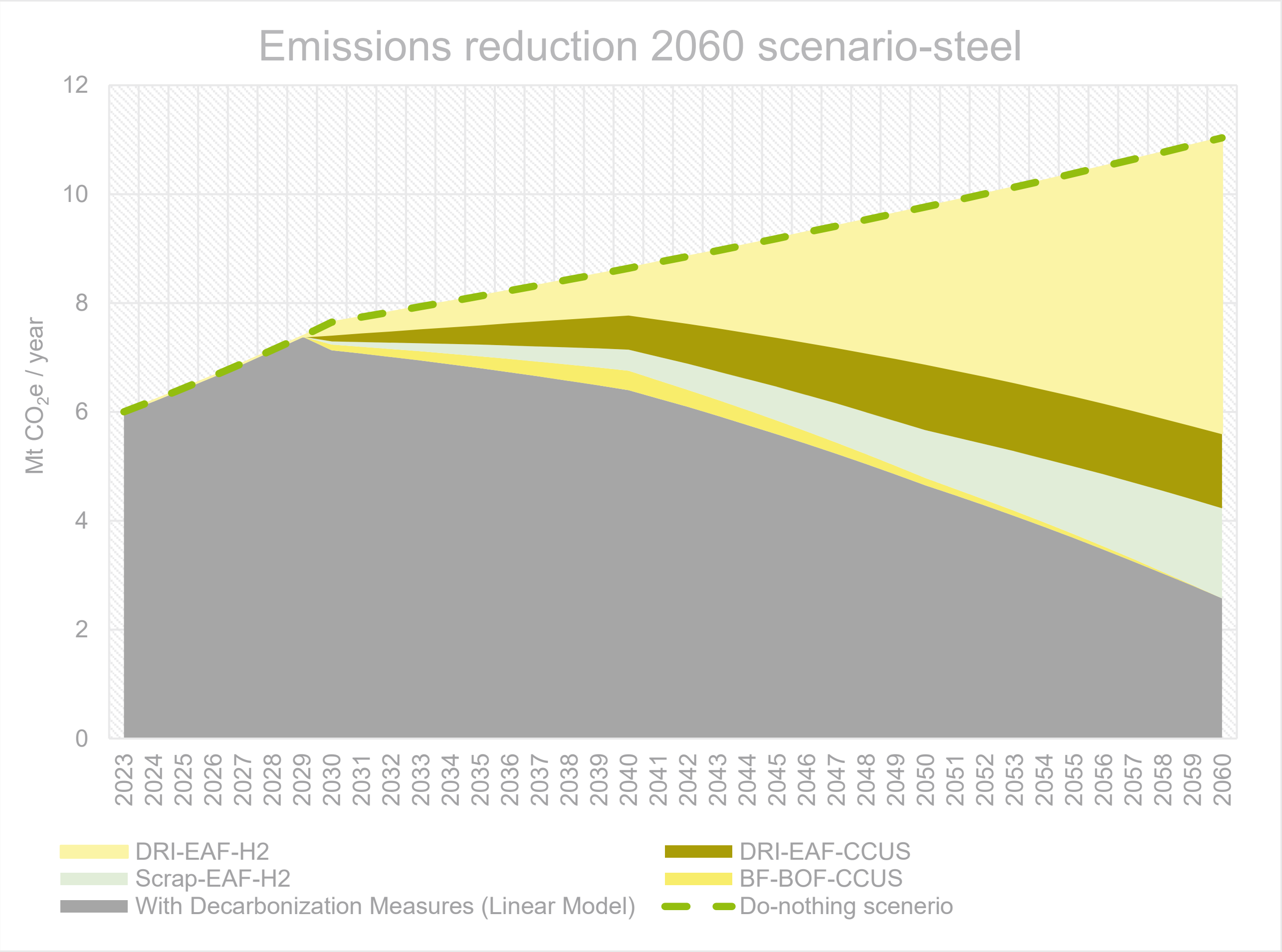
Figure 06-4: Linear growth of CO_2e reduction (%)-steel decarbonization technologies



Source: Own analysis derived from CO_2e reduction measures mix in steel decarbonization technologies (Table 07-04)

The results are illustrated in the graph below, where the CO_2e baseline is calculated by maintaining the current technology mix (2023) under a "do-nothing" scenario. In this case, emissions from the steel sector directly correlate with production output, which increases from present 6.0 Mt CO_2e/year to 11.03 Mt CO_2e/year by 2060 as steel production increases. By 2060, the implementation of decarbonization measures is projected to reduce emissions by approximately 76.7% relative to the do-nothing scenario, avoiding an estimated 8.46 MtCO_2e compared to projected emissions of 11.03 MtCO_2e without any decarbonization measures. The remaining 2.57 MtCO_2e—representing 23.3% of the emissions expected by 2060 with the decarbonization measures—is considered unabated, reflecting residual emissions from low-carbon processes that cannot be entirely eliminated.

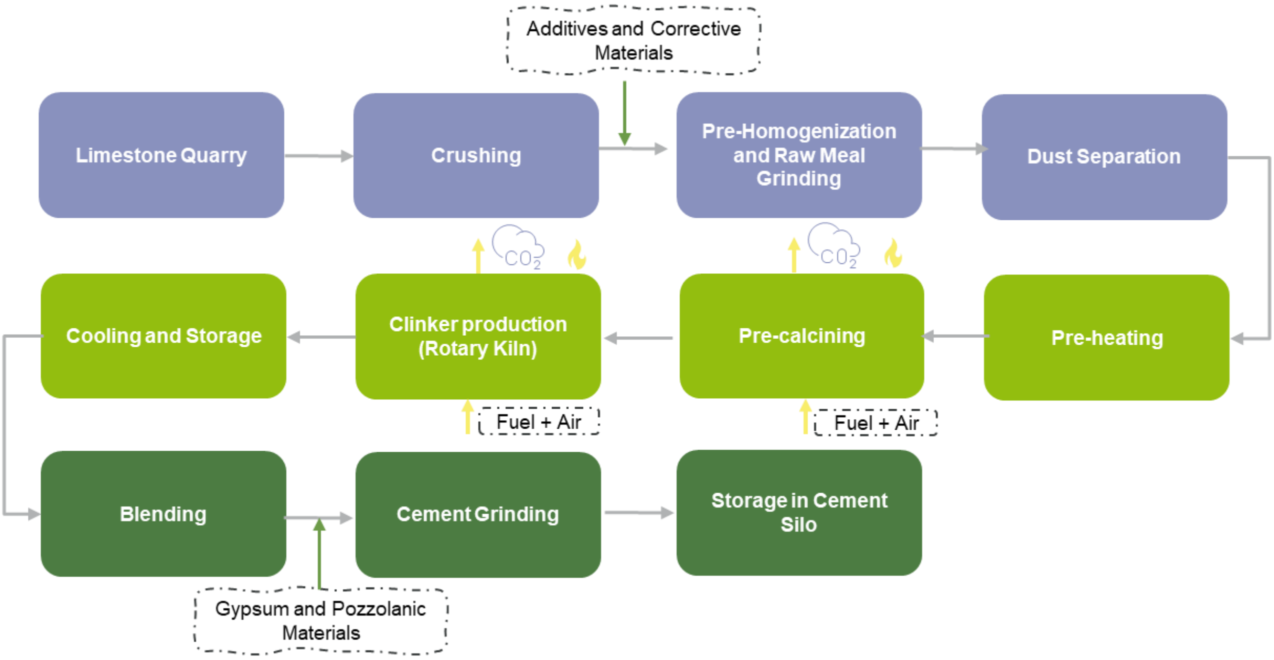
Figure 06-5: Emissions reduction projections from steel production



Source: Own analysis derived from production growth forecast (figure 6-4), CO2 footprint of decarbonization technologies (Table 07-2) and timeframes for progression of decarbonization technologies (Table 07-03)

Cement decarbonization pathways

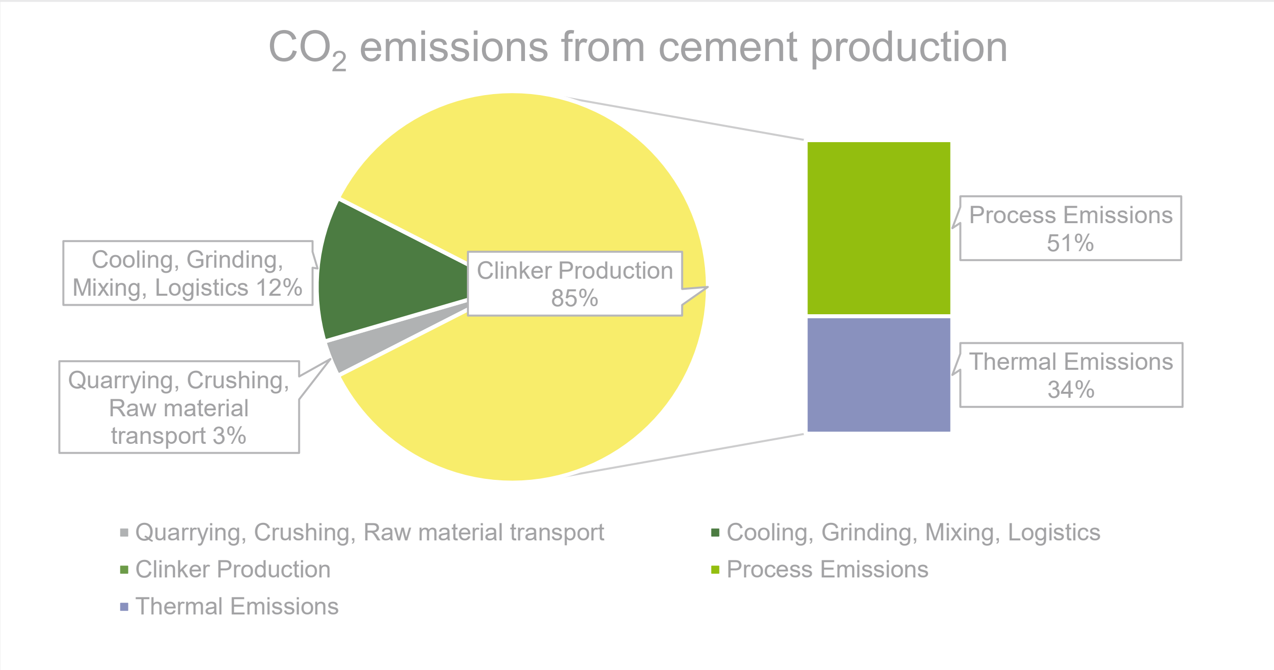
Figure 06-6: Cement production pathway



Source: Adapted from (Gupta, 2012)

