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

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Abbreviations and Acronyms

BAT	Best Available Technology
BECCUS	Bio-Energy Carbon Capture, Utilization and Storage
Bio-CH_4	Biomethane
BOF/BF	Basic Oxygen Furnace / Blast Furnace
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture, Utilization and Storage
CH_4	Methane
CIB	Turkish Steel Exporters' Association
CIS	Commonwealth of Independent States
CO_2	Carbon Dioxide
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EBRD	European Bank for Reconstruction and Development
ETS	Emission Trade System
EU	European Union
FTS	Frontier Technologies Scenario
GAMS	General Algebraic Modeling System
GHG	Greenhouse Gas
H_2	Hydrogen
HBI	Hot Briquetted Iron
IEA	International Energy Agency
IF	Induction Furnace
INDC	Intended Nationally Determined Contributions
Kg	Kilogram

kWh	Kilowatt-hour
LCP	Low Carbon Pathway Scenario
LTS	Long Term Strategy
M&E	Monitoring and Evaluation
MoIT	Ministry of Industry and Trade
MPP	Mission Possible Partnership
Mt	Million Tonnes
MWh	Megawatt-hour
NDC	Nationally Determined Contribution
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating Expense
PCI	Pulverized Coal Injection
R&D	Research and Development
SOGAD	Association of Cold Rolling, Galvanized and Coated Coil Manufacturers
SPS	Stated Policy Scenario
TIM	Türkiye Exporters Assembly
TOBB	The Union of Chambers and Commodity Exchanges of Türkiye
TR	Türkiye
TSPA	Turkish Steel Producers Association
TTP	Technology Tracking Platform
TUBITAK	Scientific and Technological Research Council of Türkiye
TURKSTAT	Turkish Statistical Institute
UN	United Nations
USA	United States of America
WoM	Without Measures Scenario
YISAD	Flat Sleet Import, Export and Industry Association

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Introduction

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

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

The steel sector is of strategic importance to virtually all countries as a key input to infrastructure, manufacturing, and construction industries. In addition to its strategic importance, the steel sector is critical for global decarbonization and green transformation, accounting for nearly 10% of global energy related CO_2 emissions and around 30% of industrial carbon emissions.[4] As of the date this report was written, Türkiye had 41 companies producing liquid steel, 3 with basic oxygen furnaces, 27 with electric arc furnaces, and 11 with induction furnaces. Together, they produced more than 35 million tonnes of steel in 2022.

Announcing its net zero emission target by 2053 in September 2021, Türkiye became a party to the Paris Agreement in November 2021.[5] In April 2023, the country has updated its first nationally determined contribution as emissions by 41% through 2030 (695 million tonnes of CO_2 eq in year 2030) compared to the Business as Usual (BAU) scenario given in Türkiye's first NDC (also INDC) considering 2012 as the base year (reference year). As officially declared, "Türkiye's updated first NDC is economy-wide and includes comprehensive mitigation and adaptation actions as well as consideration of means of implementation.Türkiye intends to peak its emissions at the latest in the year 2038".[6]

Türkiye has been a member of the European Coal and Steel Community since 1996, meaning iron and steel products are not exposed to the EU customs tax. The reporting period for the Carbon Border Adjustment Mechanism starts in 2023 and the free allocations will be gradually phased out starting from 2026. Therefore, Turkish exporters will require to take immediate action to report and reduce their direct and indirect CO_2 emissions in order not to lose their competitive power.

[1] European Commission, Delivering the European Green Deal

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

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

[4] IEA, OECD, 2021.

[5] Retrieved from https://www.iklim.gov.tr/paris-anlasmasi-i-34

[6] Republic of Türkiye Updated First Nationally Determined Contribution, April 2023.

Alongside its flagship status, the steel sector is a major contributor to national greenhouse gas emissions and decarbonizing this sector will require a combination of technological and policy measures. This report, as the key output of the Project, “Türkiye: A Low Carbon Pathway for the Steel Sector”, aims to lay the groundwork for the Turkish steel sector accomplishing green transformation in a manner that complies with Paris Agreement objectives. To this end, insights in this report are connected to several other national policy documents. The roadmap provides a basis for the implementation of the Action 1.1.1 of the Ministry of Trade’s “Green Deal Action Plan”, which appoints the Ministry of Industry and Technology to “Develop a national level roadmap, that will support the reduction of greenhouse gas emissions in priority manufacturing sectors that may be subject to Carbon Border Adjustment Mechanism”. This project also serves to achieve Türkiye’s net zero target for 2053, and interim target as per updated NDC. This includes laying the groundwork for Green Technology Roadmaps (to be prepared in 2023-2024 period).

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

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

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

Executive Summary

An Overview of Türkiye's Steel Sector: Manufacturing, Trade and Emissions

Türkiye has been a key player in the global crude steel manufacturing and semi-finished products trade. The country ranked 8th in world steel production with its 35.1 million tonnes crude steel production volume in 2022.[7] In Europe, the country ranks second in terms of capacity and production, just behind the leading country Germany, significantly outperforming all other European countries. Türkiye is also one of the world's leading steel exporters, with 14.5 million tonnes export of steel products in 2022. The EU is the largest consumer of Turkish steel, accounting for 26.8% of steel exports in 2022, followed by the Middle East/Gulf region (23.2%).[8]

Currently, 71.6% of the country's crude steel production comes from facilities with electric arc furnaces (EAF) and induction furnaces (IF), while 28.4% comes from integrated facilities (BF/BOF).[9] Moreover, the breakdown of production by product types reveals that Turkish steelmaking has historically been characterized by a long-product-oriented production structure. 65% of total production consists of long products in 2022, while the rest is made up of flat products.[11] The same share is also seen in the export structure, 67% of exports are composed of long products.

According to the Turkish Steel Producers Association (TSPA), since 2000, both EAF and BF capacities have increased significantly in Türkiye, almost reaching 3 times of the initial total production capacity. Capacity increase, on the other hand, is particularly concentrated on the EAF side, with EAF facilities accounting for 75% of total capacity as of 2022. Despite the large increase in capacity, utilization rates remained almost at the same level at around 65%. In fact, leaving out the decline in production in 2022, capacity utilization rates have slightly improved over the years.

Considering that EAF facilities are electric powered and can use scrap steel inputs, Turkish steelmaking has a relatively favorable position both in terms of emission performance and further mitigation efforts. Availability of scrap steel in international markets and decarbonization of Türkiye's electricity grid through further renewable energy investments will remain key issues for the Turkish steel sector in the upcoming decades.

According to the figures provided by TSPA, imports more than doubled between 2000 and 2022, while exports grew by nearly 3 times in the same period. The shares of the EU-27 (26.8%) and the Middle East (23.2%), the two traditional markets for Turkish steel exporters, together account for half of steel exports in 2022.[12] Exports to the EU are dominated by flat products, while exports to the Middle East are dominated by long products. The remaining important markets, North Africa and Latin America are dominated by flat and long products, respectively.

Figure 1. Capacities and Production Volumes in Türkiye, 2022 (Mt)

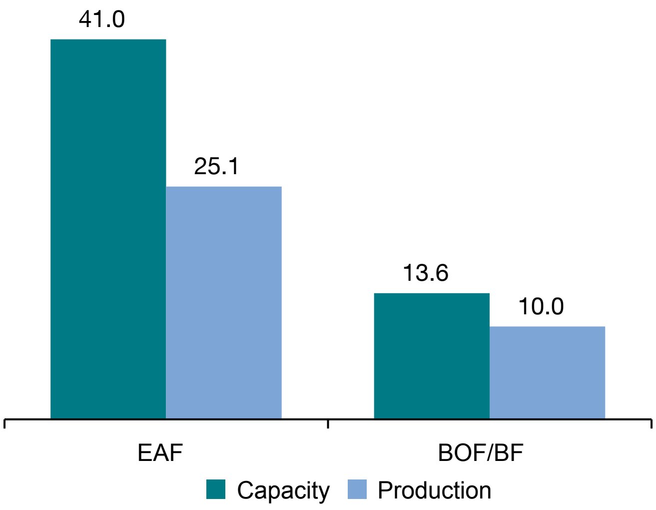
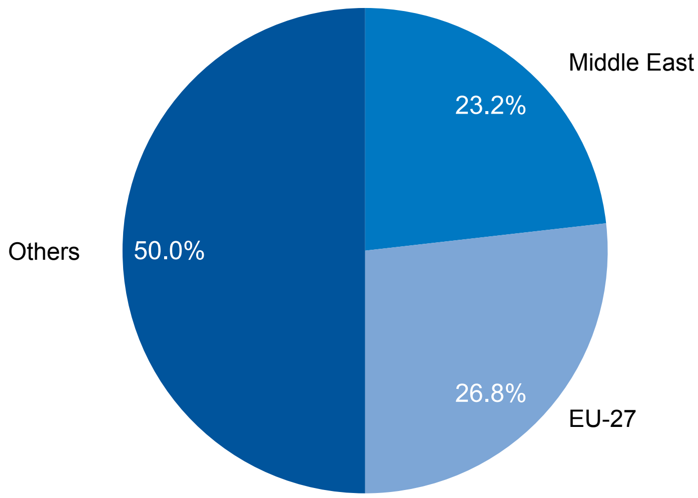


Figure 2. Breakdown of Turkish Steel Exports by Region, (2022, in terms of Tonnes)



[7]World Steel Association, World Steel in Figures 2022.
[8]TSPA, Export Figures. PwC analysis.
[9]The figures were provided by TSPA internally as part of the project.
[10]The figures were provided by TSPA internally as part of the project.
[11]The figures were provided by TSPA internally as part of the project.
[12]Turkstat foreign trade statistics

Turkish steel sector has a competitive edge in terms of carbon level originating from scope 1 emissions, as the majority of production in Türkiye is carried out in EAF facilities by using scrap steel inputs. For most countries, CO_2 emission intensity in the EAF route is below 0.6 t CO_2 per t steel, where Türkiye is among the countries with lower EAF route carbon intensities and has an average intensity of 0.29 t CO_2 per t steel (of which 0.04 is Scope 1 and 0.25 is Scope 2).[13] However, the relatively high share of fossil fuels for electricity generation (grid emissions) in Türkiye still prevents EAF and IF facilities from further reducing their emissions and therefore creates a bottleneck in the sector's transition to net zero. In this regard, Türkiye's ambition to increase renewables within its power sector will support decarbonization goals in the steel sector.

In the BOF route, on the other hand, carbon intensity in many countries varies between 1.8 and 4.0 t CO_2 per t steel, while Türkiye has an integrated route carbon intensity above the EU average at 2.20 t CO_2 per t steel (of which 2.17 is Scope 1&upstream and 0.03 is Scope 2).[14]

The structural strengths and weaknesses of the Turkish steel sector need to be considered to sustain the growth and attain success in decarbonization efforts. The steel sector will be at the very center of emission mitigation efforts and shifting international trade paradigms for the next 30 years. Turkish steel sector will need to reinforce its core strengths and address its key weaknesses to navigate through this transition.

Table 1. Strengths and Weaknesses of the Turkish Steel Sector[15]

Strengths	Weaknesses
• Robust presence of manufacturing industries and construction sector • Having a wide and diversified foreign market for steel • Logistical advantages resulting from geographical proximity to major markets • High share of EAFs in production • International competitiveness, branding and marketing	• High foreign dependency on inputs • High foreign dependency in energy supply • Increasing protectionist tendencies in the steel industry worldwide • Potential challenges that the inward processing regime will cause in the upcoming period • Insufficient R&D and innovation capabilities for value-added products

[13]Koolen, D. and Vidovic, D., Greenhouse gas intensities of the EU steel industry and its trading partners, EUR 31112 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53417-4, doi:10.2760/170198, JRC129297.
[14]ibid

Global Decarbonization Targets in Comparison with Report Findings

For benchmarking purposes, this report will refer to two key international steel decarbonization roadmap studies prepared by the International Energy Agency (IEA) and the Mission Possible Partnership (MPP).

According to IEA's Stated Policy Scenario, which builds on existing policies and plans, global GHG emissions are projected to increase by 8% and 12% in 2030 and 2050, compared to 2020, respectively. In the IEA's Sustainable Development Scenario defines an integrated pathway that is aligned with the Paris Agreement targets and achieves net zero energy related emissions by 2070. Emissions are expected to decrease by 7% and 52% by 2030 and 2050 compared to 2020, respectively.

In the Sustainable Development Scenario, material efficiency strategies contribute the largest share of cumulative direct emission reductions (40% of cumulative emission reductions) by mitigation strategy between 2020 and 2050. Subsequently, improving technology performance and deployment of carbon capture, usage and storage (CCUS) technology contribute 20% and 16% of emission reductions, respectively. Hydrogen, bioenergy, electrification, and other fuel shifts are other important emission reducing parameters considered in the scenario.

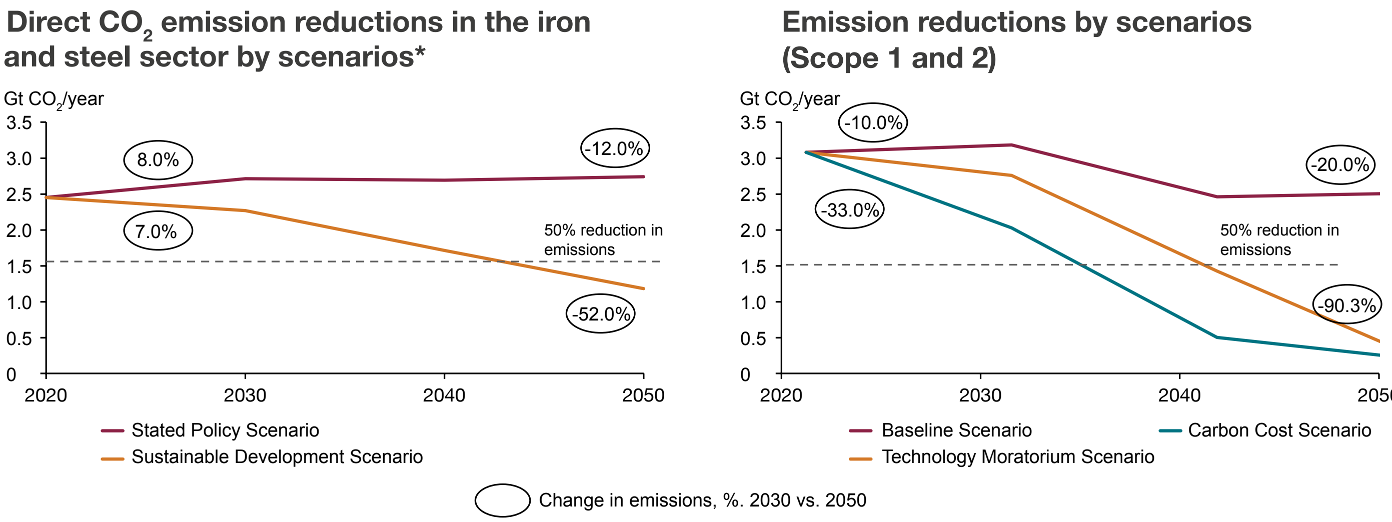
In the MPP steel sector decarbonization report, two mitigation scenarios are modeled: the Technology Moratorium Scenario and the Carbon Cost Scenario.

In the Carbon Cost Scenario, steel assets are modeled to switch to the technology with the lowest total cost of ownership, while the Technology Moratorium Scenario considers similar assumptions to the Carbon Cost Scenario, but decarbonization technologies are introduced after 2030. In the Technology Moratorium Scenario and the Carbon Cost Scenario, emission reductions of 10% and 33% are projected in 2030 compared to 2020, respectively. Moreover, in both the Technology Moratorium Scenario and the Carbon Cost Scenario, total emissions generated by the steel sector are expected to decrease by 90.3% by 2050 compared to 2020 and approach the zero target (0.3 Gt CO_2).

In the Technology Moratorium Scenario, the conventional blast furnace technology is replaced by technologies such as smelting reduction or DRI. Depending on hydrogen prices, the DRI-EAF and DRI-Melt-BOF archetypes are modeled to gradually replace natural gas with hydrogen, which will account for 45% of primary steel production in 2050. In addition, technology archetypes using CCS technologies are modeled to account for 55% of primary steel production in 2050. In the other mitigation scenario, the Carbon Cost scenario, the DRI technology archetype stands out and by 2050, DRI produced steel accounts for almost 70% of primary steel production. In addition, other innovative technologies, BAT BF-BOF with bioenergy and BAT BF-BOF with CCUS technology archetypes are considered.

[15] PwC Analysis
[16] IEA (2020), Iron and Steel Technology Roadmap
[17] MPP (2022), Making Net Zero Steel Possible

Figure 3. IEA (left) and MPP (right) Emission Reduction Scenarios[18]



This report presents the "Low Carbon Pathway for the Turkish Steel Sector" reaching net zero by 2053 in the light of these international steel decarbonization roadmaps, as well as providing detailed information on achieving the desired level of emission reductions. Various scenarios have been constructed to analyze the possible pathways that the sector can follow on the basis of input, technology and policy parameters and the corresponding investment requirements. While the Reference Scenarios are used as a point of comparison, the Mitigation Scenarios assess alternative pathways that should be aimed for, which go beyond the policies and technologies assumed in the reference scenarios for transition to low-carbon production. The reference scenarios used in this study are the without measures scenario (WoM) and the stated policies scenario (SPS), while the mitigation scenarios are the low ETS scenario, the low carbon pathway scenario (LCP), the high ETS scenario and the frontier technologies scenario (FTS).

In the Low Carbon Pathway (LCP) scenario, 17%, 47% and 99% emission reductions are achieved compared to the SPS scenario in 2030, 2040 and 2053, respectively.[19] Net zero emission levels in the steel sector can only be achieved through implementation of innovative technologies such as carbon capture, storage, and utilization. The LCP scenario resulted in a decarbonization pathway that relies on the deployment of CCUS technologies, a high share of EAF in production in the 2050s and the replacement of blast furnaces with DRI-Melt BOF technologies. This decarbonization pathway shows great similarities with both MPP Scenarios. **This should also be noted that this study's LCP scenario results in more aggressive emission reductions than both the IEA and MPP targets.**

[18]EIA & MPP
[19]In both modelling and policy recommendation pillars of the project, the scope is defined solely as liquid steel production. Further stages of the value chain such as rolling mills and processing for finished products are not included in the scope of the studies.
* Direct emissions refer to CO_2 emissions from the combustion of fossil fuels within the industrial energy use boundary and CO_2 emissions from industrial processes in these subsectors.

Potential for Emission Reduction

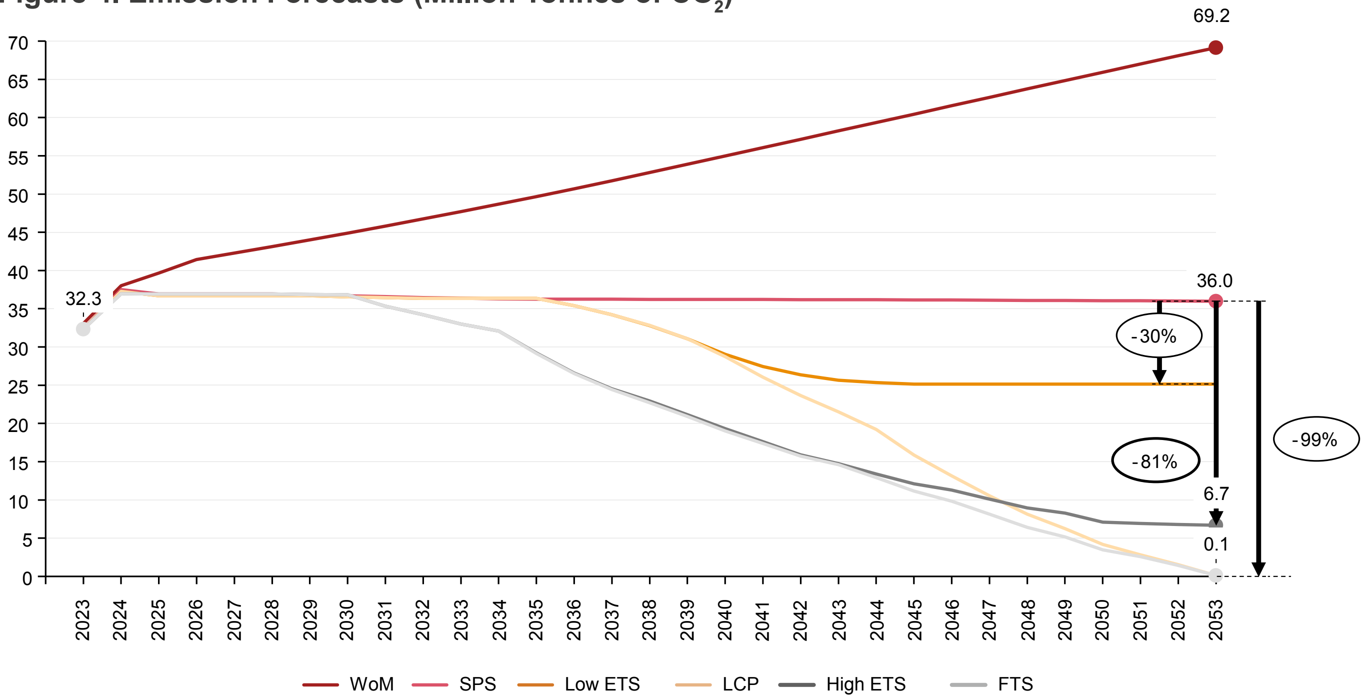
Industrial decarbonization policies will be playing a crucial role in Türkiye's emissions reduction performance in the coming decades. This study aims at supporting the Turkish steel sector in development of near and long-term decarbonization roadmaps and the corresponding investment requirements.

As part of the project, various reference and mitigation scenarios are generated over a horizon of 2023-2053 period, addressing many aspects, such as technological improvements, alternative raw materials, investment requirements and climate regulations like Carbon Border Adjustment Mechanism (CBAM) and the planned national Emission Trading System (ETS).

The findings suggest the Turkish steel sector needs to develop comprehensive, integrated, consistent policies and invest in radical technological transformation to reach net zero emissions by 2053. In this context, one of the critical actions Türkiye has recently taken is the announcement of a national hydrogen economy development strategy. The Turkish Ministry of Energy and Natural Resources has announced an ambitious goal: to reduce the cost of green hydrogen production in Türkiye to 2.4 dollars/kg H_2 by 2035 and to below 1.2 dollars/kgH_2 by 2053.[20] The announced targets are based on the mitigation scenarios, thus, by 2053, there is a transformation to hydrogen-using technology archetypes driven by the substantial decrease in the hydrogen price. Accordingly, it contributed to reaching net zero earlier than the international scenarios (MPP, EIA). Therefore, achieving national hydrogen targets will play a critical role in achieving the emission targets of the mitigation scenarios. Yet, achieving a net zero production future for the Turkish steel sector will also require deployment of carbon capture, storage and utilization technologies. Supportive policies and a strong regulatory framework should therefore be prioritized to ensure the steel sector's climate targets are met and strengthen its competitive power in international markets.

Several scenarios are built to identify pathways for the Turkish steel sector and the corresponding investment requirements. Reference scenarios act as a point of comparison and mitigation scenarios consider alternative futures that require radical policy and technological changes to transition to a low carbon development pathway. These scenarios capture measures and policies for reducing emissions.

Figure 4. Emission Forecasts (Million Tonnes of CO_2)



[20]The Turkish Ministry of Energy and Natural Resources, Türkiye Hydrogen Technologies Strategy and Roadmap, 2023.

