THE IMPACT OF CARBON POLICIES ON HOUSING AFFORDABILITY IN TURKIYE: A SYSTEM DYNAMICS ANALYSIS

by

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ABSTRACT

THE IMPACT OF CARBON POLICIES ON HOUSING AFFORDABILITY IN TURKIYE: A SYSTEM DYNAMICS ANALYSIS

Climate change has become a global priority, prompting governments and international organizations to introduce various mechanisms to combat its effects. One such mechanism is the Emissions Trading System (ETS), which charges for emissions exceeding set caps. In Turkiye, the Draft Climate Law and the Draft Regulation on Carbon Markets outline plans for an ETS establishment. The Ministry of Environment, Urbanisation and Climate Change (MoEUCC) announced that the ETS will be implemented on October 15, 2024. The major objective of this study is to investigate the impact of the planned ETS on housing affordability, considering the lack and insufficiency of studies on carbon pricing in the Turkish literature. For this purpose, a detailed conceptual model has been developed by using system dynamics, through a comprehensive literature review and expert consultation meetings. Firm-level analyses were conducted in the cement and iron-steel industries between 2024 and 2055, increases in unit prices were examined, and increase in construction costs and house prices were analysed. According to the results of the study, it is observed that the cement industry will face a 134% increase in unit prices and the steel industry will face a 47% increase in unit prices. The impact of the increased unit costs on construction costs was found to be 7% and the impact on house sales prices was found to be 5% price increase. The results show that the impact of the ETS on construction costs, house sales prices and housing affordability index is limited, but it leads to significant price increases in the industry. The study also presents a roadmap for the industry and policy recommendations for the government to minimize the cost effects of the ETS.

ÖZET

KARBON POLİTİKALARININ TÜRKİYE'DEKİ KONUT SATIN ALINABİLİRLİĞİ ÜZERİNDEKİ ETKİSİ: BİR SİSTEM DİNAMİĞİ ANALİZİ

İklim değişikliği, hükümetler ve uluslararası organizasyonlar tarafından olumsuz etkilerinin önlenmesi amacıyla çeşitli mekanizmaların geliştirilmesine neden olan küresel bir öncelik haline gelmiştir. Bu mekanizmalardan birisi, belirlenen sınırları aşan emisyonlar için ücret talep eden Emisyon Ticaret Sistemi (ETS)'dir. Türkiye'de, ETS'nin kurulmasına yönelik planları içeren İklim Kanunu Taslağı ve Karbon Piyasalarının İşleyişine İlişkin Yönetmelik Taslağı yayımlanmıştır. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı (ÇŞİDB), ETS'nin 15 Ekim 2024'te uygulanacağını duyurmuştur. Bu çalışmanın ana amacı, Türk literatüründe karbon fiyatlandırması üzerine yapılan çalışmaların yetersizliği ve eksikliği göz önüne alındığında, planlanan ETS'nin konut satın alım gücü üzerindeki etkisini araştırmaktır. Bu amaçla, kapsamlı bir literatür taraması ve uzmanlarla yapılan toplantılar sonucunda Sistem Dinamiği metodolojisi kullanılarak ayrıntılı bir kavramsal model geliştirilmiştir. Çimento ve çelik sektörlerinde 2024-2055 yılları arasında firma düzeyinde analizler yapılmış, birim fiyatlardaki artışlar incelenmiş, inşaat maliyetleri ile konut fiyatlarındaki artışlar analiz edilmiştir. Çalışmanın sonuçlarına göre, çimento sektöründe birim fiyatlarda %134, çelik sektöründe ise %47 artış olacağı gözlemlenmiştir. Artan birim maliyetlerin inşaat maliyetlerine etkisinin %7 ve konut satış fiyatlarına etkisinin %5 fiyat artışı olduğu bulunmuştur. Sonuçlar, ETS'nin inşaat maliyetleri, konut satış fiyatları ve konut satın alım gücü endeksi üzerindeki etkisinin sınırlı olduğunu, ancak sanayide önemli fiyat artışlarına yol açtığını göstermektedir. Çalışma ayrıca endüstri için bir yol haritası ve ETS'nin etkilerini en aza indirmek için hükümete yönelik politika önerileri sunmaktadır.

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LIST OF ACRONYMS/ABBREVIATIONS

3E	Economy, Energy and Environment
ACR	American Carbon Registry
AFD	Agence France Development
BAU	Business as Usual
BF	Blast Furnace
BOF	Basic Oxygen Furnace
$CaCO_{3.}$	Calcium Carbonate
CaO	Calcium Oxide
CAR	Climate Action Reserve
CBAM	Carbon Border Adjustment Mechanism
CBCC	Coordination Board on Climate Change and Adaptation
CBRT	Central Bank of the Republic of Turkiye
CCB	Climate, Community and Biodiversity
CCUS	Carbon Capture, Utilization and Storage
CDM	Clean Development Mechanism
CERT	Carbon Emission Reduction Target
CGE	Computable General Equilibrium
CH4	Methane
CIF	Climate Investment Funds
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
COP	Conference of Parties
DoCC	Directorate of Climate Change
DR	Direct Reduction
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EBRD	European Bank for Reconstruction and Development
EGD	European Green Deal

EMRA	Energy Market Regulatory Authority
ENCORD	European Network of Construction Companies
EPDK	Enerji Piyasası Düzenleme Kurulu
EPİAŞ	Enerji Piyasaları İşletme A.Ş
ETS	Emission Trading System
EU	European Union
GCC	Global Carbon Council
GDAP	Green Deal Action Plan
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GRI	Global Reporting Initiatives
GS	Gold Standard
GYODER	Real Estate Investors Association
H_2	Hydrogen
HAI	Housing Affordability Index
H-DRI	Hydrogen-based Direct Reduced Iron
HFC	Hydrofluorocarbon
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contributions
IPC	Istanbul Policy Center
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
I-REC	International Renewable Energy Certificate
ISSB	International Sustainability Standards Board
JI	Joint Implementation
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCCO_2	Life Cycle CO_2
LDC	Least Developed Countries

LULUCF	Land Use, Land-Use Change and Forestry
M.I.T.	Massachusetts Institute of Technology
MoENR	Ministry of Environment Natural Resources
MoEUCC	Ministry of Environment, Urbanization and Climate Change
MoIT	Ministry of Industry and Technology
MRV	Monitoring, Reporting, Verification
MT	Million Tons
N2O	Nitrous Oxide
NCP	Non-linear Complementary Problem
NDC	Nationally Determined Contributions
NIR	National Inventory Report
NOx	Nitrite Oxide
O & M	Operation and Maintenance
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
OTC	Over the Counter
PCI	Pulverized Coal Injection
PFC	Perfluorocarbon
PM	Particulate Matter
PMI	Partnership for Market Implementation
PMR	Partnership for Market Readiness
PMT	Monthly Principal and Interest Payment
PwC	Price Waterhouse Coopers
R & D	Research and Development
REC	Renewable Energy Certificates
REIDIN	A Real Estate Analytics Platform
SCC	Social Cost of Carbon
SF6	Sulfur Hexafluoride
SO_2	Sulfur Dioxide
TL	Turkish Liras
TRC	Transaction Registration System

TurkStat	Turkish Statistical Institute
TUSIAD	Türk Sanayicileri ve İş İnsanları Derneği
UK	United Kingdom
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNCRC	United Nations Convention on the Rights of the Child
UNEP	United Nations Environment Program
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
USD	United States Dollars
VCM	Voluntary Carbon Markets
VCS	Verified Carbon Standard
VOS	Voluntary Offset Standard
WBCSD	World Business Council for Sustainable Development
WHP	Waste Heat to Power
WHR	Waste Heat Recovery
WOM	World Meteorological Organization
WRI	World Resources Initiative
WTI	Willingness to Invest
WTP	Willingness to Pay
WWF	Worldwide Fund for Nature
YETA	Green Energy Tariff

1. INTRODUCTION

Climate change has been one of the most significant threats to the well-being of the ecosystem and the world's sustainable development. Thus, several countries, governments, and international organizations and institutions focusing on environmental, economic and sociological concerns, such as the United Nations, prioritize climate adaptation and mitigation (Yeldan *et al.*, 2020).

The most critical consequences of climate change include extreme weather events, rising sea levels, a significant reduction in the size of glaciers in the Arctic, Greenland and Antarctica, temperature increases in ocean and seawater, and acidification (Yeldan and Voyvoda, 2015).

The "Greenhouse Effect" is the phenomenon in which atmospheric gases transmit sunlight directly to the Earth but reflect less into space, causing the Earth to warm more than expected. Although the greenhouse effect is a phenomenon that benefits humans and other living things, the increase in greenhouse gases for various reasons is alarming. It jeopardizes the future of the world and living life. Among greenhouse gases, carbon dioxide (CO_2), which increases significantly due to human activities, is one of the most important gases, and studies are concentrated on it (Mercan and Karakaya, 2015).

Global greenhouse gas emissions have historically continued to increase, mainly due to human activities, and unevenly risen in recent decades, leading to a significant climate crisis. In the period 2011-2020, global surface temperature increased by 1.1^oC above the 1850-1900 period (IPCC, 2022). The increase in greenhouse gas emissions worldwide is roughly 3% each year (IPCC, 2022; Stern, 2006). Emissions of greenhouse gases are typically higher in developed countries and lower in emerging countries, although it is rising rapidly (Karapınar *et al.*, 2019).

One of the important reports in this field, the Stern Review on the Economics of Climate Change (Stern, 2006), shows that neglecting climate change could result in economic losses equivalent to 5% of world GDP. It could cause economic losses equal to 20% of global GDP in more extreme scenarios. Meanwhile, reducing greenhouse gas emissions could cost only 1% of world GDP per year to avoid the most severe impacts of climate change.

The Paris Agreement, which was adopted at the 21st Conference of the Parties (COP 21) held in Paris in December 2015, represents a significant action in terms of mitigating climate change on a global scale, with several countries being signatories (TUSIAD, 2016). The goal of the Paris Agreement is to limit the increase in global average temperature to 2^oC below pre-industrial levels and ideally to 1.5^oC. Towards this goal, mitigation initiatives through carbon pricing in developing economies are significant as they are cost-effective and generate revenue for transformation (Uyduranoglu and Ozturk, 2020).

According to literature, two main instruments as Market-Based Mechanisms that can be utilized to combat climate change: Carbon Tax and Emissions Trading Scheme (ETS) (TUSIAD, 2016). The European Union Emission Trading Scheme (EU ETS), which entered into force in EU countries on January 1, 2005, is currently the largest international greenhouse gas emission trading system (Mercan and Karakaya, 2015).

Turkiye is a developing economy with a trend of significantly climbing GHG emissions. Turkiye's total GHG emissions rose by 144.9 percent from 1990 to 2022, ranking the country among the world's top 20 largest GHG emitters (Turkish Statistical Institute, 2024a). Turkiye announced at the United Nations General Assembly on September 21, 2021, that it will become a party to the Paris Agreement and adopt a 2053 Net Zero Emission Target, and the Turkish Grand National Assembly unanimously adopted the Law on the Approval of the Ratification of the Paris Agreement on October 6, 2021 (Şahin *et al.*, 2021). Turkiye accelerated its climate actions after becoming one of the parties to the Paris Agreement.