The cement production follows a linear path. Typically, the location of cement plants are situated in close vicinity to naturally occurring materials like limestone or chalk to provide Calcium Carbonate ($CaCO_3$). In the first step, these raw materials are extracted from the quarry and mixed with materials such as iron ore, bauxite, clay or sand. This raw material is further crushed and milled to produce 'raw meal'. The raw meal is treated for dust separation and sent to the cyclone pre-heater. With the cyclone pre-heater the raw meal is heated up by the counterflow principle to around 900 °C, via the heat transfer of flue gases from the kiln and fed into the pre-calciner. Calcination is the chemical decomposition of limestone ($CaCO_3$) into lime (CaO). Majority of the high temperature reaction occurs in the pre-calciner, which is essentially a combustion chamber at the bottom of the preheater above the kiln, and partially in the kiln. The chemical decomposition of limestone accounts to around 51% of total CO_2 emissions of the cement manufacturing process. Whereas the remaining emissions are made up by fuel combustion, quarrying, crushing, raw material transport, cooling, grinding, mixing and logistics. The pre-calcined meal then enters the rotary kiln, where temperatures reach up to 2000 °C, the extreme heat, chemical and physical reactions result in the production of clinker. Previously, wet kilns were employed for the production of clinker, however, these have been phased out nowadays. In this process, the grinded raw material was made into a slurry after the addition of water. This resulted in better homogeneity and less energy consumption during the grinding process and low dust creation. On the other hand, the heat consumption was quite large as a lot of water had to be evaporated from the process. After the rotary kiln, the hot clinker is cooled by air. The cooled clinker is mixed with gypsum and other pozzolanic materials to produce cement. Depending on the type of cement, several other components could be added such as slag, fly ash, limestone or other materials to reduce the clinker content. Subsequently, the final cement product is standardized and stored in cement silos. (KEI, 2024) (Cembureau, 2024) (Agico, 2020)

Figure 06-7: CO_2 emissions from cement production



Source: Author's own analysis based on (U.S. Department of Energy, 2024)

Decarbonization in the cement industry is a major target for reducing CO_2 emissions and achieving Net Zero. The cement industry not only produces emissions from the burning of fossil fuels in the cement kilns but also by the decomposition of calcium carbonate to calcium oxide known as the calcination process. Therefore, it is critical that reduction of emissions should be based upon, not only by switching the burned fuel in the kiln but also to investigate the process emissions too. Four main pathways exist for decarbonization in the cement sector:

Decarbonization Pathway 1: CCUS

As majority of the CO_2 emissions in cement plant arise from decomposition of $CaCO_3$ in the cement kiln, CCUS provides a unique opportunity to reduce the overall carbon footprint of the cement production process. Three major technologies for CO_2 capture exist differing mainly on the basis of TRLs; Post-combustion capture, Pre-combustion capture and oxy-fuel combustion.

Post-combustion capture employs the use of chemical solvents to capture CO_2 from the flue gas of the cement kiln. It is often regarded as an end-of-pipe technology. This does not require significant changes to the existing plant. However, flue gas pre-treatment is required to address the challenges of solvent degradation and energy consumption. Waste heat utilization can be used to mitigate the energy demand in post-combustion technology.

Pre-combustion CO_2 capture is based on the capture of CO_2 before the burning of fuel. In the context of cement plants, fuels such as natural gas or coal can be reformed via SMR (Steam Methane reforming) / ATR (Auto Thermal reforming) / PO_X (Partial Oxidation) to produce syngas, which can be directly combusted or converted to CO_2 and H_2. Hydrogen combustion in cement kilns can lead

to a drastic reduction in emissions. However, precombustion systems are complex and require a great amount of modification to existing plants as well as the need for efficient H_2 burners.
Oxyfuel combustion refers to the usage of pure oxygen (instead of air) for combustion. This process involves the separation of N_2 and O_2 from air via cryogenic distillation or pressure swing adsorption and burning the fuel in the presence of pure oxygen which results in a near pure CO_2 exhaust stream along with presence of H_2O. Usually, exhaust gases are recirculated to retain the operational conditions and lower the flame temperature. The absence of N_2 also results in fewer NO_x emissions. The almost pure CO_2 stream has the added advantage of lowering the complexity and size of the separation plant and in turn leading to a much reduced overall CAPEX. Nevertheless, the addition of an air separation unit can lead to an increase in energy consumption and elevated OPEX. While oxy-fuel combustion may not be the preferred route for existing / brownfield cements plants due to complexities in modification of the process or operational challenges, it is a good choice for new / greenfield cement plants as the capture and removal of CO_2 is quite straight-forward (DNV, 2024) (S Barbhuiya, 2024) (GEI , 2019) (Marmier, 2023) (IEA Technology Roadmap, 2024)
Decarbonization via CCUS presents a viable business case for the cement industry. Since the cement plant flue gas contains more CO_2 than power plants, it allows the use of carbon capture technologies (specifically post combustion capture) to be retrofitted to existing plants without too many modifications. Saudi Arabia has already announced the development of the Jubail CCS hub, which could present an opportunity for the storage of CO_2 captured from the cement plants situated in the Eastern region. Many of the other plants situated in the middle of the country might require dedicated pipelines for the transport of CO_2. For greenfield projects, oxy-fuel combustion would be the go-to technology as it provides much better performance than post combustion capture. At present, CCUS is considered to be very costly and will likely be adopted in the near and distant future, but the magnitude of implementation shall depend also on government policies and regulations.

Decarbonization Pathway 2: Alternative Fuels

Combustion of alternative fuels to meet thermal energy requirements for clinker production has long been exercised in the cement sector. Alternative fuels provide the dual advantage of reducing fossil fuel dependence as well as rerouting waste from landfills. Several types of alternative fuels are used in the cement industry such as:

- Biomass
- Municipal Solid Waste (MSW)
- Refuse derived fuels (RDF) such as non-recyclable plastics
- Old tires

Fuel switching from conventional to alternative also results in a decrease in thermal efficiency. Several key parameters are therefore required to be inspected in order to achieve optimum performance, which include higher substitution rates of alternative fuels along with combustibility, moisture content and size of plant.
The following table represents allowable limits in EU for alternative fuels

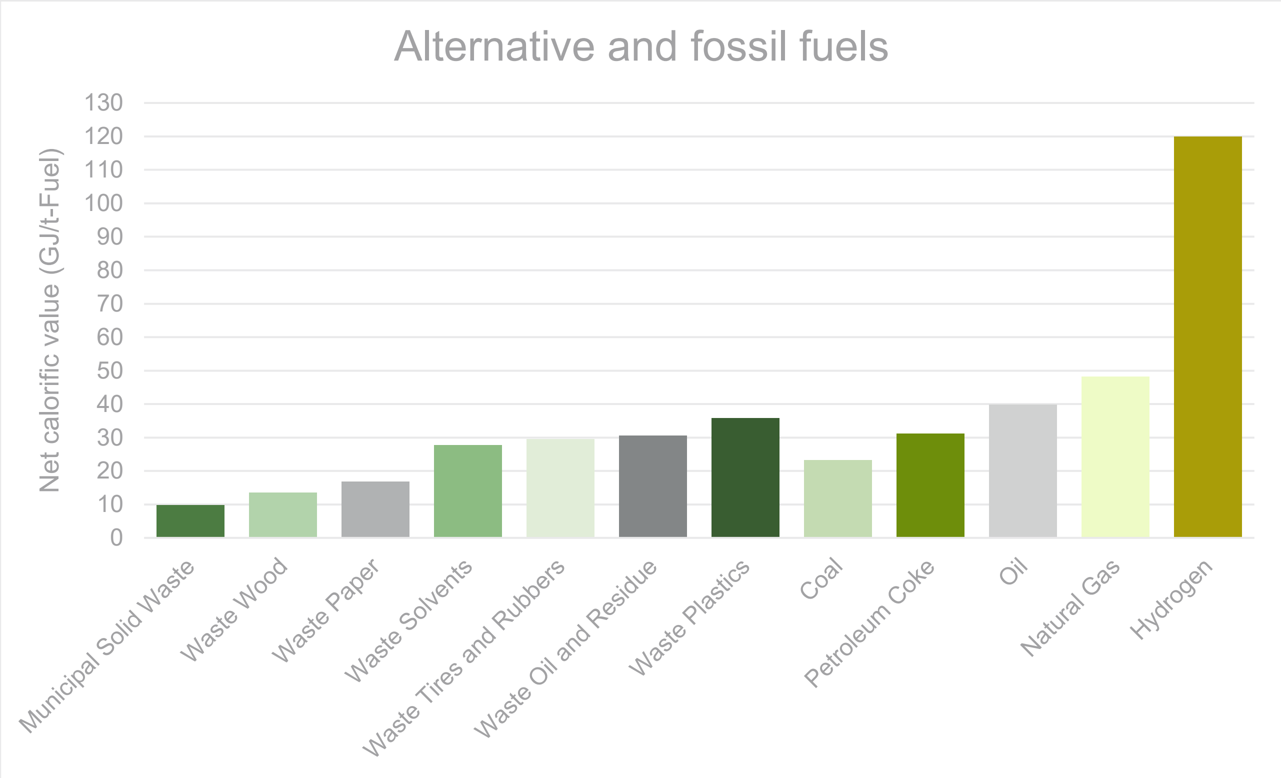
Table 06-5: Allowable limits for alternative fuels in EU

Component	Allowable Limit
Moisture	<4%
Chlorine	0.1% - 1%
Sulfur	0.2% - 2%
Nitrogen	<1.4%
Polychlorinated biphenyls (PCB)	<50 ppm
Heavy metals	<2500 ppm
Mercury (Hg)	<10 ppm
Cadmium (Cd) + Titanium (Ti)	<100ppm
Ash content	<0.5%
Calorific values	>17 GJ/t-fuel

Source: Based on (GEI, 2023)

Several factors such as availability in the local area, the presence of harmful components and heavy metals, chlorine content, sulphur content, poly-chlorinated biphenyl (PCB) content, moisture content, and calorific value all impact the practicality of alternative fuel usage. Hydrogen has been touted as a potential fuel in cement kilns to reduce carbon emissions. Since the burning of hydrogen is an exothermic reaction and only produces water, herein lies the potential of integrating such a process with cement production for waste heat recovery, steam generation and usage of water for electrolysis. An example is the Polatlı Anka cement plant in Ankara, Türkiye operated by Limak Cement where hydrogen mixed fuel was used in the preheating unit (International Cement Review, 2024).