The low carbon pathway (LCP) scenario, which is the least-cost and optimal mitigation scenario in which all feasible low-carbon technologies as well as financial and regulatory policies are introduced, a **99.7% emission reduction (compared to SPS scenario) can be achieved by 2053 with a Turkish ETS regime with prices close to 1/3 of the EU CBAM prices.**

To reach the net zero target, frontier technologies with high capital expenditure (CAPEX) requirements are introduced after the 2040s. **The net zero target is only achieved by combining green hydrogen and CCUS technologies with additional use of biomass as an input fuel.** The technologies prioritized in the multi-objective optimization model considering the cost and emissions intensities are provided in the table below:

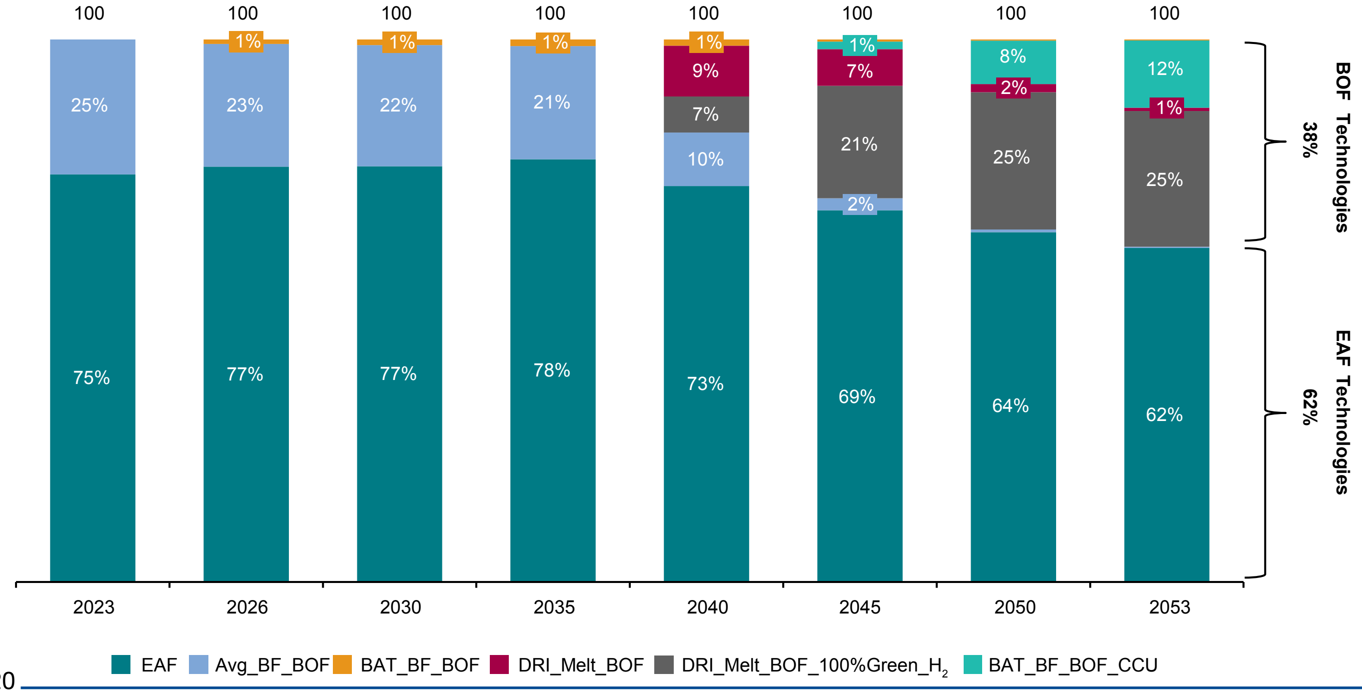
Table 2. Model-Decided Priority Steelmaking Technologies in the LCP Scenario

Technology Archetype	Expected Date of Entry (Decided by the Model)	Emission Reduction Effect (tCO_2/tS)	Investment Requirement (EUR/tS)	Emission reduction cost per unit (EUR/tCO_2)
Avg_BF_BOF Conventional integrated plant	-	-	-	-
BAT_BF_BOF Integrated plant employing best available technologies	2024	Low	High	Very High
BAT_BF_BOF_H_2_PCI H_2 replacing pulverized coal injection	2035	Medium	High	High
DRI_Melt_BOF Natural gas based DRI replacing the BF facility	2036	High	Medium	Low
DRI_Melt_BOF_%100_H_2 100% green hydrogen based DRI replacing the BF facility	2036	Very High	Medium	Low
BAT_BF_BOF_CCU Integrated plant with carbon capture and utilization extension	2044	Very High	Very High	Low
EAF Conventional electric arc furnace plant	-	-	-	-
DRI_EAF EAF plant using natural gas based DRI	2029	Low	Medium	High
DRI_EAF_100green_H_2 EAF plant using %100 green hydrogen based DRI	2043	Low	Medium	Very High

Modelling results describing the technology transition in the next 30 years from the LCP scenario are summarized below:

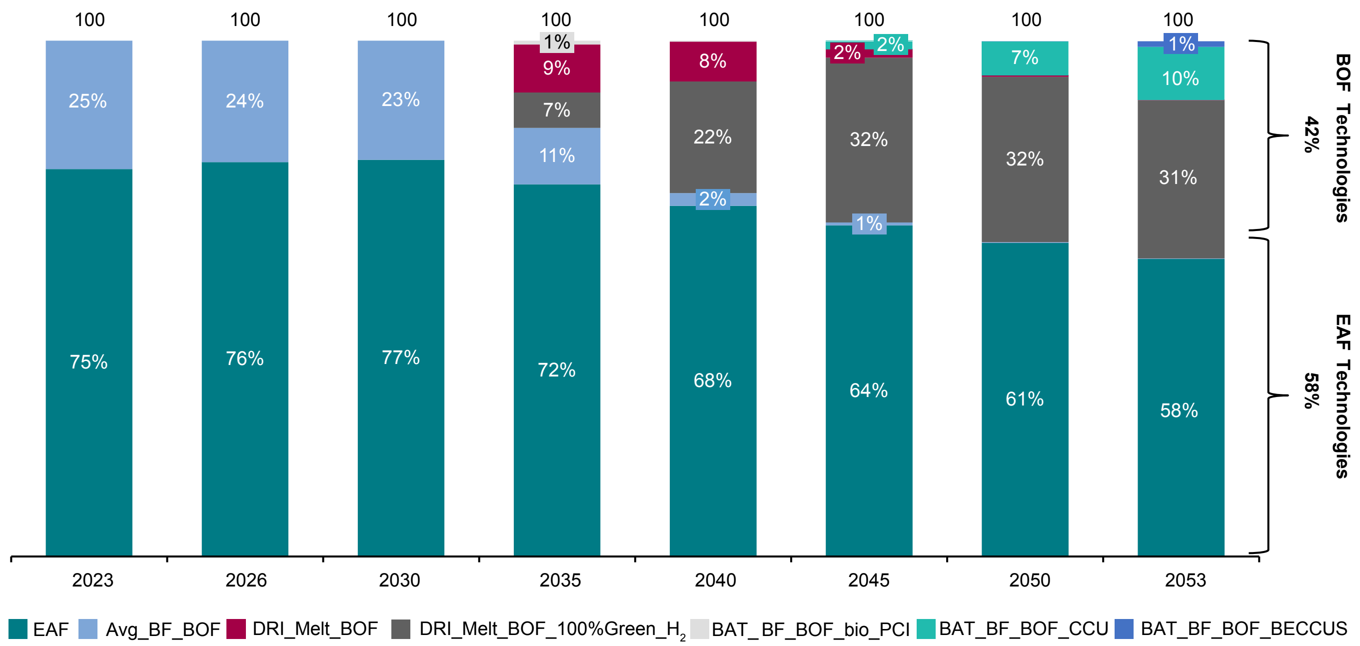
- According to the modelling results, in the LCP scenario total emissions can be reduced by **20.6% in 2040 and 99.7% in 2053** compared to the stated policy scenario (SPS) used as a point of comparison and one of the reference scenarios.
- It is also assumed that blast furnaces will not be shut down and will be used until the end of their lifespans, which extends beyond the 2050s. Therefore, any **capacity switch from blast furnaces to EAF route is not considered** in the planning period.
- In the optimal scenario (LCP), the EAF route continues to have the largest share in the production of steel. However, with the expected increase in scrap prices and the introduction of new BOF technologies, **EAF use will decrease to 62%** of total production capacity by 2053.
- EAF technology share will be firstly gradually replaced by DRI technology and later on will be replaced by **BOF using hydrogen-based DRI.** In 2053, 13% of the production capacity for traditional EAF will be shifted to DRI and hydrogen-based technologies.
- **Five BOF technology archetypes are deployed** in different years to transform the steel sector and the transformation is achieved by starting with natural gas based DRI and hydrogen based DRI technologies (in 2029 for EAF route and 2036 for BOF/BF route) and later CCUS technologies (in 2044 for BOF/BF route).
- **Natural gas based DRI** eliminating the need for blast furnaces in integrated facilities will have 9% share production capacity in 2040 and this ratio will decrease with the utilization of other technologies (e.g. hydrogen). Yet, a small share of natural gas based DRI production will also prevail by 2053.
- Aggressive transition is accomplished by **combining CCUS and hydrogen technology**. In 2053, green hydrogen technologies account for **25% (21.8 million tonne)** of output, while CCUS technologies account for **12% (10.8 million tonne)**. Thus, **16.2 million tonnes of CO_2 emission reduction** is expected to be realized with **CCUS** technologies in 2053. Furthermore, it is modeled that **381.8 million GJ of hydrogen** will be required in 2053.

Figure 5. Technology Shares of Production Capacity (%): LCP



Under the FTS scenario, which is the most ambitious scenario in line with the Paris Agreement, frontier technologies are deployed into steel production earlier than the LCP scenario. As in the case of the LCP scenario, FTS scenario can also achieve a **99% reduction** in emissions compared to the SPS scenario by 2053. However, considering the total CO_2 emissions compared to the SPS scenario in the period 2020-2053, the LCP scenario provides 336 million tonnes of CO_2 reduction in the total CO_2 emissions, while the FTS scenario provides 446 million tonnes of CO_2 reduction. (SPS scenario total CO_2 emissions are projected to exceed 1.2 billion tonnes in the same period). For the FTS scenario, share of EAF facilities decreases to 58% in total production capacity which is lower than the corresponding share for the LCP scenario (62%). In addition, capacities using BOF based **DRI will account for 31%** of steel production and those using **CCUS technologies for 11%** in 2053. In this context, in the FTS scenario, **13.3 million tonnes of CO_2 reduction** is projected in 2053 with **CCUS** technologies. Furthermore, **hydrogen** demand is projected to reach **396.7 million GJ** in 2053.

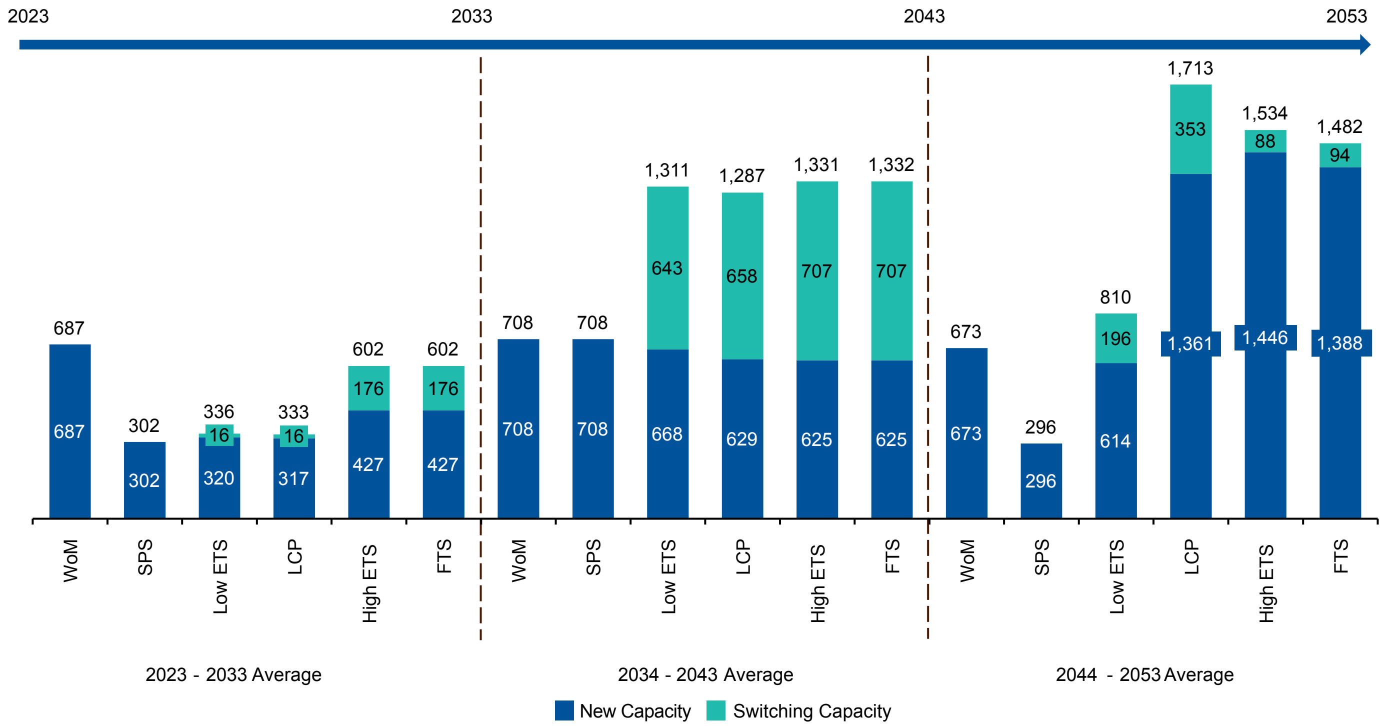
Figure 6. Technology Shares of Production Capacity (%): FTS



Investment Needs

The modelling efforts suggest that of Türkiye's steel sector should enter a rapid technological transformation as from early 2030's in order to reach the ambitious emission reduction goals. Between 2023 and 2053, average annual investments in decarbonisation technologies of between 0.8 and 1.1 billion dollars will be needed to achieve this. The model's findings indicate that in the years 2023-2033, the LCP scenario requires an average of 333 million dollars, while FTS scenario should spend an average of 602 million dollars annually. Between 2034 and 2043, an average yearly financing of 1.3 billion dollars is required to reach net zero in the optimal scenario (LCP). Additionally, it is anticipated that the yearly investment needed in the final ten years of the model period will rise to an average of 1.7 billion dollars for the LCP scenario.

Figure 7. Average Annual Investment Requirement (Million Dollars)*



The decarbonization paths of Türkiye's steel industry demonstrate the necessity of creating finance structures and strategies. The steel sector and decision-makers should start devising large-scale investment schemes in the early years, taking into account the volume of investment demands. To enable the steel industry to carry out the required technological transition in the medium to long term, steps that would accelerate the mobilization of extra funds should be emphasized right away. For the Türkiye's steel industry to have access to increased capital flows that will encourage decarbonization initiatives, policymakers and financial institutions should work together to develop financing structures. Recognizing the need of establishing a long-term financial plan to achieve the required investments to decarbonize the sector is extremely important. Early investment by the nation is crucial if the industry is to undergo the necessary technological change and reach net zero.

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

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

- The project expert's opinion and literature review on the best applications for steel sector decarbonization (especially those without significant material cost and those that should be applied regardless of cost).
- Sector specific information and assumptions shared by key project stakeholders (representing official organizational views).
- Model and scenario analysis results.

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

*In the WoM scenario, the average annual investment value for the period 2023-2033 is higher due to the assumption of BOF capacity to remain at its current level.

A) Input and Technology Related Policies

1. **Input Optimization:** These policies cover actions on securing domestic and international scrap supply, increasing the utilization of alternative raw materials and renewable energy inputs in the steelmaking.

2. **Technologies Reducing Direct Carbon Output:** These policies cover actions that ensure and expedite the utilization of best available technologies to increase energy and emissions efficiency and the integration of disruptive technologies into steelmaking, including the use of H_2 in various forms.

3. **Carbon Capture, Utilization and Storage (CCUS) Technologies:** These policies cover actions on the integration of CCUS into the production process where other decarbonization solutions are insufficient. This section also addresses the actions needed to strengthen the legal, financial, and technical infrastructure required for the integration of the CCUS into steelmaking.

4. **Process Improvement:** These policies cover actions on the installation of digital tracking and energy management systems and increasing maintenance and inspection standards in steel factories. In addition, retrofitting/renovation/decommissioning activities in factories by utilizing low-carbon technologies and improving energy efficiency and raw material input in sinter and pelletizing plants are the other focus points.

5. **Green Energy:** These policies cover actions on developing a resource plan to promote the use of renewables to replace fossil fuels in steelmaking and to prepare the necessary infrastructure for further penetration of renewable energy sources. Policies also include the development of medium-long term strategies for the commercial deployment of green H_2, which will be a key input in the future of steelmaking.

6. **Inclusive Employment and Upskilling/Reskilling of Labor Force:** These policies cover actions on policy measures required to identify the new skills required by green steel technologies and to upskill/reskill the existing workforce in this regard. The policies also uncover different options for cooperation with sector stakeholders to increase the relatively low female employment rate in the steel sector.

B) Policy and Market

7. **Emission Trading System (ETS):** These policies cover actions on installation of a Turkish ETS, a major policy lever to lower CO_2 emissions. Policies also outline actions such as incentivizing green transformation for those operating in strategic sectors and providing free allowances for selected sectors.

8. **Trade Models:** These policies cover actions on analyzing possible trade shifts and market changes and implementing necessary responses in order to protect the competitiveness of the steel sector. The chapter also discovers potential trade policies in response to the possible implementation of EU CBAM and reviews the limitations on investment in green transformation under the Trade Agreement between the European Coal and Steel Community and Türkiye.

9. **National Policy Documents:** These policies cover actions on drafting strategy documents including R&D and innovation and sustainable energy transition, which need to be developed at national level with a holistic perspective. In addition, policies also include defining an industrial policy framework in line with the country's climate commitments and specifying mitigation targets for the sector in the Long-Term Climate Change Strategy and Climate Change Action Plan.

10. **Green Transformation Finance:** These policies cover actions on the necessary steps to mobilize the public and private financing to expand the utilization of low-emission technologies required for the decarbonization of the steel industry and to facilitate renewable energy investments.

11. **Cooperation:** These policies cover actions on the active participation of steel producing companies in international platforms.

12. **Circular Economy:** These policies cover actions on developing high-quality and value-added steel products to support the decarbonization of steel-consuming end-user sectors, and to adopt circular economy principles and practices for by-product and waste management in steel facilities.

A more detailed discussion of the policy actions can be found in the section "3. The Roadmap for Decarbonization of the Turkish Steel Sector" of this report and in the detailed "Policy Recommendations Document" prepared as part of this project.

The policy actions recommended in this report are also to serve as key inputs for the on-going development of Türkiye's economy-wide LTS, as well as subsequent development of its second NDC. It would be critical to ensure policy coherence and consistency across different government strategic documents and send strong market signals to project developers, financiers and investors on which pathway Türkiye is committing to decarbonize its steel sector, alongside other key sub-sectors of its overall industry sector, in the context of achieving its overall economy-wide net zero target.

1 Current Situation Analysis of Turkish Steel Sector

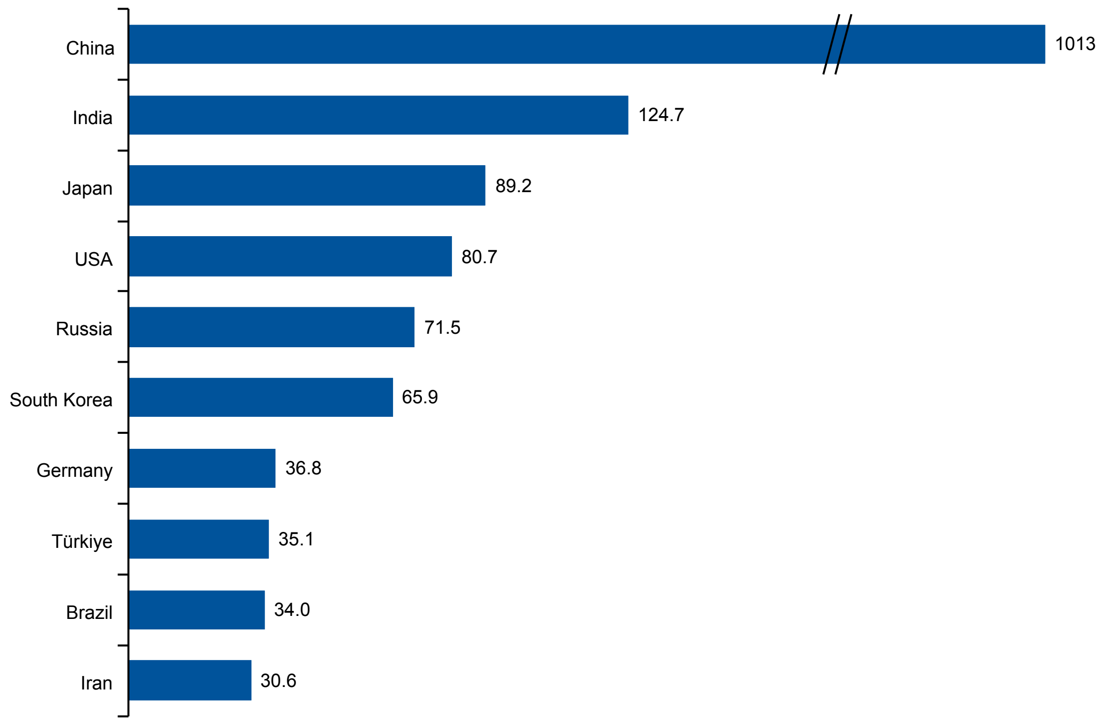
1. Current Situation Analysis of Turkish Steel Sector

1.1. An Overview of The Turkish Steel Sector

1.1.1. Capacity and Production

Türkiye has been a key player in the global crude steel manufacturing and intermediate goods trade. The country ranked 8th in the world in crude steel production in 2022, producing 35.1 million tonnes of crude steel.[21] In the same year, Türkiye was the 8th largest steel exporter and the 6th largest steel importer in the world.[22] The country is a significant exporter of steel products to Europe, the Middle East, North Africa, and the United States.

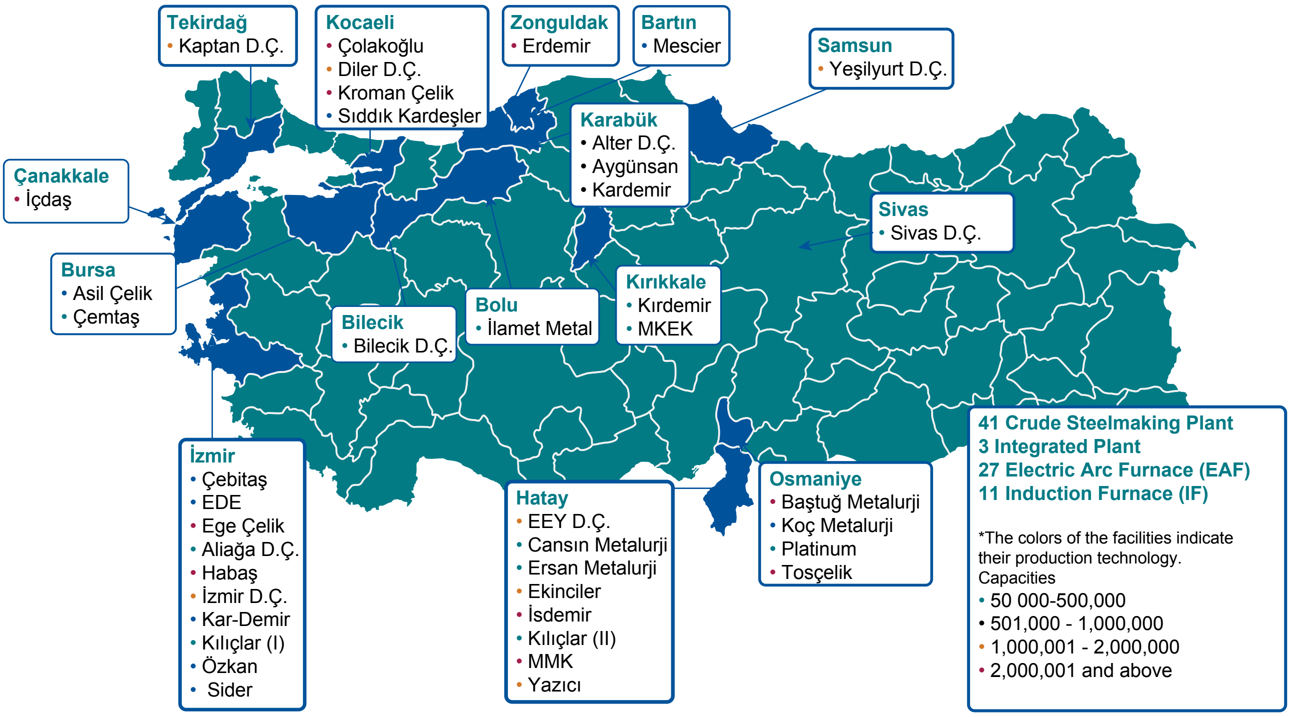
Figure 8. Production Volumes of Leading Countries in Crude Steel Production, 2022 (Million Tonnes)[23]



According to the TSPA, currently 71.5% of the country's crude steel production comes from facilities with electric arc furnaces (EAF) and induction furnaces (IF), while 28.5% comes from integrated facilities (BOF/BF)[24], and there are 41 operational steel plants (3 BOF, 27 EAF and 11 IF) spread across 15 cities in Türkiye. Having a strong EAF presence in the steelmaking provides Türkiye clear advantages in terms of emission mitigation efforts.

[21]World Steel Association, December 2022 Crude Steel Production and 2022 Global Crude Steel Production Totals
[22]World Steel Association, December 2022 Crude Steel Production and 2022 Global Crude Steel Production Totals
[23]World Steel Association, December 2022 Crude Steel Production and 2022 Global Crude Steel Production Totals
[24]The figures were provided by TSPA internally as part of the project.

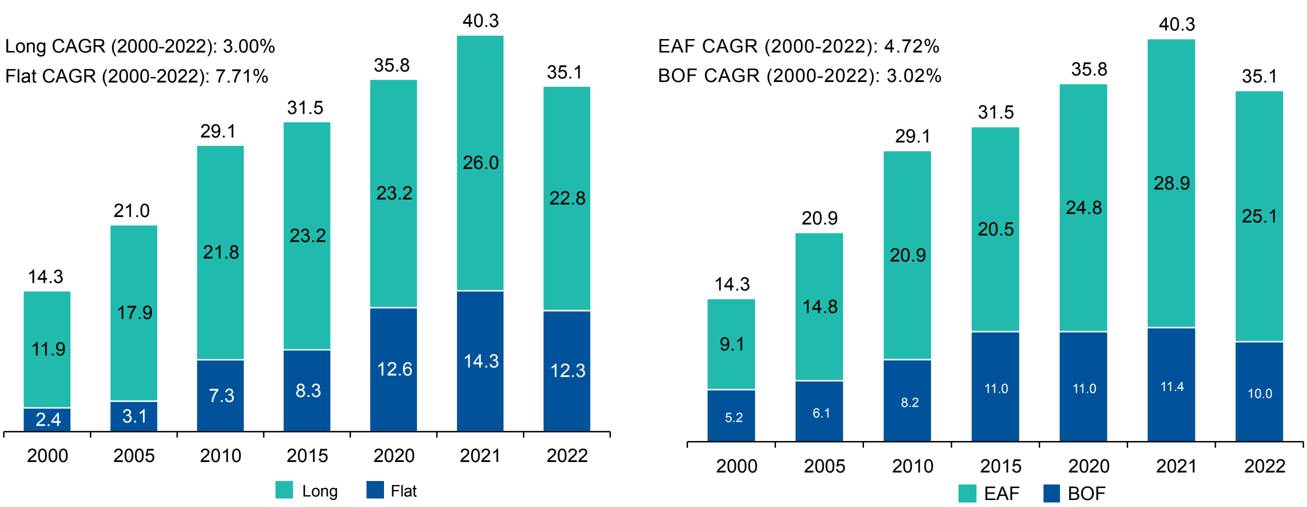
Figure 9. Steel Plants in Türkiye[25]



According to the TSPA, steel production in Türkiye has grown at a 4.2% average annual growth rate since 2000.[26] Türkiye's steel production surged in 2021 due to the recovery from the COVID-19 pandemic, but declined significantly in 2022, mainly resulted from the escalation in energy prices and the impact of dumped steel imports from countries such as Russia, Iran, India, and China.

Although, flat steel production grew at a faster pace than long steel production in the last two decades, Turkish steel production is still dominated by long steel products. In the year 2022, 65% the total crude steel production was for long steel products. In the production route, EAF plants grew at a faster pace than BOF plants, increasing their weight within the production, reaching to a share of 71.5% in 2022.

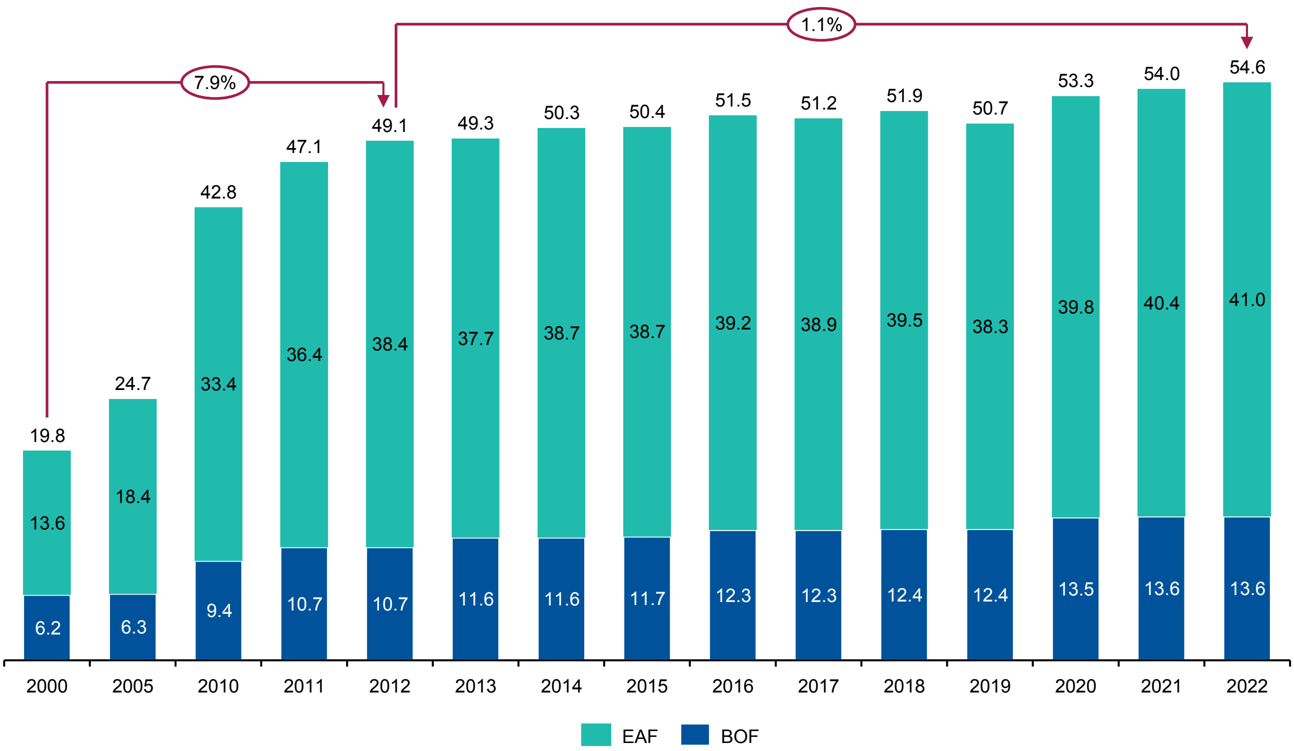
Figure 10. Türkiye's Crude Steel Production by Type and Route (Million Tonnes)[27]



[25] Retrieved from www. celik.org.tr/harita/
[26] The raw figures were provided by TSPA internally as part of the project and analysis conducted by PwC.
[27] The figures were provided by TSPA internally as part of the project.