Turkiye started to prepare the necessary legal infrastructure in 2013 to operate a GHG Emissions Monitoring, Reporting and Verification system in line with the EU ETS under the World Bank's Partnership for Market Readiness (PMR) project (Karapınar *et al.*, 2019). Accordingly, Turkiye established a Monitoring Reporting Verification system in 2015 and made the first action towards designing a domestic ETS (Aşçı, 2024). By monitoring the emissions of certain sized facilities in the electricity, iron and steel, aluminum, cement, glass, ceramics, lime, mineral wool, paper, refinery products and chemicals sectors for about nine years, the country had sufficient industry-specific memory to establish its own ETS system.

According to the draft "Regulation on the Functioning of Carbon Markets" dated November 2023, Turkiye's Emissions Trading System (ETS) will be launched in 2025 (Aşçı, 2024). Following the Climate Law, which is expected to be accepted in 2024, the "Regulation on the Functioning of Carbon Markets" is planned to be finalized and published. The scope of Turkiye's national ETS is expected to be the same as that of the GHG MRV system's scope, for the pilot phase. Therefore, cement and steel will be among the covered industries.

1.1. Research Gap

Governments and international organizations are implementing various measures and regulations to reduce the negative impacts of climate change, with carbon emissions restrictions being a key focus. The emissions trading system is the primary method for limiting carbon emissions and has been implemented in many countries. Since Türkiye signalled the possibility of establishing an emissions trading system in 2015, some studies have been conducted from a general economic perspective. These studies mainly employed the computable general equilibrium methodology, focusing on macroeconomic changes. Specifically, Turkiye's Nationally Determined Contribution and future projections of emission levels have been widely covered.

However, industry-specific studies are limited and mainly conducted from an economic modelling perspective. In industry-specific studies conducted worldwide, the unit cost increases of producers and the carbon cost pass-through to consumers have been analyzed. Although few studies analyze the impact of emissions trading systems on housing affordability in the global literature, no study has been conducted specifically in Turkiye yet. This study focuses on the microeconomic level by examining the effect of emissions trading systems on firm-level emissions and the cost impact on products on a firm basis. It then explores, from a broader perspective, how changes in the cost of these products would affect households' ability to purchase a home.

1.2. Aim and Objectives of the Study

This study aims first to analyze the impact of the emissions trading system on firm-level emissions and product costs. The study examines the emissions of a cement and steel firm, analyzing the carbon pricing burdens that lead to cost increases in product prices based on emission levels. After determining the per-unit cost changes of cement and steel products, the study evaluates their effects on construction costs and house sale prices. With changing house prices, the housing affordability for a mean-income family is analyzed. The main objective is to investigate whether the emissions trading system will cause a downsizing in the housing sector as it imposes extra costs on the cement and steel industries, the primary materials used in construction. Simultaneously, the study examines the effects of the emissions trading system on the emission levels and unit product prices of cement and steel production facilities. In addition, the study aims to identify the best possible support mechanisms and strategies for producers to encourage emission reductions.

1.3. Research Methodology

Turkiye's literature has economy, energy, and environment (3E) models. However, most of these are based on Computable General Equilibrium (CGE) or regression analysis. While CGE studies macroeconomic equilibrium, regression forecasts future

data from past data. Since this study analyzes the impact of a policy that has yet to be implemented in the Turkish market, it is unsuitable to use the regression analysis method based on past data. As the study aims to investigate the effects first on the firm level and, after that, the widespread effect on housing affordability, applying the CGE model is also unsuitable, which focuses on macroeconomic data. Instead, the System Dynamics methodology, a powerful approach for analyzing the behaviour of complex systems over time, is more suitable for this analysis. This methodology allows for modelling complex systems, such as the relationship between the Turkish cement and steel market, construction costs, and housing affordability. The study adopts a bottom-up approach to analyze how increasing costs of materials like cement and steel affect the construction sector, starting from the firm level.

1.4. Scope and Limitations

The study focuses exclusively on concrete and steel rebars used in construction. However, the emissions trading system will also lead to increased costs for other cement and steel materials, even if their quantities are relatively small. Since economic modelling is outside the scope of this study, it has not been conducted. The economical data used in this study is based on relevant global reports and their future forecasts. The uncertainty surrounding economic changes over the next 30 years could particularly affect housing affordability. The study does not anticipate significant changes in construction materials over the next 30 years, as there are currently no competitive substitutes on the market for concrete and steel. It is considered that the companies kept their production routes the same during the years under analysis.

1.5. Organization of the Study

This study consists of six main chapters. Chapter 1 aims to give general information about the study, including the research gap, aim and objectives, scope, and limitations. Chapter 2 offers a detailed literature review on greenhouse gas emissions and climate change, related global legal frameworks and agreements, and carbon policy

mechanisms, such as market-based and tax-based mechanisms, from a global perspective. This chapter provides a holistic view of why countries implement these policies. It also investigates carbon policies and market developments in Türkiye. Additionally, the chapter examines cement and steel production methodologies, emissions sources, and the environmental impact of the construction industry. Chapter 3 investigates the methodology used in this study, system dynamics, in detail. It covers principles and concepts, application areas, the developed model and its sub-model structure, the stock and flow diagram, and data collection sources for the model's implementation. Chapter 4 presents the analysis of the developed model, the cost effects on the construction industry, and changes in housing affordability. This chapter finally discusses the results of the study on the basis of similar studies in the literature and the perspectives of the experts consulted. Chapter 5 concludes the study with a summary of the findings, contributions to knowledge, contributions and recommendations to the field, limitations of the study and suggestions for future research.

2. LITERATURE REVIEW

2.1. Greenhouse Gas Emissions and Climate Change

Greenhouse gases (GHGs) are gases with the ability to release ultraviolet light in a specific thermal infrared spectrum. The greenhouse effect results from greenhouse gases trapping high temperatures in the lower atmosphere, preventing heat from escaping back into space and the earth from cooling (Borduas and Donahue, 2018). The greenhouse gas effect significantly contributes to the earth's sustainability and living conditions; however, human activity has disrupted the natural balance of greenhouse gases, and greenhouse gas emissions have increased far more than they should have. The upset of this natural equilibrium brings about the greenhouse gas effect and global warming.

Greenhouse gases consist of water vapor, carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), and ozone (O3) gases, all of which exist in the atmosphere in certain amounts naturally. They also include fluorinated compounds generated by industry, such as sulfur hexafluoride (SF6), perfluorocarbon (PFC), and hydrofluorocarbon (HFC) (Mercan and Karakaya, 2015). CO_2, which exists in a small amount in the atmosphere (0.03%) and has an average persistence period of 100 years, has the largest share of greenhouse gasses, due to human activities (Lu *et al.*, 2012).

The IPCC's sixth assessment report indicates that the average global surface temperature increase is approximately $0.74(\pm)\ 0.18\ ^oC$ during the past century. This rising temperature has led to crucial global climate change, rising sea levels, extreme flooding, moving landscapes, spreading infectious diseases, and other consequences. Greenhouse gas concentrations in the atmosphere have increased since about 1750, and CO_2emissions have been approximately 2400 ± 240 GtCO_2 from 1850 to 2019. Of this total, 42% occurred between 1990 and 2019 and 58% between 1850 and 1989 (IPCC, 2022).

According to the study conducted by the International Monetary Fund (2023), as seen in Figure 2.1, to keep the temperature change around 2^oC or 1.5^oC, carbon dioxide (CO_2) and other greenhouse gas (GHGs) emissions must be decreased by around 25-50% below 2019 levels by 2030. The national targets set under the Paris Climate Agreement aim to reduce emissions by only 13% according to the 2019 levels. If the required reductions in emissions do not achieve, it is almost impossible to meet the targets outlined in the Paris Agreement. Under the "business as usual" (BAU) scenario, which represents the real-world dynamics as of today, it is estimated that global emissions will increase in the absence of new mitigation measures or an improvement of existing ones (Parry *et al.*, 2023).

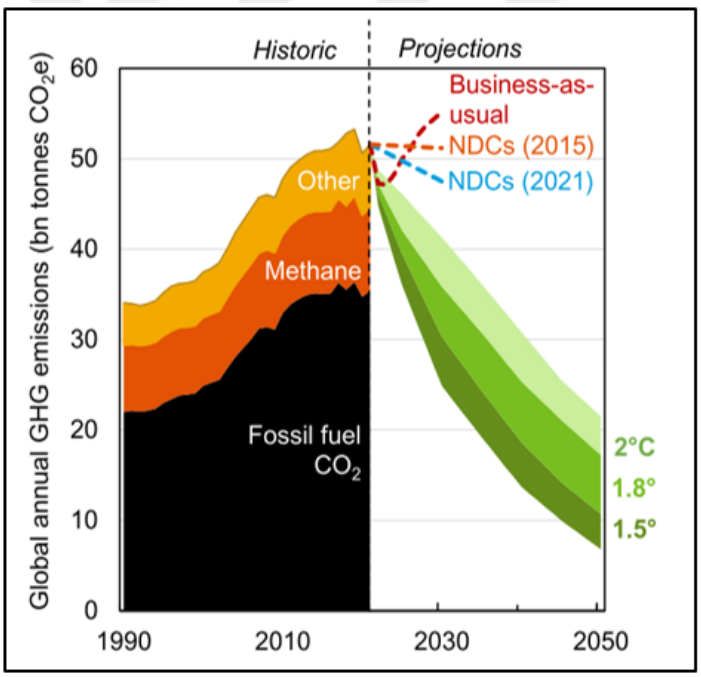


Figure 2.1. Global GHG emission projections according to the business-as-usual scenario and nationally determined contributions (NDCs) targets (Parry *et al.*, 2023).

Nationally determined contributions (NDCs) published by October 2021 represent internationally projected greenhouse gas emissions for 2030, showing that these emission targets could challenge efforts to keep temperatures below 2^oC and that the world will probably surpass the likely in the twenty-first century with these targets.

In addition to that, there are discrepancies between anticipated emissions from implemented policies and those from NDCs (IPCC, 2022).

According to the study conducted by the Istanbul Policy Center, the difference between carbon dioxide (CO_2) emissions and greenhouse gas emissions should also be considered when calculating the carbon budget. CO_2 accounts for three-quarters of emissions of the seven greenhouse gases listed in the Kyoto Protocol. Furthermore, CO_2 accumulates more and has the most significant effect of warming the planet since it stays in the atmosphere more than other greenhouse gases. Therefore, mitigation strategies for greenhouse gases other than CO_2 are considered more complex, uncertain, and secondary. For this reason, carbon budgets, especially in IPCC reports, are calculated for CO_2 emissions and not for all greenhouse gases, and research and studies have focused more on CO_2 emissions (Şahin *et al.*, 2021).