Figure 06-8: Net calorific values of alternative and fossil fuels



Source: Author's own analysis based on (GEI, 2023)

Therefore, co-firing alternative fuels with fossil fuels is commonly practiced for the reduction of overall CO_2 emissions as well as a waste management strategy. (Risk Engineering Services. (n.d.). , 2024) (BEUMER Group, 2024) (GCCS, 2024) (G Clark, 2024). Alternative fuels can also offer mitigation for carbon emissions; however, it seems unlikely that green hydrogen will be implemented as an alternative fuel in cement kilns as there will be more incentive in exporting it to foreign countries. The Kingdom has already signed agreements for export of 200,000 tonnes of green hydrogen and Europe by 2030. annually to Germany (ACWA Power, 2024). At present, green hydrogen is more expensive than other conventional alternative fuels which are mostly by-products of other processes (e.g. MSW, Old tyres, Petroleum coke etc.). Furthermore, there is no dedicated hydrogen infrastructure existing in Saudi Arabia so it is logical for the country to produce green as well as blue hydrogen and export it to other countries in the near future (~5 years). However, in the distant future (~10 - 15 years), hydrogen use can be envisaged for new cement plants to reduce emissions. In terms of technological aspects, water requirements for hydrogen production also pose a challenge with Saudi Arabia being an arid land.

Technical challenges such as redesigning of burners for H_2 combustion and control of flame temperature also limit the implementation for now. H_2 could potentially also be blended with natural gas and used in kilns to further enhance fuel switching. Then again, fuels such as municipal solid waste (MSW), petroleum coke and tire derived fuel can be used for combustion in kilns to reduce emissions. There is also a possibility for cement plants to partner up with local waste management companies to source MSW for usage in kilns.

Decarbonization Pathway 3: Clinker to cement ratio

Clinker production is the most energy intensive step of cement production. Coincidentally, it is also the process step associated with the highest amount of CO_2 emissions. Average clinker-to-cement ratio lies between 0.64 - 0.76. Although, it is also reliant on the type of cement produced, for example Portland cement can have clinker-to-cement ratio up to 0.88 in the US. Since the ratio directly affects emissions, it is therefore logical to reduce the ratio in order to reduce electricity consumption and CO_2 emissions. Replacement of clinker with SCMs (supplementary cementitious materials) can assist in lowering the energy intensity of per tonne of cement produced and thus in turn lower the CO_2 emissions. Materials such as fly ash, blast furnace slag, natural pozzolans, ground limestone, and calcined clay can help in reducing the clinker content. However, it is imperative that these materials do not adversely affect the properties and performance of cement (GEI , 2019) (Dekeukelaere, 2021) (Marmier, 2023) (IEA Technology Roadmap, 2024) (Gangotra, 2024)

The reduction of clinker to cement ratio also plays a very important role for the reduction of carbon emissions. Saudi Arabia has an abundance to locally available supplementary cementitious materials (SCMs) such as limestone, pozzolan and clay. These materials can be added to the blending process to reduce clinker content. Other materials such as fly ash (by-product of coal fired power plants) and blast furnace slag (by-product of steel production) can also be used, nevertheless, both these products shall be available in minimal quantity in the future.

Decarbonization Pathway 4: Energy Efficiency

Improvement in energy efficiency can help cement plants reduce their overall CO_2 footprint. The production of cement is heavily reliant on high energy usage, particularly from clinker production, raw meal preparation and grinding. There are several areas in a cement plant where energy efficiency can help mitigate CO_2 emissions. One of the main areas of focus is the kiln, an optimised kiln operation can significantly reduce the overall emissions. Implementation of advanced control systems for monitoring and regulation of parameters such as temperature, airflow and fuel-to-air ratios can maximize energy efficiency. Additionally, heat recovery systems can be utilized to capture excess heat and further optimize the process. This also presents an interesting opportunity to combine CCUS with waste heat recovery systems, since the former requires significant thermal energy as well. Nowadays, most cement plants operate with the more efficient dry manufacturing process for cement with several heat integrated options such as multi-stage pre-heaters and pre-calciners. This is already an upgrade from the now almost defunct wet manufacturing process where energy consumption was already quite high due to the necessity of evaporation of water. Elsewhere, within the grinding step, the use of a vertical roller mill compared to the ball mill system can also reduce energy consumption from about 25% - 40%. Other niche strategies could include the use of mineralizers, materials which increase the combustibility of raw materials by lowering the viscosity and temperature of clinker melt or the operation of kiln with oxygen-enriched air (IEA Technology Roadmap, 2024) (Marmier, 2023) (GEI , 2019) (Dekeukelaere, 2021) (S Barbhuiya, 2024) (Direct Industry Connect, 2024)Energy efficiency will also play a significant role towards net zero. For existing plants, waste heat recovery will be important, especially since Saudi Arabia is a dry country.

Other strategies such as air-to fuel ratio control and integration of vertical roller mills can improve the performance.

Table 06-6: CO_2e reduction measures from cement production

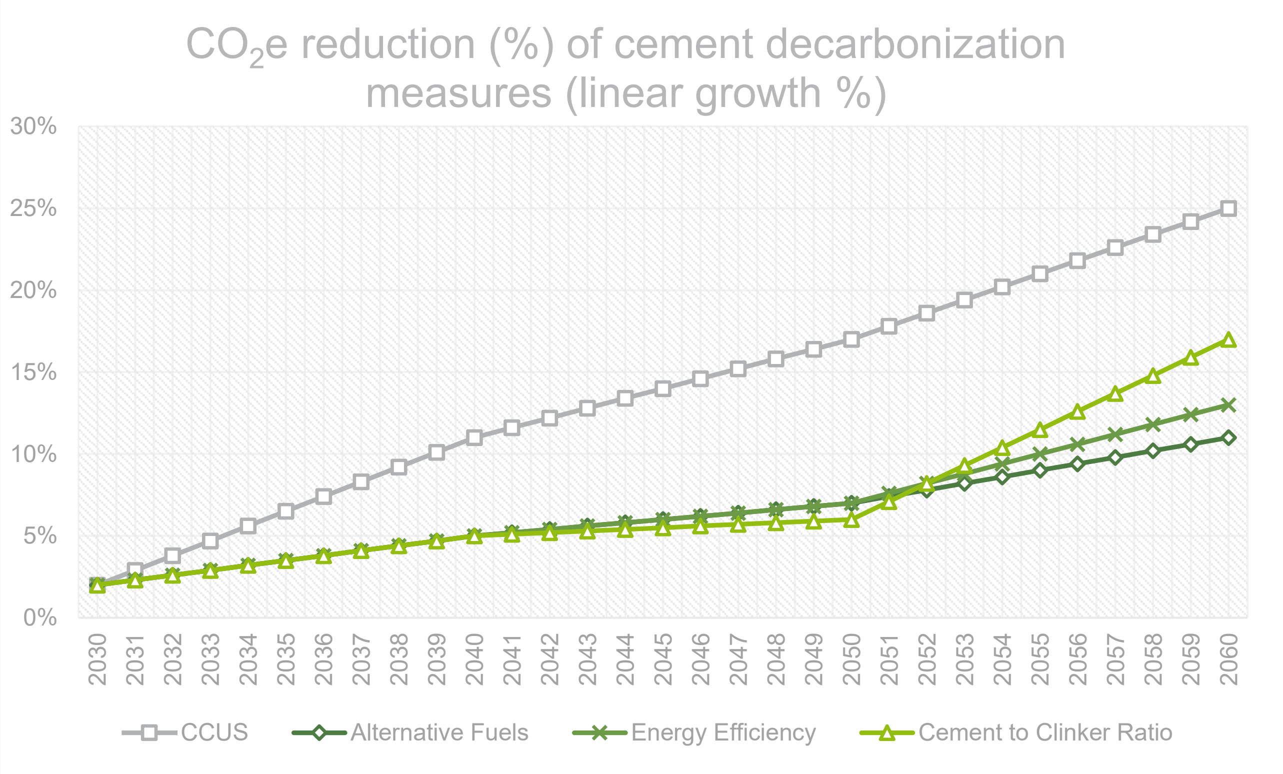
CO_2 reduction measures	2030	2040	2050	2060
CCUS	2.00%	11.00%	17.00%	25.00%
Alternative Fuels	2.00%	5.00%	7.00%	11.00%
Energy Efficiency	2.00%	5.00%	7.00%	13.00%
Cement to Clinker ratio	2.00%	5.00%	6.00%	17.00%
Total	8.00%	26%	37%	66%

Source: TRACTEBEL internal database based on market research and discussions with SMEs (subject-matter experts)

The decarbonization measures mix for Saudi Arabia (Table 07-6) forecasts as to when each pathway will play its role. At present, there are no immediate plans for CCUS and Alternative fuels specifically Hydrogen to be used as a decarbonization levers in the cement industry. There seems to be no pressure on the cement manufacturers to decarbonize. From 2030, we can start witnessing a shift where early adopters will try to implement decarbonization measures such as pilot scale CCUS plants or the usage of hydrogen in cement kilns. From 2040 onwards, there will be widespread usage of CCUS to help companies to decarbonize along with the increase in share of hydrogen as the infrastructure is developed. Full scale implementation along with standardization of green cement, new cement plants will already be equipped with CCUS units to ensure maximum reduction of emissions. Energy efficiency also plays a vital role for decarbonization, however most new plants will already operate at best available techniques so the potential for decarbonization is limited. In addition to energy efficiency, usage of some alternative fuels such as old tyres, plastics etc. can adversely affect the efficiency of the plant. Clinker to cement ratio, has the ability to reduce emission but is prevented by maximum allowable percentage of SCMs in cement. The reduction measures mix also highlights that for each year how much the relevant measure can reduce emissions with respect to its application and implementation, the percentages are based on discussions with subject matter experts and market research. The projections for the future years were then extrapolated based on linear forecasting functions. It is evident that until 2060 some residual emissions will still remain when compared to the Business-As-Usual (BAU) scenario. It is important to note that the figures and calculations are based on a crystal ball view to show how the decarbonization of cement industry can look like. In conclusion, the reduction measures percentages can also increase or decrease based on the actual implementation that is often influenced by regulatory framework and government policies.

A linear growth model on the uptake potential for the four decarbonization technologies in cement production, across different timeframes is presented below. This figure reflects the expected evolution of the cement sector toward decarbonization, leveraging advanced technologies and adapting to resource availability.