In 2022, the production capacity of the Turkish steel sector was 54.6 million tonnes in total, with 41 million tonnes of capacity at EAF facilities and 13.6 million tonnes of capacity at BOF facilities. Steel sector production capacity had a CAGR of 7.9% between 2000 and 2012 and a modest 1.1% CAGR between 2012 and 2022. Production capacity at EAF facilities increased by 9% annually from 2000 to 2012 and continued to grow at a slower rate of 0.7% annually between 2012 and 2022. BOF facility production capacity expanded by 4.7% annually between 2000 and 2012 and continued to rise at a slower rate of 2.4% annually between 2012 and 2022.[28] **These numbers indicate that Türkiye's capacity increase has slowed down in the last 10 years in both EAF and BOF facilities.**

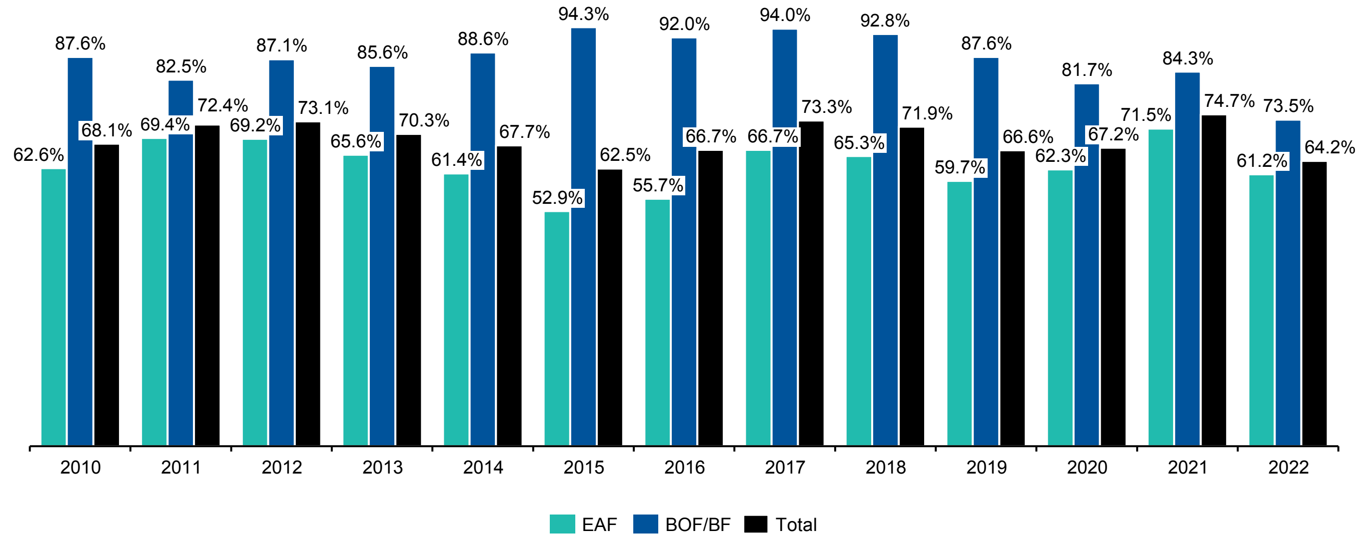
Figure 11. Türkiye's Crude Steel Manufacturing Capacity (Million Tonnes)[29]



In 2022, Türkiye recorded capacity utilization rates of 73.5% for BOF plants and 61.2% for EAF plants.[30] The Figure 12 demonstrates that the capacity utilization rates of the steel production facilities using BOF technology are historically higher than the rates of those using EAF facilities. However, considering that capacity utilization rates are almost the same despite the nearly threefold increase in EAF capacity over the years, it can be concluded that Turkish EAF steel producers could utilize their additional capacities over the years.

[30] TSPA, PwC Analysis
[31] The figures were provided by TSPA internally as part of the project.
[32] TSPA, PwC Analysis

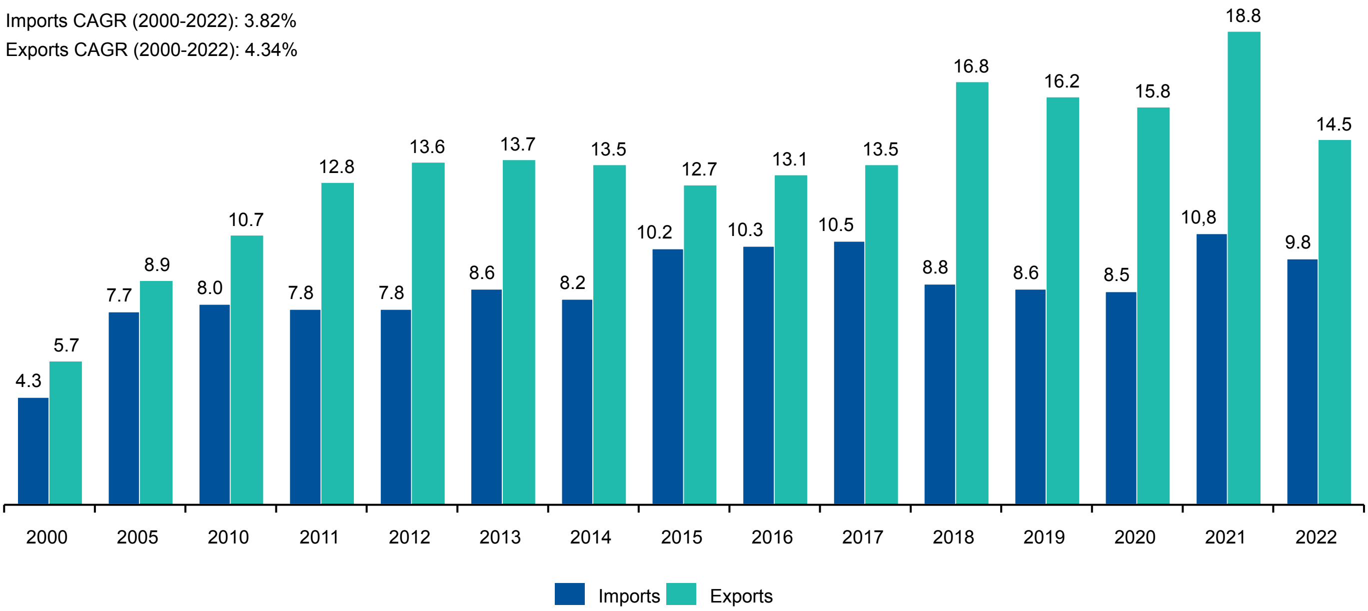
Figure 12. Capacity Utilization Rate of Steel Plants in Türkiye[31]



1.1.2. Türkiye's Steel Trade and the EU Share of Exports

An analysis of the period between 2000 and 2022 reveals that Türkiye has traditionally been a net steel exporter. While import volumes grew by about two-fold, with a CAGR of 3.82% in this period, exports increased nearly three-fold, with a CAGR of 4.34%. However, in 2022, the difficulties in production due to the rising costs also affected the export performance, resulting in a 22.8% year-on-year decline.

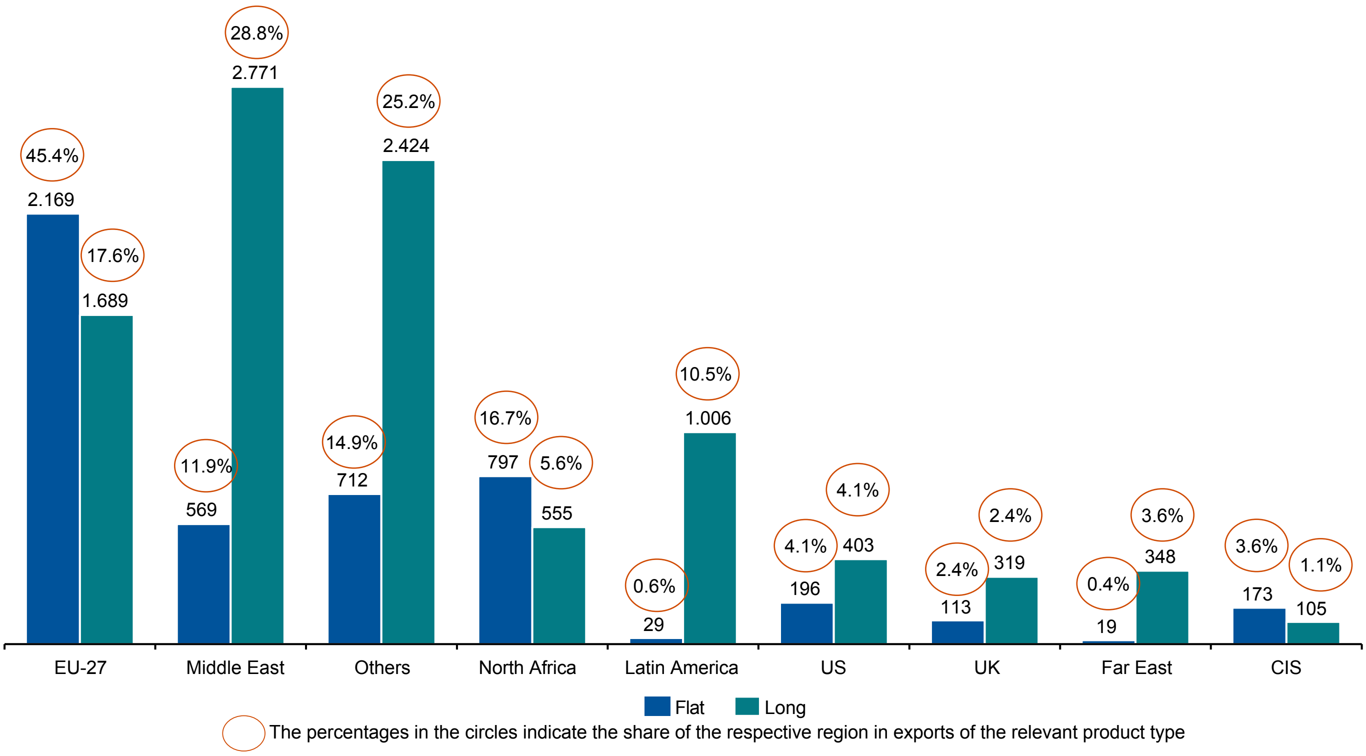
Figure 13. Turkish Steel Imports and Exports (Million Tonnes)[32]



[31] The figures were provided by TSPA internally as part of the project.
[32] The figures were provided by TSPA internally as part of the project.

According to the TSPA, the EU-27 was the main destination for Turkish steel exports in 2022, accounting for more than a quarter (26.8%) of total exports. Higher share of exports to the EU consists of flat products, with EU members receiving close to half of Turkish exports of this product group. The Middle East, one of Türkiye's traditional steel export destinations, ranks second in receipt of exports (23.2%), closely following the EU-27. Exports to the Middle East mostly consist of long steel products. North Africa (9.4%) and Latin America (7.2%) are the other significant export markets, with the former receiving mostly flat products and the latter mostly long products.

Figure 14. Breakdown of Türkiye's Steel Exports Volume by Region, (2022, Million Tonnes)[33]



1.2. Benchmarking Industry Activities

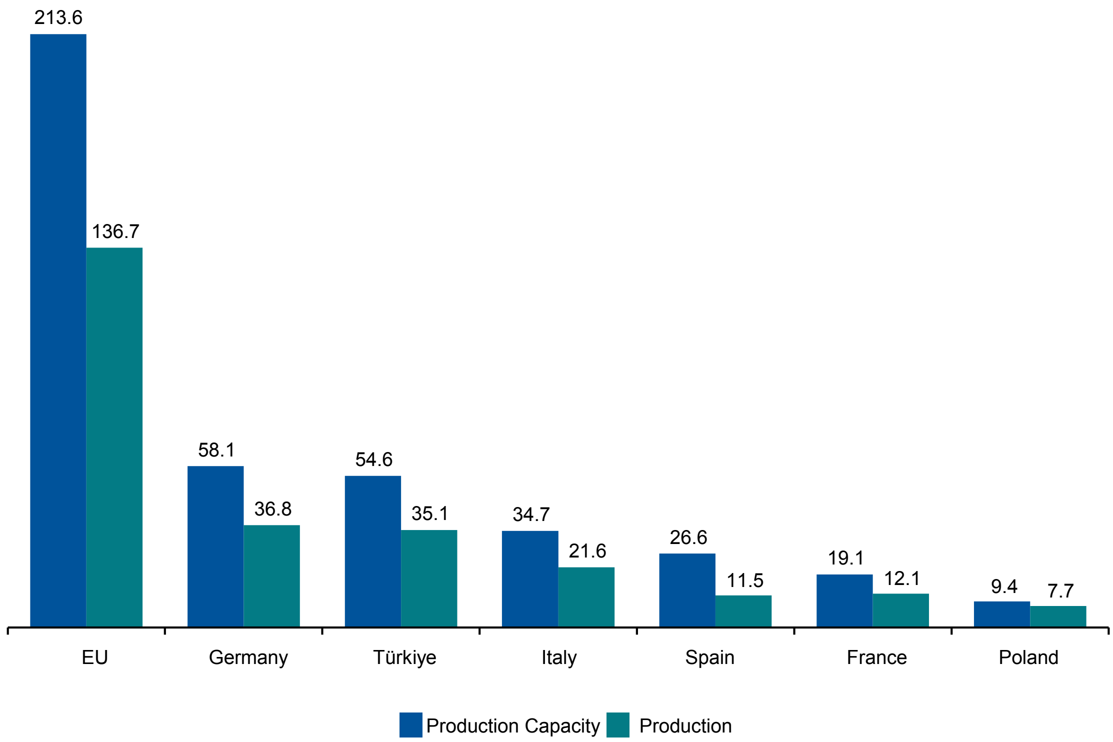
1.2.1. Benchmarking Capacity for Producing Steel

The total crude steel production capacity of the EU-27 in 2022 was 213.6 million tonnes, whereas the production capacity of Türkiye was 54.6 million tonnes in the same year.[34] In comparison, production capacity in Germany, the leading country in the EU, was 58.1 million tonnes. Production capacity in Türkiye is significantly higher than the remaining European producers.

According to the World Steel Association, total steel production in the EU fell by 10.5% year-on-year to 136.7 million tonnes in 2022, reflecting the impact of invasion of Ukraine by Russia, repercussions of persistently high inflation and rising interest rates around the globe.[35] In that year, Germany topped the list, producing 36.8 million tonnes of steel, more than a quarter of total EU production. Despite this, Germany's steel production had fallen by 8.4% year-on-year. Following Germany with 15.8% and 8.9% of total EU production, production in Italy and France decreased by 11.6% and 13.1% year-on-year, respectively. In 2022, Türkiye's steel production decreased by 12.9%, contracting slightly higher than the EU average, but still ranked as the second largest crude steel producer among European countries with a production of 35.1 million tonnes.

[33]The figures were provided by TSPA internally as part of the project.
[34]OECD (2022). Latest Developments in Steelmaking Capacity. Retrieved from www.oecd.org/industry/ind/latest-developments-in-steelmaking-capacity-2022.pdf
[35]Retrieved from www.worldsteel.org/media-centre/press-releases/2023/december-2022-crude-steel-production-and-2022-global-totals/

Figure 15. Steel Production Capacities and Production Volumes of Selected European Players, (2022 Million Tonnes)[36]



In 2021, the BOF/BF production route accounted for around 56% of total steel production in the EU, whereas the EAF production route accounted for about 44%.[37] On the other hand, the global share of BF/BOF production was 70.8% in 2021.[38] In comparison, in 2022, BOF/BF accounted for 28.4% of total production in Türkiye, while EAF and IF facilities were responsible for 71.6% of total production.

1.2.2. Benchmarking CO_2 Emissions

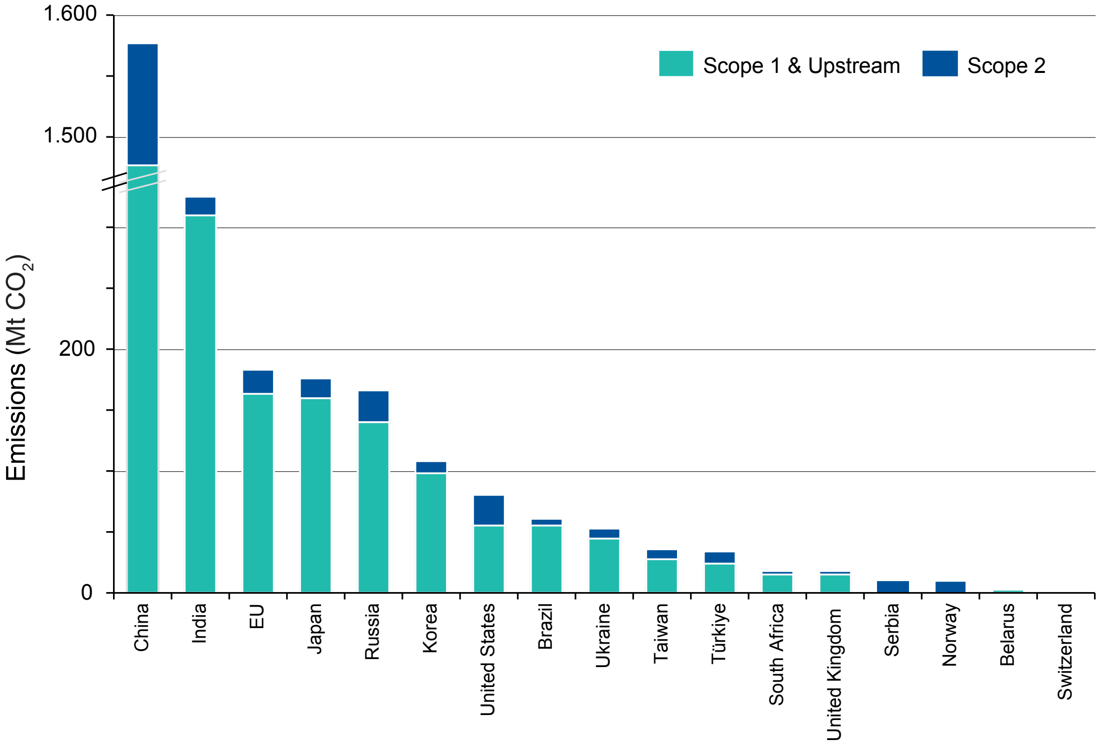
Türkiye, with comparably higher share of EAF production capacities, is in a better position than most of its competitors in terms of average emission intensity from the steel sector, since EAF is usually regarded favorably in terms of both energy intensity and carbon emissions. In addition, as also indicated in the section above, the majority of the existing EAF facilities have been built in the last two decades with updated technologies, thereby giving Turkish steelmakers an advantage in terms of production efficiency and emission results. On the other hand, decarbonization of the EAF route will be supported by Türkiye's goals to increase of the share of renewable sources in electricity production in line with the recently released Turkish National Energy Plan will make this route even more favorable in the mid-to-long term.[39]

Decarbonization of the BF-BOF route, on the contrary, will require more radical transformation and utilization of disruptive technologies such as hydrogen and carbon capture. Türkiye's average emissions in this route is currently higher than the EU averages. Therefore, the 3 integrated facilities in Türkiye have started to consider decarbonization efforts to sustain their competitiveness in the following decades.

The figure 16 reflects information from the EU's Joint Research Center for 2018 showing Türkiye's total CO_2 emissions (Scope 1 and upstream emissions[40] + Scope 2 emissions) benchmarked against other countries. The numbers indicate that most of the global CO_2 emissions from the steel sector can be attributed to Asian countries. China, with 1,576 million tonnes of CO_2 emissions, significantly exceeded the emissions of other countries such as India (325 million tonnes), the EU (183 million tonnes), Japan (176 million tonnes), and Russia (166 million tonnes). With 34 million tonnes, emissions in the Turkish iron and steel sector are relatively lower than other players, primarily attributed to its production structure that places greater emphasis on the EAF + IF route, as opposed to the BOF/BF route. It must be noted that emissions are highly dependent on the percentage of total national steel production represented by each production route (e.g., integrated or EAF).

[36]This chart was developed by consolidating data from TSPA, OECD and GMK Center.
[37]European Steel Association
[38]World Steel Association, World Steel in Figures 2022
[39]Turkish Ministry of Energy and Natural Resources, Türkiye National Energy Plan, 2022
[40]Upstream emissions include scope 1 emissions in the country of origin of the imported product and (negative) scope 1 emissions of the exported product, but exclude other associated emissions, e.g. from transportation and mining.

Figure 16. Total CO_2 Emissions from the Iron and Steel Sector[41]



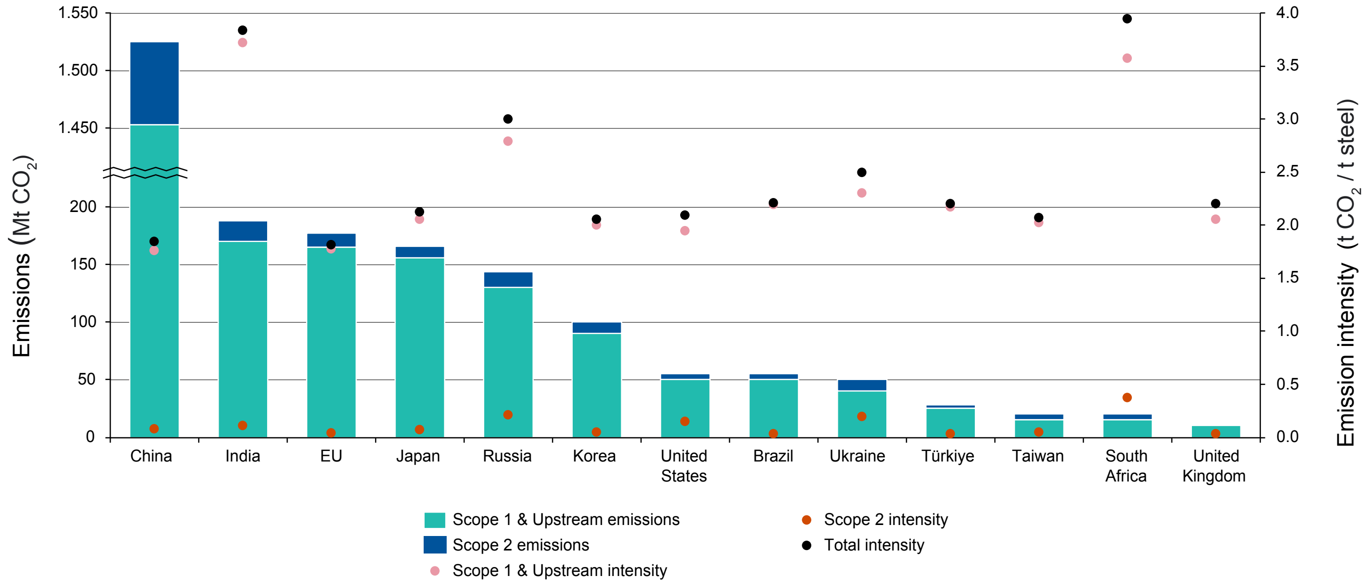
The relatively high share of EAF+IF production technologies in the Turkish steel sector shows that Türkiye is in an advantageous position compared to its global competitors against additional cost that could be brought from EU CBAM. Within the EU's list of the top five steel exporters, Türkiye has the lowest average carbon intensity compared to the other four steel producing countries: Russia, Ukraine, China, and South Korea.

The following figure indicates the total CO_2 emissions (Scope 1 and upstream emissions + Scope 2 emissions) of the integrated route. China reports 1,525 million tonnes of CO_2 emissions, followed by India (188 million tonnes), the EU (177 million tonnes), Japan (166 million tonnes), and Russia (144 million tonnes) from integrated steel plants.

The dots in the graph below demonstrate CO_2 emission intensities for the integrated route, calculated by dividing the integrated route emissions by the production of crude steel via the integrated route. The total carbon intensity of most countries ranges between 1.8 and 4.0 t CO_2 per t steel. The EU and China report the lowest carbon intensities at 1.81 and 1.84 t CO_2 per t steel, respectively, whereas on the higher end, South Africa and India have carbon intensities above 3.8 t CO_2 per t steel. Türkiye has an integrated route carbon intensity above the EU average at 2.20 t CO_2 per t steel.

[41]Koolen, D. and Vidovic, D., Greenhouse gas intensities of the EU steel industry and its trading partners, EUR 31112 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53417-4, doi:10.2760/170198, JRC129297.