More than 1.7 trillion tons of CO_2 have been emitted in the world since 1751. Before 1750, carbon dioxide (CO_2) emissions from the combustion of fossil fuels were practically zero. The United Kingdom was the world's first industrialized country and the first emitter of fossil fuel CO_2. According to the best available data (from 1750 onwards), as indicated in Figure 2.2, the United Kingdom was responsible for most global emissions until the 1910s. After the 1910s, the United States gained momentum, mainly due to industrialization, and became the world's largest emitter, surpassing the United Kingdom in cumulative carbon emissions. While the portrait did not change until the 1980s, after the 1980s, Germany accelerated its emissions and became the world's second-largest emitter after the United States. In 1990, Russia became the second largest emitter, and in the 2000s, China overtook Germany to become the second largest emitter, but the USA never lost its first place. In 2022, the cumulative emissions of the top 5 emitters are as follows: USA 429.91, China 260.62, Russia 199.29, Germany 93.99, UK 78.83 billion tons. In contrast, Turkiye has only 11.79 billion tons of cumulative carbon emissions (0.66% of global cumulative carbon emissions) and most of the countries in the emissions from Africa have covered less than 0.01% of the total emissions in the past 266 years (Ritchie *et al.*, 2023). Figure 2.3

shows that, China, the US, India, the EU27, Russia and Brazil were ranked as the world's top six GHG emitters in 2022.

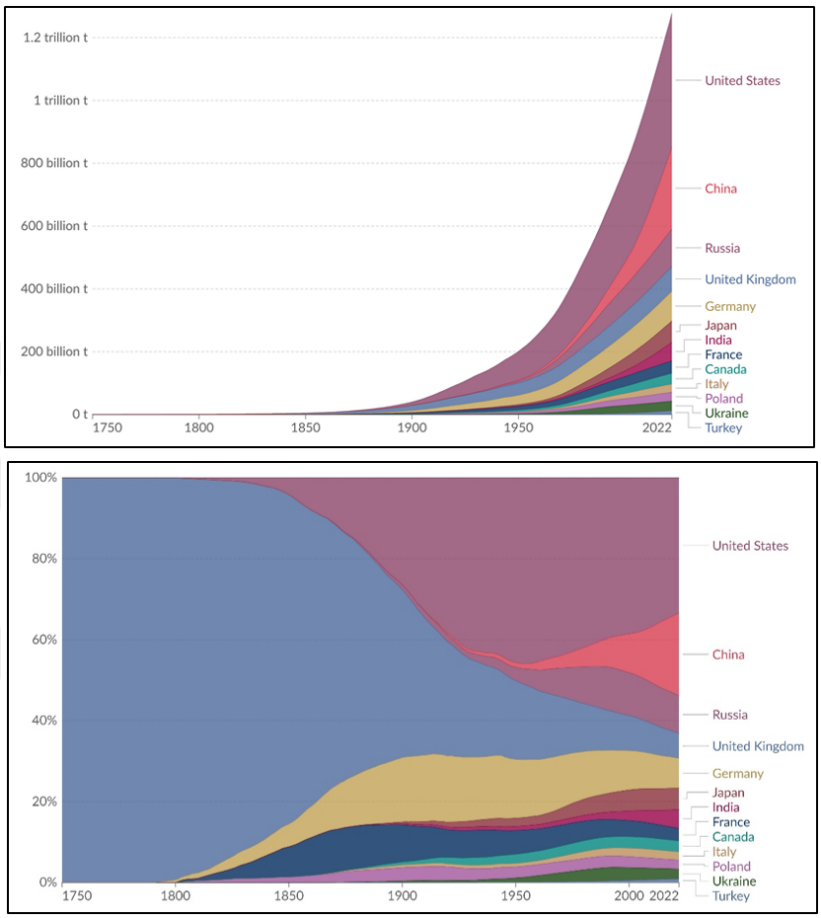


Figure 2.2. Cumulative carbon dioxide (CO_2) emissions by country from the year 1750 to 2022 according to relative values and percents (Ritchie *et al.*, 2023).

The analysis of global emissions shows that countries with historically highest emissions may not be the most significant emitters today, as shown in Figure 2.3. For instance, the United Kingdom was liable for just 0.86% of global emissions in 2022. The difference between historical responsibility and current annual emissions creates stress with the argument that those who contributed the most in the past should do the most to reduce emissions today. CO_2 remains in the atmosphere for hundreds of years once released. This disparity also causes international agreements difficulty in deciding who is obliged to act (Ritchie *et al.*, 2023; Mercan and Karakaya, 2015).

In addition, just transition, one of the mechanisms under the Paris Agreement, becomes even more critical due to this inequality.

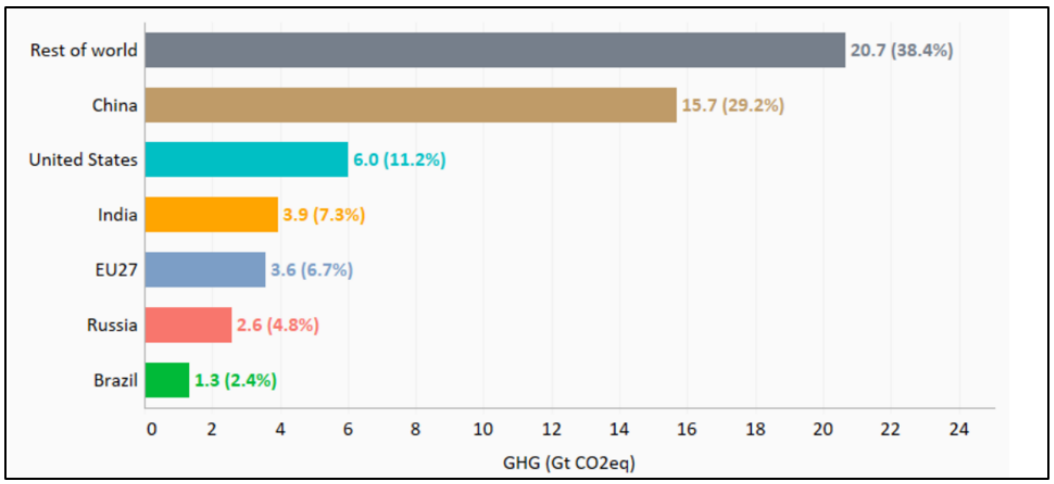


Figure 2.3. Global greenhouse gas emissions and the contribution of major emitting economies and the rest of the world in 2022 (Crippa, *et al.*, 2023).

2.2. Global Legal Framework

One of the major topics in global policy debates is reducing greenhouse gases, particularly carbon emissions, which account for 56% of the greenhouse effect (Wen *et al.*, 2016). In recent years, global community leaders have worked strictly to fight against climate change and reduce carbon emissions (Lu *et al.*, 2012).

A series of steps have been taken nationally and internationally by introducing climate change to the global agenda. In this context, the conference organized by the United Nations in 1972 was the first international step. Following this conference, many conferences on climate change were organized, and the climate change problem introduced the world agenda. The first decision taken at the beginning of this journey was the establishment of the "Intergovernmental Panel on Climate Change (IPCC)" in 1988 with the support of the United Nations Environment Program and the World Meteorological Organization. The IPCC publishes an Assessment Report every 5 to 7 years to show climate change's current effects and status. The first Assessment Report

was published in 1990; the following were published in 1995, 2001, 2007, 2014, and the last in 2023. These reports are carried out by many scientists from different disciplines within the IPCC, aiming to raise awareness of international policies to be implemented on climate change and to help discussions on climate change. Climate change was scientifically explained for the first time in the report published by the IPCC in 1990 (Mercan and Karakaya, 2015).

Based on the solid evidence that increased pollution (especially CO_2 emissions) is a primary cause of global warming, in the 1992 Rio Summit, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted, which entered into force in 1994 (Telli *et al.*, 2008). While setting greenhouse gas reduction targets, the UNFCCC separated countries into two groups in terms of their level of development. Between these groups, the Annex-2 list consists of countries that were Organization for Economic Co-operation and Development (OECD) members in 1992 and before and EU countries and the Annex-I list consists of countries in the process of transition to a market economy in addition to the countries in the Annex-II list (Mercan and Karakaya, 2015). Under the UNFCCC, so-called Annex-I countries agreed, on a voluntary basis, in order to restrict their emissions to levels in 1990. The OECD (1992) and EU countries formed the Annex-II group, which complied with providing technical and financial help to countries who stayed outside of Annex-I in order to guide them adopt environmental limits to cut greenhouse gas (GHG) emissions (Telli *et al.*, 2008).

In 1997, with the Protocol prepared at the third Conference of the Parties held in Kyoto, an important step was taken to reduce the amount of greenhouse gas emissions to certain levels according to the level of development of countries worldwide. The Kyoto Protocol is the first global climate agreement. With this protocol, collaborating targets were decided for 37 developed, developing countries, and the European community to mitigate GHG emissions by 2012 (Lu *et al.*, 2012). The Kyoto Protocol entered into force on February 14, 2005, while first commitment period was covering the years 2008-2012; the second commitment period was covering the years 2013-2020.

Worldwide countries and leaders at the UN Framework Convention on Climate Change (UNFCCC) in Copenhagen signed Copenhagen Accord, a new climate agreement. It underlies the urgency to fight with climate change likewise the principle of common but differentiated obligations and respective capabilities, recognizes that global temperature increase must be limited to less than 2 degrees Celsius, and commits to taking action to achieve this goal likewise science and based on equity and financial plans (Zhu *et al.*,2010).

In 2015, the 21st Conference of the Parties (COP 21) to the UN Framework Convention on Climate Change (UNFCCC) in Paris was a turning point in climate change action, with 196 Parties coming together and 147 Parties submitting 119 Intended Nationally Determined Contributions (INDCs) which cover 86% of global emissions. The Paris Agreement was also accepted at this conference, which aims to keep global temperatures 1.5 or 2 ∘C below pre-industrial levels and recognizes this would essentially decrease the climate change risks and impacts. Signatories will continue to prepare and submit their Nationally Determined Contributions (NDCs) at the end of each five-year period, as required by the Paris Agreement (Alkan *et al.*, 2018). The Paris Agreement approaches with a different perspective from the Kyoto Protocol. Rather than building a perceptible global goal for greenhouse gas emissions that all state parties must fulfill, the Paris Agreement addresses global warming below a certain threshold (TUSIAD, 2016).

China and the USA, the world's two largest emitters (around 45% of total emissions), became parties to the Paris Agreement in 2016. During the period, they submitted their INDCs and NDCs, which Climate Action Tracker assessed as insufficient (the USA) and highly insufficient (China) based on fair share. The USA withdrew from the agreement under the Trump administration in 2020 and became a party again in 2021 under the Biden administration (UNFCCC, 2015; Climate Action Tracker, 2023).

Lastly, the decision adopted at the 26th Conference of the Parties (COP 26) of the UN Framework Convention on Climate Change (UNFCCC) in Glasgow (Glasgow

Climate Pact) underlined both the 1.5-degree target and the need to reduce emissions by 45% below 2010 levels by 2030. Today, 76 countries responsible for 74.2% of global emissions, containing the USA, China, the EU, many European countries, Japan and South Korea, have published net zero emission targets (Şahin *et al.*, 2021).

The Kyoto Protocol and the Paris Agreement have established important mechanisms such as the Clean Development Mechanism, Joint Implementation Mechanism, Emissions Trading, Voluntary Markets to encourage parties to reduce carbon emissions, as shown in Table 2.1.

Table 2.1. Defined flexibility mechanisms (Mercan and Karakaya, 2015).