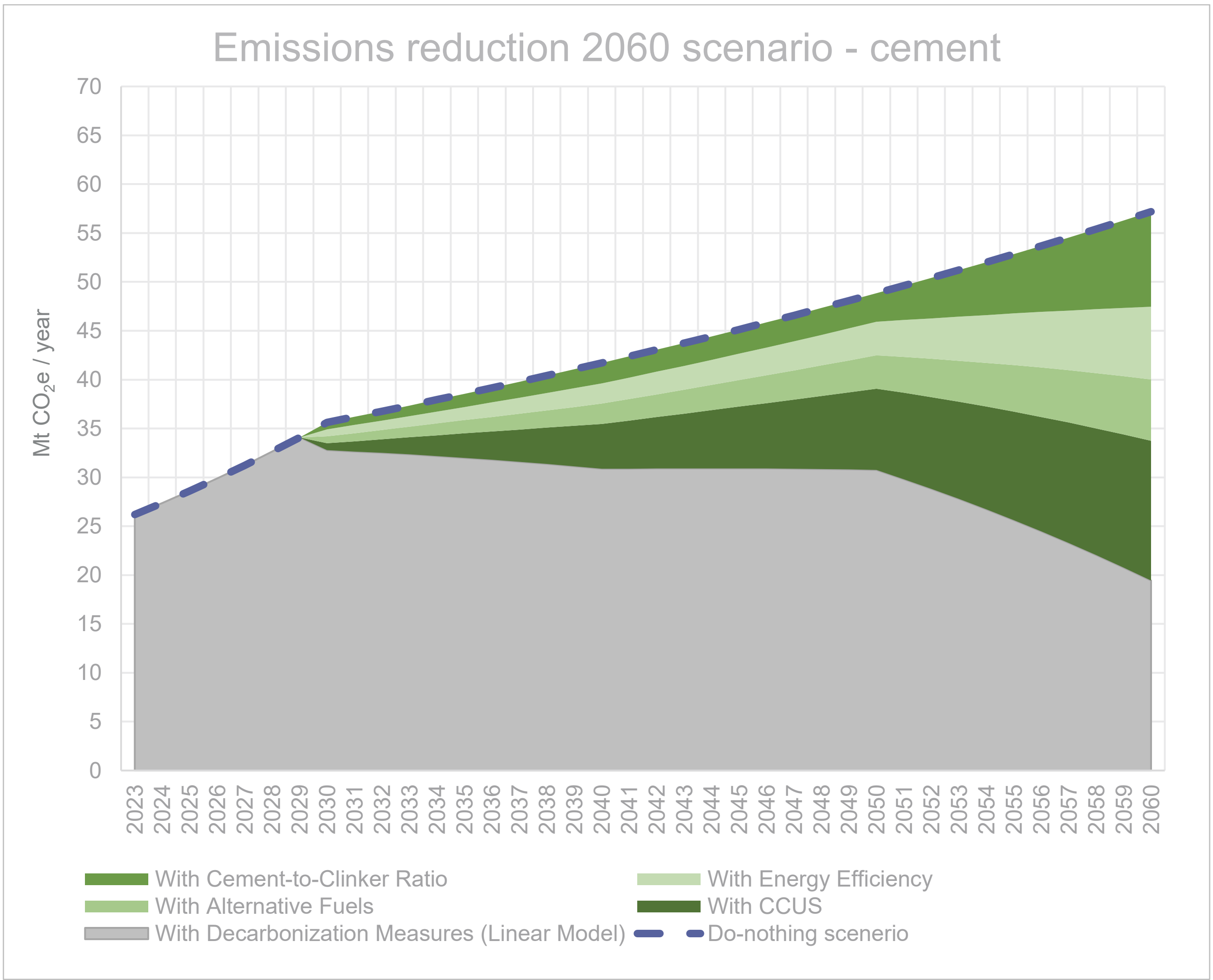
Figure 06-9: Linear growth of CO_2e reduction (%)-cement decarbonization measures



Source: own analysis derived from CO_2e reduction measures from cement production (Table 07-06)

The results are illustrated in the graph below, where the CO_2e baseline is calculated by maintaining the current technology mix under a "do-nothing" scenario. In this case, emissions from the cement sector directly correlate with production output, which increases from present 26.2 Mt CO_2e/year to 57.2 Mt CO_2e/year by 2060 as cement production increases. By 2060, the implementation of decarbonization measures is projected to reduce emissions by approximately 66% relative to the do-nothing scenario, avoiding an estimated 37.74 $MtCO_2e$ compared to projected emissions of 57.2 $MtCO_2e$ without any decarbonization measures. The remaining 19.44 $MtCO_2e$—representing 34% of the emissions expected by 2060 with the decarbonization measures—is considered unabated, reflecting residual emissions from low-carbon processes and process emissions from the calcination of calcium carbonate that cannot be entirely eliminated.

Figure 06-10: Emissions reduction projections from cement production



Source: Author's own analysis

The Net Zero Emissions scenario for Saudi Arabia, with the implementation of decarbonization measures, can significantly reduce overall cement sector emissions. However, achieving net zero will require more than just technological solutions, as these measures alone can reduce emissions by up to 66%. The rapid development associated with ongoing giga-projects has accelerated the demand for new infrastructure, thereby increasing cement consumption.

Novel and upcoming technologies can also play a vital role for the decarbonization of cement sector and transition to net zero. Technologies such as electrification of kilns, rotodynamic heating, LEILAC technology[12] can be seen as alternatives to aforementioned decarbonization levers. Companies such as Hoffmann Green Cement Technologies[13] and CemGreen[14] have already launched joint ventures to further develop and scale up technologies for sustainable cement production.

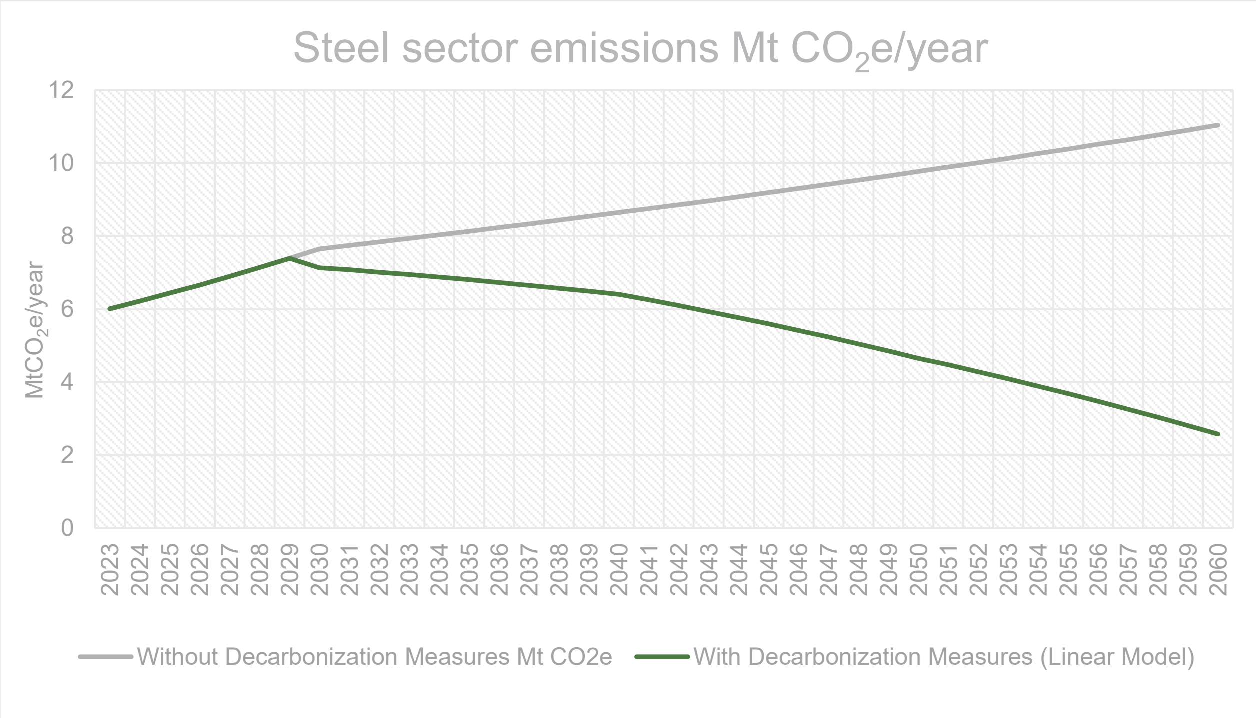
[12] LEILAC process, is a new low-cost, efficient carbon abatement technology for the cement and lime industries. (https://www.leilac.com/technology/)
[13] Hoffmann Green Cement Technologies offers an alternative approach to cement production by eliminating clinker usage. (https://www.ciments-hoffmann.com/en/newsroom/our-news/start-of-construction-of-h-ksa-1-the-first-hoffmann-unit-in-saudi-arabia/)
[14] CemGreen specializes in production of Supplementary Cementitious Materials (SCMs) from clay rich materials. (https://www.cemnet.com/News/story/177905/city-cement-and-next-generation-scm-launch-low-carbon-concrete-in-saudi-arabia.html)

In conclusion, all decarbonization levers are important albeit in different implementation levels and will play a substantial role for the cement industry in Saudi Arabia. On a more local level, each cement plant should view decarbonization on a best-case scenario for itself. For example, a plant located in central region of Saudi Arabia like Riyadh might use energy efficiency as decarbonization rather than CCUS since there is scarcity of water. Similarly, a plant located near the Eastern region can capture CO_2 and store in the Jubail CCS hub. On a more national level, each decarbonization lever needs to be regulated and relevant framework for implementation should be introduced.