Figure 17. Integrated Route CO_2 Emissions and Carbon Intensity[42]



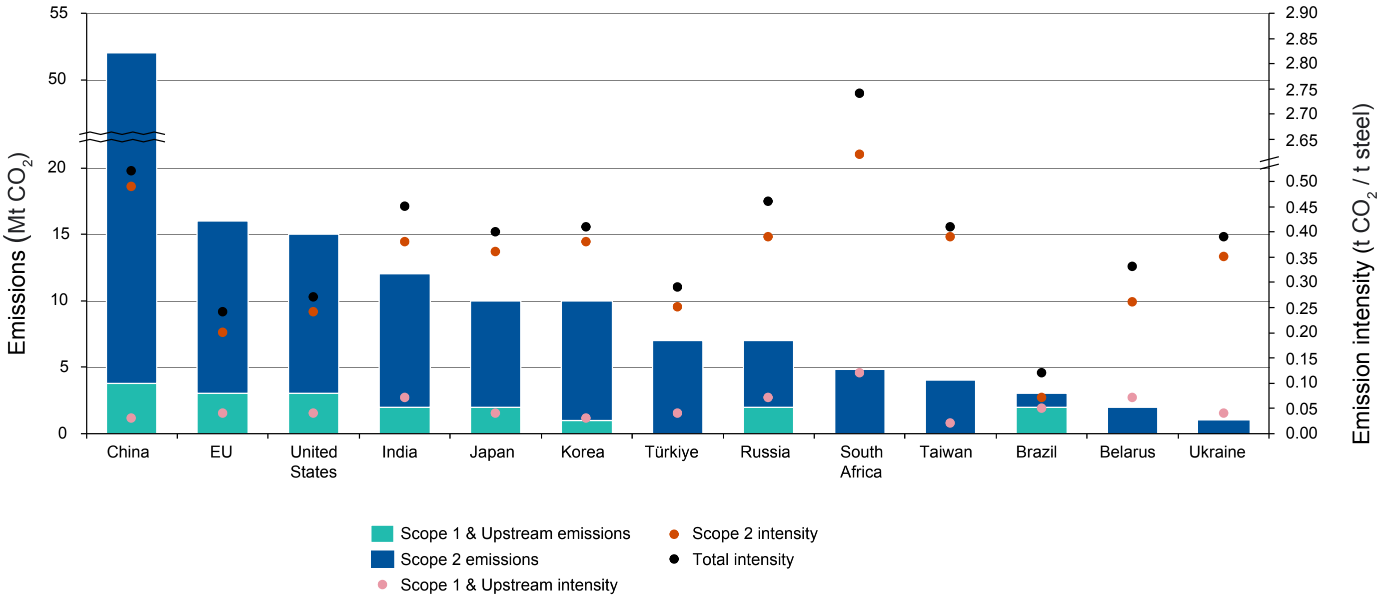
In comparison, the below figure demonstrates the same parameters for the EAF route. It is crucial to note that emissions in the EAF route are typically reported including Scope 2 emissions, since electricity required for the EAF represents the highest energy demand in this process. As in the case of integrated route, China also dominates the total emissions from the EAF route with 52 million tonnes of total CO_2 emissions, followed by EU (16 million tonnes) the US (15 million tonnes), India (12 million tonnes), Korea (10 million tonnes) and Japan (10 million tonnes). Türkiye, with its total of 7 million tonnes Scope 1&2 emissions from this route, comes 7th at the global scale.

The graph demonstrates that, for most countries, the CO_2 emission intensity of the EAF route is below 0.6 t CO_2 per t steel. On the lowest end of the spectrum, Brazil has the lowest carbon intensity of the EAF route (0.12 t CO_2 per t steel), mainly driven by the availability of less carbon-intensive hydroelectric power, whereas on the higher end, South Africa has around 2.74 t CO_2 per t steel because South African electricity is the most CO_2 emission-intensive (0.99 t CO_2 per MWh). Türkiye is among the countries having lower EAF route carbon intensity, with an average of 0.29 t CO_2 per t steel while the EU-27 average for 2020 was 0.265 t CO_2.[43] The grid emission factor of Türkiye is 0.447 tCO_2/MWh based on Ministry of Energy and Natural Resources data calculated in 2020 and published in 2022.[44]

Considering the relatively high amount of EAF and IF technologies, the Turkish steel sector can be considered to have an advantage over its competitors in the EU market in terms of potential carbon costs originating from Scope 1 emissions. However, due to the GHG emissions resulting from electricity generation (grid emissions) in Türkiye, Scope 2 emissions of facilities with EAF and IF technologies pose a significant challenge to the Turkish steel sector and therefore can be regarded as a bottleneck in the transition of the sector to net zero.

[42]Koolen, D. and Vidovic, D., Greenhouse gas intensities of the EU steel industry and its trading partners, EUR 31112 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53417-4, doi:10.2760/170198, JRC129297.
[43]Ministry of Energy and Natural Resources, European Environment Agency
[44]Ministry of Energy and Natural Resources, Turkish National Electricity Grid Emission Factor Fact Sheet

Figure 18. EAF Route CO_2 Emissions and Carbon Intensity[45]



The Turkish steel sector, on the other hand, depends heavily on imported raw materials for production. The sector imports 60% of its iron ore, 70% of its scrap steel, and 90% of its coal.[46] Considering the possibility that the scope of the EU CBAM will be further expanded to embedded emissions of transportation and to goods further down the value chain, the Turkish steel sector may give rise to a large amount of GHG emissions due to the production and transportation of imported raw materials (Scope 3 emissions).

1.3. Strengths and Weaknesses of the Turkish Steel Sector

1.3.1. Strengths

Robust presence of manufacturing industries and construction sector

Manufacturing industries have traditionally been the backbone of the Turkish economy while the construction sector has been powering economic growth for the last 20 years. Combined share of these sectors reaches a quarter of the country's GDP, and they consume steel inputs in large quantities.[47] Although there has been a downturn in the construction sector in recent years, a strong rebound is expected in the upcoming years, driven both by reconstruction efforts in the earthquake zone and by the urban renewal projects in the rest of the country.

Having a wide and diversified foreign market for steel

In 2021, Turkish steel exports reached a total of 178 countries and are diversified across a wide variety of regions, including remote countries like USA, Canada, Singapore, and Peru which are among the top export destinations.[48] This has allowed Turkish steel producers to diversify their customer base and take the advantage of growing demand in emerging economies. Turkish steel producers also can ramp up their exports by taking advantage of potential trade shifts in any of these regions.

[45]Ministry of Energy and Natural Resources, Turkish National Electricity Grid Emission Factor Fact Sheet
[46]The data was compiled by consolidating Turkstat foreign trade statistics.
[47]Turkstat National Accounts
[48]Trademap, PwC Analysis

Logistical advantages resulting from geographical proximity to major markets

Due to its geographical proximity to Europe, the Middle East, and North Africa, Türkiye is able to deliver steel to major buyers in these regions at low logistics costs. Leveraging this advantage, Türkiye steel exports to these 3 regions (26.8% for the EU, 23.2% for Middle East and 9.4% for North Africa) account for majority (59.4%) of the total export figure in 2022.[49]

High share of EAFs in production

EAF facilities are considered more attractive for emission mitigation in steelmaking, both because they have lower emission intensity and their decarbonization routes are relatively simpler and less demanding. In Türkiye, where most EAF plants have been built in the last 20 years with updated technologies, EAF represents 75.1% of production capacity and 71.1% of production in 2022. Given that emission-based customs duties are expected to increase significantly in the next decades, having an EAF-dominated steelmaking ecosystem is a major opportunity for Türkiye.

International competitiveness, marketing and branding

By investing heavily in updated technology and equipment, Turkish steelmakers are able to efficiently produce steel products that meet international standards and ship them to major markets at low logistics costs. Moreover, with its long history in steelmaking, Türkiye has accumulated considerable know-how and qualified workforce over the years. High quality and reliability coupled with competitive prices, enabled Turkish steelmakers to secure a significant global share, supported by long marketing and branding efforts.

1.3.2. Weaknesses

High foreign dependency on inputs

Lacking the necessary amounts of inputs to sustain production, namely iron ore and scrap steel, Turkish producers rely largely on imports. This both increases production costs and leaves Turkish producers vulnerable to possible volatility and shifts on these commodities in international markets. While possible price increases could hamper profitability, the reduced availability of these commodities on the international markets may cause Turkish producers to suffer from a production bottleneck.

High foreign dependency on energy supply

Lacking large energy reserves, Türkiye has to rely on external suppliers to drive its manufacturing-oriented economy. With 99.3% of natural gas and 56.9% of coal imported in 2021, the country's energy supply chain is dominated by certain countries, Russia in particular. This reliance makes Türkiye vulnerable to developments in global energy prices.[51] For example, the import bill for energy resources increased by 90.5% to 96.54 billion dollar in 2022 due to the global energy crisis.[52] The EAF-dominated Turkish steel ecosystem suffered in 2022 due to hikes in energy prices and experienced losses in both production and exports. Energy prices will remain a major challenge for Turkish producers in the medium term, given the expectations for persistently high energy prices.

Increasing protectionist tendencies in the steel sector worldwide

The protectionist tendencies sparked by the US in 2018 have increased coupled with countries' policies to protect their strategic industries following the Russian-Ukrainian War. Moreover, the EU's emission-based customs duty CBAM is expected to be introduced by other countries, with a potential to further disrupt the trade patterns in the world. Türkiye needs to follow the trade regimes and developments in the world to sustain competitiveness of its players in the global markets.

[49]KTurkstat Foreign Trade Statistics, PwC Analysis
[50]The data provided by Turkish Steel Producers' Association (TSPA) internally as part of this project.
[51]EMRA2021 Natural Gas Sector Report, General Directorate of Turkish Coal Enterprises 2021 Coal Production-Consumption Statistics
[52]Turkstat Foreign Trade Statistics

Potential challenges that the inward processing regime will cause in the upcoming period

The Inward Processing Regime, an international trade instrument also employed by Türkiye to promote domestic manufacturing, has both increased import dependency and weakened the development of local raw material and component industries, alongside its positive effects. With the implementation of emission restrictions such as EU CBAM, inward processing regime can be affected and limited to exports to the underdeveloped markets as increased dependence on imports makes the sector vulnerable to disruptions especially in the supply chain.

Insufficient R&D and innovation capabilities for value-added products

Higher value-added steel products are a viable option to overcome increasing protectionist measures creating additional costs for exports. However, the lack of sufficient R&D infrastructure and insufficient commercial, scientific, and technological relations in the triangle of companies, universities and the government undermine the development of value-added, innovative steel products in Türkiye.

2 Modelling and Scenario Analysis of Steel Sector Decarbonization

2. Modelling and Scenario Analysis of Steel Sector Decarbonization

A key lever of this project is **the modelling and scenario analysis work, that forecasts and quantifies the impact of different combinations of policies and technologies on the future emissions of the sector.** To be able to carry out the modelling work, demand and supply projections of the Turkish Steel Sector have been developed under different assumptions up until 2053, and key decarbonization levers and technologies that will achieve decarbonization in the sector have been identified and modelled. Over the period of 2023–2053, the model generates the possible pathways for decarbonization of steel sector in Türkiye, running on 2 set of scenarios to forecast and benchmark the sector's future emissions. 2 reference scenarios and 4 mitigation scenarios have been developed to forecast the future trajectory of the Türkiye's steel sector.

Reference scenarios generated as "reference" or "counter" points against which the mitigation scenario's performance is evaluated in terms of emission results. Under the reference scenario umbrella, two scenarios have been generated i) Without Measures and ii) Stated Policy. The Without Measures (WoM) scenario, assumes a "no policy" baseline where no explicit mitigative action is taken and no technological transformation takes place. Another reference scenario, the Stated Policy Scenario (SPS), is generated as a reference scenario to explore the potential effects of the stated policies – declared as of writing of this report- including renewable energy investments, process efficiency improvements, EU CBAM constraints and introduction of a national ETS. In essence, SPS is generated to project the emissions where stated policy steps are taken but not technological transformation is achieved.

Mitigation scenarios are generated to forecast the impact of radical policy action and investment in technology on the emission levels of the sector. The four mitigation scenarios used in this project are i) Low ETS, ii) High ETS, iii) Low Carbon Pathway (LCP) and iv) Frontier Technologies (FTS). The Low ETS scenario assumes that national ETS prices will be lower than the EU carbon prices and all feasible low-carbon technologies as well as envisioned policies will be introduced. High ETS scenario assumes that national ETS prices will be equal to the EU carbon prices. Moreover, High ETS scenario assumes a more aggressive technological transition than the Low ETS scenario, with earlier introduction dates for new disruptive technologies. Low Carbon Pathway and Frontier Technologies assume varying levels of mitigative policy actions and adoption of low carbon technologies towards a net zero target in 2053. The Low Carbon Pathway (LCP) scenario is designed to be the (cost-effective) optimal scenario for decarbonization of the Turkish steel sector. The more aggressive Frontier Technologies Scenario (FTS) is differentiated from the LCP Scenario by earlier introduction of frontier technologies.

The steel sector model prepared within the scope of the project is a long-term scenario analysis and optimization model developed to analyze various decarbonization scenarios for the Turkish steel sector. It is a large-scale linear programming model developed in GAMS (General Algebraic Modeling System) software that aims to minimize the total discounted cost under technological and economic constraints while achieving a given emission target.

Decarbonization of the Turkish steel sector requires deployment of new and emerging technologies to achieve higher levels of emission reduction levels in support of the country's overall decarbonization plans. Technologies that have been prioritized by the optimization model generated as part of this study (details of which will be provided under section 2 of this report), are as follows:

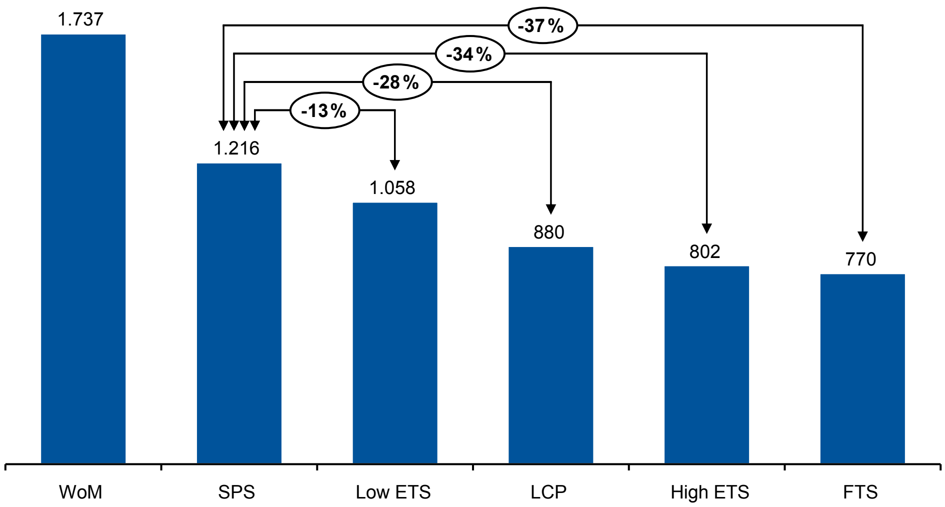
Table 3. Model-Decided Technology Prioritization in the Low Carbon Pathway Scenario

Technology Archetype	Expected Date of Entry	Emission Reduction Effect (tCO_2/t)	Investment Requirement (EUR/t)	Emission reduction cost per unit (EUR/tCO_2)
BOF Technologies				
Avg_BF_BOF Conventional integrated plant	-	-	-	-
BAT_BF_BOF Integrated plant employing best available technologies	2024	0.41	1066.85	2602.1
BAT_BF_BOF_H_2_PCI H_2 replacing pulverized coal injection	2035	0.73	1066.85	1461.4
DRI_Melt_BOF Natural gas based DRI replacing the BF facility	2036	1.33	603.34	453.6
DRI_Melt_BOF_%100_H_2 100% green hydrogen based DRI replacing the BF facility	2036	2.15	603.34	280.6
BAT_BF_BOF_CCU Integrated plant with carbon capture and utilization extension	2044	2.86	1298.55	454
EAF Technologies				
EAF Conventional electric arc furnace plant	-	-	-	-
DRI_EAF EAF plant using natural gas based DRI	2029	-0.56	698.34	1247
DRI_EAF_100green_H_2 EAF plant using %100 green hydrogen based DRI	2043	0.21	698.34	3325.4

2.1. Summary of the Emission Results from the Model

According to the WoM scenario, where no technological transformation is assumed the steel sector is estimated to reach a total CO_2 emission value of 1.7 billion tonnes in the 34-year period between 2020 and 2053. Total CO_2 emissions is projected to exceed 1.2 billion tonnes in SPS scenario over the period of 2020-2053. With the introduction of new technologies and potential national ETS, the model suggests the total CO_2 emissions over the next 30 years will likely decrease significantly. Low ETS scenario has a total CO_2 emissions 28% lower than the SPS scenario, whereas the High ETS scenario can achieve 34% reduction in total CO_2 emissions over the period 2020-2053. Paris aligned LCP scenario can achieve 336 million tonnes CO_2 reduction in total CO_2 emissions, and FTS scenario can achieve 446 million tonnes CO_2 reduction when compared to the SPS scenario over 2020-2053 period.

Figure 19. Cumulative CO_2 Emissions over 2020-2053 (Million Tonnes of CO_2)



In the LCP scenario net zero emission transition is achieved through a combination of hydrogen and CCUS technologies.

- EAF route continues to have largest share in the production of steel with 62% share in 2053. While a part of the EAF technology will be converted to natural gas-based DRI technology, most of it will be replaced by BF-BOF technologies.
- Based on the net present value (NPV) of the total investment calculated using a discount rate of 7%, in the 2023-2053 period, total investments required to reach net zero is approximately 11 billion dollars for LCP.
- It is anticipated that the LCP scenario's transformation will cost a net present value of the total carbon cost of 10.44 billion dollars between 2023 and 2053, assuming reduced carbon pricing in Türkiye and attaining the zero emission target.

The FTS scenario aims to invest in alternative futures that require radical policies and technological changes earlier than the LCP scenario to transition to a low carbon development pathway.

- By 2053, only 58% of production is covered by EAF and 42% is covered by combination of BOF technologies.
- The net zero target is only achieved by combining green hydrogen and carbon capture, storage and utilization technologies with additional use of biomass as an input fuel.
- In the FTS scenario, total annual investment cost is projected to reach around 2.5 billion dollars in 2053.
- The NPV of total investments required to reach net zero for the aggressive FTS scenario is around 12.5 billion dollars in total investments in the upcoming 30 years.
- Due to the higher ETS price assumption, the FTS scenario is expected to require a carbon cost of 37.02 billion dollars on a net present value basis between 2023 and 2053.

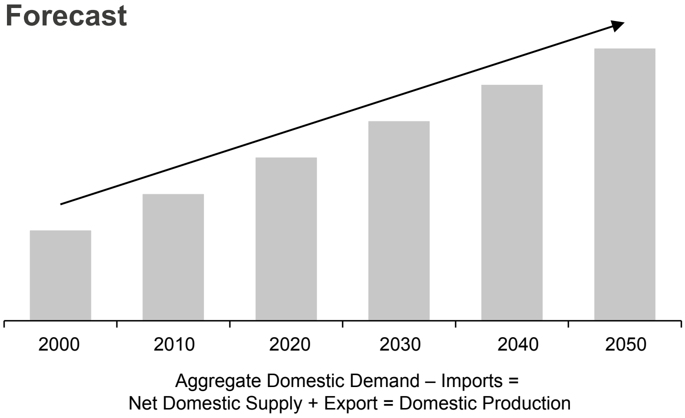
2.2. Sector Growth Methodology and Projections

The project forecasts 30 years of steel production using the supply-demand model. Projections were carried out for long steel and flat steel on a product type basis and for BOF and EAF production routes. Domestic demand was projected using market growth estimates. Net domestic supply values were calculated by subtracting imports from domestic demand. Domestic production was calculated by adding net domestic supply and exports.

To make the projections for the Turkish steel sector, sector data was obtained with the help of industry umbrella organizations, the TSPA and the Turkish Steel Exporters' Association (CIB). In addition, meetings to discuss projections and assumptions were held frequently and the projections were verified from the perspective of industry representatives.

Considering previous studies on the global and national steel sector, as well as the views of representatives from the Steering Committee, the assumptions and final projections were generated by receiving the evaluations of the Ministry of Industry and Technology to confirm its accuracy.

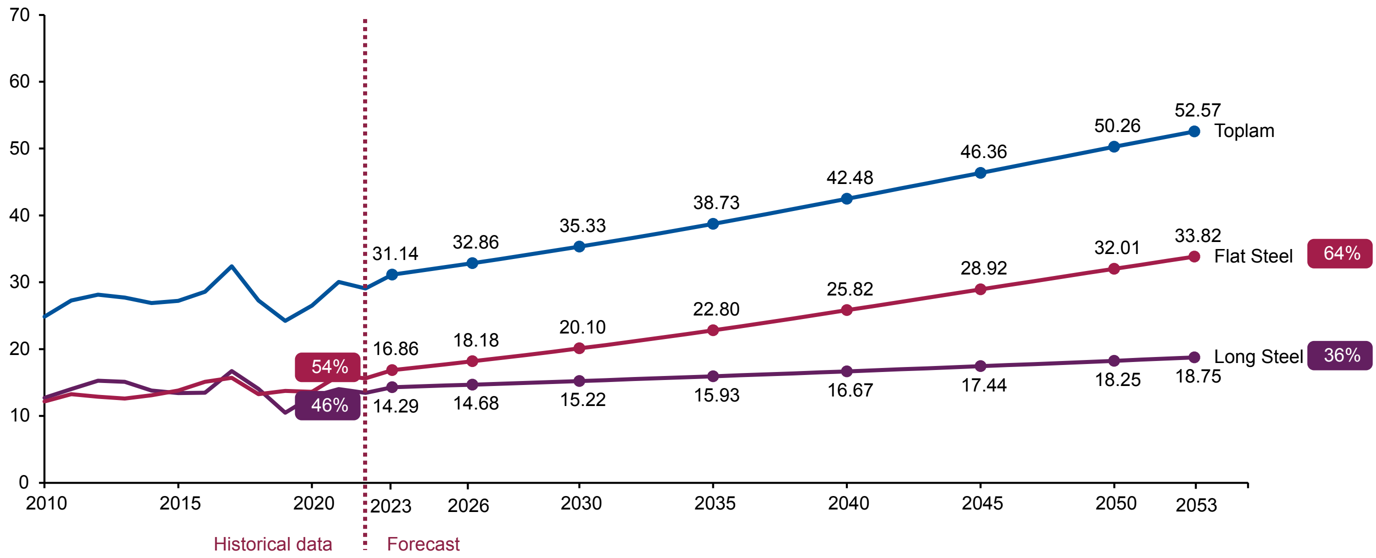
Figure 20. Methodology for Sectoral Growth Forecast



Domestic Demand Forecasts

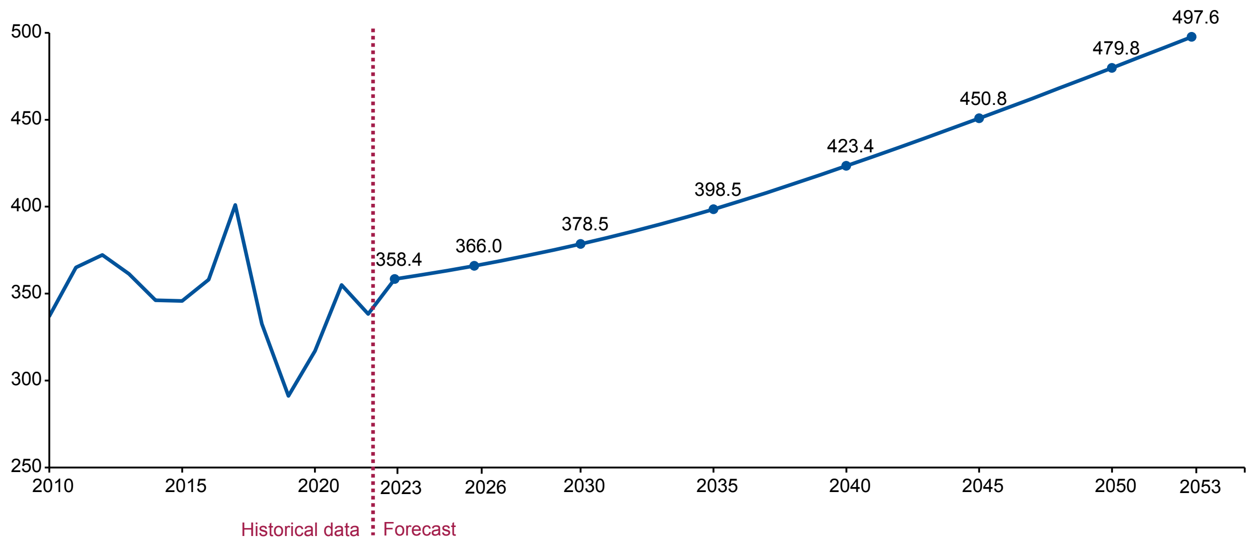
Assessing several factors, including mainly trends in construction and manufacturing, and population growth, steel demand in Türkiye is presumed to achieve strong growth figures and total steel demand is projected to exceed 52 million tonnes in 2053. Long steel is estimated to show similar growing performance as in the past period. Flat steel, on the other hand, is assumed to maintain high performance until the year when emissions expected to peak, after which it continues to grow at a high rate, albeit with a relative decline. Thus, with the expectation of faster growth for flat products, the flat steel products share of total steel demand, which is 54% in 2023, is projected to reach 64% by 2053.

Figure 21. Demand Forecast by Steel Product (Million Tonnes)



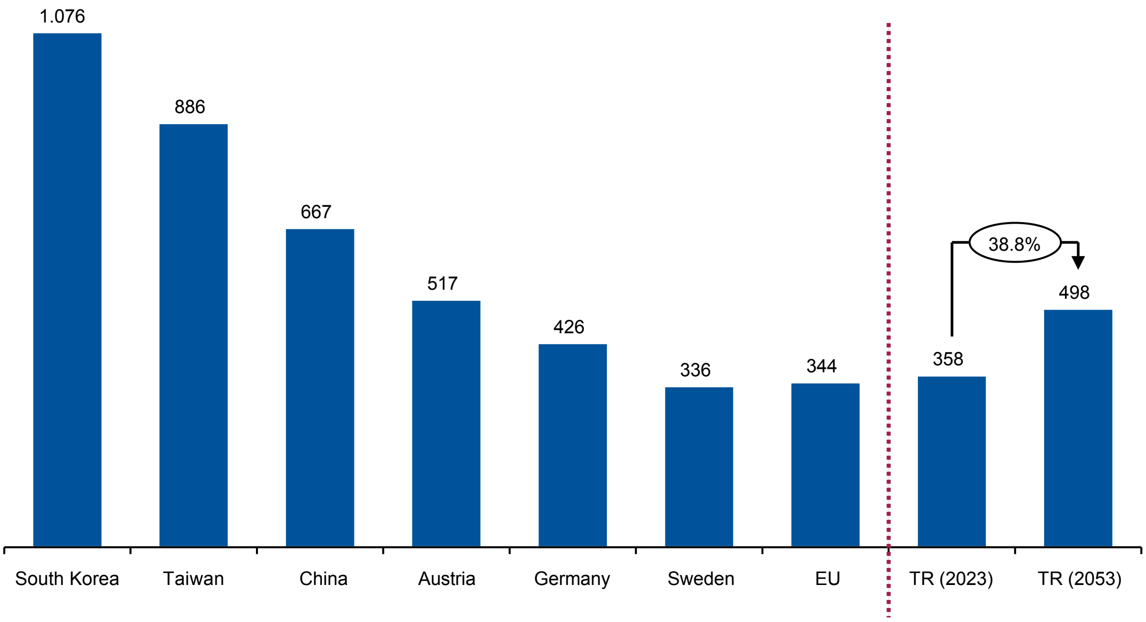
Türkiye's per capita steel consumption surpassed 400 kg in 2017 and stood at 338.3 kg in 2022. Based on steel demand growth projections for the upcoming period and population forecasts, per capita steel consumption is projected to reach 497.6 kg in 2053.

Figure 22. Steel Consumption Per Capita (Kg/Person)



With these growth assumptions, Türkiye's steel consumption per capita, which is currently close to the level of Sweden, will increase to Austria's current level.