Mechanism Type	**Relevant Article Number**	**Participant Country**		**Applicable Carbon Unit**
		Investor (Buyer)	**Host (Seller)**	
Clean Development Mechanism (CDM)	Kyoto Protocol, Article 12	Annex-B Countries	Non-Annex I Countries	Certificated Emission Reduction (CER)
Joint Implementation (JI)	Kyoto Protocol, Article 6	Annex-B Countries		Emission Reduction Unit (ERU)
Emission Trade (ET)	Kyoto Protocol, Article 17, Paris Agreement, Article 6.2	Annex-B Countries All countries		Allowed Amount Unit (AAU)
Voluntary Market	Paris Agreement, Article 6	All countries		Verified Emission Reductions (VER)

The Kyoto Protocol (KP) introduces three flexibility mechanisms for the countries. These mechanisms are designed to reduce greenhouse gas emissions at a lower cost. The Clean Development Mechanism (CDM) and the Joint Implementation Mechanism (JI) are project-based mechanisms that enable parties to carry out activities to reduce greenhouse gas emissions outside their countries. Emissions Trading (ET) is a market-based mechanism. Under the CDM, an Annex-1 country with an emission

reduction target (Annex B) can undertake projects with a non-Annex-1 country that is not targeted at emission reductions. In this way, more cost-effective mitigation is achieved, and the transformation of less developed countries is supported. The JI Mechanism allows joint projects to be carried out only among Annex-1 countries. Emissions Trading will be discussed in detail in the following sections (Ministry of Environment and Forestry, 2011; Mercan and Karakaya, 2015).

Article 6 of the Paris Agreement was created to facilitate international cooperation in addressing climate change through voluntary mechanisms. Article 6.2 explicitly outlines methods to ensure the transparency of the inter-country transfer of GHG emission reductions and removals and avoid double counting emissions under different NDCs. This article allows for authorizing emission reductions generated by voluntary carbon market activities to contribute to other countries' NDCs or international mitigation efforts strategies (UNDP, 2024).

In line with the European Union's (EU) commitment to tackle climate change, in December 2019, the EU announced the European Green Deal (EGD), which is considered the flagship of the climate policies that have been adopted so far. EU Green Deal's main aim is to put climate change and environmental crisis at the center of all regulation's dimensions. The key pillars of the EGD established to reshape the EU economy for a sustainable future. For this purpose, the EU will pursue the strategies listed below (Yeldan *et al.*, 2020).

- Reducing greenhouse gas emissions on a set schedule to make the EU achieve net-zero targets by 2050
- Providing clean, accessible and secure energy
- Zero pollution
- Protection of ecosystems and biodiversity
- A just, healthy and eco-friendly food system through a 'Farm to Fork' strategy
- Intelligent and sustainable transportation
- Energy and resource-efficient buildings

- Encouraging new circular economy business models
- Supporting those most affected by transformation (commitment to "leave no one behind")

A key consideration for reduction efficiency at the global level is leakage: a carbon price applied in one country or region can cause a shift in the production of energy or carbon-intensive products to countries without a carbon price. As the influence of GHG emissions on climate change is global and independent of where emissions occur, this emission leakage from one country to another can diminish the efficiency of a carbon price. One solution is border tax adjustments at the country or regional level, whereby tariffs on imports assure that they are responsible for a similar tax burden to domestic industries (Sathre and Gustavsson, 2007; Alexeeva, 2010).

In this regard, the EU introduced a Carbon Border Adjustment Mechanism (CBAM) in October 2023 with a transition phase of 2 years. Under the CBAM regulation, greenhouse gases emitted during the production of a product entering the EU market from abroad will be priced if they are not taxed or priced in the country of origin; if they are priced there, this price will be deducted from the carbon price applicable in the EU (Yeldan *et al.*, 2020).

2.3. Carbon Policies

The significant adverse effects of climate change drive the global collaboration to adopt essential evaluates to mitigate greenhouse gas emissions (Du *et al.*, 2022). Numerous legal initiatives and policy frameworks are in place to reduce carbon emissions. As illustrated in Figure 2.4, economic and financial instruments used to fight with climate change can be categorized into two main groups: market-based instruments and non-market-based instruments. Subgroups include feed-in tariffs, including subsidies and incentives, green certificates that can be traded, and tax reduction instruments. Emission reduction policies through carbon pricing have become more prominent in recent years. Among these instruments, emissions trading and carbon tax are the most

emphasized market-based instruments in the literature and in practice (Karakaya *et al.*, 2023).

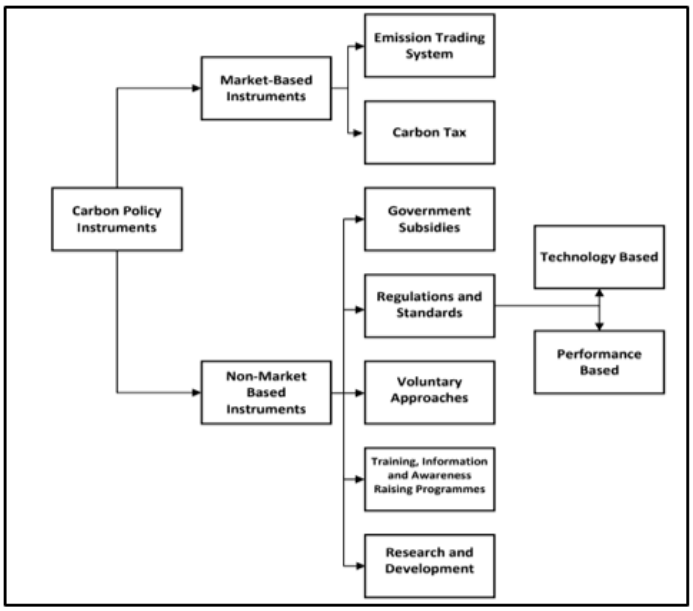


Figure 2.4. Policy instruments to reduce GHG emissions (Karakaya *et al.*, 2023).

2.3.1. Mechanisms and Key Features

The fundamental reason and logic of the carbon regulations and legislations are providing some incentives for emitting lesser or finding alternate sources that has less carbon emission (Kunsch *et al.*, 2001).

A climate change policy, to be effective, needs to influence decisions on economic activity. Three ways exists to handle this: a) by requiring businesses and individuals to evolve their perspective concerning technology choices and emissions; b) by subsidizing businesses and individuals to invest in and use lower-emission products and services; or c) pricing the GHG externality so that decisions take this external cost into account (Aldy and Stavin, 2012).

Environmental taxes offer some fiscal advantages by reducing carbon emissions released into the world. Short-term solutions to achieve this goal include reducing

energy use or switching to fuels with a lower carbon footprint. Financial decisions are expected to lead to industrial production with less carbon in the medium term. Carbon limits can encourage longer-term structural changes in production and consumption patterns, such as the shift from fossil energy sources to renewable energy sources that mitigate the consequences of climate change (Sathre and Gustavsson, 2007).

2.3.1.1. Emission Standards. Emission standards regulate the amount of acceptable pollutant discharge. Regulations usually define verified emission reduction technologies and environmentally hazardous activities to ensure compliance. Government agencies typically regulate emission standards under legislation or authorization. While this policy is easy to integrate and achieve the emission mitigation goal, it has been debated for being overly rigid, insensitive to geographical and technological differences, lacking flexibility, and complex to establish regulatory frameworks (Lu *et al.*, 2012). The government regulates the carbon emissions of all activities up to a certain number and strictly enforces this for all units, which is also known as Command and Control (Zhu *et al.*,2010).

2.3.1.2. Renewable Energy Subsidies. Carbon subsidies are incentives that governments provide to encourage businesses and consumers to adopt clean energy sources and decrease their emissions. Policies that encourage energy production from renewable energy sources include renewable portfolio standards (minimum renewable energy use), subsidies for renewable generation, guaranteed prices (feed-in-tariffs) for renewable energy, subsidies for electric vehicles or solar panels (Aldy and Stavin, 2012; IMF, 2012).

2.3.1.3. Feebates. Feebates are designed to generate a portion of revenue or to be revenue neutral, depending on whether the pivot point is above or below the industry average emission rate. For instance, new vehicles are charged the difference between CO_2 per kilometer and a "pivot point" level in vehicle sales, with corresponding discounts for vehicles with CO_2 per kilometer below the pivot point (IMF, 2012).

2.3.1.4. Carbon Tax. Carbon tax reduces carbon dioxide emissions from fossil fuels (coal, natural gas, gasoline, diesel, etc.) by imposing a tax based on their carbon content or the carbon emissions emitted (Ming, 2014). It is market-based and is also referred to as a price instrument to control pollution as it sets a price for carbon emissions (Zhu *et al.*, 2010). The behind reason of integrating a carbon tax is to upgrade and change of the logic of the business by presenting that these sustainable initiatives are more profitable than paying an emissions tax (Wong and Lacarruba, 2012). Carbon taxes can be applied upstream to producers and even to a product's end user. This flexibility strongly influences public awareness and behavior (Lu *et al.*, 2012).

According to the Zhu *et al.* (2010), if the level of the carbon tax is chosen appropriately, it can be an encouragement for effective emission reductions and incentivize firms to choose the appropriate level of emission reductions emissions (Zhu *et al.*,2010). Brouwers *et al.*, (2018) approaches with a different perspective and states that, companies that already have a relatively high level of carbon efficiency compared to their industry rivals may not be encouraged to develop their performance further.

Since stakeholders' perceptions of a firm's green reputation can also strongly affect its financial performance, policymakers should endeavor to complement the value-based market mechanism with a principle-based mechanism (e.g. naming and shaming, mandatory emissions disclosures) (Brouwers *et al.*, 2018).

Carbon taxation is relatively simple and easy to manage and can consists of all primary emission sources compared to emissions trading. Implementing a carbon tax does not require establishing new mechanisms, as the administrative systems of general taxes can be used. In most countries, carbon taxes are applied directly to consumers through the taxation of fuel at the pump (TUSIAD, 2016). However, in practice, the integration of carbon taxation is quite limited, with only 39 countries implementing carbon taxes; this limited application is mainly because of low levels of public support and political feasibility (Uyduranoglu and Ozturk, 2020; World Bank, 2024).

2.3.1.5. Carbon Crediting Mechanism. Under the Carbon Crediting Mechanism, tradable carbon credits are generated and represent one tCO_2e through voluntary emission reduction activities. For instance, carbon credits can represent avoided emissions or removals, including methane captured from landfills before it is released into the atmosphere or carbon sequestration through afforestation. These credits can be sold to buyers to generate revenue (IMF, 2012).

2.3.1.6. Emission Trading System. In the Emissions Trading Scheme (ETS), in other words the cap-and trade system, the authority sets an emissions cap for the companies for a certain period. It distributes emission allowances for free or auctions at a cost. If emitters want to buy more allowances, they must buy credits from other less polluting emitters and offer their excess allowances. Therefore, the mechanism results in a obligated emission cap while giving sources flexibility in their compliance. The carbon price is decided by the demand and supply of carbon emission allowances issued by the regulator (Lu *et al.*, 2012).