Outward reduction strategies to offset residual emissions

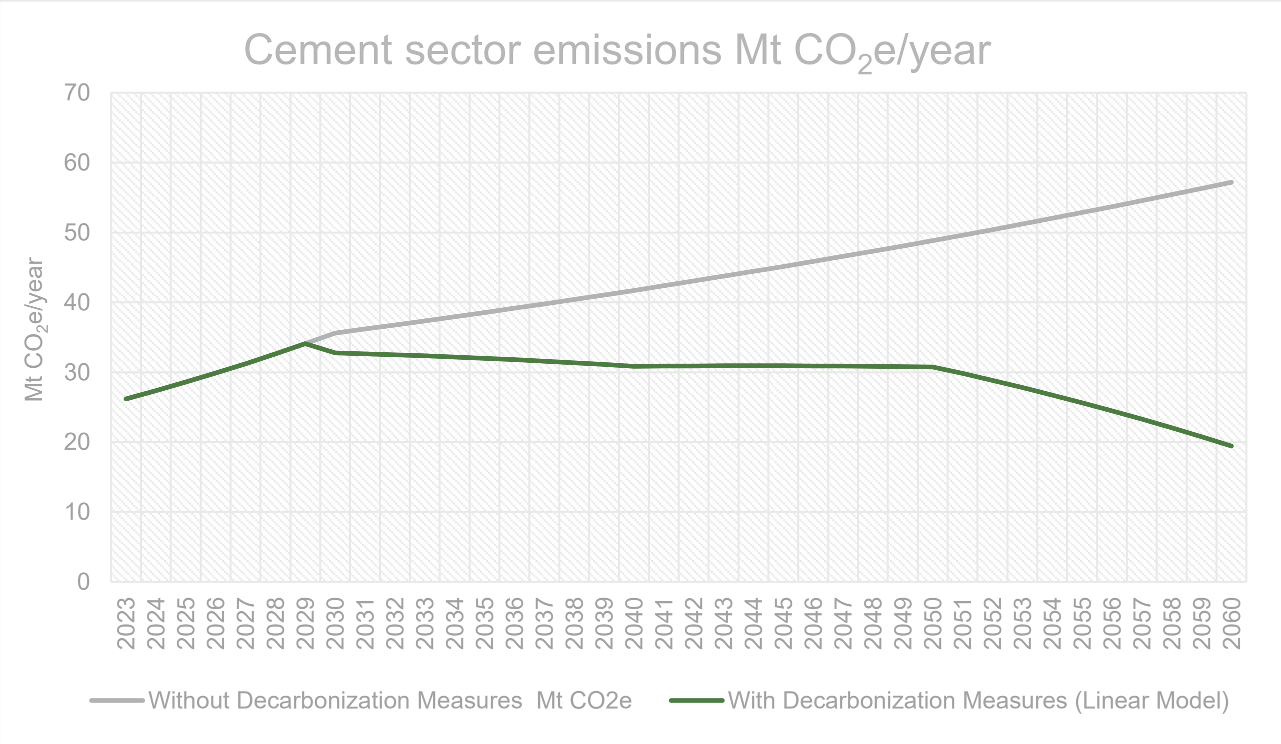
An outward reduction strategy could contribute steel and cement industries to achieve net-zero targets by 2060. By 2060, with the projected decarbonization measures, unabated emissions in Saudi Arabia are projected to be 2.57 $MtCO_2e$/year from the steel industry and 19.44 $MtCO_2e$/year from the cement industry. While domestic decarbonization technologies (e.g., CCUS, alternative fuels, hydrogen DRI) will play a significant role, "outward" or offset-based mechanisms are also essential to address residual emissions that cannot be fully abated technically or economically. CO_2 offsetting refers to compensating for such residual emissions by financing projects that reduce or remove greenhouse gases elsewhere. For hard-to-abate sectors like steel and cement, offsetting provides a complementary approach to close the gap to net-zero when direct emissions reductions reach their practical limits.

Figure 06-11: Steel emission projections with/without decarbonization measures



Source: Author's own analysis derived from steel production growth forecast (figure 6-4), CO2 footprint of steel decarbonization technologies (Table 07-2) and timeframes for progression of steel decarbonization technologies (Figure 07-03)

Figure 06-12: Cement emission projections with/without decarbonization measures



Source: Author's own analysis derived from cement production growth forecast (figure 6-3), CO2 reduction footprint of decarbonization measures (Table 07-6) and penetration rates (%) of cement decarbonization measures (Table 07-9)

Few options for off-set based mechanisms include:

- **Tree Plantation Under the Saudi Green Initiative:** Saudi Arabia's Green Initiative aims to plant 10 billion trees over the coming decades, contributing to both climate goals and ecosystem restoration. Steel and cement companies could sponsor afforestation projects as a form of carbon offsetting (SGI , 2025). it could be voluntary industry participation, where steel/cement producers can purchase, or "own" credits generated through public tree planting or state-sponsored with credits given back to industry.
- **Carbon trading at the Regional Voluntary Carbon Market:** Saudi Arabia also launched a regional voluntary carbon market under the Public Investment Fund (PIF) and Saudi Tadawul Group, with its first and second auctions held in 2022–2023 where 3.6 million tonnes of credits were sold. As part of the imitative, a voluntary carbon market exchange platform has been established recently, which is managed by The Regional Voluntary Carbon Market Company (RVCMC). Through the platform, RVCMC has facilitated auctions of another +2.5 million tonnes of carbon credits in 2024 that connected 23 Saudi businesses with 17 climate projects (e.g. landfill gas projects, methane capture etc.) from across the world. The auction clearing price was SAR 37.5/tonne of carbon credits (SPA, 2024). Steel and cement companies could also voluntarily purchase these offsets to neutralize their residual emissions. This will also create the opportunity for the steel and cement industries to integrate their corporate environmental, social, and governance (ESG) strategies or customer-driven net-zero pledges. However, volume and price

competitiveness of regional voluntary carbon credits could be limited and there will be a need for industry-specific guidance on offset eligibility and reporting.

- **CO_2 Credit Purchasing via Article 6 of the Paris Agreement:** International carbon credit trading under Article 6.2 (bilateral cooperation) or Article 6.4 (centralized UN mechanism) enables purchasing verified emission reduction units from projects abroad voluntarily (e.g., renewable energy, reforestation, methane recovery) and partnering with developing countries to finance emission reduction projects in exchange for internationally transferred mitigation outcomes (ITMOs) (UNEP-CCC , 2025). However, currently, no legal obligation exists for Saudi industrial firms to purchase carbon credits from projects abroad. A possible hybrid model could emerge where steel/cement industry bears part of the cost, especially when linked to ESG compliance or net-zero goals, with government co-funding through international carbon market participation.

07. Saudi steel and cement: driving economic diversification and decarbonization

This section examines the potential for adopting decarbonization technologies in Saudi Arabia's steel and cement industries, focusing on technology aspects, market dynamics, regulatory frameworks, and economic factors influencing the transition to low-carbon operations. A SWOT analysis is done in this regard identifying challenges and opportunities for achieving a realizable decarbonization paths for Saudi Arabia.

Economy, market, and regulatory aspects

Market & regulatory landscape

Currently, there is no industry-specific regulations or incentives in Saudi Arabia specifically targeted for promoting decarbonization in the steel and cement sectors. The success of decarbonization efforts depend on the development of supportive policies, such as subsidies for clean technologies, tax incentives, or the establishment of a domestic carbon pricing mechanism. To name a few important existing policies/programs, several notable existing initiatives could be adapted to address the specific needs of the steel and cement industries:

- **The Circular Carbon Economy (CCE) National Program:** Saudi Arabia is actively promoting the CCE program, under the **Saudi Green Initiative (SGI)** which includes initiatives like establishment of clean hydrogen hubs and CCUS hubs across Saudi Arabia and use of CCUS technologies to reduce emissions in hard-to-abate sectors. Notably, the initiative is supporting the Alsafwa Cement Company's Pilot Project that focuses on CCUS, aiming to showcase emission reductions in the cement sector (SGI, 2022)
- **Standard Incentives Program**: Saudi Arabia has introduced a Standard Incentives Program for the industrial sector to encourage local manufacturing and reduce reliance on imports. The program includes financial support covering up to 35% of initial capital investment with a maximum of SAR 50 million (US$ 13.3 million) per project, including the automotive, downstream chemicals, or machinery and equipment sectors. Saudi Arabia is actively establishing Special Economic Zones (SEZs), such as King Abdullah Economic City, Jazan SEZ, Ras Al-Khair SEZ, King Abdullah Financial District (ECZA, 2025), as part of its broader Vision 2030 strategy, which would also create favourable conditions for businesses, including tax benefits and energy subsidies. The National Incentives Committee (NIC) established in 2021 under the authority of the Council of Ministers is tasked with providing financial and non-financial incentives including but not limited to tax incentives, government subsidies, low- or no-interest loans etc. to enable industrial investments, spur their growth, and achieve sustainable industrial development in Saudi Arabia (DGA, 2025)
- **Enlisting Carbon Reduction Projects under the National Greenhouse Gas Crediting and Offsetting Mechanism:** Saudi Arabia's National Greenhouse Gas Crediting and

Offsetting Mechanism (GCOM), launched in 2023 by the Ministry of Energy, provides a structured, voluntary platform for registering and trading domestic carbon reduction and removal projects within Saudi Arabia. Designed to support the Kingdom's climate commitments under Vision 2030 and the Circular Carbon Economy framework, GCOM allows project developers—across sectors such as energy, industry, waste, and agriculture—to enlist eligible projects that follow international standards like Verra and Gold Standard. Enlisted projects must go through third-party validation and verification before being issued credits. At present, the GCOM platform is accepting project submissions across various sectors, including energy, waste, and nature-based solutions. For hard-to-abate sectors like steel and cement, GCOM offers a domestic pathway to reduce outward emissions through projects such as energy efficiency, alternative fuels, or carbon capture. Participation not only supports ESG objectives and future compliance readiness but also contributes to the development of a local carbon credit ecosystem tailored to national priorities (GCOM, 2025).

To spur the decarbonization measures in the domestic market, an effective way is to establish **an industrial emission trading system (ETS)**. An ETS is a market-based approach where a cap is set on total emissions, and companies can buy or sell allowances based on their emission levels. Saudi Arabia currently lacks a domestic industrial ETS that mandates or incentivizes emission reductions in the steel and cement industries. The European Union Emissions Trading System (EU ETS), established in 2005, serves as a prominent example, covering sectors like power and heat generation, cement production, and iron and steel manufacturing (European Commission , 2023).

In the EU ETS, emission caps decrease annually to reduce overall greenhouse gas emissions. The cap is projected to decline from 1,571 million tonnes (Mt) in 2021 to approximately 800 Mt by 2030 (Global Cement , 2023). Companies exceeding their emission allowances (known as EU Allowances or EUA) must purchase additional permits, effectively putting a price on carbon emissions.
The steel and cement industry, being energy-intensive have to deal with higher emission prices due to the EU ETS. In the past, carbon prices were low as €50/tonne, but they have increased significantly in recent years, going over €100/tonne in 2023 before slightly dropping in 2024 due to various factors, including lower emissions from power and industrial sectors and economic conditions. For companies to invest in reducing emissions, the EU ETS mechanism tries to ensure that it's cheaper to invest in green technologies than to buy emission allowances (EUA). Although carbon prices are quite volatile in the short term, but they are expected to further rise to encourage these investments. (Global Cement , 2023). For instance, the steel industry, assuming annual direct emissions of 185 Mt in the EU and a carbon price of €97/tonne, the direct carbon costs could amount to €9.6 billion by 2030 (EUROFER, 2021)

The EU also has a system called **CBAM (Carbon Border Adjustment Mechanism)** that charges importers a similar carbon price to the EU ETS prices to protect local industries. The EU's CBAM aims to prevent carbon leakage by imposing a carbon price on imports of certain goods, including steel and cement, equivalent to the carbon price that would have been paid if the goods were produced under the EU's carbon pricing rules. The CBAM entered into force on October 1, 2023, with a transitional phase requiring importers to report emissions embedded in their products. Full implementation, including financial adjustments, is scheduled for 2026. (European Commission , 2023). The price of CBAM certificates is linked to the price of EU allowances (EUA) under the EU ETS. For instance, with a carbon price of €70/tonne and an average carbon intensity of 1.85 tonnes CO_2 per tonne of steel, the cost increase would be approximately €130/tonne of steel, representing a 16% rise on a base price of €800/tonne (PwC, 2023).