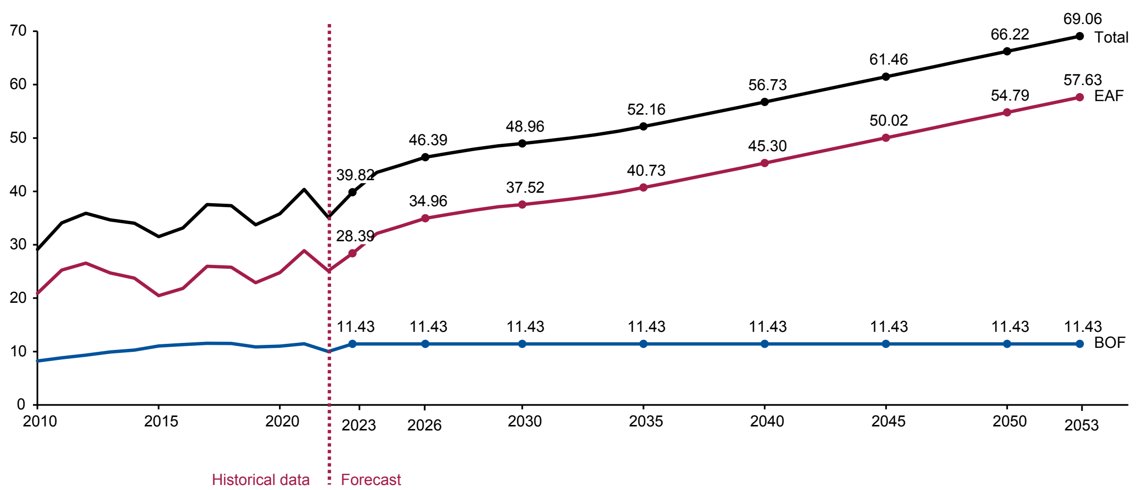
Figure 23. Steel Consumption per Capita by Country (Kg/Person)[53]



Production Forecasts by Production Route (Crude Steel)

Türkiye's crude steel production forecasts have been developed by using import and export assumptions. In the LCP scenario, it is estimated that Türkiye's ETS will be lower than the EU ETS during the forecast period. Thus, the potential negative effects of EU CBAM on exports will slightly decrease the total production figures compared to the reference scenario. In this scenario, it is assumed the increasing steel demand will mainly be met by the increased amount of steel produced using the EAF route alone. Therefore, while the BOF steel production percentage will decrease, the share of steel produced using the EAF route will increase during the projection period. The amount of Turkish steel produced using EAF is forecasted to increase from 71.3% in 2023 to 83.4% in 2053. It is projected that within the total 69.06 million tonnes of crude steel production in 2053, 57.63 million tonnes will be produced by using the EAF route and 11.43 million tonnes will be produced by using the BOF route.

Figure 24. Production Forecast by Production Routes in LCP Scenario (Million Tonnes)



[53]World Steel Association (2022). Retrieved from https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/

World Economic Forum predicts 30% growth in global steel demand by 2050[54] and this increase is expected to be seen particularly in India, Africa, and Southeast-Asia. On the other hand, according to International Energy Agency (IEA), India will be the pioneer in global steel production growth to 2050[55] with the expectation of three to fourfold rise in the country's steel production by 2050. The agency also has assumptions on the emerging countries in Latin America, Africa and Asia expecting between twofold and above fourfold growth in steel production of respective countries by 2050 in different scenarios. As of 2022, Türkiye has produced more than 35 million tonnes of steel accounting for 1.92% of world crude steel production. According to the sectoral growth projections conducted as part of this project, similar to other emerging and developing countries, Turkish steel sector will achieve twofold growth in production and is expected to reach ~70 million tonnes crude steel production by 2053.

2.3. Low-Carbon Steelmaking Technologies

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

Steelmakers will be lowering their emissions by increasing process and energy efficiency, adapting to new technologies and switching to lower-emission inputs. One method to significantly reduce emissions is to swiftly integrate new technology into production operations. While some low-carbon steelmaking technologies are commercially available today, others are in the pilot/demo phase or still in R&D stage. Hydrogen and carbon capture are breakthrough technologies that will nearly eliminate emissions, and global commercialization of these technologies is expected in the late 2020s and early 2030s.

Manufacturing technologies in the steel sector have been analyzed in detail based on production routes (EAF, BOF/BF) and processes through literature review. As a result, technologies have been mapped by their energy savings potential, CO_2 emission reduction potential, CAPEX & OPEX (based on literature), and development status/technological maturity.

The commercialization years of decarbonization technologies for the steel sector are estimated reviewing the most up to date international resources and revised (when necessary) in line with the opinions of industry stakeholders and project experts, revealing a set of assumptions on possible timeframes for their market entry. To provide input for scenarios the transition of the Turkish steel sector to low-emission production and model the associated effects, technology entry years and maximum penetration rates are defined. To be able to forecast technology entry years and their share in the future production, two workshops were held under the leadership of TSPA. During these workshops representatives from both the BOF/BF and EAF manufacturers provided their opinions on technology details, year of introduction of these technologies in the Turkish steel sector and maximum production (penetration cap) shares.

Technology Archetypes (Based on MPP Archetypes)

Technology archetypes defining input combinations for various processes have been assessed using Mission Possible Partnership[56] (MPP) framework as a reference. This technology framework is accepted as the reference state for the Turkish steel sector, to achieve low carbon production in BF-BOF and EAF routes.

BF-BOF Technologies

In addition to the conventional BF-BOF technologies, 11 technology archetypes were considered for modelling of this production route. Short descriptions of these technologies are provided below.

[54] Retrieved from https://www.weforum.org/reports/the-net-zero-industry-tracker/in-full/steel-industry/
[55] The IEA, Iron and Steel Technology Roadmap
[56] The MPP, Making Net Zero Steel Possible

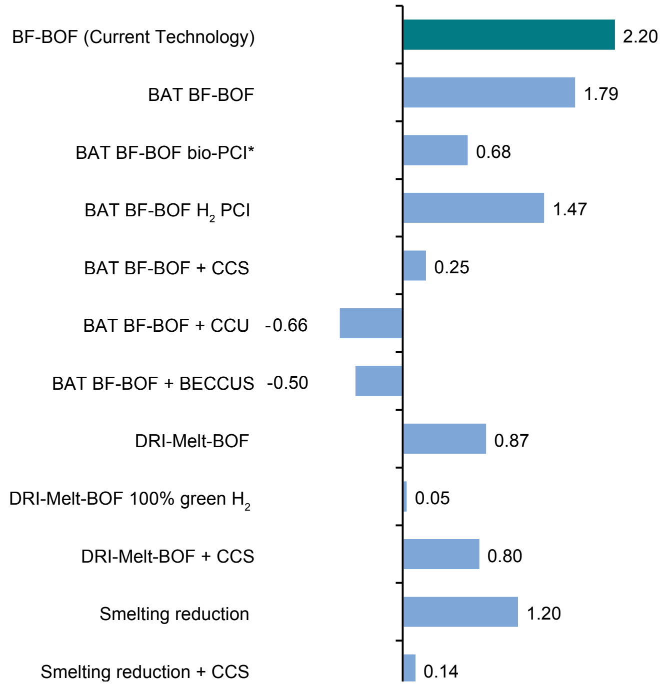
Table 4. Short Definitions of BF-BOF Technologies

Technology Name	Description
BAT BF-BOF	Integrated plant employing best available process technologies
BAT BF-BOF bio-PCI	Pre-treated biomass (e.g. charcoal) replacing pulverized coal injection
BAT BF-BOF H_2 PCI	H_2 replacing pulverized coal injection
BAT BF-BOF + CCS	Integrated plant with carbon capture and storage extension
BAT BF-BOF + CCU	Integrated plant with carbon capture and utilization extension
BAT BF-BOF + BECCUS	Bioenergy with carbon capture, storage and utilization
DRI-Melt-BOF	Natural gas based DRI replacing the BF facility
DRI-Melt-BOF 100% green H_2	100% green hydrogen based DRI replacing the BF facility
DRI-Melt-BOF + CCS	Combination of natural gas based BOF-DRI and carbon capture and storage
Smelting reduction	Liquid metal production without coke, through and oxygen treatment (e.g. Hiserna)
Smelting reduction + CCS	Combination of smelting reduction technology with carbon capture and storage

Emission performances of the above-mentioned BF/BOF technologies are provided in the chart on the right-hand side. These technologies are used in the optimization model with their respective penetration years, input use and CAPEX and OPEX figures to find the low-cost scenario options for the Turkish steel in the planning period which spans the next 30 years.

Scenario-based technology entry years and penetration caps for these technologies are detailed in the table below. In the aggressive FTS scenario, technology entry years are earlier and closer to the estimations of global sources and, while in the more realistic LCP scenario, the technology entry years are determined as the years when Türkiye would be ready for the specific technology. In general, it is assumed that the technologies will be implemented with 5-10 years' time lag in Türkiye. These assumptions are based on consultations with the industry representatives during technology workshops organized by TSPA. In these consultations, the integrated plant representatives underlined that BAT BF-BOF bio-PCI technology, which can only be applied in smaller blast furnaces, cannot be used in their specific plants. Therefore, this technology was deprioritized in the technology foresight scenarios for the BOF route.

Figure 25. Average Emissions per Tonne Steel Produced for BOF Route (Scope 1&2), (Tonne CO_2)[57]



[57]The MPP, Making Net Zero Steel Possible & Koolen, D. and Vidovic, D., Greenhouse gas intensities of the EU steel industry and its trading partners, EUR 31112 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-53417-4, doi:10.2760/170198, JRC129297.

Table 5. The Year Technology is Commercially Available and Penetration Cap for the BOF-BF Route

MPP		Low Carbon Pathway Scenario			Frontier Technologies Scenario		
Technologies	Commercially Available Year	Commercially Available Year	Penetration Cap (%, 2030)	Penetration Cap (%, 2053)	Commercially Available Year	Penetration Cap (%, 2030)	Penetration Cap (%, 2053)
BF-BOF (Currnet Technology)	2020	2020	100	100	2020	100	100
BAT BF-BOF	2020	2025	50	100	2020	100	100
BAT BF-BOF bio-PCI*	2020	2055			2035		30
BAT BF-BOF H_2 PCI	2020	2035		50	2030		100
BAT BF-BOF + CCS	2025	2043		50	2038		100
BAT BF-BOF + CCU	2028	2043		50	2038		100
BAT BF-BOF + BECCUS	2028	2055			2043		30
DRI-Melt-BOF	2028	2036		50	2031		100
DRI-Melt-BOF 100% green H_2	2026	2036		50	2031		100
DRI-Melt-BOF + CCS	2026	2043		50	2038		100
Smelting reduction	2028	2045		50	2040		100
Smelting reduction + CCS	2030	2045		50	2040		100

EAF Technologies

In addition to the conventional EAF technologies, 7 technology archetypes are considered when forecasting the EAF route technologies in the next 30 years. Short descriptions of these technologies are given.

Table 6. Short Definitions of EAF Technologies

Technology Name	Description
DRI-EAF	EAF plant using natural gas based DRI
DRI-EAF 50% green H_2	EAF plant using %50 natural gas and %50 green hydrogen based DRI
DRI-EAF 100% green H_2	EAF plant using %100 green hydrogen based DRI
DRI-EAF + CCS	Combination of natural gas based EAF-DRI and carbon capture and storage
DRI-EAF 50% bio-CH_4	EAF plant using %50 natural gas and %50 biomethane
Electrolyser-EAF	High temperature iron ore electrolysis, similar to aluminium smelting process
Electrowinning-EAF	Low temperature iron ore electrolysis through and alkaline solution

Emission performances of the above-mentioned EAF technologies are provided in the chart on the right-hand side. As in the case of the BOF technologies, the alternative technologies for the EAF route are also considered in the long-term optimization model scenarios.

Scenario-based technology introduction years and penetration caps for these technologies are detailed in the table below. Technology entry years were determined as the years when Turkish steel sector will be ready for technology, depending on the scenario requirements. While some technologies can be deployed early in both scenarios, after consulting with local industry experts, some technologies, such as DRI-EAF 50% bio-CH_4 and electrowinning, are not expected to be deployed until 2053.

Figure 26. Average Emissions per Tonne Steel Produced for EAF Route (Scope 1&2), (Tonne CO_2)

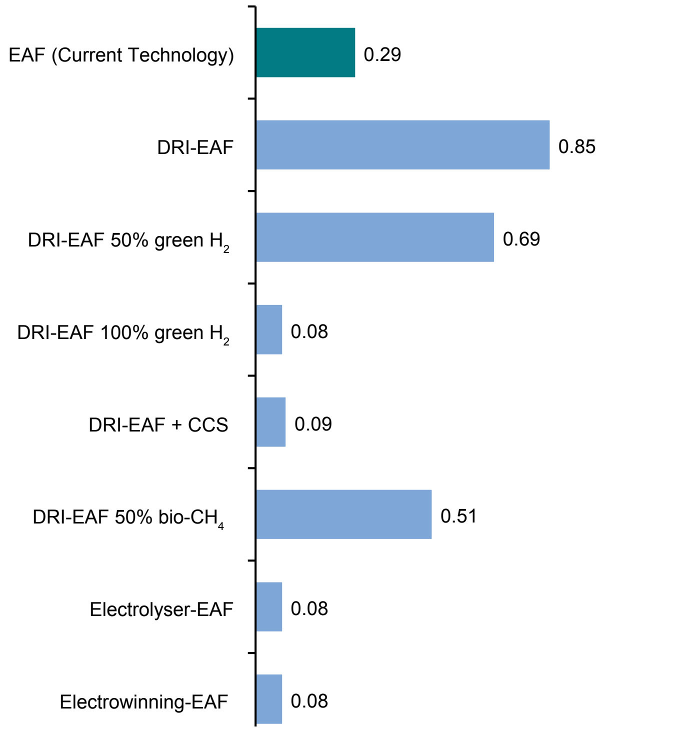


Table 7. The Year Technology is Commercially Available and Penetration Cap for EAF Route

MPP		Low Carbon Pathway Scenario			Frontier Technologies Scenario		
Technologies	Commercially Available Year	Commercially Available Year	Penetration Cap (%, 2030)	Penetration Cap (%, 2053)	Commercially Available Year	Penetration Cap (%, 2030)	Penetration Cap (%, 2053)
EAF (Current Technology)	2020	2020	100	100	2020	100	100
DRI-EAF	2020	2030		70	2025	50	100
DRI-EAF 50% green H_2	2026	2036		70	2031		100
DRI-EAF 100% green H_2	2026	2036		70	2031		100
DRI-EAF + CCS	2028	2043		50	2038		100
DRI-EAF 50% bio-CH_4	2028	2070			2070		
Electrolyser-EAF	2035	2050		50	2045		30
Elektrowinning-EAF	2035	2055			2050		

2.4. Low-Carbon Scenarios Through 2053

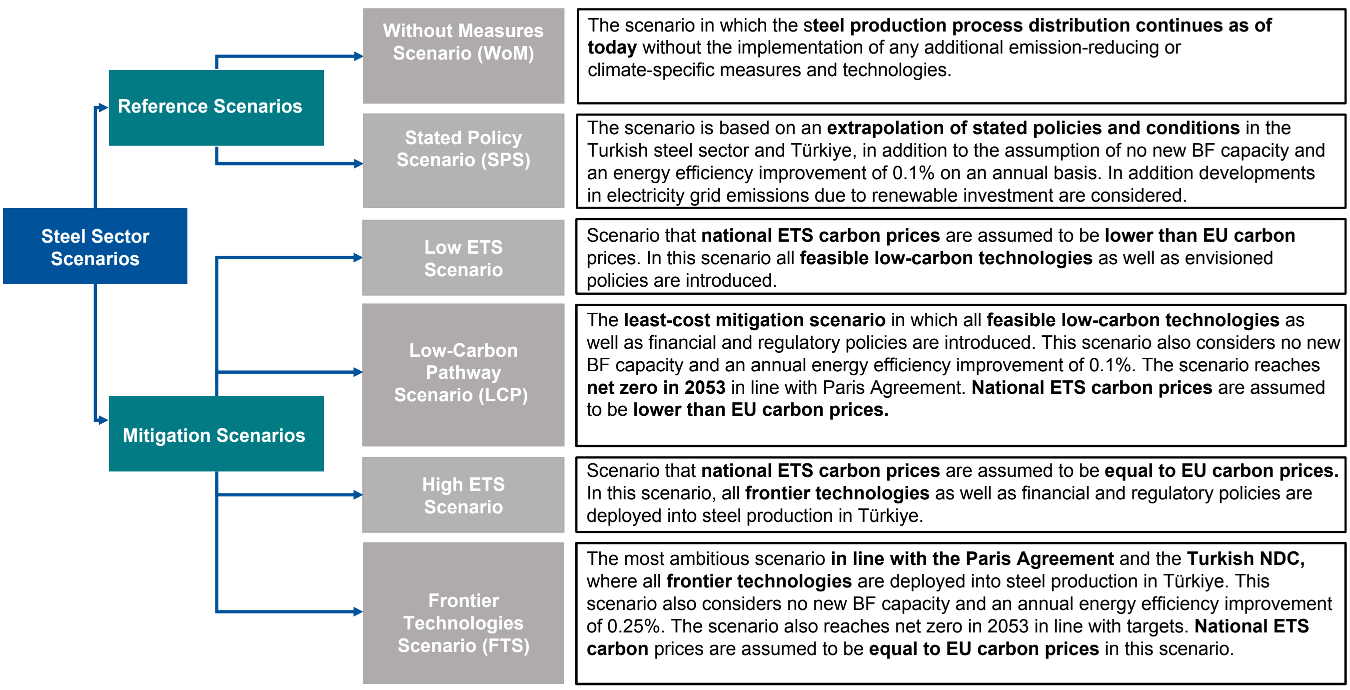
This study employs two sets of scenarios, reference and mitigation, that represent different aspects of technology investments and policy actions required to reduce emissions in the steel sector, whereby:

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

Mitigation scenarios consider a more radical policy and technology change to transition to a low carbon pathway. To reflect the possible outcomes of the national ETS (soon) to be established, two scenarios were generated with different ETS price assumptions. These are the Low ETS scenario which assumes a lower ETS price than the EU ETS and a moderate technological transformation, and the High ETS scenario which assumes an ETS price equal to the EU ETS and a more aggressive technological transformation.

In addition, in line with Türkiye's 2053 net zero emissions target, two different net-zero scenarios are also devised for the Turkish steel sector. The LCP scenario, which considers an ETS price lower than EU ETS and technological transformation, is considered as the optimal scenario for the transition of the Turkish steel sector. The more aggressive Frontier Technologies Scenario (FTS) is differentiated from the LCP Scenario by the early introduction of disruptive technologies and higher penetration rate assumptions, with an ETS price equal to EU ETS carbon price.

Figure 27. Steel Sector Scenarios

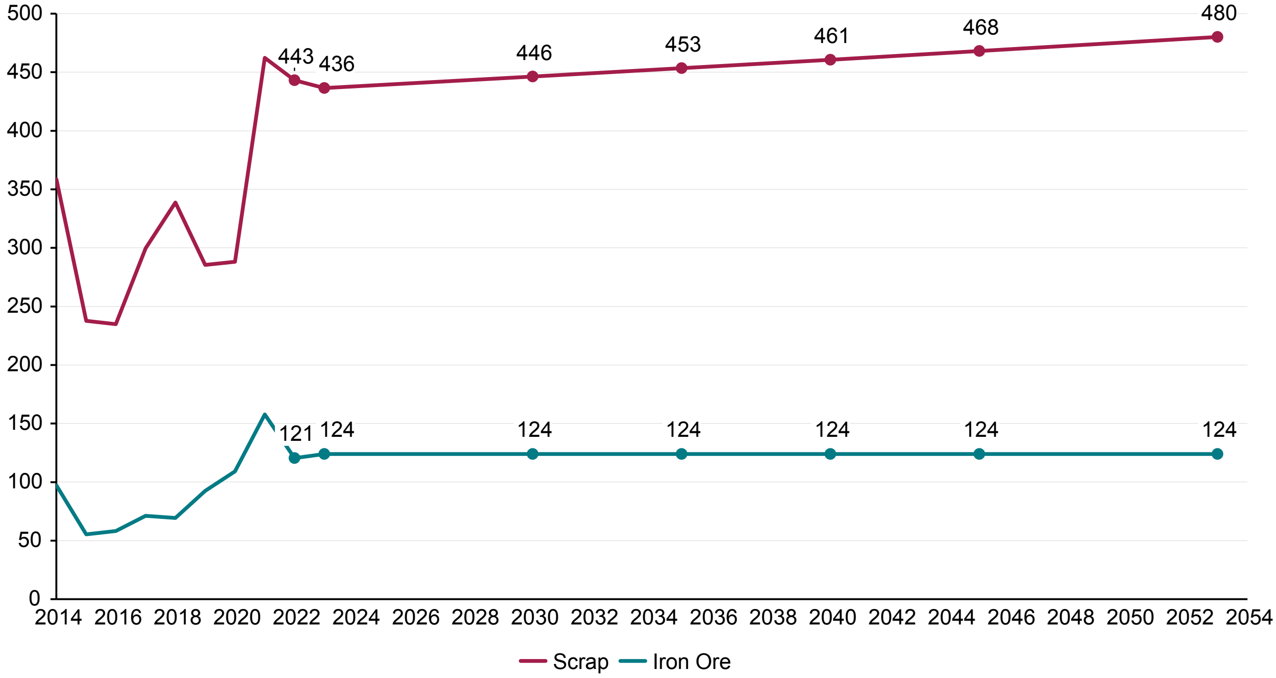


Scenario Based Assumptions

Scrap & Iron Ore Price Forecast[58]

As part of the modelling work, future scrap and iron ore prices are estimated. The iron ore prices are based on Chinese iron ore prices, which converge to the current Turkish prices.[59] Scrap steel is one of the industry's key raw materials. In line with countries' emission reduction and decarbonization targets, the demand for scrap steel is expected to rise in the next years. Therefore, in the modeling study, it is assumed that the price of scrap steel will relatively increase compared to iron ore. Considering that the price of iron ore has fluctuated less in the past years, the price of iron ore was kept constant at the 2022 price. On the other hand, due to the high volatility in price and increasing demand, the price of scrap steel is projected to increase from 435 dollars in 2023 to 480 dollars in 2053.

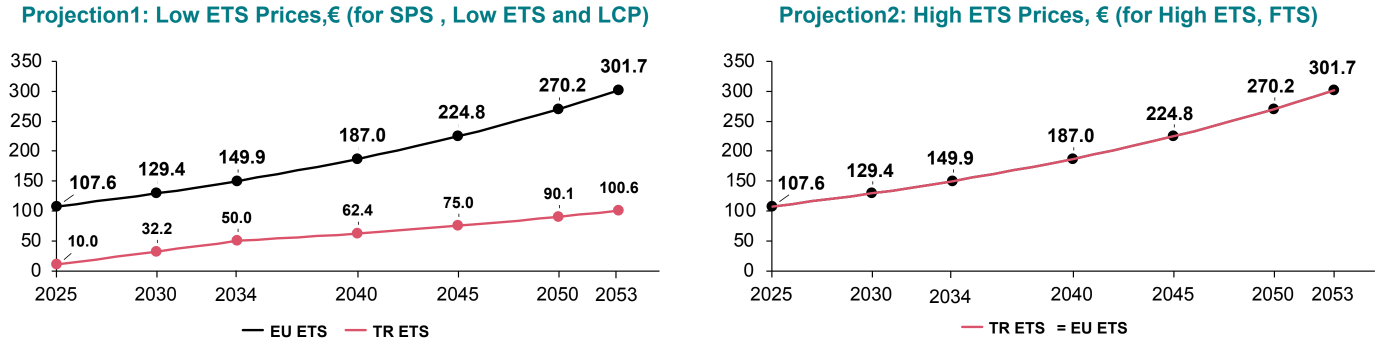
Figure 28. Scrap and Iron Ore Price Forecast (Dollar/Tonne)



Carbon Price Projections for Türkiye

Two different projections were developed using different assumptions for the CBAM and the planned domestic ETS. Under first projection (which assumes: Low ETS prices for SPS, Low ETS and LCP scenario TR ETS<EU ETS), carbon price in Türkiye is projected to start at **10 euros in 2025 and reach 50 euros in 2034**, after which it aligns with the EU carbon prices. Under second projection (which assumes: High ETS prices for High ETS and FTS scenario which is more aggressive, TR ETS=EU ETS), Türkiye's carbon price is projected to be the same as the EU carbon price, starting from 2025. Projection results are as follows.

Figure 29. Türkiye's Carbon Price Projections



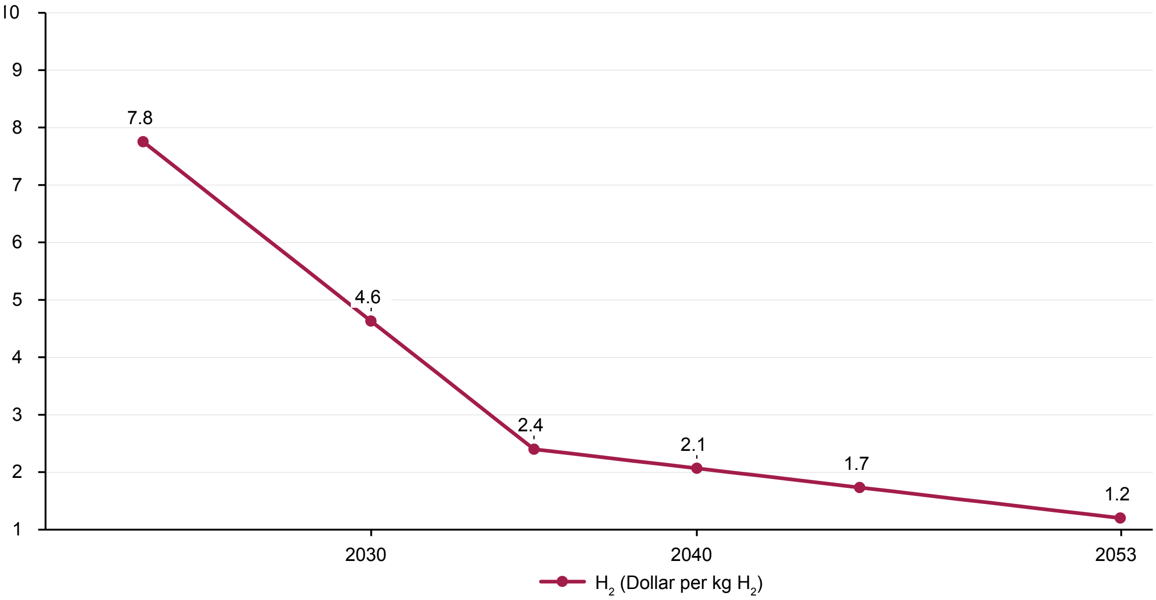
The projection work used the EBRD's "Potential Impacts of The Carbon Border Adjustment Mechanism on Türkiye's Economy" Report , and the results were sense checked with the officials of The Ministry of Environment, Urbanization and Climate Change, Ministry of Industry and Technology and the EBRD.

[58]Retrieved from https://www.steelorbis.com/price-forecasters/orbis-turkish-scrap-forecaster/
[59]Chinese iron ore prices are taken as a basis in the projection with the guidance of TSPA.