The ETS has three key pillars: sector coverage, carbon emission cap and carbon quota allocation. Grandfathering, benchmarking and auctioning are now mainstream carbon quota allocation methods. Carbon quotas are often allocated free of charge (grandfathering and benchmarking) and supplemented by paid allocation (auctioning) to reduce the burden on carbon-intensive companies. The grandfathering method is based on companies' historical carbon emissions by default. The benchmarking method applies industry average or advanced emission levels as standard. The auctioning method puts all quotas on the trading market for uniform auction, which puts economic pressure on carbon-intensive companies and is less feasible in the first phase of ETS implementation (Du *et al.*, 2022).

2.3.2. Carbon Markets

Carbon markets are separated into two fundamental categories: Compliance and Voluntary Carbon Markets. The details of these markets are given in Figure 2.5.

Compliance markets are mainly shaped by the Kyoto Protocol Flexibility Mechanisms, described in detail in the previous section, which allow countries to reduce their responsibilities in compliance carbon markets, and the National Compliance Carbon Market, which will be explained in detail in this section. Voluntary Carbon Markets can be operated by governments or traded over the counter (OTC) by independent organizations.

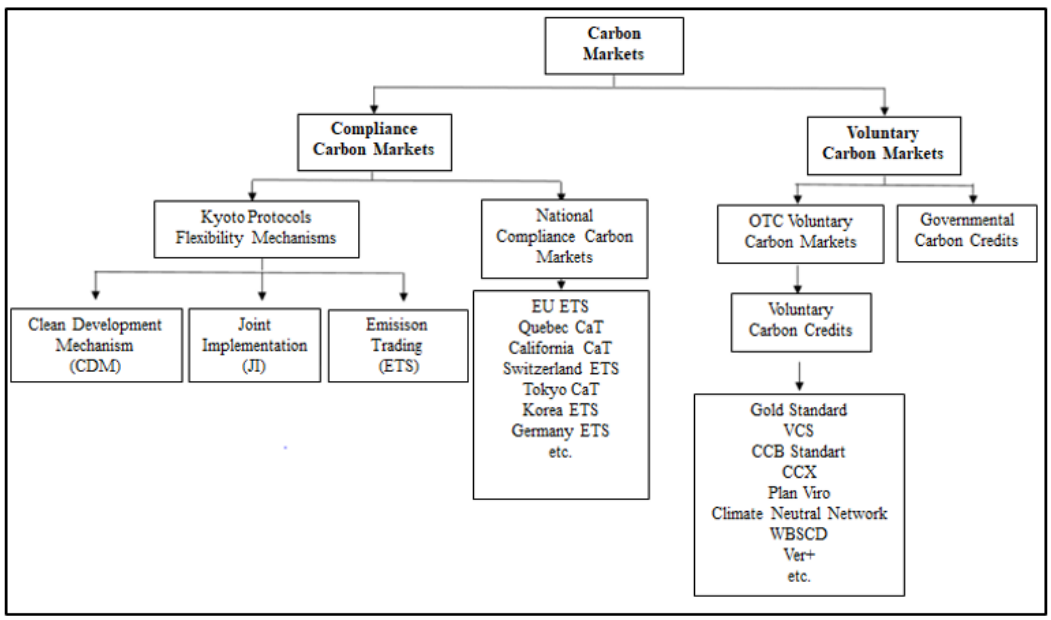


Figure 2.5. Global carbon markets (Yüksel *et al.*, 2022).

Price-based instruments, which have been frequently used in climate change policies in recent periods, aim to reduce emissions by making production, consumption and services with high carbon emissions more expensive through government intervention by setting an emission price. Such cost-effective methods encourage the development of emission-reducing production technologies and innovation in clean technologies (Aldy and Stavin, 2012). Governments, particularly in middle-income countries, are increasingly incorporating crediting frameworks into their policies to support both compliance and voluntary markets. However, despite the emerging demand for compliance markets, the demand for carbon credits continues to be driven mainly by voluntary markets (World Bank, 2024a).

2.3.2.1. Voluntary Carbon Markets. Voluntary Carbon Market (VCM) projects registered under different VCM standards provide emission reduction units to environmentally responsible businesses. Under VCM, there is no legally binding cap on the emissions or emission allowances allocated to a business entity. However, the relevant entities self-introduce these in line with their climate targets. Generally, such targets and offsets used by relevant commercial entities complement their commercial promotion strategies (UNDP, 2024).

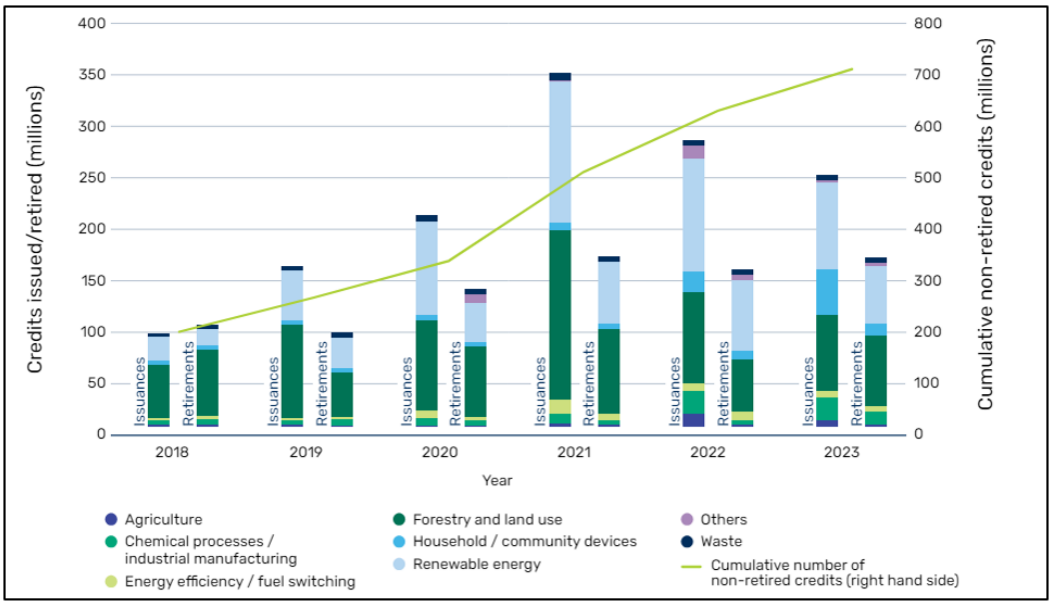


Figure 2.6. Issuances and retirements by project category in voluntary carbon credit mechanisms (World Bank, 2024a).

The main carbon standards dominating the market include the Verified Carbon Standard (VCS), the Gold Standard (GS), the American Carbon Registry (ACR) and the Climate Action Reserve (CAR). The scope of each of these standards ranges. For instance, the VCS serves as a blueprint for various projects, including renewable energy installations, reforestation efforts, energy efficiency improvements and methane capture initiatives, while the GS covers renewable energy, household clean cooking solutions, reforestation and clean, safe drinking water supplies (VCS, 2024; GS, 2024).

As illustrated in Figure 2.6, demand for carbon credits remains stable mainly from 2022 to 2023 and issuances have consistently exceeded retirements for the last five years. As a result, over 700 million unretired credits are currently from the leading independent mechanisms. Around 38% of these credits come from renewable energy projects and 32% from deforestation prevention/transformation projects (World Bank, 2024a).

2.3.2.2. Compliance Carbon Markets. The literature on environmental economics indicates two primary tools as Market-Based Mechanisms that can be used to address climate change (TUSIAD, 2016):

(i) Taxation (e.g. carbon tax) or subsidies (e.g. energy efficiency subsidies, subsidies for renewable energy technologies, feed-in tariffs for renewable energy),
(ii) Emissions trading system (ETS) based on quota allocation and cap and trade system

Tradable emission permits and carbon pricing mechanisms are standard market-based instruments for limiting global greenhouse gas emissions, particularly carbon dioxide emissions. A tradable emission permit scheme based on the principle of "cap and trade" allows the regulator to issue the required number of permits annually to limit the annual level of emissions, and these emission permits can be traded on a private market between emitting parties. A carbon taxation scheme is based on the logic of imposing a tax on polluters equal to the CO_2 equivalent or a tax per unit of emissions (Kunsch and Springael, 2008).

Carbon pricing options offer the most cost efficient option to tackle the climate change and it can also help countries around the world meet their mitigation commitments. While there are two main policy options - carbon taxation and emissions trading systems - the primary function of both policy options is the same, but the methods used in pricing are very different (Aydın, 2023).

These two choices and probable solutions must be examined to build the most effective ways to reduce climate change with minimal damage to a country's economic prospects (Aydın, 2023).

Today, carbon pricing mechanisms cover almost a quarter of global emissions. Carbon pricing and markets continue to evolve and grow, reaching a record revenue of $104 billion at the end of 2023 ($75 billion from ETSs, $29 billion from carbon taxes), driven by high carbon prices in the EU. The total number of instruments in place has also increased: as of 2023, 75 national carbon pricing instruments are in operation (39 taxes versus 36 ETSs). In addition, large middle-income countries such as Brazil, India, Chile, Colombia, and Turkiye are making significant progress in implementing emissions trading schemes. The status of implementation of ETS and carbon tax system is shown in Figure 2.7, indicating that some countries are implementing only ETS or Carbon Tax, some countries prefer to implement both, and emerging markets are also moving towards implementing carbon policies. Global carbon emissions coverage could increase to 30% once the carbon taxes and emissions trading systems (ETSs) are under consideration (World Bank, 2024a).

According to Du *et al.* (2022), due to its versatility and cost-effectiveness, the emissions trading system (ETS) has become one of the most effective instruments for several governments to accomplish Net Zero Targets (Du *et al.*, 2022).

EU Commission (2016) states that, emissions trading systems are among the most cost-effective instruments for reducing greenhouse gas emissions. Unlike traditional 'command and control' arrangements such as carbon taxes, trading uses market forces to find the cheapest ways to reduce emissions (EU Commission, 2016).

Karakaya *et al.* (2023) also indicated that ETS systems are more politically feasible instruments in comparison to taxes. A significant reason for this is that free permits can be distributed in the initial phase of an ETS.

The other reason is that taxes are more likely to be met with public opposition. In addition to public opposition, another challenge in implementing a carbon tax is affecting macroeconomic indicators such as economic growth, welfare and employment. So that, a taxation system may create costs for businesses, leading to lower output and lower growth (Karakaya *et al.*, 2023).

ETS schemes can be implemented at the regional level (EU ETS), national level (e.g. South Korea, Norway, Switzerland, New Zealand, Kazakhstan) or city or state level (California, Quebec, Beijing). In addition, multi-lateral bodies such as the ICAO (International Civil Aviation Organization), with 191 members, can use the ETS. In the national contribution declarations submitted before the Paris Agreement, around 90 countries had indicated their intention to use the carbon market (Karakaya *et al.*, 2023).