However, as of now, Saudi Arabia's steel and cement exports are primarily directed to countries in the Middle East and Asia, not the EU. From Saudi Arabia, current cement exports are modest, at 8-9 Mt/year (16%-17% of total production), mainly to Yemen, Ghana, Jordan, and Bahrain (CEMNET, 2023) . Similarly, steel exports are 1-2 Mt/year (17%-18% of total production), primarily to Türkiye, Jordan, Hong Kong, UAE, and Egypt (OEC World , 2024). Both industries may see a decrease in exports in the short term to meet rising domestic demand due to Vision 2030 infrastructure projects. Therefore, the immediate impact of the CBAM on Saudi steel and cement exports will be limited unless the export market will be expanded to the EU. Nevertheless, as global carbon pricing mechanisms evolve, there could be indirect effects on Saudi steel and cement industries through changes in global market dynamics.

In terms of carbon market potential in Saudi Arabia, local companies would likely give preference for purchasing domestically generated credits over international offsets. Notably, large-scale developments such as NEOM have begun incorporating corporate GHG accounting and carbon offsetting strategies (KAPSARC, 2023). To support this shift, two recently launched complementary voluntary initiatives the Domestic Greenhouse Gas Crediting and Offsetting Mechanism (GCOM) and the Regional Voluntary Carbon Market (RVCM) – are expected to play an important role in shaping Saudi Arabia’s emerging carbon market ecosystem. A national GHG crediting and offsetting framework established under the GCOM is also expected to support and stimulate investment in emission reduction projects across all sectors. Looking ahead, the establishment of a domestic emission-cap-based compliance market could further incentivize private-sector participation, especially from hard-to-abate industries like steel and cement.

Economic aspects and transition costs

Implementing decarbonization technologies in the steel and cement industries involves significant capital expenditures (CAPEX). In the absence of specific regulatory mandates or financial incentives, steel and cement industries may be reluctant to bear these costs, especially if they lead to higher end-product prices that could reduce competitiveness. The extent of price increases depends on factors such as the specific technology implemented, scale of investment, and market dynamics.

- The cost of implementing CCUS in Saudi Arabia’s steel and cement industries varies significantly, influenced by sector-specific factors such as CO_2 concentration, flue gas temperature, and facility scale. According to recent estimates, capture costs for steel plants range from US$64 to US$98 per tonne, with an average of US$74/t$CO_2$, while costs for cement plants range from US$53 to US$101 per tonne of CO_2, averaging around US$68/t$CO_2$. The relatively high carbon capture costs—especially compared to sectors like ammonia production (US$10 to US$13 per tonne of CO_2) and refineries (US$50 to US$63 per tonne of CO_2)—are mainly due to the low CO_2 concentrations in flue gas from steel and cement plants, and technical complexities (Rowaihy, 2025) . Smaller facilities face higher per-tonne costs due to limited economies of scale. As a result, CCUS adoption in these sectors is likely to increase the overall cost of production, potentially leading to higher market prices for steel and cement products. Based on average CCUS costs, as mentioned above, for steel and cement plants; a carbon intensity of 1.6 tCO_2e/tonne of steel (from a BF-BOF plant as an example) and 0.53 tCO_2e/tonne for cement (please refer to the carbon intensity discussion in chapter 7) ; and market prices of 2,996 SAR/tonne for steel and 280 SAR/tonne for cement (see chapter 05); the additional CCUS-related costs could raise final product prices by approximately up to 20% for steel and 70% for cement.

- Transitioning to green hydrogen-based steel production involves substantial investments in electrolysers and related infrastructure. The Hydrogen Council estimates the current global average green hydrogen production cost at approximately US$4.5 to US$6.5 per kg as of 2023, reflecting a 30% to 65% increase over earlier projections due to higher capital costs in regions with less favourable renewable resources, rising interest rates, and ongoing supply chain pressures (Hydrogen Council, 2023). In contrast, Saudi Arabia's green hydrogen production cost, based on locally available renewable sources, is estimated to range between US$2.34 and US$3.08 per kg (KAPSARC , 2024). This is still notably higher than the cost of grey hydrogen produced via SMR in Saudi Arabia, which ranges from US$0.90 and US$1.5 per kg, depending on natural gas prices between US$1.25 and US$5.25 per MMBtu (KAPSARC, 2021). As a general example, shifting from natural gas to green hydrogen in DRI-EAF-based steel production could increase the price of final steel products by 60% to 80% (Benavides, 2024), potentially affecting their market competitiveness.
- Investments in energy efficiency measures in steel and cement industries, such as upgrading equipment and optimizing processes, can lead to significant energy savings and emission reductions. While specific costs vary, these measures often require substantial upfront capital but can result in long-term operational savings. The impact on final product prices depends on the balance between initial investments and achieved efficiencies.

For cement industry, shifting to alternative fuels like biomass or waste-derived fuels requires modifications to existing kiln systems, involving additional capital expenditures. While these fuels can reduce CO_2 emissions, the associated costs depend on fuel availability and necessary technological adaptations. These changes may influence the final price of cement products. Reducing the clinker-to-cement ratio by incorporating supplementary materials (e.g., fly ash, slag) can lower CO_2 emissions. This approach will require investments in material handling and processing infrastructure. The impact on cement prices depends on the cost and availability of these supplementary materials. With the lowering of clinker content, cement price can decrease as less energy is required for producing cement. However, processing and procurement costs and availability of supplementary materials also affects the cement price. For example, two such supplementary materials, fly ash (a byproduct of coal fired power plants) and slag (a byproduct of BF/BOF) process will be less available in the future due to phasing out of their technologies. Additionally, locally sourced supplementary materials can help in reducing the overall cement price. It should also be noted that the supplementary materials can only be added up to a certain percentage for cement production to comply with standards. All in all, there exists an economic trade-off between cost of supplementary materials and cost of cement produced by lowering the clinker to cement ratio. Another important aspects is the energy supply costs at industries, which is a critical factor influencing the competitiveness of the steel and cement industries. The lower energy costs in Saudi Arabia provide its steel and cement industries maintaining a competitive domestic production with its regional counterparts. Saudi Arabia provides natural gas to industrial consumers at subsidized rates, although recently the Ministry of Energy has increased the service tariff to 1.2 SAR/MMBtu by 4.58%, which is added on top of the local natural gas base price (Argaam, 2024). The current natural gas supply cost for industries ranges from 5.84 SAR/MMBtu (in Riyadh) to 7.23 SAR/MMBtu (in Dammam). Industrial electricity prices have been relatively low due to government subsidies, typically ranging from US$0.03 to US$0.05 per kilowatt-hour (kWh). In 2018, the government revised electricity tariffs, setting the industrial sector rate at 0.18 SAR per kilowatt-hour (kWh), approximately US$0.048/kWh. However, this advantage also reduces the financial incentive to invest in energy efficiency and alternative energy sources, potentially impacting the adoption of decarbonization technologies. Notably, energy supply costs in Saudi Arabia are far below than the EU region (e.g. Germany) where industries must pay higher energy prices and are obliged to comply with the EU ETS.

Table 07-1: Industry energy price comparison (Saudi Arabia & an EU country-Germany)

Energy Source	Saudi Arabia	EU/Germany*
Natural Gas ($/MMBtu)	5.84 – 7.23 SAR/MMBtu (~1.58-1.95 US$/MMBtu)	0.062 €/kWh (~19.8 US$/MMBtu)
Electricity	0.18 SAR/kWh (~0.048 US$/kWh)	0.23 €/kWh (~0.25 US$/kWh)

*as an example of high energy price and ETS compliance market

Source: (SERA, 2025) (MODON, 2025) (Eurostat Electricity Price, 2024) (Eurostat NG Price, 2024)

The transition to low-carbon technologies in Saudi Arabia's steel and cement industries requires substantial capital investments, impacting product pricing. While global mechanisms like CBAM currently have limited direct effects on Saudi steel and cement industries, future market shifts and international regulatory pressures may drive domestic industries toward decarbonization. Given Saudi Arabia's low energy prices, financial incentives and regulatory frameworks are needed to encourage the domestic adoption of cleaner technologies.

On the other hand, Saudi Arabia's advantage in renewable energy, particularly solar, enables one of the world's lowest Levelized Costs of Electricity (LCOE), with estimates reaching as low as US$13-19/MWh in recent tenders (SPPC, 2024). This low-cost renewable electricity, coupled with abundant land for solar infrastructure, positions the Kingdom as a competitive producer of green hydrogen. In turn, this supports cost-effective production of green steel. However, while these advantages lower production costs, export competitiveness is contingent on market access, certifications (e.g., EU green steel labelling), and logistics. Moreover, without clear carbon pricing or premium markets in Saudi Arabia's main exporting regions for steel and cement products (which is currently Middle East and Asia), the financial payoff of clean exports remains uncertain in the short-term. Hence, Saudi Arabia's low LCOE forms a strong foundation, but its full export competitiveness potential depends on integration with global regulatory and trade frameworks.

Technology integration, supply-chain and enabling infrastructure for decarbonization technologies

Steel industry

Despite the higher technology readiness levels of certain steel production options (TRL level 6 and above), actual decarbonization potential would realize in Saudi Arabia depending upon various issues like transition challenges/advantages, technology know-how, supply chain and supply-demand dynamics.

While the BF-based steel production process comprises 70% of global steel production, KSA's position with only 10% BF-based steel production highlights a key advantage for the Kingdom (Global Steel Plant Tracker, 2024). Among the successfully demonstrated and widely adopted technologies, the DRI route with natural gas is already utilized in 70% of KSA's steel production, positioning the country well for further decarbonization. While many global steel producers must overhaul their production processes—transitioning from the traditional BF-BOF route to DRI—KSA already possesses the necessary expertise, workforce, and infrastructure. The only exception is the Rajhi Al Assemah Steel plant in Jeddah, which will require a major transformation. However, compared to European plants that lack any DRI presence, the transition for Rajhi Al Assemah will be significantly less challenging, benefiting from the country's established knowledge and operational experience. However, despite this strategic advantage, KSA accounts for only 0.5% of global steel production This small market share presents a challenge when negotiating with technology providers for new plant installations, as larger global players may secure priority access to key technologies.