Hydrogen Price Projection

The Ministry of Energy and Natural Resources has declared hydrogen as a priority area due to its key role in combatting climate change and achieving Türkiye's net zero and sustainable energy targets and consequently published "Türkiye's Hydrogen Technologies Strategy and Roadmap Report".[60] The modelling work makes a projection of hydrogen prices up until 2053, taking into account the national goal of reducing the cost of green hydrogen production to below 2.4 dollars/kgH_2 by 2035 and below 1.2 dollars/kgH_2 by 2053.

Figure 30. Hydrogen Price Projection



Input Price Projections

Input price (of fuel, feedstock, etc.) used in different technologies is also embedded in the model, tailoring the data retrieved from MPP (Mission Possible Partnership)[61] , Steelonthenet[62], SteelOrbis[63] and IEA (International Energy Agency)[64] through expert and stakeholder views. Input prices can fluctuate widely on a monthly or even weekly basis. This project used inflation-adjusted real prices and accepted this to remain constant unless there was a trend that would radically change the trend. The parameters in the MPP dataset, that are directly used as input in the model are as follows: Blast furnace /basic oxygen furnace gas, Coke oven gas (COG), Biomass, Electricity, Steam, Blast furnace slag, other slag. The data that was not directly available on the MPP were either obtained from alternative sources or derived by calibrating the MPP data. Data obtained in such manner are; coke, thermal coal, metcoal, and natural gas.

Electricity Grid Emission Factor Projection

Türkiye's Transmission Line Connected Consumption Grid Emission Factor is announced as 0.447 tCO_2/MWh for the year 2020, by TR Ministry of Energy and Natural Resources[65]. For the project modelling work, the grid emission factor is projected in line with the reduction targets set in the National Energy Plan announced in January 2023 and Türkiye's updated NDC targets. The grid emission factor is forecasted to decrease by 41% until 2035 and further by another 41% between 2035-2053. The projection estimates the grid emission factor for the year 2053 to be 0.0157 tCO_2/MWh.

2.5. Greenhouse Gases (GHG) and Policy Interaction Model

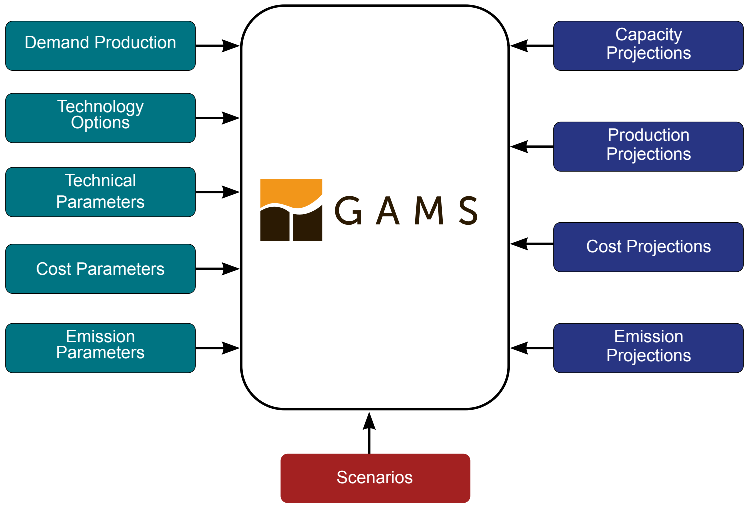
2.5.1. The Modelling Approach

The steel sector model used as part of this project is a multi-objective, long-term scenario analysis and optimization model developed to analyze various scenarios for the Turkish steel sector. The model uses large-scale linear programming with the objective of minimizing discounted total costs under technological and economic constraints while achieving a certain emission target. Finally, the model calculates the optimal solution for the period of 2020-2053.

[60] Ministry of Energy and Natural Resources (2023). The Türkiye Hydrogen Technologies Strategy and Roadmap Report
[61] https://github.com/missionpossiblepartnership/mpp-steel-model/tree/main/mppsteel/data/import_data
[62] https://www.steelonthenet.com/
[63] https://www.steelorbis.com/price-forecasters/orbis-HRC-CIS-export-forecaster/
[64] https://www.iea.org/
[65] https://enerji.gov.tr/evced-cevre-ve-iklim-elektrik-uretim-tuketim-emisyon-faktorleri

The general framework of the optimization model is illustrated in Figure 31. As seen in this figure, the optimization model developed on GAMS (the General Algebraic Modeling System), requires several sets of inputs, i.e., demand projections, current and future technological options, their costs, and technical features along with emission parameters. Set-up as such, the optimization model runs specific scenarios generated. The solution produced by the model lays out the optimal capacity projection -over the planning horizon- that satisfy the projected demand, production by each technology, the annual, nominal, and discounted cost of each scenario and total emissions under the proposed framework.

Figure 31. General Framework of the Optimization Model



2.5.2. Model Results

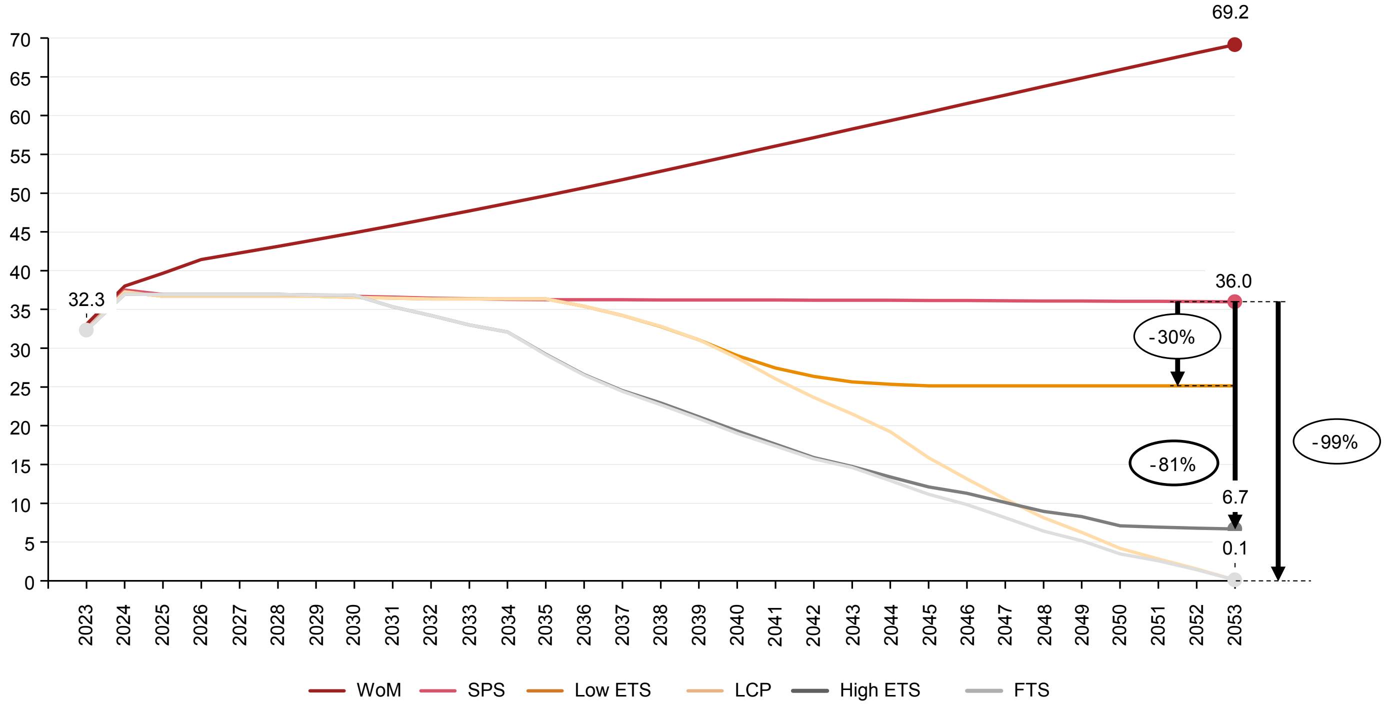
Within the aforementioned scope, the modelling work aims to forecast; emission levels, costs, technology transformation, investment requirements and the impact of climate policy initiatives on these under different scenarios, for the next 30-years.

In the next section, the model results will be discussed in detail through the lenses of emissions, technology transformation, CO_2 costs and raw material requirement projections. The investment needs required to achieve decarbonization based on the scenarios are provided under section 2.6. In the emission section, scope 1 and 2 emissions, and scenario-based emission reduction assumptions are analyzed in detail. In the investment section, the required investment is projected based on scenarios by correlating the fuel and technology price. The cost of decarbonization transformation need, including carbon fees, for Turkish steel sector is also assessed. Finally, in the transformation section, technology transformation for the EAF and BOF routes is examined based on mitigation scenarios through 2053.

Emissions

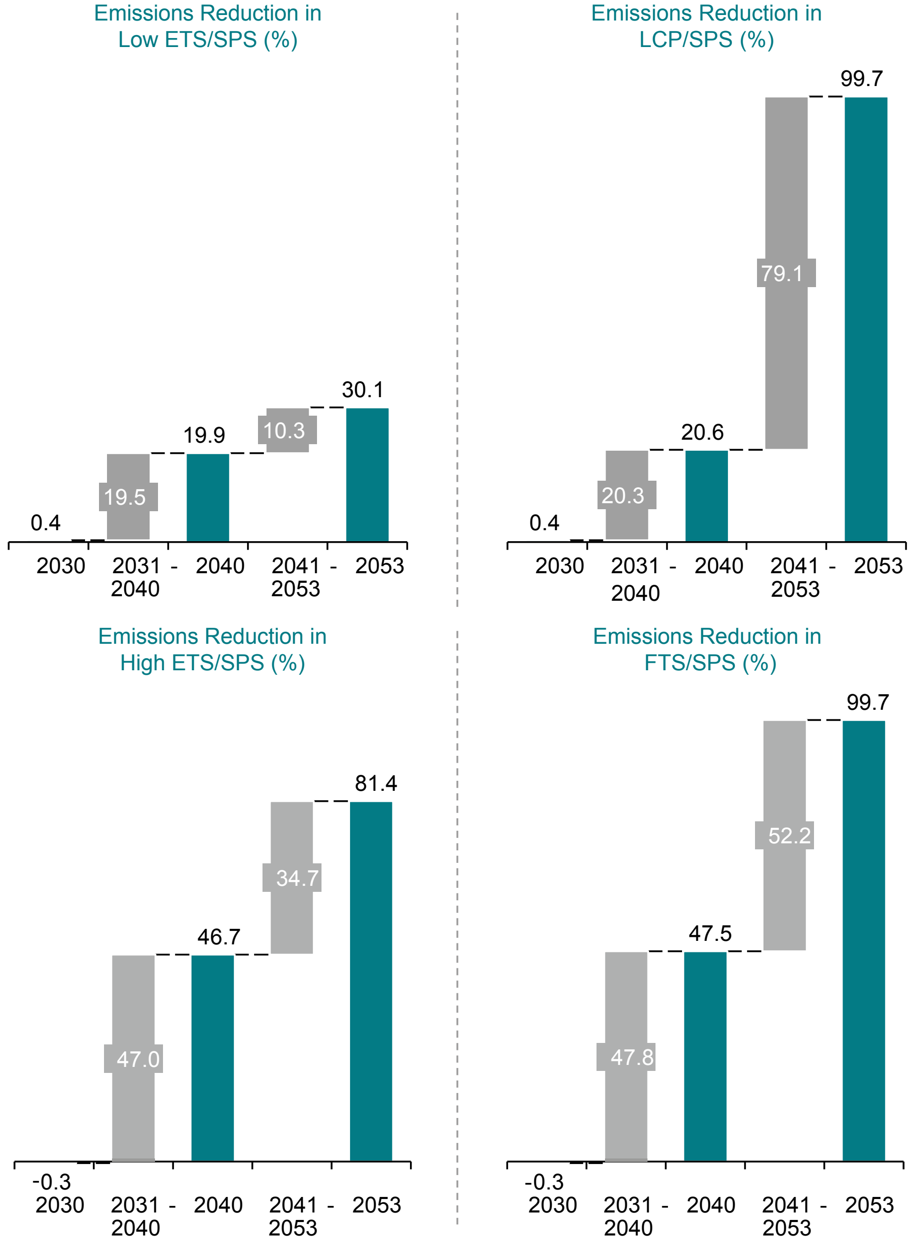
The emission forecasts by scenarios will help understanding the Turkish steel sector's emission reduction potential under different technological transformation pathways. In the WoM scenario, where no mitigation action and technological transformation is assessed, emissions are expected to increase significantly reaching the highest level, 69.1 million tonnes by 2053. Total emissions in the SPS scenario, assuming no additional investment or mitigation policy is applied other than stated ones as of now, remain stable with the increase of EAF capacity, decreasing grid emissions, and efficiency factors. Under the SPS scenario 36 million tonnes of CO_2 emissions are expected to be produced in 2053. According to the Low ETS scenario, 25.1 million tonnes of CO_2 reduction can be achieved by 2053, representing 30% decrease in total emissions compared to SPS scenario. In the High ETS scenario, even higher emission reductions are estimated to be achieved as higher carbon prices push more aggressive technological transformation and emissions are projected to decrease to 6.7 million tonnes by 2053, indicating 81% emission cut compared to SPS scenario. In order to achieve zero emissions by 2053, even more radical technological investments are needed as both LCP and FTS scenarios suggest.

Figure 32. Emissions (Million Tonnes of CO_2)



The Figure 33 presents the emission projections for the Low ETS, High ETS, LCP and FTS scenarios in comparison to the SPS scenario. In the mitigation scenarios, it is noticeable that emission reductions start as of 2030 with the introduction of new technologies. Different technology entry years and maximum penetration rates are defined under scenarios, resulting in different emission reduction projections. According to the modeling results, total emissions can be reduced by 20.6% by 2040 and 99.7% by 2053 in the LCP scenario. The crucial point in this scenario is most of the emission reductions are assumed to be obtained after the year 2040 to achieve the net zero target by 2053. In the FTS scenario, which is the most aggressive scenario, the projected emission reduction is higher as technologies are expected to be implemented earlier. Therefore, the FTS scenario achieves a 47.5% emission reduction by 2040, higher than Türkiye's latest NDC target (41% emission reduction in 2030). On the other hand, in the Low ETS scenario and High ETS scenario, emission reduction ratios are lower, and the scenarios cannot reach the net zero emissions in 2053. In Low ETS scenario, total emissions can be reduced by 19.9% in 2040 and 30.1% by 2053. High ETS scenario, the total emission reduction in 2040 reaches 46.7% which is still higher than the National NDC targets, but the total emission in 2053 cannot reach net zero. In the FTS and High ETS scenarios, where the technology introduction years are earlier, emission reductions are similar until the introduction of the CCUS technology.

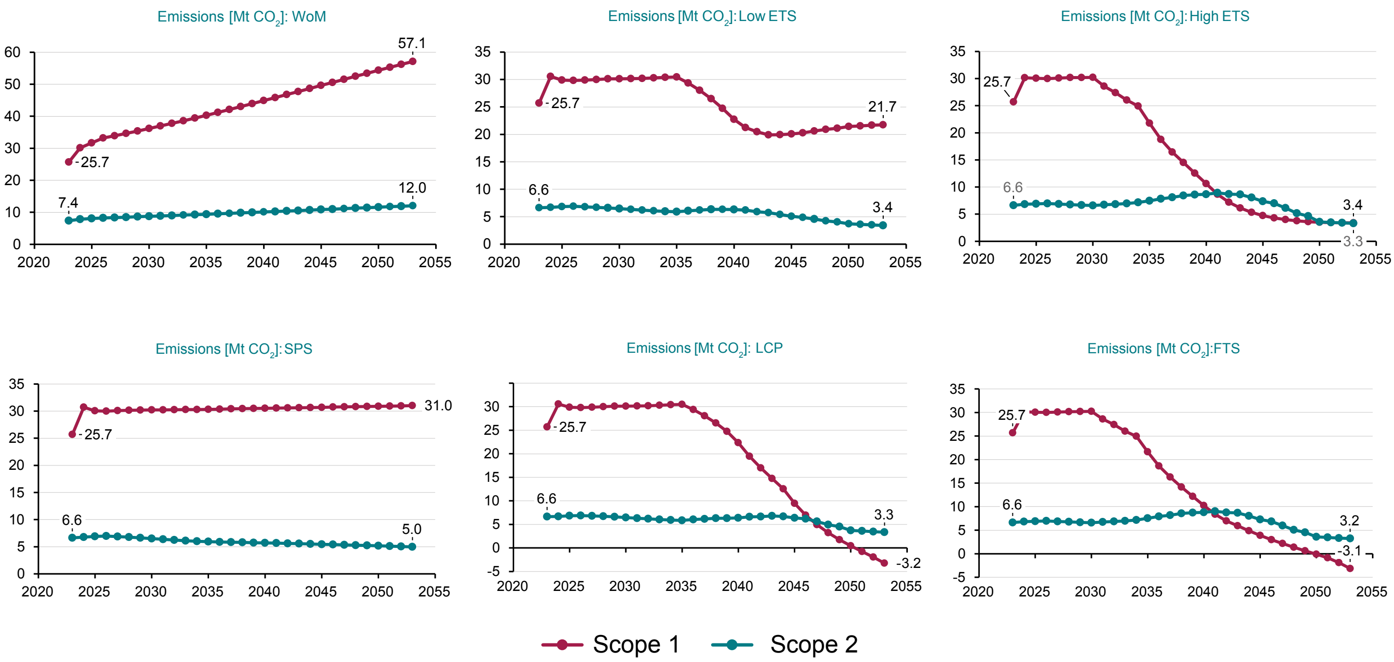
Figure 33. Emission Mitigation Rates in the Steel Sector Compared to the SPS Scenario (%)



Scope 1 and Scope 2 emissions are modelled separately for the same transition scenarios as well. In the WoM scenario, 83% of total emissions are obtained from Scope 1 emissions, which are calculated as 57.1 million tonnes of CO_2 in 2053. In this scenario, scope 2 emissions are expected to reach 12.0 million tonnes of CO_2 as a result of the continuation of the historical trend, assuming there will be no change in the grid emission factor. In the SPS scenario, Scope 1 emissions are not expected to change after 2025 when they reach 31 million tonnes of CO_2. Due to the gradual decrease in electricity grid emissions, Scope 2 emissions are projected to decrease slightly from 6.6 million tonnes of CO_2 to 5 million tonnes of CO_2, despite the growth of production figures.

In the Low ETS scenario, Scope 1 and 2 emissions are expected to decrease due to factors such as reduced electricity grid emissions, introduction of new technologies, and increased process efficiency. In addition, the High ETS, LCP and FTS scenarios lead to a more radical reduction in Scope 1 emissions due to higher process efficiency assumptions and early introduction and higher penetration of disruptive technologies. In the LCP and FTS scenarios, Scope 1 emissions should reach negative values with the use of biofuels and CCU technologies to achieve net zero future.

Figure 34. Scope 1 and Scope 2 Emissions by Scenario (Million Tonnes of CO_2)



Technology Transformation

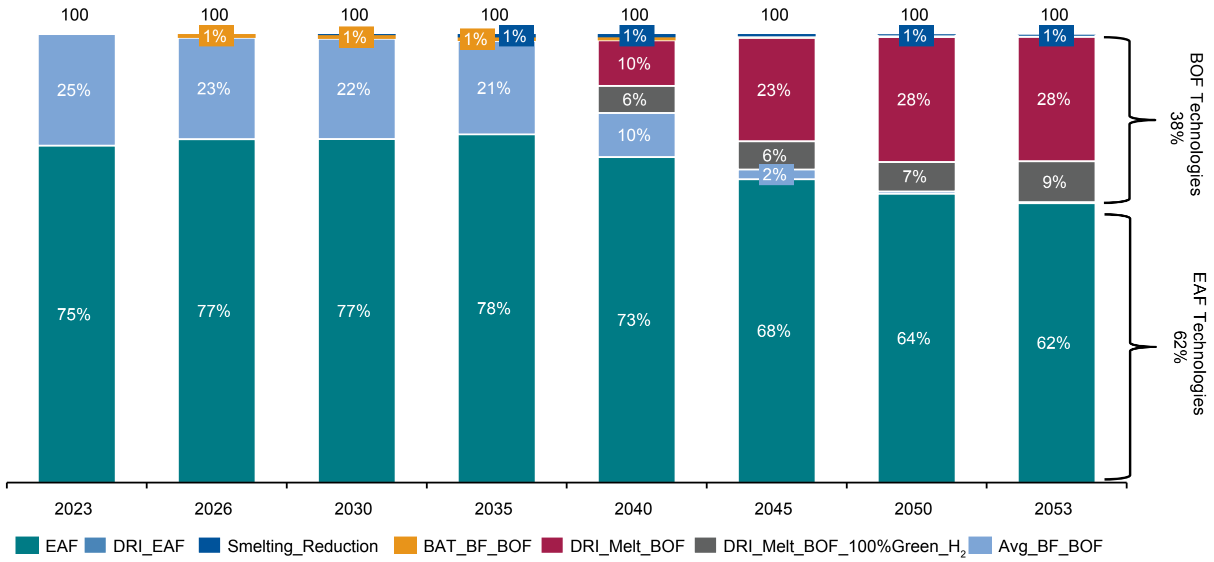
The optimization model has identified varying technology utilization pathways for different scenarios. Different CAPEX, OPEX, and carbon price estimates, together with emission limits in specific scenarios, result in different technology combinations for the next 30 years. No capacity transition from blast furnaces to the EAF route is expected, as it is assumed that blast furnaces will not be shut down and will be used until the end of their lifetime, which extends beyond the 2050s. The technologies in the model that may switch are listed in the switching matrix.

Figure 35. Technology Switching Matrix for both LCP and FTS Scenario

	Avg BF-BOF	BAT BF-BOF	BAT BF-BOF_bio PCI	BAT BF-BOF_H_2 PCI	BAT BF-BOF+BECCUS	BAT BF-BOF+CCU	BAT BF-BOF+CCUS	DRI-EAF	DRI-EAF_100% green H_2	DRI-EAF_50% bio-CH_4	DRI-EAF_50% green H_2	DRI-EAF+CCUS	DRI-Melt-BOF	DRI_Melt_BOF_100%Green_H_2	DRI-Melt-BOF+CCUS	EAF	Electrolyzer-EAF	Electrowinning-EAF	Smelting Reduction	Smelting Reduction+CCUS
Avg BF-BOF	1	1	1	1	1	1	1						1	1	1				1	1
BAT BF-BOF		1	1	1	1	1	1						1	1	1				1	1
BAT BF-BOF_bio PCI			1		1	1	1							1	1					1
BAT BF-BOF_H_2 PCI				1	1	1	1							1	1					1
BAT BF-BOF+BECCUS					1															
BAT BF-BOF+CCU						1														
BAT BF-BOF+CCUS							1													
DRI-EAF								1	1	1	1	1					1	1	1	1
DRI-EAF_100% green H_2									1											
DRI-EAF_50% bio-CH_4									1	1		1					1			1
DRI-EAF_50% green H_2									1		1	1					1			1
DRI-EAF+CCUS												1								
DRI-Melt-BOF													1	1	1					
DRI_Melt_BOF_100%Green_H_2														1						
DRI-Melt-BOF+CCUS															1					
EAF								1	1	1	1	1				1	1	1		
Electrolyzer-EAF																	1			
Electrowinning-EAF																		1		
Smelting Reduction																			1	1
Smelting Reduction+CCUS																				1

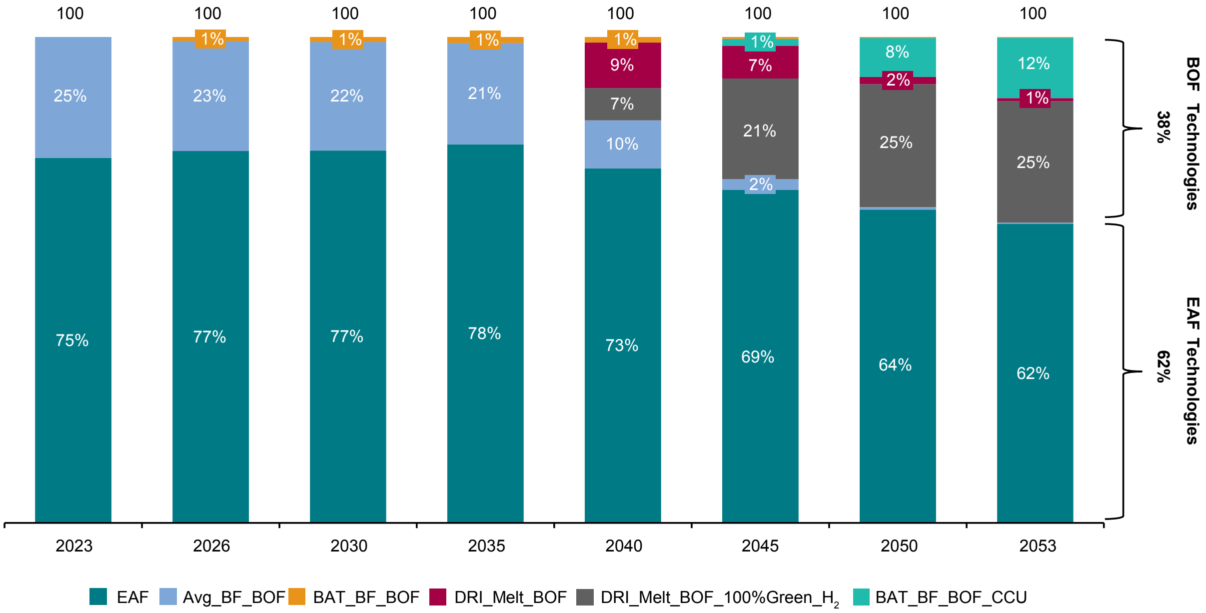
The transformation in the Low ETS scenario incorporates new technologies into the system mostly after the 2030s. In this scenario, EAF route continues to have largest share in the production of steel. The EAF share of production increases from 75% to 78% in 2035. However, with the expectation of an increase in scrap prices and the introduction of new BOF technologies, the EAF share of production decreases to 62% over the years. EAF-DRI technology is deployed in 2029 but captures a low share of production as traditional BOF production is upgraded to new BOF technologies over the years. The transition is mainly achieved through DRI integration. As a result of the modeling study, the proposed technology transitions involve interconversion rather than shutdown. For example, DRI_Melt BOF technologies are not expected to shut down, it is assumed that they will be equipped with H_2 integration and CCUS units later on. By 2053, 62% of production is done with conventional EAF, 28% with DRI-BOF, and the rest with DRI-BOF using hydrogen input. Smelting reduction technology, an innovative technology, starts to capture a very low share in 2045.