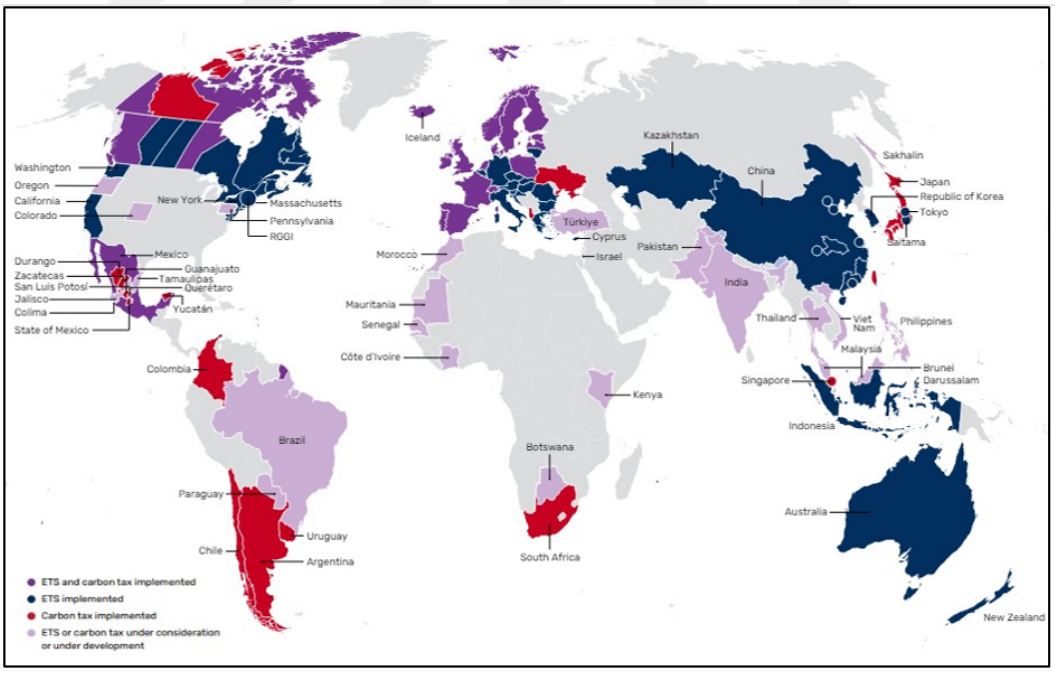


Figure 2.7. Global map of carbon tax and ETS implementations (World Bank, 2024a).

Market-based approaches set a single price for each ton of carbon emissions. The cost of emissions is increased by selling ETS emission permits or carbon taxes per

unit. The solution to alleviate the financial burden of the price is to incentivize the industry to reduce emissions and the amount of environmentally harmful production. Furthermore, this type of abatement scheme can help achieve cost-effective emission reductions as producers can choose how to reduce their emissions (invest in renewable energy or purchase carbon credits) (TUSIAD, 2016).

An essential consideration in carbon tax or emissions trading is how the carbon price will be applied and how the price will be decided. Theoretically, the carbon price is based on the cost of loss caused by greenhouse gas emissions that create negative externalities being met by those responsible for that damage. The Social Cost of Carbon (SCC), calculated as the present-day economic value of the climatic disasters caused by one ton of CO_2 emissions, requires quite a complex modelling (Karakaya *et al.*, 2023). According to a recent empirical study by Tol (2023), depending on the assumptions, the social cost of SCC is estimated to increase as climate-related awareness increases, and SCC is estimated to be in the high range of $122-525$ per ton in the low interest (discount) rate scenario. If the goal is to implement a carbon price that internalizes the negative externalities caused by carbon, the ideal would be to set a price equal to the SCC. However, this is difficult to do for many economic and political reasons (Karakaya *et al.*, 2023; Tol, 2023).

In practice, it is recommended that the carbon price is initially set at a low level. This step may be more politically acceptable and facilitate public acceptance of this new policy. Gradually, the carbon price should be increased in the coming periods. This increase is necessary because a high carbon price is needed to incentivize the required technological changes, and the SCC increases each year (Karakaya *et al.*, 2023).

In many countries, unit carbon prices per ton of CO_2 equivalent (tCO_2e) in global Emissions Trading Systems (ETS) and carbon tax systems have remained too low. Most of these countries have set carbon prices well below the levels required to meet the Paris Agreement targets of limiting global warming to 1.5 or 2 degrees Celsius. These low-carbon prices do not encourage companies to invest in low-carbon

technologies. Companies often pay relatively low carbon prices rather than higher costs for these investments. Consequently, current carbon pricing structures need to deliver the significant transformation needed towards sustainable, low-carbon activities.

According to the World Bank (2024a) study, achieving the 1.5^oC pathway requires greater ambition in ETSs and carbon taxes. In 2017, the High-Level Commission on Carbon Prices stated that carbon prices should be US$40-80/ton of carbon dioxide equivalent (tCO_{2e}) in 2020 and hit US$50-100/t CO_{2e} by 2030 to stay on track to restrict temperature increases to well below 2ºC (Stiglitz *et al.*,2017).

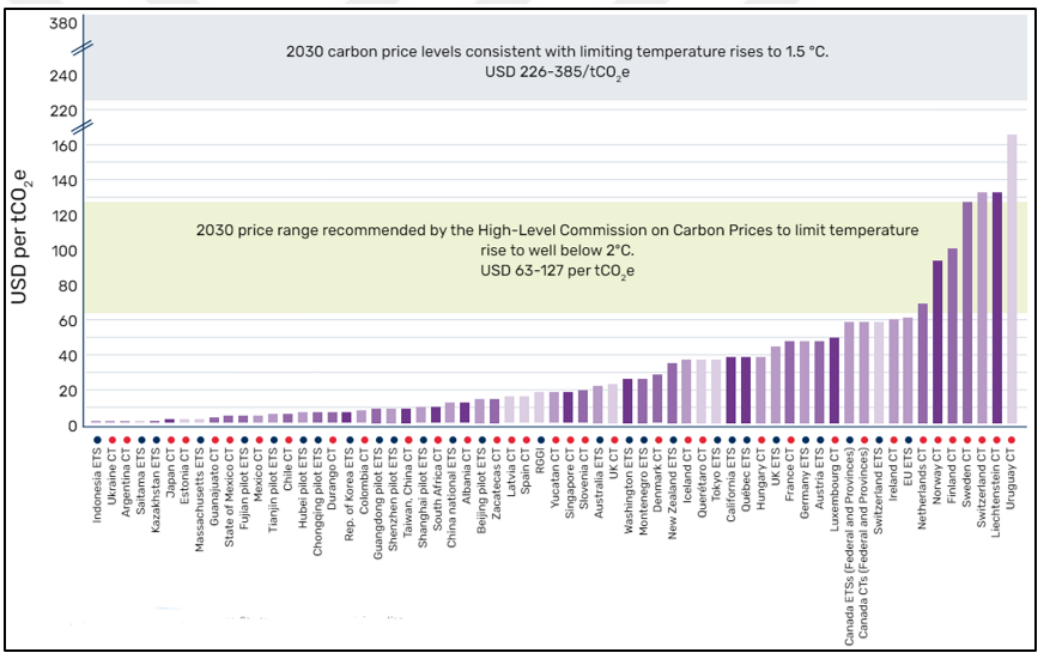


Figure 2.8. Worldwide prices and coverage of ETSs and carbon taxes, as of April 1, 2024 (World Bank, 2024a).

As illustrated in Figure 2.8, in 2024, only seven carbon pricing instruments comprising less than 1% of global greenhouse gas emissions achieved price levels at or above the inflation-adjusted minimum level of USD 63 per t CO_2e. Moreover, all current carbon prices are below the lower carbon price bound set by the Intergovernmental Panel on Climate Change (IPCC) predicts that the marginal abatement cost to limit warming to 1.5^oC is between USD 170 and 290 per tCO_2e (226 to 385 in 2024 USD).

While carbon taxes and ETSs are steadily rising in scope and new initiatives are being constructed, most of these carbon pricing instruments are insufficient enough to drive the level of change needed to meet the Paris Agreement's temperature targets (World Bank, 2024a).

Carbon taxes and emissions trading systems are market-based mechanisms, but their implementation and methodologies are very different. While ETSs and carbon taxes both follow the 'polluter pays' principle, they differ in price setting, scope and cost coverage, level of emission reductions, control mechanisms, simplicity and flexibility of the system, government perspective and ease of linking with other nations' structures. The extensive literature review, Table 2.2, shows that both mechanisms can be applicable and have strengths and weaknesses depending on the country's strategy.

For instance, in contrast to the emissions trading system, no new mechanisms need to be established, as the existing general tax administration systems can be used in carbon taxation. In addition to that, still the emission control mechanism depend on carbon trading is more adaptable with market rationality, significant obstacles can occur in the audit and monitoring phases. The quota allocation method, whether favorable pricing will be applied during allocation, how the price will be decided, and how industrial allowances will be determined are crucial elements for the system's accomplishment. Industrial instability and firm attendance are also significant to the design of this system (TUSIAD, 2016).

In a carbon tax, while the price of each ton of carbon emissions is set and thus the carbon price is known, the extent to which this price will reduce emissions is unknown. In emissions trading, on the other hand, it is known from the beginning how much emissions will be reduced, and emission permits are allocated accordingly. However, it is uncertain what the emission price will be after implementation. Because in this system, prices depend on the supply and demand of permits traded in the market. Therefore, there is uncertainty about reducing emissions in the carbon tax and carbon price in ETS. Which instrument is preferred depends on the objectives of policymakers.

For example, a certain amount of emission reductions will be achieved in the future. In that case, an ETS is more attractive to policymakers and is preferred to a carbon tax, which involves uncertainty about the amount of reductions (Karakaya *et al.*, 2023). Emissions trading is a flexibility mechanism, while emissions taxes are not. Companies pay a carbon tax for each ton of carbon dioxide they emit. Each company will then reduce its emissions until the marginal abatement cost equals the tax it pays on its emissions (Mercan and Karakaya, 2015). Another important administrative challenge common to both policy instruments is which ministry will control them. The Ministry of Environment may face difficulties in implementing and managing a market-based instrument, while the Ministry of Economy may face technical problems in emission monitoring, distribution, and permit management (Karakaya *et al.*, 2023).

Table 2.2. Comparison of carbon tax system and ETS.

CRITERIA	**CARBON TAX SYSTEM**	**EMISSION TRADING SYSTEM**	**REFERENCES**
Principle	Polluter pays principle.	Polluter pays principle.	Kunsch and Springael (2008), EU Commission (2016), TUSIAD (2016), Karakaya *et al.* (2023), Zhu *et al.* (2010), ICAP (2023).
Price	Price is stable and does not change for a certain period.	Price is determined by supply and demand and may fluctuate.	TUSIAD (2016), Karakaya *et al.* (2023), ICAP (2023), Wolfgang (2022), Haites *et al.* (2018), Lu *et al.* (2012).
Scope	Extensive coverage in terms of industry and institution size.	Small businesses not included.	Du *et al.* (2022), EU Commission (2016), Uyduranoglu and Ozturk (2020), Wolfgang (2022), Lu *et al.* (2012).

Table 2.2 Comparison of carbon tax system and ETS. (cont.)