Expanding steel production in KSA using DRI – whether powered by natural gas, a natural gas-hydrogen blend, or pure hydrogen – poses a supply and demand risk. Currently, only two licensors, MIDREX and ENERGIRON, provide DRI technology. Given the global push for cleaner steel production, securing agreements for new plant installations is crucial. The capacity for deploying DRI plants remains limited, with only 7% of global steel production using this method today. As demand surges, lead times for plant commissioning have already extended to 6-7 years, underscoring the urgency of strategic commitments.

Another set of solutions involves CCUS technologies. While CCUS is well-established in the energy sector, its effectiveness for steel flue gases remains uncertain. The CO_2 concentration in steel production affects the capture rate, making integration challenging. Combining CCUS with hydrogen injection theoretically enables near-total emissions abatement. However, improper implementation could paradoxically reduce CO_2 capture efficiency, making careful optimization essential.

Despite these challenges, KSA has unique opportunities for industrial integration. Its well-developed oil and gas sector provides expertise that can be leveraged for CCUS applications and off-gas conversion, linking the chemical and steel industries. Furthermore, KSA's vast land availability and abundant solar resources enhance its potential for renewable energy and green hydrogen production, supporting a transition to cleaner steel manufacturing. With strategic planning, investments, and timely commitments, KSA can solidify its leadership in decarbonized steel production, mitigating global competition risks while capitalizing on its existing advantages.

Table 07-2: SWOT analysis - Steel Industry

	Strengths	**Comments**
1	Established DRI usage	• 70% of KSA steel production already uses the DRI route, which is decarbonization-friendly. • Local expertise and capabilities in DRI technology reduce the need for major restructuring in workforce training and maintenance skills.
2	Abundant natural gas resources	• Availability of natural gas supports the DRI process, offering a competitive advantage in transitioning toward greener production.
3	Existing knowledge base	• Expertise in the oil and gas sector can be leveraged for integrating industrial processes such as CCUS and off-gas conversion
4	Favourable geographical conditions	• Large, unpopulated areas and abundant sunlight provide ideal conditions for renewable energy and green hydrogen production
5	Low renewable energy production cost	• The low LCOE of solar energy (US$13-19/MWh) positions KSA as a competitive producer of green hydrogen
	Weaknesses	**Comments**
1	Small global contribution	• KSA represents only 0.5% of global steel production, limiting its leverage in negotiations with technology providers
2	Reliance on limited technology providers	• Dependence on two primary licensors (MIDREX and ENERGIRON) for DRI technology might increase vulnerability to competition and delays in securing plant installations
3	Challenges with CCUS for steel	• Carbon capture technologies are not yet fully proven for the specificities of steel production, such as flue gas compositions and CO_2 concentrations
4	Capacity constraints	• Global capacity to install DRI plants is limited, leading to potential wait times of 6–7 years for new plants to become operational
5	Domestic carbon pricing	• Absence of domestic carbon pricing and industrial ETS weakens financial drivers for clean technology adoption.
6	Financial motivation for clean technology investment	• While current low energy prices (natural gas and electricity) enhance domestic and regional cost competitiveness for steel production in KSA, they also weaken the economic incentive to adopt decarbonization technologies that entail additional production costs
	Opportunities	**Comments**
1	Decarbonization pathways	• Expanding the use of DRI with blends of natural gas, hydrogen, or pure hydrogen can lead to significant reductions in emissions

2	Industrial integration	• Potential for combining the steel sectors to utilize CCUS and off-gas conversion, creating synergies for cleaner production
3	Renewable energy deployment	• Leveraging solar energy to produce green hydrogen and power steel production processes
4	Global decarbonization race	• Early investment in green steel technologies can position KSA as a leader in sustainable steel production, attracting international partners and markets
5	Integration with international export markets	• Integration with international decarbonization mechanisms (e.g., CBAM preparedness) can open access to premium export markets.
6.	Incentives for technology transition upgrades	• The national programs such as CCE, GCOM, and Standard Incentives Program can potentially extend financial benefits/incentives to steel industries for technology upgrades.
	Threats	**Comments**
1	Global competition for resources	• Larger players in the steel industry may secure priority access to technology providers, delaying KSA's progress
2	Technology bottlenecks	• Limited availability of proven CCUS solutions tailored to steel production could slow down decarbonization efforts
3	Market dynamics	• Expanding production using DRI technologies risks may create an imbalance in demand and supply for natural gas and hydrogen
4	Implementation risks	• The CO_2 concentration directly impacts the efficiency of the capture rate, and while integrating CCUS solutions with hydrogen injection appears to be a promising approach to achieve emissions reduction, it may decrease the CO_2 capture efficiency and could become counterproductive if not implemented correctly.
5	Exposure of global exports to evolving global carbon regulations in the future	• Potential trade barriers and evolving carbon pricing schemes (e.g., EU CBAM) may penalize carbon-intensive exports (steel and cement) in the long-term

Source: Own analysis

Cement Industry

Among the key decarbonization pathways for Saudi Arabia's cement sector, CCUS emerges as a cornerstone technology in the decarbonization roadmap, particularly because of its potential to address the process emissions from calcination, which are otherwise unavoidable. Globally, CCUS is being piloted in cement plants such as Heidelberg Materials' Brevik plant in Norway, indicating growing maturity of post-combustion systems (Heidelberg materials, 2025). These technologies, especially when coupled with waste heat recovery, are technically feasible for Saudi Arabia's dry-process cement plants. However, the technological adaptation required for pre-combustion and oxy-fuel systems – like air separation units and burner redesign – makes retrofitting complex and energy-intensive. Given that many of Saudi Arabia's plants are brownfield, retrofitting could be challenging. However, the cement sector will benefit from the national programs under Vision 2030 and the Circular Carbon Economy framework for cluster-based CCUS hub deployments, particularly in industrial hubs like Jubail (GCI, 2024). Yet, unless accompanied by skilled workforce development, safety standards, and public engagement strategies, CCUS may face operational and societal hurdles.

The second decarbonization lever, the adoption of alternative fuels (AF) such as non-recyclable plastics/RDF, biomass, or waste tires, offers considerable potential for emissions reduction and waste management synergy. AF use is already mainstream in Europe, with thermal substitution rates exceeding 43% with alternative fuels derived from waste and biomass (current technical potential is even larger at 60% replacement with waste, and in the future up to 95% replacement (CE Stakeholder EU, 2019). For Saudi Arabia, where waste generation is high and landfill diversion targets are part of Vision 2030, this represents a practical and scalable opportunity. Initiatives such as those by the Saudi Investment Recycling Company (SIRC) aim to divert 94% of municipal solid waste in Riyadh from landfills (SGI , 2025), creating a long-term supply of combustible alternative fuels. Technologically, modern cement kilns in the country are compatible with co-firing, although achieving consistent combustion efficiency requires stringent control over fuel moisture, ash content, and calorific value. However, the current waste-to-energy and RDF supply chain in the Kingdom is underdeveloped, and the absence of national quality standards for alternative fuels could lead to operational inefficiencies or emissions of undesirable pollutants such as chlorine or heavy metals. Further, kiln operators may lack training in AF-specific combustion dynamics, especially when switching from relatively stable fossil fuels to heterogeneous waste-derived materials. While international companies like GEOCYCLE offer technical partnerships (Geocycle, 2025), local infrastructure gaps – like preprocessing plants and regional logistics – remain a barrier to scale-up. Additionally, technological dependency on imported pre-treatment and control systems creates exposure to international supply chain volatility.

Another technologically critical pathway is the reduction of the clinker-to-cement ratio, primarily through the use of supplementary cementitious materials (SCMs). This pathway is among the most cost-effective globally, with emissions reduction potential of 20–30% per tonne of cement when materials like fly ash, slag, calcined clay, or volcanic pozzolans are used (IEA, 2018). The pathway does not require major changes to kiln hardware, making it accessible and fast to implement. However, in Saudi Arabia, access to SCMs is constrained. The country's limited coal-fired power generation reduces fly ash availability, and blast furnace slag (e.g. from local steel plants that has only 10% of its production based on BF-BOF) might be available in limited volumes. Having said that, the Kingdom has natural reserves of clay and volcanic ash, particularly in the western region (Aramco World, 2016), which remain underutilized. With adequate investment in processing technology, Saudi Arabia could reduce its reliance on imported SCMs and foster a local green materials supply chain. Moreover, there is no clear mandate or incentive under Saudi law to reduce clinker content or encourage low-carbon cement procurement. Notably, the Saudi Standards Metrology & Quality Organization (SASO) sets the technical standards for building materials in Saudi Arabia (SASO, 2025) . Setting blended cement regulatory standards and also institutional support – such as adjusting public procurement specifications or developing new national standards for low-clinker cements – could overcome initial market resistance. However, performance concerns among end users, especially for giga projects may require strict compressive strength and durability criteria, and that could be a challenge, particularly in hot and arid conditions where curing properties are more sensitive to mix composition.

Finally, energy efficiency measures offer a more mature and readily implementable decarbonization option. Technologies such as vertical roller mills, high-efficiency separators, advanced kiln controls, and waste heat recovery are widely available and proven. Most Saudi cement plants already operate using the dry process (CEMNET, 2023), providing a relatively modern base from which to optimize further. Despite the technical viability, uptake is often limited by soft factors: lack of skilled technical personnel, absence of mandatory energy audits, and the relatively low price of electricity and fuels due to subsidies. This undermines the financial case for adopting energy-efficient upgrades. Yet, there are notable opportunities. In general, integrating energy efficiency with digital tools (iFactory , 2022) could yield an incremental gain of 5–10% in industries. Saudi Arabia's push toward industrial digitalization could support such applications. Moreover, coupling waste heat recovery with CCUS systems – where waste heat is reused to power solvent regeneration – can further optimize performance. However, deployment will depend heavily on top-down mandates, incentives, and access to technical expertise.