Figure 36. Technology Shares of Production Capacity (%): Low ETS Scenario



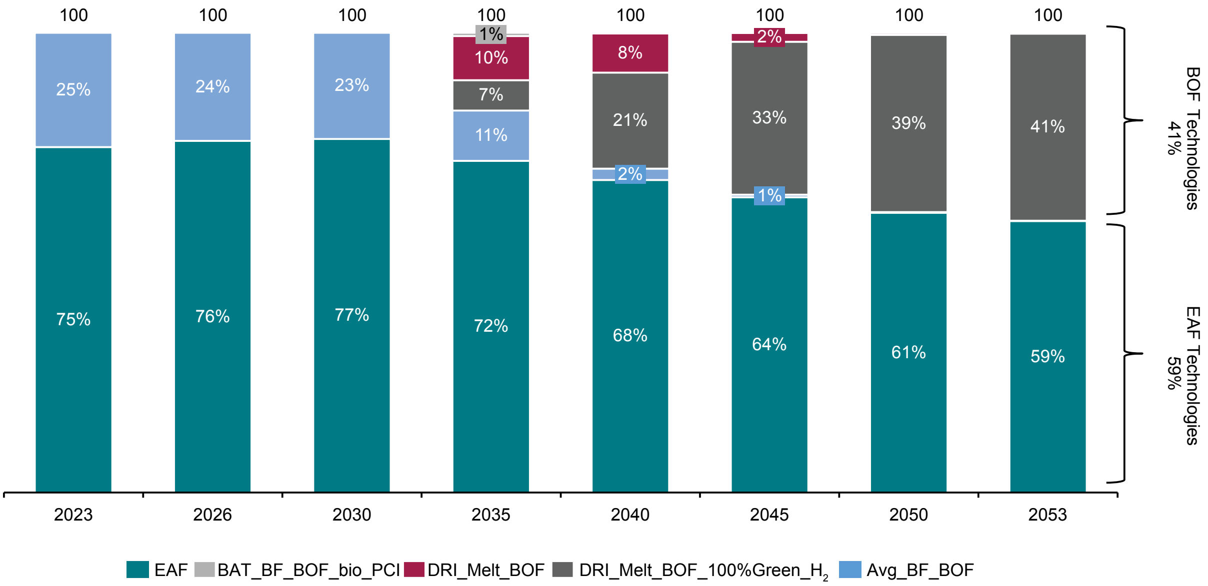
In the LCP scenario, an emission target aiming to reach zero emissions by 2053 is introduced in line with the national targets. In this scenario, there are nine technology archetypes with different phases and penetration rates. Most of the production still relies on EAF, and the EAF share of production is almost same as Low ETS scenario. On the other hand, the LCP scenario includes CCU integration into BOF to achieve zero emission targets. Also, in the LCP scenario radical technologies such as bio-PCI in BOF and hydrogen in DRI-EAF are used in production at low rates. In this scenario, transition is achieved through a combination of hydrogen and CCU technologies. In 2053, CCU technologies account for 12% of production and green hydrogen technologies account for 25%.

Figure 37. Technology Shares of Production Capacity (%): LCP



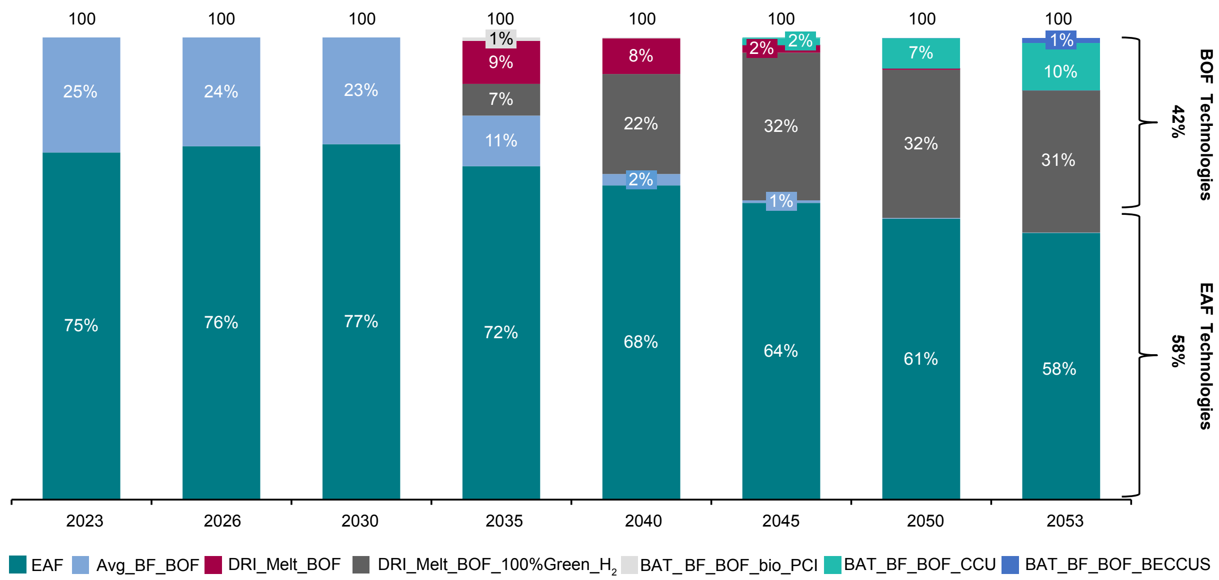
In the High ETS scenario, the transformation starts early compared to the Low ETS scenario as higher national carbon prices push steel producers to invest decarbonization technologies earlier to minimize the cost. Higher share of BOF facilities start using DRI after the 2030s compared to the Low ETS scenario. By 2053, EAF accounts for 59% of production, with 41% coming from 100% green hydrogen integration in DRI-BOF technology. In addition, in this scenario, BOF-bio PCI technology (uses biofuels as an input), which is not preferred in other scenarios, is responsible for a small percentage of production after 2035.

Figure 38. Technology Shares of Production Capacity (%): High ETS Scenario



In the FTS scenario, like LCP scenario, an emission target aiming to reach zero emissions in 2053 is introduced in line with national targets with earlier integration of disruptive technologies such as CCUS. The FTS scenario and the High ETS scenario have almost the same EAF-BOF distribution. The prevalence of BOF technologies in the FTS scenario differs from the other scenarios due to the introduction of the net zero emission target. In the FTS scenario, five BOF technology archetypes are deployed in different years to transform the steel sector. As in the High ETS scenario, the transformation is achieved by starting with natural gas based DRI and hydrogen based DRI technologies and later CCUS technologies are deployed to achieve the emission target. In 2053, processes using DRI will account for 31% of steel production and those using CCUS technologies for 11%.

Figure 39. Technology Shares of Production Capacity (%): FTS



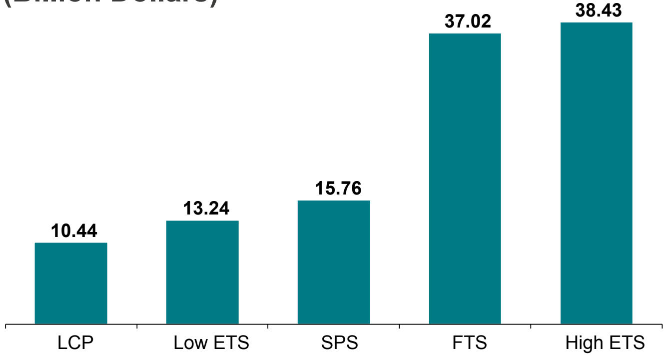
CO_2 Costs[66]

Different scenarios are developed to analyze the impact of the planned national ETS in the optimization model developed for the steel sector. In that regard, future carbon prices under the planned national ETS and EU carbon prices are projected under two scenarios, lower national carbon prices in Türkiye than EU and equal price levels for each year. Carbon prices give producers the option of either reducing their emissions to avoid paying a fee or continue emitting but having to pay for their emissions. Scenario-based CO_2 costs, applied on only Scope 1 emissions, reveals that SPS scenario, where emission are higher as no technological transformation is assumed to envisage, has a carbon cost of a net present value of 15.76 billion dollars covering 2023-2053.

[66]Carbon cost is calculated based on the assumption of possible carbon pricing (indicative) as a result of meetings with stakeholders based on expert opinion (see Scenario Based Assumptions for detailed information).

Low ETS scenario and LCP scenario assume lower carbon prices in Türkiye compared to EU, with a total of 16% and 34% lower CO_2 cost (net present value terms) over 2020-2053 period compared to SPS scenario. The transformation in the LCP scenario is expected to require a net present value of the total carbon cost of 10.44 billion dollars between 2023 and 2053. On the other hand, for FTS and High ETS scenarios, assuming Türkiye setting equal National ETS carbon prices as EU ETS prices, carbon cost is considerably higher compared to other scenarios. The FTS scenario is expected to require a carbon cost of 37.02 billion dollars on a net present value basis between 2023-2053, whereas more rapid emission reduction is assumed.

Figure 40. NPV of Total CO_2 Cost over 2023-2053 (Billion Dollars)

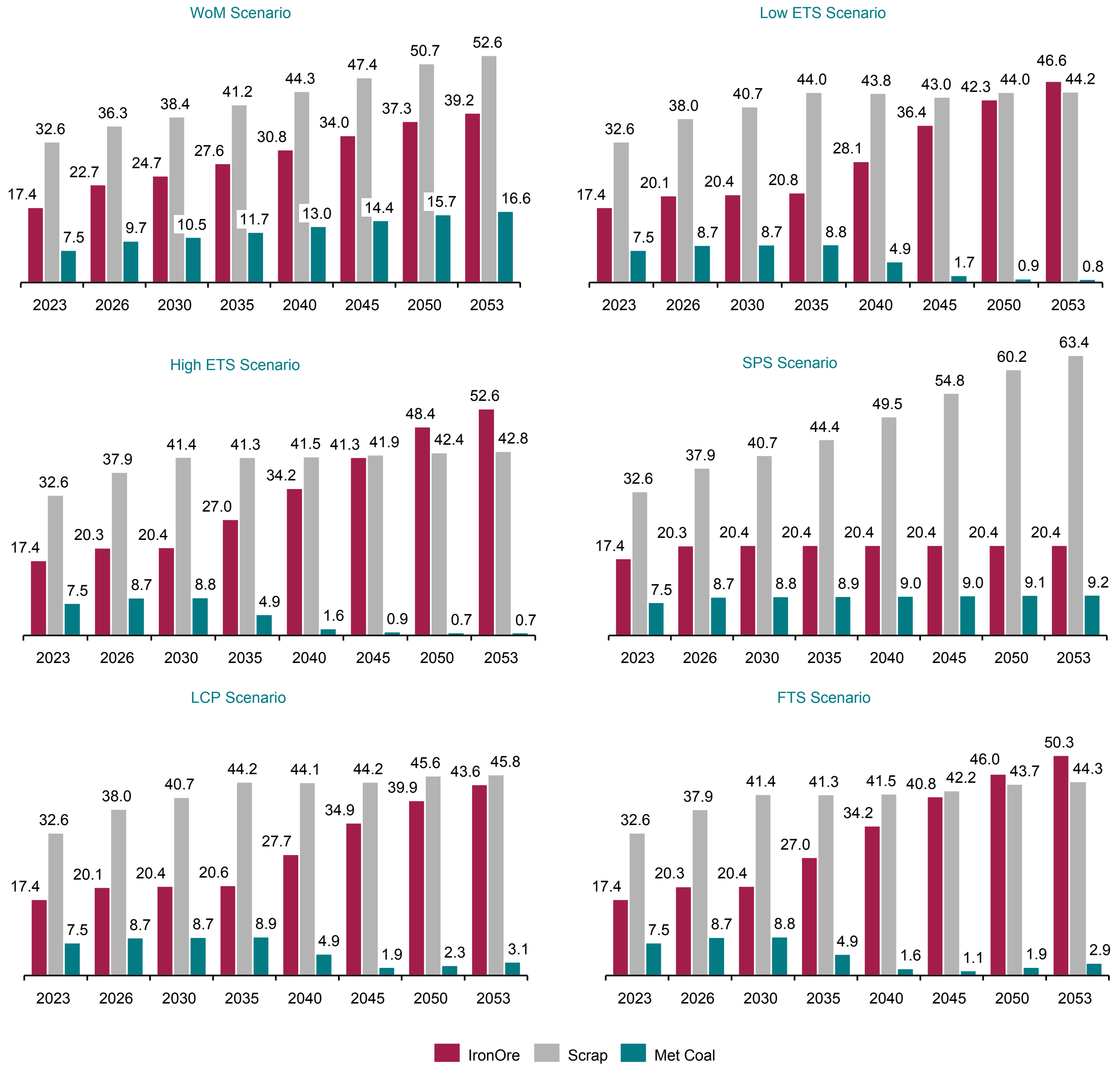


Raw Material Requirement Projection

The model also calculates raw material and energy needs for each technological transformation requirement by scenarios. In this context, demand for iron ore, scrap and metallurgical coal between 2023 and 2053 are projected. Scrap utilization is expected to be lower in the WoM scenario compared to the SPS scenario, predicting that scrap utilization reaches 52.6 million tonnes for the WoM scenario and 63.4 million tonnes for the SPS scenario in 2053. The SPS scenario stands out as the scenario with the highest scrap utilization (63.4 million tonnes) compared to the other scenarios due to the increase in the share of EAF in the production projection and the lack of technological transformation. In the Low ETS scenario, iron ore utilization increases over the years which is caused by the use of technologies such as DRI_Melt_BOF. Thus, by 2053, iron ore utilization is projected to exceed scrap utilization and reach 46.6 million tonnes with the gradual decrease in the share of EAF technologies in production. In the LCP scenario, unlike the Low ETS scenario, it is noteworthy that the scrap input has a slightly higher share than the iron ore input. Main driver of this is mainly the lower share of DRI_Melt_BOF 100% Green H_2 technology in the LCP scenario. In 2053, the LCP scenario forecasts 43.6 million tonnes of iron ore, 45.8 million tonnes of scrap and 3.1 million tonnes metallurgical coal use. In the High ETS scenario, similar to the Low ETS scenario, there is a tendency to use iron ore instead of scrap due to more DRI_Melt_BOF 100% Green H_2 technology in production. Moreover, the High ETS scenario has the lowest metallurgical coal requirement among the 6 scenarios with 0.7 million tonnes of metallurgical coal in 2053. In the FTS scenario, similar to the High ETS scenario, iron ore is preferred over scrap depending on the share of BOF technologies in production. In 2053, 50.3 million tonnes of iron ore, 44.3 million tonnes of scrap and 2.9 million tonnes of metallurgical coal are expected to be used in the FTS scenario.

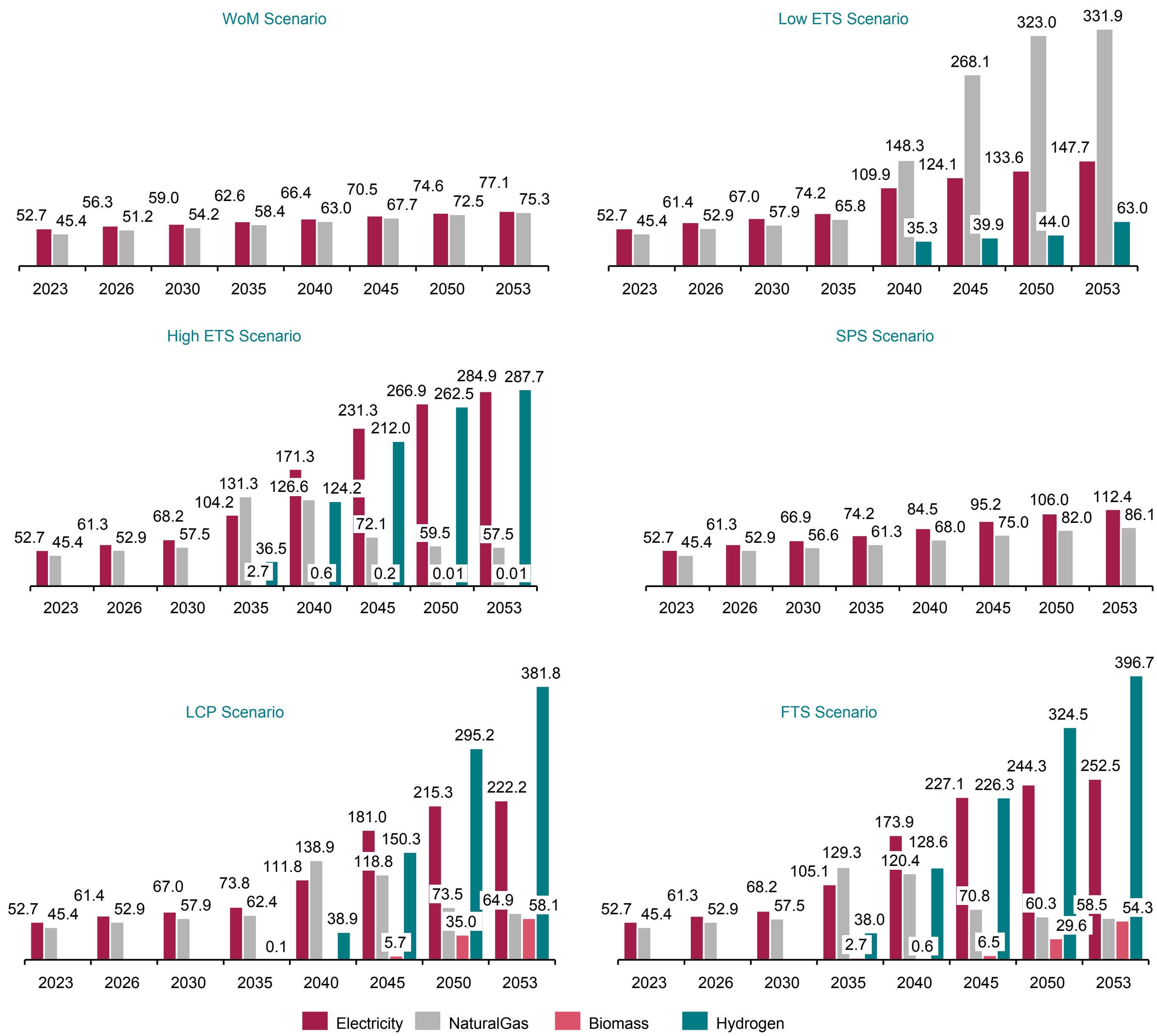
In the WoM scenario, the usage metallurgical coal increases in the following years and reaching 16.6 million tonnes in 2053. The main reason of this is due to the increase of BOF share in production over the years. In the SPS scenario, met coal use increases, albeit at a lower rate compared to the WoM scenario, as the share of BOF still maintains its share in production. In the mitigation scenarios, with the introduction of different production routes and various different energy sources materials, the usage of met coal is expected to decrease.

Figure 41. Raw Material Requirement Projections by Scenarios (Million Tonnes)



Since any technological transformation is not foreseen in the WoM and SPS scenarios, only electricity and natural gas use is needed, as currently used. In the Low ETS scenario, hydrogen is included among the inputs in addition to electricity and natural gas with the implementation of 100% green hydrogen integration to DRI-BOF technology in 2036, reaching 35.3 million GJ by 2040. In the LCP scenario, hydrogen demand reaches 381.8 million GJ in 2053 with the implementation of hydrogen in DRI-EAF technology in 2043 and hydrogen in PCI technology in BOF in 2035 and 100% green hydrogen integration in DRI-BOF technology. Besides, biomass is also used as an input after 2043 with the introduction of CCU integration into BOF, reaching 5.7 million GJ in 2045. In the High ETS scenario, a small amount of biomass utilization is observed starting from 2035 with the introduction of BAT_BF_BOF_bio_PCI technology in production. Moreover, electricity and hydrogen utilization amounts converge in 2053, reaching 284.9 million GJ and 287.7 million GJ, respectively. Furthermore, with the transition from DRI_Melt-BOF technology to 100% green hydrogen integration to DRI-BOF technology, natural gas use decreases as hydrogen use rises. In the FTS scenario, hydrogen use increased with the introduction of both 100% green hydrogen integration to DRI-BOF technology and CCU integration into BOF technology. Thus, FTS scenario has the highest hydrogen requirement among the 6 scenarios. Furthermore, with the introduction of BAT_BF_BOF_BOF_bio_PCI, BAT_BF_BOF_CCU and BAT_BF_BOF_BECCUS technologies, biomass use also increases, reaching 54.3 million GJ in 2053.

Figure 42. Energy Source Projections by Scenarios (Million GJ)



2.6. Investment Needs to Achieve Decarbonization

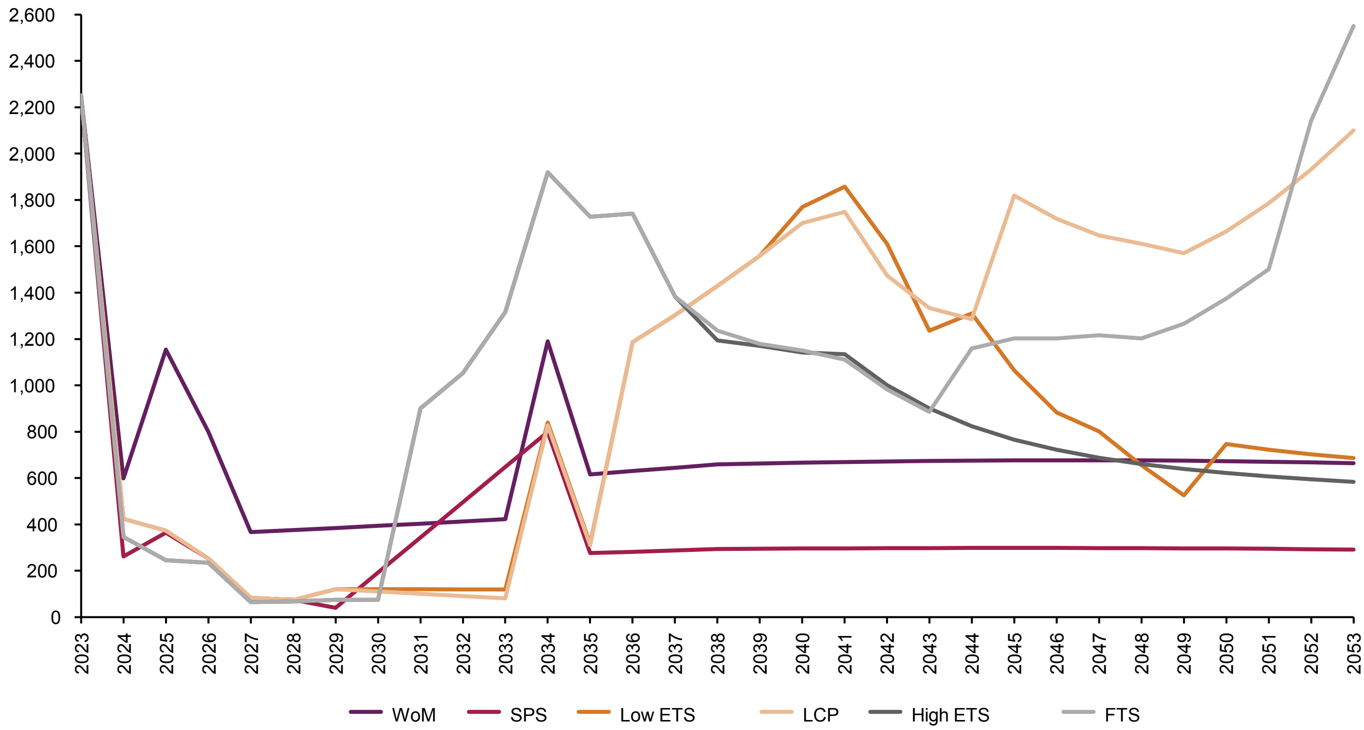
The Turkish steel sector needs new technologies to be designed and implemented through effective investments to achieve the national emission reduction levels committed in line with the Paris Agreement and to transition to a low-carbon economy. Investments are evaluated based on the technologies selected for the different steel sector transition pathways.

Each scenario indicates different pathways towards decarbonization with different technology introduction years, production shares and technology combinations. The objective of the optimization model, which uses input and technology-based data sets, is to minimize cost by considering the emission targets defined in the scenarios. So, different cost and investment needs for different mitigation scenarios are estimated.

Investment requirements are directly related to technology entry years and technology-related CAPEX costs. Total investment amounts of mitigation scenarios are calculated in terms of the introduction of new technologies and capacity shifts in existing technologies, separately. Modelling results indicate that after the period starting in 2030, the cost of investment rises in mitigation scenarios, especially for those with net zero emission targets (LCP and FTS) as expected. Furthermore, the costs of inputs (fuel, feedstock, etc.) used in different technologies have also been included in the model in the light of expert and stakeholder opinions by benefiting from MPP (Mission Possible Partnership)[67], Steelonthenet[68], SteelOrbis[69] and IEA (International Energy Agency)[70] data.

The initial large technological investments are required at the beginning of the year 2034 and accelerate by 2041 in the LCP scenario. In this scenario, annual investments exceed 2.1 billion dollars in 2053. The FTS scenario suggests earlier technology investments, specifically in the 2030-2035 period, in comparison to the LCP scenario as it has more ambitious emission reduction targets annual investment cost for the FTS scenario is assumed to be lower than 1 billion dollars before 2030s, accelerates after that time and reaches to 2.5 billion dollars in the 2030-2035 period.

Figure 43. Annual Investment Cost by Scenario (Million Dollars)*



[67]https://github.com/missionpossiblepartnership/mpp-steel-model/tree/main/mppsteel/data/import_data
[68]https://www.steelonthenet.com/
[69]https://www.steelorbis.com/price-forecasters/orbis-HRC-CIS-export-forecaster/
[70]https://www.iea.org/
*Capacity increases are assumed to meet demand and production projections in 2025 and 2034.

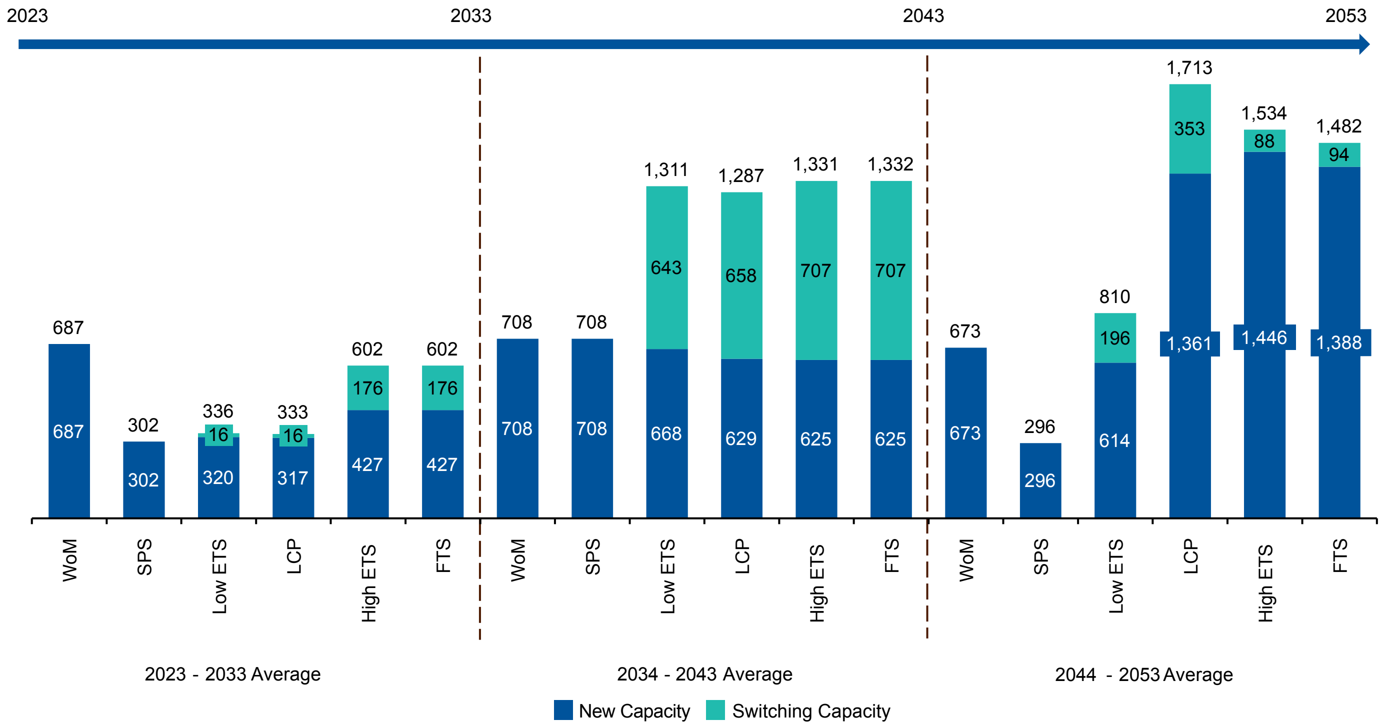
In mitigation scenarios, in addition to new capacity investments, a switch to new technologies is also foreseen. In the LCP scenario, the first cross-technology switching investment is expected in 2035, while in the FTS scenario, the first switching investment is expected five years earlier. In the LCP scenario, investments in new capacity are expected to accelerate more than investments in technology transition in the last decade of the projection period.