CRITERIA	**CARBON TAX SYSTEM**	**EMISSION TRADING SYSTEM**	**REFERENCES**
Cost Bearing	Cost can be applied directly to customers or producers. Efficient and cost-effective mitigation due to.	Cost is only applicable to producers. Efficient and cost-effective mitigation with its flexibility.	TUSIAD (2016), ICAP (2023).
Emission Level	Emission mitigation outcome is not certain.	Emission mitigation outcome is certain, by setting	Karakaya *et al.* (2023), ICAP (2023), Haites *et al.* (2018).
		a cap total amount of emission permission is determined.	
Control Mechanism	Direct taxation of fossil fuel use, etc.	Cap and trade system applied based on industry emission levels, similar to the stock exchange.	Ming (2014), Du *et al.* (2022), ICAP (2023), Wong and Lacarruba (2012), Karakaya *et al.* (2023).
Simplicity	Easy to implement. Does not require the establishment of a new system, functions as other tax schemes, ease to administration.	Requires the establishment of a new system and imposes high operational and administrative costs.	TUSIAD (2016), Karakaya *et al.* (2023), ICAP (2023), Wolfgang (2022), Haites *et al.* (2018).

Table 2.2 Comparison of carbon tax system and ETS. (cont.)

CRITERIA	**CARBON TAX SYSTEM**	**EMISSION TRADING SYSTEM**	**REFERENCES**
Flexibility	Does not provide any flexibility, the relevant carbon tax has to be paid.	Provides flexibility to reduce emission levels with different mechanism.	TUSIAD (2016), ICAP (2023), Haites *et al.* (2018).
Government Perspective	Direct revenue from taxation.	Indirect revenue with auctions of the carbon permits.	Karakaya *et al.* (2023), ICAP (2023), Haites *et al.* (2018).
Linking with Other Nations Structures	Harmonization with other countries' systems is not applicable.	Harmonization with other nation's systems is applicable.	Haites *et al.* (2018).

Historically, large portions of revenues from ETSs or carbon taxes have been allocated to green and development projects or the general budget. As illustrated in Figure 2.9, the climate and nature projects stream accounts for over half of the global carbon revenue raised in 2022. For instance, in the EU ETS system, the EU mandates that its member states allocate at least half of ETS revenues to climate and energy-related targets. The auction revenues of allowances also deliver the EU ETS funds for low-carbon innovation and energy transition funds such as the Innovation Fund and the Modernization Fund. The general budget channel accounts for around a quarter of global carbon revenue. Households and businesses, which may be affected unfairly by carbon pricing, receive 10% of global carbon revenue in redistributions (World Bank, 2024a).

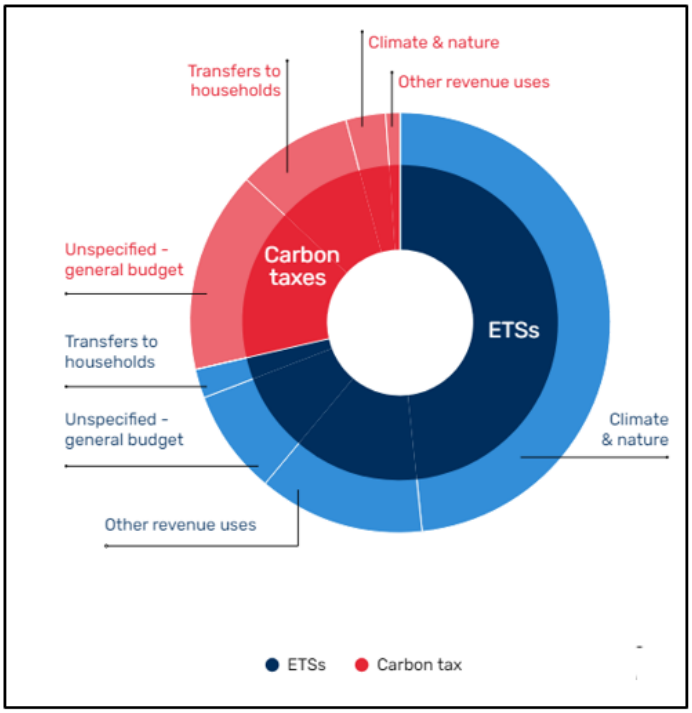


Figure 2.9. Worldwide revenue usage from Carbon Taxes and ETSs in 2022 (World Bank, 2024a).

2.3.2.3. Historical Development. The first country that imposed a carbon tax was Finland in 1990. After Finland, the Netherlands (1990), Norway and Sweden (1991), Denmark (1992), Germany (1999) and the United Kingdom (2002) tested different carbon tax policies, and some of them have been using carbon taxes for a long time of period (Aydın, 2023; Lu *et al.*, 2012; TUSIAD, 2016). Although different types of carbon taxation have been discussed and piloted among European countries since the early 1990s, carbon taxes were not adequately implemented till early 2010 (Aydın, 2023). Recently, several developed countries, such as Australia, Germany, Italy, the Netherlands and Switzerland, have applied a carbon tax system that is important in reducing fossil energy consumption and carbon emissions (Ming, 2014).

The concept of cap and trade, which is the foundation of emissions trading systems, was first introduced in a series of micro-economic computational simulation studies conducted by Ellison Burton and William for the National Air Pollution Control Administration between 1967 and 1970 in the USA (Zhu *et al.*,2010).

Emissions trading was first introduced in the USA in the 1970s and continues to be widely used. Following the achievement of the emission trading mechanism implemented in the USA (especially the Acid Rain Program), this mechanism was included in the Kyoto Protocol. With the inclusion in the Kyoto Protocol, the emission trading system has a crucial position among different mechanisms in the fight against global warming. Emissions trading is allowed among Annex B countries, which are composed of Annex 1 countries that have signed the Kyoto Protocol and taken emission reduction obligations (Mercan and Karakaya, 2015).

In 2022, the UK established the world's first business-to-business emissions trading system. Later in 2005, the European Union established the first multinational emissions trading system, laying the foundation for one of the largest emissions trading structures today. Following the EU, other countries such as the US, Japan, and Australia have also established emissions trading systems. China, one of the world's biggest emitters, introduced a pilot ETS system in 2013 and officially launched it in 2017 (Zhou *et al.*, 2021).

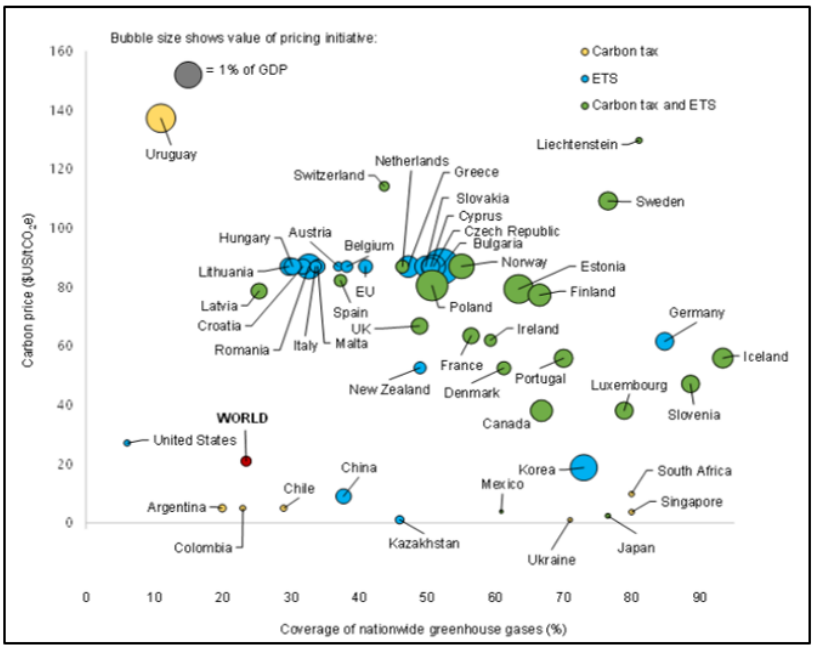


Figure 2.10. Carbon pricing schemes and coverages (Parry *et al.*, 2023).

The EU ETS is an emissions trading system that adopts cap and trade. The EU ETS is one of the largest ETSs today, containing roughly half of the EU's greenhouse gas emissions. The system covers 31 countries (27 EU countries, Iceland, Liechtenstein, Norway and Croatia-joined in 2013) (Brouwers *et al.*, 2018). The revenue received from EU ETS is being used for two funds: Innovation Fund (supporting breakthrough innovation in industry), Modernization Fund (supporting lower-income member states).

ETS programs also have many sub-national pricing schemes, the largest of which is California's ETS. Major pricing initiatives have been launched in China and Germany, prices in the EU ETS are equivalent to USD 70 per ton by July 2024, and Canada has committed to a price equivalent to USD 140 by 2030. However, as indicated in Figure 2.10, GHG emissions subject to (national and sub-national) carbon pricing varied from less than 30 per cent in some cases to more than 70 per cent in others, with economy-wide average prices in 2021 ranging from less than USD 5 to USD 115 per ton (Parry *et al.*, 2023).

Although using ETSs and carbon taxes has increased in developing countries, high-income countries still dominate. The growing interest from developing countries is driven by the need for climate change reduction strategy, managing transition risks, exploring income opportunities, and preparing for joining the European Union (World Bank, 2023a).

2.4. Public Policy in Turkiye

In future simulations, seasonal and regional differences in Turkiye's climate change are predicted, and the Mediterranean Basin, including Turkiye, is considered one of the most vulnerable regions in terms of the influences of climate change (Yeldan *et al.*, 2015; TUSIAD, 2016).

As a country facing crucial vulnerability to the effects of climate change, Turkiye has made ambitious climate change promises, including ratifying the Paris Agreement

in October 2021 and committing to net zero emissions by 2053. The country is shaping new institutional structures on climate change topics, including restructuring the Ministry of Environment, Urbanization and Climate Change (MoEUCC) on October 11, 2021, and updating its National Climate Change Action Plan covering 2024-2030 (World Bank Group, 2022).

The national inventory system in Turkiye has a centralized management system. The Ministry of Environment, Urbanization and Climate Change (MoEUCC) is the National Focal Point of the UNFCCC and is liable for climate change and air pollution policies and measures (Turkish Greenhouse Gas Inventory, 2023).

Especially the recent increase in climate-related disasters such as floods, forest fires, and marine contamination, as well as the probable effects of the European Union (EU) Green Deal on the Turkish economy, has contributed to the national climate change agenda (World Bank Group, 2022; Telli *et al.*, 2008).

2.4.1. Turkiye's National Greenhouse Gas Emissions

Turkiye's latest National Inventory Report (NIR) for 2023 provides information on national GHG emissions and removals for the period 1990-2021. Due to corrections and adjustments, countries publish their emission reports to the UNFCCC with a 2-year lag.

In comparison to other nations, Turkiye's historical obligations are very limited and it is responsible for only 0.66 percent of global cumulative carbon emissions, corresponding to 11.79 billion tons of cumulative carbon emissions by 2022. However, as a developing economy, its GHG emissions are also increasing, putting Turkiye among the top 20 GHG emitters in the world, as the share of global emissions and GHG per capita indicated in Figure 2.11. Therefore, actions to reduce emissions in Turkiye are very important as they can guide mitigation activities in other developing economies (Parry *et al.*, 2023).