Table 07-3: SWOT analysis - Cement Industry

	Strengths	**Comments**
1	Established dry process infrastructure	• Most Saudi cement plants already operate using the energy-efficient dry process, providing a strong base for retrofitting and further optimization
2	Technical feasibility of CCUS integration	• Post-combustion CCUS is maturing globally and can be technically integrated into dry-process kilns with waste heat recovery support.
3	Cement kilns compatible with AF	• Modern kilns are capable of co-firing alternative fuels, such as RDF, biomass, and waste tires, which helps reduce fossil fuel dependency.
4	Cost-effectiveness of clinker substitution	• Using SCMs (e.g., slag, calcined clay, fly ash) can reduce emissions by 20–30% per tonne of cement without major plant modifications
5	Availability of local clay and volcanic ash	• The western region has natural reserves of clay and volcanic ash, which are suitable for producing SCMs.
6	Proven energy efficiency technologies	• Equipment like vertical roller mills, WHR systems, and kiln automation is readily available and widely implemented across global best-in-class plants.
	Weaknesses	**Comments**
1	Complexity of CCUS retrofitting	• Pre-combustion CCUS require major modifications (e.g., air separation units), creating complexity for brownfield cement plants.
2	Underdeveloped AF supply chain	• The RDF and waste-to-energy infrastructure is immature in Saudi Arabia, leading to inconsistent availability and challenges in maintaining fuel quality.
3	Limited local SCM availability	• Fly ash supply chain availability could be scarce, due to minimal coal use; only ~10% of local steel is BF-BOF-based, limiting slag supply for cement blending.
4	Lack of performance-tested blended cement standards	• No wide-spread adaption of blended cement standards in Saudi Arabia; blended cement adoption is limited due to durability concerns in hot, arid environments.
5	Skills and training gaps	• Limited availability of trained personnel to manage AF combustion variability, CCUS systems, and energy monitoring tools.
5	Domestic carbon pricing	• Absence of domestic carbon pricing and industrial ETS weakens financial drivers for clean technology adoption.
6	Financial motivation for clean technology investment	• While current low energy prices (natural gas and electricity) enhance domestic and regional cost competitiveness for cement production in KSA, they also weaken the economic incentive to adopt decarbonization technologies that entail additional production costs • Low domestic electricity and fuel prices reduce the financial incentive for energy-saving investments in cement production.

	Opportunities	Comments
1	Vision 2030 and CCE backing	• National programs (e.g., Circular Carbon Economy, Vision 2030) support CCUS hubs and decarbonization clusters (e.g., Jubail).
2	Growth in waste recycling initiatives	• Programs like SIRC aim to divert 94% of MSW from landfills in Riyadh, creating potential for long-term AF supply (SGI, 2025).
3	International technical partnerships	• Collaborations with private companies can fast-track deployment of AF systems and fuel processing expertise.
4	Digitalization for efficiency gains	• Integrating digital tools in process optimization can unlock 5–10% incremental energy efficiency gains
5	Integration with international export markets	• Integration with international decarbonization mechanisms (e.g., CBAM preparedness) can open access to premium export markets.
6.	Incentives for technology transition upgrades	• The national programs such as CCE, GCOM, and Standard Incentives Program can potentially extend financial benefits/incentives to steel and cement industries for technology upgrades.
7	Local SCM processing potential	• With investments in calcination technology, local volcanic ash and clays could reduce dependence on imported SCMs.
8	Green public procurement	• Revising public procurement specifications to Favor low-carbon cement can accelerate demand for blended products.
	Threats	**Comments**
1	High CCUS capital and operational costs	• CCUS remains capital-intensive, and lack of carbon pricing or ETS in KSA reduces financial motivation for deployment.
2	AF combustion and emissions risks	• Variability in chlorine, moisture, and heavy metal content of AF may pose operational and environmental risks.
3	Dependence on imported tech	• Pre-treatment systems and CCUS units rely on foreign suppliers, creating exposure to supply chain delays and cost volatility.
4	Resistance to blended cements	• Market scepticism over performance in extreme climate conditions may limit acceptance of low-clinker cement in large projects.
5	No mandate to reduce clinker content	• Without regulatory pressure or incentives, producers have little motivation to shift toward SCM use.
6	Exposure of global exports to evolving global carbon regulations in the future	• Potential trade barriers and evolving carbon pricing schemes (e.g., EU CBAM) may penalize carbon-intensive exports (steel and cement) in the long-term

Source: Own analysis

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Annex - Plant Data

Steel plant installed capacity

Plant name	Municipality	Province/ state	Operating status	Capacity (ttpa)	Main production process	Main production equipment
Al Atoun Yanbu steel plant	Yanbu	Medina Province	construction	910	electric	EAF
Al Ittefaq Arab Steel Dammam plant	Dammam	Eastern Province	operating	2600	integrated (DRI)	DRI, EAF
Al Ittefaq Arab Steel Dammam plant	Dammam	Eastern Province	announced	1900	electric	EAF
Al Ittefaq National Steel Dammam plant	Dammam	Eastern Province	operating	1000	electric	EAF
Al Qaryan steel plant	Dammam Industrial City	Dammam	operating	350	steelmaking (other)	other
Al Qaryan steel plant	Dammam Industrial City	Dammam	announced	150	steelmaking (other)	other
Aramco Ras Al-Khair steel plant	Ras Al-Khair	Eastern Province	announced	1500	integrated (DRI)	DRI, EAF
Arkan Steel Jeddah plant	Jeddah	Makkah	announced	600	electric	EAF
Essar Ras Al-Khair steel plant	Ras Al-Khair	Eastern Province	announced	4000	integrated (DRI)	DRI, EAF
Gulf Tubing Company Ras Al-Khair steel plant	Ras Al-Khair	Eastern Province	construction	630	electric	EAF
Rajhi Al Assemah Steel Jeddah plant	Jeddah	Makkah	operating	1180	integrated (BF)	BF, BOF
SABIC Hadeed Al Jubail steel plant	Al Jubail	Eastern Province	operating	6000	integrated (DRI)	DRI, EAF
Solb Steel Jizan plant	Jizan	Jizan Region	operating	1200	electric	EAF
Tosyali Ras Al-Khair steel plant	Ras Al-Khair	Eastern Province	announced	4000	unknown	unknown

Source: (Global Steel Plant Tracker, 2024)

Steel industry historical data

Year	Consumption (Mt)	Production (Mt)	Steel Capacity (Mt)	Per Capita (kg)	Export (Mt)	Import (Mt)	Production (Mt)	Capacity utilization %
2012	13.010	5.203	6.895	480	0.285	8.092	5.20	75.46%
2013	11.888	5.471	10.695	425	0.247	6.664	5.47	51.15%
2014	12.809	6.291	11.195	442	0.123	6.641	6.29	56.19%
2015	12.024	5.662	11.495	401	0.129	6.491	5.66	49.26%
2016	11.675	5.461	11.565	380	1.141	7.36	5.46	47.22%
2017	8.303	4.831	11.565	270	1.138	4.61	4.83	41.78%
2018	10.151	8.187	11.603	334	1.775	3.74	8.19	70.56%
2019	13.639	8.191	11.603	447	2.50	7.95	8.19	70.59%
2020	13.510	7.775	11.603	436	1.30	7.04	7.78	67.01%
2021	11.092	8.735	11.603	354	1.52	3.88	8.74	75.28%
2022	13.706	9.860	11.903	426	1.08	4.93	9.86	82.84%
2023	13.649	10.245	12.117	410	1.81	5.21	10.24	84.55%

Source: (World Steel Association, 2024), (KAPSARC, Global Steel Production, 2024), (OECD, 2023)

Cement plant installed Capacity

Company Name	Facility Name	City	Type Of Works	Cement Type	Status	Capacity (Mt/year)
City Cement Company	Marat	Marat	Integrated	Grey	Operating	5.28
Al Jouf Cement Company	Turaif	Turaif	Integrated	Grey	Operating	3.50
Al-Gharbiah Cement	Jeddah white	Jeddah	Integrated	White	Operating	0.12
Arabian Cement Company	Rabigh	Rabigh	Integrated	Grey	Operating	6.00
Eastern Province Cement Company (EPCCO)	Al Khursaniyah	Dammam	Integrated	Grey	Operating	5.39
Al Safwa Cement Company	Farasan	.	Integrated	Grey	Operating	3.47
Hail Cement Co.	Hail	Turbah	Integrated	Grey	Operating	2.00
Najran Cement Company (NCC)	Aakfa Cement Grinding Mill	Aakfa	Grinding	Grey	Operating	2.00
Najran Cement Company (NCC)	Sultana	Al Mundifin	Integrated	Grey	Operating	4.10
Northern Region Cement Company (NRCC)	NRC Plant	Arar	Integrated	Grey	Operating	3.10
Northern Region Cement Company (NRCC)	NRC White Plant	Arar	Integrated	White	Operating	0.85
Qassim Cement Company (QCC)	Qassim	Buraydah	Integrated	Grey	Operating	4.75
Saudi Cement Company (SCC)	Hofuf Plant	Al-Hofuf	Integrated	Grey	Operating	9.70
United Cement Industrial Company	United Cement Industrial Company	Jeddah	Integrated	Grey	Operating	2.00
Riyadh Cement Company	Muzahmiyah	Riyadh	Integrated	Grey	Operating	3.80
Saudi White Cement Co.	Muzahmiyah White	Riyadh	Integrated	White	Operating	0.23
Southern Province Cement Company (SPCC)	Bisha	Bisha	Integrated	Grey	Operating	3.44
Southern Province Cement Company (SPCC)	Jizan	Jizan	Integrated	Grey	Operating	2.71
Southern Province Cement Company (SPCC)	Tihamah	Makkah	Integrated	Grey	Operating	5.20
Tabuk Cement Company (TCC)	Duba	Tabuk	Integrated	Grey	Operating	3.30
Umm Al-Qura Cement Co.	Hurat Hadon	Radwan Village	Integrated	Grey	Operating	2.22
Yamama Saudi Cement Company (YSCC)	Riyadh New Plant	Riyadh	Integrated	Grey	Operating	9.29
Yanbu Cement Company (YCC)	Ras Baridi	Ras Baridi	Integrated	Grey	Operating	10.00

Source: (CEMNET, 2023)

Cement industry historical data

Year	Cement Capacity (Mt)	Production (Mt)	Consumption (Mt)	Export (Mt)	Import (Mt)	Capacity utilization %	Cement Per Capita (kg)
2012	56.100	53.220	52.670	0.680	0.400	94.87%	1964
2013	56.100	55.710	55.260	0.510	4.950	99.30%	1990
2014	60.700	57.220	56.560	0.630	2.510	94.27%	1973
2015	69.825	61.490	60.740	0.700	1.310	88.06%	2050
2016	78.950	55.940	54.790	0.860	0.130	70.85%	1822
2017	80.125	47.130	47.070	0.160	0.020	58.82%	1530
2018	81.300	42.181	40.910	4.277	0.092	51.88%	1388
2019	83.050	44.322	42.323	7.536	0.268	53.37%	1453
2020	84.800	53.417	51.081	6.629	0.563	62.99%	1723

2021	87.440	53.702	51.941	8.176	0.035	61.42%	1716
2022	90.080	52.595	50.759	8.938	0.000	58.39%	1633
2023	92.450	49.582	47.815	8.525	0.014	53.63%	1489

Source: (CEMNET, 2023)

H2-diplo
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