In both High ETS and FTS scenarios, new capacity cost is higher than the switching cost in most years. Investments in new technologies to achieve the zero emissions target accelerate from 2043 onwards. In the FTS scenario, total annual investment cost is projected to reach around 2.5 billion dollars, while it is forecasted to exceed 2 billion dollars in the LCP scenario in 2053.

Figure 44. Annual Investment Cost by Years (Million Dollars)

Examination of the average annual investments calculated at 10-year intervals reveals the scenario with the lowest investment requirement is SPS as expected. The average annual investment for mitigation scenarios, which is below 1 billion dollars in 2023-2033, increases to 1.2-1.3 billion dollars in 2034-2043, and reaches 1.4-1.7 billion dollars in 2044-2053. Between 2023 and 2033, the investment requirement of the FTS scenario is higher than that of the LCP scenario due to more aggressive technology entry years. The scenarios with the highest annual average investment in the same period are the Hight ETS and FTS scenarios. Between 2034 and 2043, the Low ETS, LCP, High ETS, and FTS scenarios have similarly high average annual investment due to technological deployment. In the 2043-2053 period, the LCP scenario has the highest average annual investment cost required to achieve the net zero target.

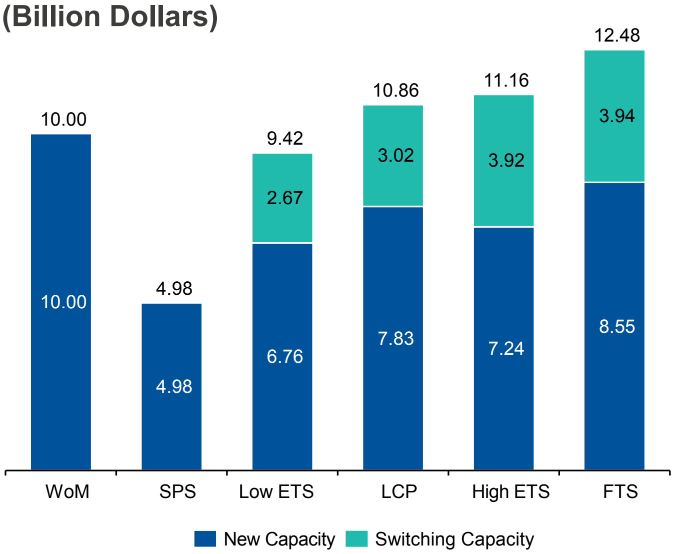
Figure 45. Average Annual Investment (Million Dollars)*



*In the WoM scenario, the average annual investment value for the period 2023-2033 is higher due to the assumption of BOF capacity to remain at its current level.

Based on the NPV of the total investment calculated using a discount rate of 7%, in the 2023-2053 period, the mitigation scenarios show the NPV of total investment costs is between 9 and 13 billion dollars. The NPV of total investments required to reach net zero is approximately 11 billion dollars for LCP, while that is around 12.5 billion dollars for FTS in the upcoming 30 years. The investments required to switch the capacity share in the LCP scenario are projected to be less than in the FTS scenario. In the FTS scenario, investments for switching capacity require 31% of total investments, while in the LCP scenario it requires 28% of the total investment cost.

Figure 46. NPV of Total Investments, 2023-2053 (Billion Dollars)



Financing Investments

Reaching the ambitious emission reduction goals of Türkiye's steel sector will require a steep rise in technology investment. Model results suggest the deployment of technological transformation is required to begin from now and spur in the early 2030s and investment in clean energy technologies will need to accelerate in the following 20 years. Achieving the emission reduction targets in mitigation scenarios will require annual investments of around 0.8-1.1 billion dollars between 2023 and 2053. According to the optimization model, in the 2023-2033 period, 333 million dollars should be spent on average each year for the LCP scenario 602 million dollars for the FTS scenario. To reach net zero in the optimal scenario (LCP), even more funds are needed, 1.3 billion dollars annually between 2033 and 2043, with the annual investment required on average projected to increase to 1.7 billion dollars for the last decade of the model period. (see Figure 45)

The Turkish steel sector's decarbonization trajectories highlight the need for development of financing mechanisms and plans. Although most of the new technology investments are expected after the 2030s, funds should be generated with a longer-term perspective to ease the high investments in the later period. Therefore, measures for boosting the mobilization of additional funds should be prioritized in the short term to enable the steel sector to make the necessary technological transformation in the medium to long term. Policymakers and financial institutions need to collaborate and develop financing mechanisms, so the Turkish steel sector has access to scaled-up capital flows to foster decarbonization investments in the future. It is highly critical to recognize the importance of having a long-term financial plan to achieve the necessary investments to decarbonize the industry. It is essential that the country begins investing early so that the required technological transformation enables the industry to reach the net-zero.

3 The Roadmap for Decarbonization of the Turkish Steel Sector

3. The Roadmap for Decarbonization of the Turkish Steel Sector

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

Policy recommendations that make up the “Decarbonization Roadmap” are essentially derived from 1. Sector Analysis and 2. Modelling and Scenario Analysis. The set of recommendations generated have been opened to several rounds of feedback from the SteerCo members and wider sector representatives.

Special note on recommended technologies: The set of technologies and techniques recommended as part of the roadmap, is in large part based on the “new technologies” defined in Section 2.2. This technology set has then been fortified with the Turkish Scientific and Technological Research Council of Türkiye - TUBITAK’s “Iron and Steel Sector Decarbonization Roadmap” work. This work was carried out in parallel to the project work, and has been co-created with sector experts, academia and TUBITAK’s own experts. While all the technologies and techniques in TUBITAK’s work do not have specific and granular enough data to be included in the modelling work, these were included in the roadmap nevertheless, as this body of work has to be aligned with declared national strategies and policies.

Within an overarching methodology, policy recommendations are grouped under **Input and Technology** and **Policy and Market** high level policy themes, and under these two policy themes **12 main policy areas** have been generated.

A) Input & Technology

A.1) Input Optimization

A.2) Technologies Reducing Direct Carbon Output

A.3) Carbon Capture, Utilization and Storage (CCUS) Technologies

A.4) Process Improvement

A.5) Green Energy

A.6) Inclusive Employment and Upskilling / Reskilling of Labor Force

B) Policy & Market

B.1) Emissions Trading System

B.2) Trade Models

B.3) National Policy Documents

B.4) Green Transformation Finance

B.5) Cooperation

B.6) Circular Economy

3.1.A) Input & Technology

Decarbonization policy areas related to input and technology are detailed below. Specific technologies that have been prioritized by the model are distinguished with the color green[71]. Some of the technologies you will see below are not prioritized by the model results, however, are still included in the policy roadmap due to them being priority suggestions of Turkish Scientific and Technological Research Council of Türkiye (TUBITAK).

- **Phase 1** (2023-2025)
- **Phase 2** (2026-2038)
- **Phase 3** (2039-2053)

[71]Technologies with less than 1% share in production capacity by model outcomes are not “prioritized” by this project’s methodology.

A.1) Input Optimization	Application Time/Interval Phase 1 (2023-2025)	Phase 2 (2026-2038)	Phase 3 (2039-2053)
Undertake studies to understand and enhance Türkiye's domestic scrap supply and make targeted investments to further increase these, based on the results.	●	●	
Monitor possible protectionist initiatives planning to ban scrap export and examine trends in the global scrap market to diversify scrap import sources.	●	●	●
Develop methods and applications to improve scrap sorting and preparation processes in manufacturing facilities.	●		
Increase the yield of low-grade ores (used in blast furnaces and other furnaces) using ore processing/beneficiation methods.		●	
To transform ore into a suitable form for direct use in EAF and IF, carry out R&D, feasibility and prototype studies for DRI/HBI technologies fueled by energy sources with low carbon output/renewable energy, and provide incentives, financing and investment based on these studies.		●	●
Adopt methods using alternative raw materials in producing steel from scrap.	●		

A.2) Technologies Reducing Direct Carbon Output	Application Time/Interval Phase 1 (2023-2025)	Phase 2 (2026-2038)	Phase 3 (2039-2053)
Encourage research and implementation of technologies classified as "Best Available Techniques (BAT)" for the Turkish steel sector:			
Heat or energy recovery from solid and gas streams, coke dry quenching and cogeneration units.		●	
Use of advanced electrostatic precipitators, activated carbon regeneration (ACR) process and selective catalytic reduction (SCR).		●	
Use of neutralization, flocculation, and sedimentation in the treatment section of pelletization plants.		●	
Comprehensive monitoring of the coke oven, the use of gas-tight pumps and fostering desulphurization through absorption systems.		●	
For blast furnaces, use exhaust gas cleaning systems with electrostatic precipitators or bag filters, and appropriate burners to enhance combustion.		●	
Dry dedusting through electrostatic precipitators for BOF, wet dedusting through electrostatic precipitator or scrubber, injection of inert gas or vapor into the blowpipe to disperse dust.		●	
Primary and secondary dedusting of the electric arc furnace for EAF, including scrap preheating, charging, melting, casting, ladle furnace and secondary metallurgy.	●	●	

	Application Time/Interval		
A.2) Technologies Reducing Direct Carbon Output	**Phase 1** (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Encourage research and implementation of technologies classified as "Reducing Direct Carbon Output" for the Turkish steel sector:			
H_2 utilization in blast furnaces.			●
Use of H_2 at varying rates together with natural gas as a reductant in DRI production.			●
Smelting reduction through H_2 plasma reduction.			●
Use H_2 to reach the high temperatures required in burners and in other heating processes.			●
Use electrolysis at lower temperatures (≈110°C) in the aqueous alkaline electrolyte environment.			●
Use higher temperatures (≈1600°C) for the electrolysis of iron ore, similar to the medium in aluminum production.			●
Evaluate alternative raw materials and inputs (bio-CH_4, bio-PCI, etc.) to reduce the use of coke in blast furnaces.		●	
Use improved and alternative coal raw materials in coke ovens and develop efficient coal blending models (charcoal, etc.)		●	
Research, develop and create prototypes of national and international good practice examples and technologies for continuous casting and semi-finished product processing.		●	

	Application Time/Interval		
A.3) Carbon Capture Utilization and Storage (CCUS) Technologies	**Phase 1** (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Encourage research and implementation of technologies classified as "Carbon Capture, Utilization and Storage" for the Turkish steel sector:			
Use non-gaseous H_2 enrichment and/or CO_2 reduction in blast furnaces.			●
Convert output gases captured by carbon capture into fuel (CCU).			●
Convert output gases captured by carbon capture into chemicals (CCU).			●
Capture natural gas-based CO_2 for DRI.		●	
Use a new type of coal-based smelting reactor (HIsarna process) that replaces various energy-intensive steelmaking processing stages and can be combined with CCUS.			●
Strengthen the financial, legal, and technical infrastructure to increase Türkiye's carbon capture and utilization capacity.	●	●	

A.4) Process Improvement	Application Time/Interval		
	Phase 1 (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Establish digital monitoring systems integrated with energy management systems in facilities to increase energy efficiency, maximize production and improve maintenance practices.	●		
Increase maintenance requirements and inspections for steel production facilities to improve process reliability and to increase energy efficiency.	●		
Plan and implement facility retrofitting and renovation activities in a timely manner, introducing low-emission technologies.		●	●
Improve energy, raw material input and efficiency for sinter and pelletization plants.		●	

A.5) Green Energy	Application Time/Interval		
	Phase 1 (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Prepare resource plans to increase the use of renewable energy in the steel sector and evaluate the use of small modular reactors (SMR).	●	●	●
Install renewable energy infrastructure to provide adequate renewable sources and put necessary additional incentive mechanisms into effect.	●	●	
Detect available and appropriate technologies to make green H_2 commercially available and cost-effective for the steel sector.	●	●	●

A.6) Inclusive Employment and Upskilling/ Reskilling of Labor Force	Application Time/Interval		
	Phase 1 (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Determine the new qualifications and skills required for the green transformation of the steel sector and coordinate efforts to train the labour force.	●	●	●
Ensure equal opportunity for all in steel sector employment.	●	●	●
Harmonize higher education curriculum and programs with the green steel skill requirements.	●	●	●

3.2. B) Policy & Market

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

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

	Application Time/Interval		
B.1) Emission Trading System	**Phase 1** (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Establish an ETS in Türkiye that complies with the EU legislation and establish appropriate mechanisms to encourage those operating in strategic sectors to invest in green transformation.	●	●	
Encourage free allowances for emission-intensive facilities with high carbon leakage risk and for facilities with emissions below the sector average.	●	●	

	Application Time/Interval		
B.2) Trade Models	**Phase 1** (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Carry out studies to ensure that the practices in Türkiye meet the required qualifications and are recognized by the EU, in line with the principles of emission measurement and reporting under EU CBAM.	●		
Analyze trade and market shifts arising from increasing trade between countries that have not taken decarbonization steps and take measures to protect national competitiveness in the sector.	●	●	●
Establish a national carbon pricing mechanism and make necessary arrangements to implement it in relevant areas.	●	●	
Identify EU CBAM related trade policies necessary to ensure Türkiye's continued trade with the EU.	●		
Review limitations on investment in green transformation of the sector, under the Treaty on Trade Between the European Coal and Steel Community and the Republic of Türkiye, and conduct necessary negotiations with the EU.	●	●	

B.3) National Policy Documents	Application Time/Interval **Phase 1** (2023-2025)	 **Phase 2** (2026-2038)	 **Phase 3** (2039-2053)
Carry out feasibility studies for R&D and innovation issues that need to be evaluated at the national level.	●	●	●
Develop a clear, long-term vision for sustainable energy transition as part of the steel industry's national energy and climate strategies.	●		
Set mitigation goals for the industry in the Long-Term Climate Change Strategy and the Climate Change Action Plan.	●		
Identify where national legislation differs from EU legislation and ensure coordination to secure full harmonization that protects the right to free movement of goods.	●	●	

B.4) Green Transformation Finance	Application Time/Interval **Phase 1** (2023-2025)	 **Phase 2** (2026-2038)	 **Phase 3** (2039-2053)
Provide public incentives for the deployment of low-emission technologies.	●	●	●
Increase the supply of renewable energy, by facilitating currently unlicensed renewable energy investments.	●		
Mobilize the financial and banking sector for the deployment of low-emission technologies.		●	

B.5) Cooperation	Application Time/Interval **Phase 1** (2023-2025)	 **Phase 2** (2026-2038)	 **Phase 3** (2039-2053)
Carry out studies regarding the participation of steel producing companies in international platforms.	●		

	Application Time/Interval		
B.6) Circular Economy	**Phase 1** (2023-2025)	**Phase 2** (2026-2038)	**Phase 3** (2039-2053)
Develop high quality, value-added, lightweight steel products to contribute to the decarbonization of steel-consuming end-user sectors.		●	●
Encompass the inputs and outputs of the steel sector in the Circular Economy Action Plan to be prepared at the national level.	●	●	
Develop innovative processes and applications for recycling of solid waste from electric arc and ladle furnaces based on the circular economy concept.	●	●	●
Develop techniques for utilizing casting waste in both continuous casting and part-casting.	●	●	●
Develop methods and practices for by-product and waste management in iron and steel plants.	●	●	●
Develop technologies and applications for the recovery of waste gases and heat.	●	●	●

Technology Tracking Platform (TTP)

The Technology Tracking Platform (TTP), a mechanism to be established by the Ministry of Industry and Technology, will track and monitor the specified technologies listed below and other technologies deemed appropriate by the Ministry that will contribute to green transformation, together with the industry stakeholders under the leadership of the Ministry of Industry and Technology. The following technologies are shortlisted based on the work of the IEA, MPP, TUBITAK Specialization Working Group and modelling study.

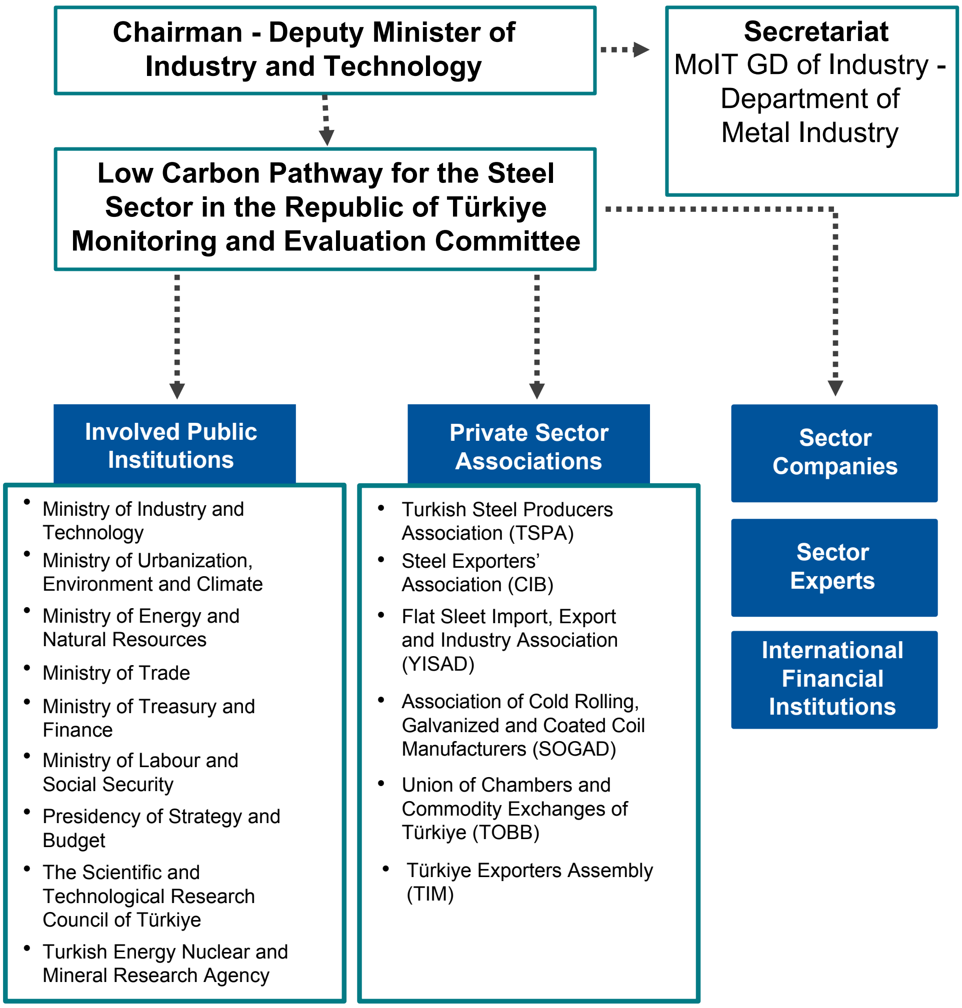
Input & Technology	02. Technologies Reducing Direct Carbon Output	**Encourage research and implementation of technologies classified as "Best Available Techniques (BAT)" for the Turkish steel sector:** - Heat or energy recovery from solid and gas streams, coke dry quenching and cogeneration units. - Use of advanced electrostatic precipitators, activated carbon regeneration (ACR) process and selective catalytic reduction (SCR). - Use of neutralization, flocculation, and sedimentation in the treatment section of pelletization plants. - Comprehensive monitoring of the coke oven, the use of gas-tight pumps and fostering desulphurization through absorption systems. - For blast furnaces, use exhaust gas cleaning systems with electrostatic precipitators or bag filters, and appropriate burners to enhance combustion. - Dry dedusting through electrostatic precipitators for BOF, wet dedusting through electrostatic precipitator or scrubber, injection of inert gas or vapor into the blowpipe to disperse dust. - Primary and secondary dedusting of the electric arc furnace for EAF, including scrap preheating, charging, melting, casting, ladle furnace and secondary metallurgy. - Other technologies deemed appropriate by the Ministry	**BAT technologies are reflected in the scenarios as overall process efficiency.** Process efficiency rates SPS, Low ETS and LCP: 0.1% High ETS and FTS: 0.25% In addition, BAT integration and related technologies are foreseen in the mitigation scenarios on the BF/BOF route. • Low ETS Scenario: BAT_BF_BOF and BAT associated technologies are foreseen. • LCP: BAT_BF_BOF and BAT associated technologies are foreseen. • High ETS Scenario: BAT associated technologies are foreseen. • FTS: BAT associated technologies are foreseen.

Input & Technology	02. Technologies Reducing Direct Carbon Output	**Encourage research and implementation of technologies classified as "Reducing Direct Carbon Output" for the Turkish steel sector:** - H_2 utilization in blast furnaces. - Use of H_2 at varying rates together with natural gas as a reductant in DRI production. - Smelting reduction through H_2 plasma reduction. - Use H_2 to reach the high temperatures required in burners and in other heating processes. - Use electrolysis at lower temperatures (≈110°C) in the aqueous alkaline electrolyte environment. - Use higher temperatures (≈1600°C) for the electrolysis of iron ore, similar to the medium in aluminum production. - Evaluate alternative raw materials and inputs (bio-CH_4, bio-PCI, etc.) to reduce the use of coke in blast furnaces. - Use improved and alternative coal raw materials in coke ovens and develop efficient coal blending models (charcoal, etc.). - BAT BF-BOF bio-PCI (Pre-treated biomass (e.g. charcoal) replacing pulverized coal injection) - BAT BF-BOF H_2 PCI (H_2 replacing pulverized coal injection) - DRI-Melt-BOF (Natural gas based DRI replacing the BF facility) - DRI-Melt-BOF 100% green H_2 (100% green hydrogen based DRI replacing the BF facility) - Smelting reduction (Liquid metal production without coke, through and oxygen treatment) - DRI-EAF (EAF plant using natural gas based DRI) - DRI-EAF 50% green H_2 (EAF plant using %50 natural gas and %50 green hydrogen based DRI) - DRI-EAF 100% green H_2 (EAF plant using %100 green hydrogen based DRI) - DRI-EAF 50% bio-CH_4 (EAF plant using %50 natural gas and %50 biomethane) - Electrolyser-EAF (High temperature iron ore electrolysis, similar to aluminium smelting process) - Electrowinning-EAF (Low temperature iron ore electrolysis through and alkaline solution) - Other technologies deemed appropriate by the Ministry	**Technologies prioritized in mitigation scenarios are as follows:** • Low ETS Scenario: DRI-EAF, DRI-Melt-BOF, DRI-Melt-BOF 100% green H_2 and Smelting reduction technologies are foreseen. • LCP: DRI-Melt-BOF and DRI-Melt-BOF 100% green H_2 technologies are foreseen. • High ETS Scenario: DRI-Melt-BOF, DRI-Melt-BOF 100% green H_2 and BAT BF-BOF bio-PCI technologies are foreseen • FTS: DRI-Melt-BOF, DRI-Melt-BOF 100% green H_2 and BAT BF-BOF bio-PCI technologies are foreseen - BAT BF-BOF H_2 PCI, DRI-EAF 100% green H_2, DRI-EAF 50% green H_2, DRI-EAF 50% bio-CH_4, Electrolyser-EAF and Electrowinning-EAF technology archetypes were included in the model, but not prioritized as a result of the model.
Input & Technology	03.Carbon Capture, Utilization and Storage (CCUS) Technologies	**Encourage research and implementation of technologies classified as "Carbon Capture, Utilization and Storage" for the Turkish steel sector:** - Use non-gaseous H_2 enrichment and/or CO_2 reduction in blast furnaces. - Convert output gases captured by carbon capture into fuel (CCU). - Convert output gases captured by carbon capture into chemicals (CCU). - Capture natural gas-based CO_2 for DRI. - Use a new type of coal-based smelting reactor (HIsarna process) that replaces various energy-intensive steelmaking processing stages and can be combined with CCUS. - BAT BF-BOF + CCS (Integrated plant with carbon capture and storage extension) - BAT BF-BOF + CCU (Integrated plant with carbon capture and utilization extension) - BAT BF-BOF + BECCUS (Bioenergy with carbon capture, storage and utilization) - DRI-Melt-BOF + CCS (Combination of natural gas based BOF-DRI and carbon capture and storage) - Smelting reduction + CCS (Combination of smelting reduction technology with carbon capture and storage) - DRI-EAF + CCS (Combination of natural gas based EAF-DRI and carbon capture and storage) - Other technologies deemed appropriate by the Ministry	**The technologies prioritized in mitigation scenarios are as follows:** • Low ETS Scenario: CCUS technologies are not foreseen. • LCP: BAT BF-BOF + CCU technology is foreseen. • High ETS Scenario: CCUS technologies are not foreseen. • FTS: BAT BF-BOF + CCU and BAT BF-BOF + BECCUS technologies are foreseen. - BAT BF-BOF + CCS , DRI-Melt-BOF + CCS, Smelting reduction + CCS and DRI-EAF + CCS technology archetypes were included in the model, but not prioritized as a result of the model.

Monitoring and Evaluation Mechanism

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

Structure of the M&E Committee



4 Conclusions

4. Conclusions

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

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

The net zero target can only be achieved with a combination of green hydrogen and carbon capture, storage, and utilization technologies. The Turkish Ministry of Energy and Natural Resources announced an ambitious goal to reduce the cost of green hydrogen to 2.4 dollars/kgH_2 by 2035 and below 1.2 dollars/kgH_2 by 2053. Hydrogen[72] will play a significant role in Türkiye's decarbonization pathway. Supportive policies and a strong regulatory framework should therefore be prioritized to support the sourcing of the required hydrogen, so the steel sector is able to meet its industry climate targets and strengthen its competitive power.

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

Implementation of this roadmap will require the continuous support and effective coordination of all related stakeholders. The proposed monitoring and evaluation committee should play a leading role in following the developments affecting the steel sector, and the committee should upgrade the established forecasts and policy framework when needed and guide all stakeholders in implementing the related policies under their control and ownership.

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

[72]The Turkish Ministry of Energy and Natural Resources, Türkiye Hydrogen Technologies Strategy and Roadmap, 2023.