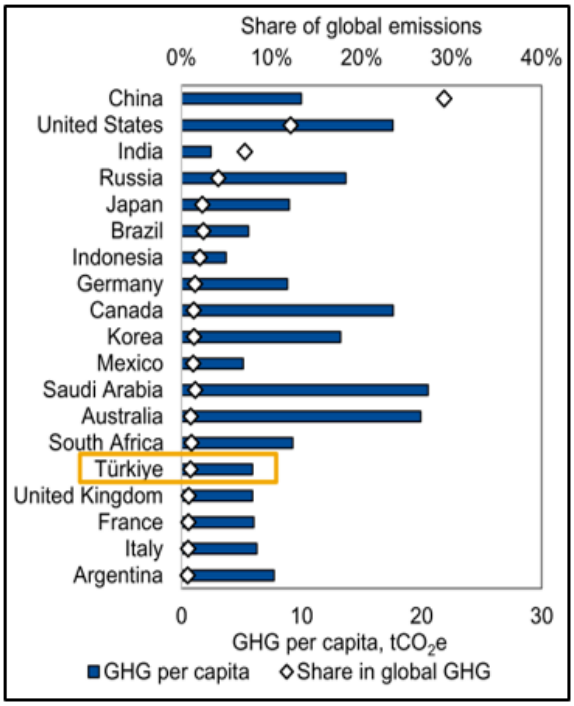


Figure 2.11. Per capita GHG emissions and global shares of the countries, 2020 (Parry *et al.*, 2023).

Whereas Turkiye listed 17th among the countries in the world regarding total greenhouse gas emissions in 2021, it ranked 85th among 198 countries in per capita emissions. The rise in emissions since 1990 in Turkiye, which ranks below the world average in per capita emissions, is significant. Between the 1990-2022 period, total annual emissions climbed by 144.9 percent and per capita emissions by 61 percent (Yeldan *et al.*,2015; Turkish Statistical Institute, 2024a; Climate Watch, 2022).

According to the Turkish Statistical Institute (TurkStat) (2024a), as graphically illustrated in Figure 2.12, 2022 GHG emission inventory, GHG emissions are 2.4% lesser than the previous year and it was measured as 558.3 million tons (Mt) of CO_2 equivalent. Total greenhouse gas emissions per person were calculated as 6.8 tons CO_2 equivalent and 6.6 tons CO_2 in 2021-2022 respectively.

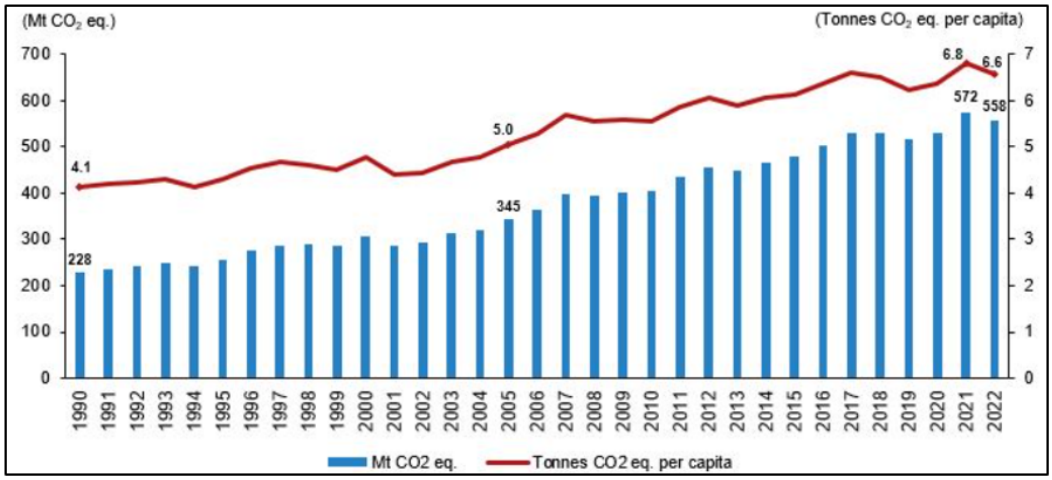


Figure 2.12. Turkiye's total and per capita greenhouse gas emissions, 1990-2022 (Turkish Statistical Institute, 2024a).

As shown in Figure 2.13, in 2022, the biggest pie in total greenhouse gas emissions as CO_2 equivalent was energy emissions with 71.8%, followed industrial processes and product use with 12.5%, agriculture with 12.8% and waste with 2.9%. According to inventory, the emissions coming from the energy sector rose by 179.8% in 2022 compared to 1990 and were calculated as 400.6 Mt CO_2 equivalent. Emissions coming from industrial processes and product use increased by 208.1% compared to 1990 and was calculated as 69.9 Mt CO_2 equivalent (Turkish Statistical Institute, 2024a).

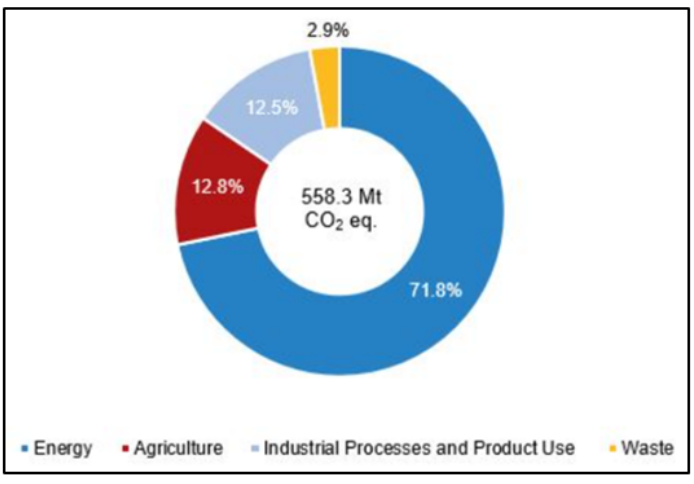


Figure 2.13. Turkiye's greenhouse gas emissions by the industry in 2022 (Turkish Statistical Institute, 2024a).

Population and GDP are the main drivers of Turkiye's GHG emissions (Şahin *et al.*, 2021). As stated in the Turkiye's 2023 NIR, Figure 2.14 shows the trend from 1990 to 2021, most of the fluctuations in the emissions trends occurs from the changes in economic movements. When GDP was 149 billion USD in 1990, it increased to 717 billion USD in 2020, and GHG emissions increased in parallel. It is seen that population statistics are another influencer on emission trends in nations' inventories. The mid-year population of Turkiye rose by approximately 51.3% from 1990 to 2020, from 55.1 million to 83.4 million.

Therefore, CO_2 equivalent emissions per person also could fluctuates due to the population changes (Turkish Greenhouse Gas Inventory, 2023). In a general perspective, the fact that Turkiye is a developing country has a great impact on the rapidly increasing trend in its GHG emission levels (Uyduranoglu and Ozturk, 2020).

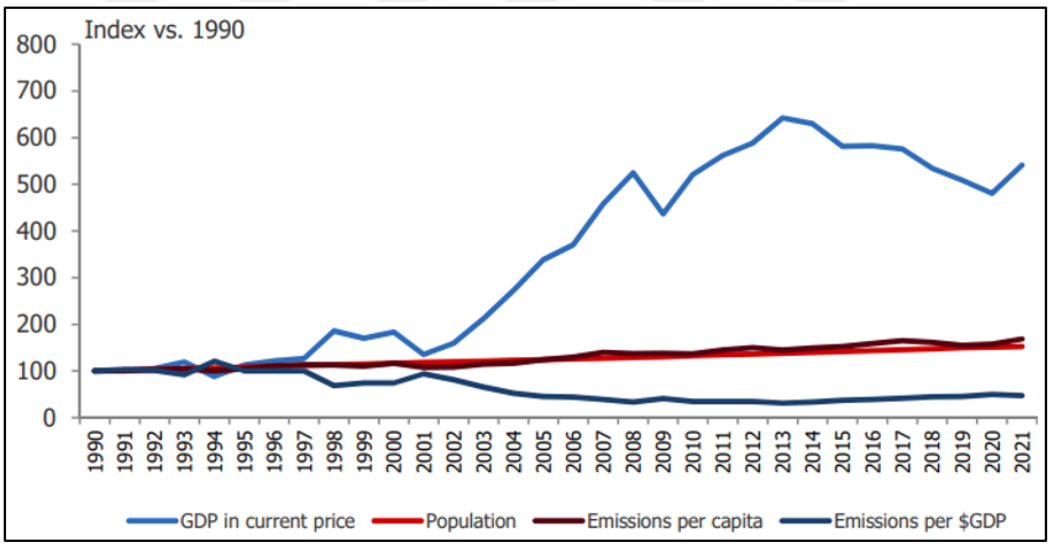


Figure 2.14. Trends in per capita emissions and dollar value of GDP in Turkiye relative to 1990 (Turkish Greenhouse Gas Inventory, 2023).

Even though Turkiye's GHG emissions per capita are lower than in the EU countries and OECD, a strong pressure for a powerful mitigation plan is on the table for the country. Dependence on coal in the country is high and is not likely to lose its momentum with the current investment plans. In terms of the construction sector,

residential and non-residential buildings are less energy efficient than the EU average. As for the manufacturing industry, its carbon intensity is higher than the EU average, which means that Turkiye could be exposed to risks when the EU's CBAM becomes fully operational in 2026 (World Bank Group, 2022). Also, the increase in GHG emissions per capita in Turkiye is steeper than population growth, which indicates a trend towards carbon-intensive activities (Alkan *et al.*, 2018; Şahin *et al.*, 2021).

2.4.2. Turkiye's Nationally Determined Contribution (NDC)

Turkiye's Intended Nationally Determined Contribution (INDC), which was submitted before the Paris Conference in 2015, that it aims to decrease GHG emissions by approximately 21% below business-as-usual (BAU) levels by 2030 starting in 2020. However, this goal has been criticized as 'critically not enough' and incompatible with the global warming target, which is below two ^oC. In addition to that, Turkiye was the only G20 member that has declined to approve the Paris Agreement from 2015 to 2021 (Uyduranoglu and Ozturk, 2020).

Turkiye's INDC is depending on the BAU scenario and a 21% mitigation goal coming from the projected emissions for 2030; in other words, it is a reduction from an increase. As illustrated in Figure 2.15, the BAU scenario shows a relatively sharply climbing emissions pathway in contrast to historical trends. In parallel, BAU emissions are projected to jump from 430 Mt CO_2e in 2013 to 1,175 Mt CO_2e in 2030. The target, which is 21% reduction for 2030, corresponds to 929 Mt CO_2e (Karapınar *et al.*, 2019).

As shown in Figure 2.15, Turkiye's Intended Nationally Determined Contribution (INDC) submitted to the United Nations in 2016 for the Paris Agreement projects BAU GHG emissions of 1175 million tons in 2030. This number is exactly 175 percent higher than the BAU projections in the IMF's report (2023) which assess Turkiye's climate change actions. The disparity is mainly due to the Turkish government's expectation of doubling electricity demand by 2030, while the IMF forecasts only a 16 percent increase in electricity demand. In the long-term perspective, Turkiye's current 2030

commitment is inconsistent with its 2053 net zero emissions target. In accordance with IMF's scenarios, the 2030 target will be achievable in BAU without any reduction step (Parry *et al.*, 2023).

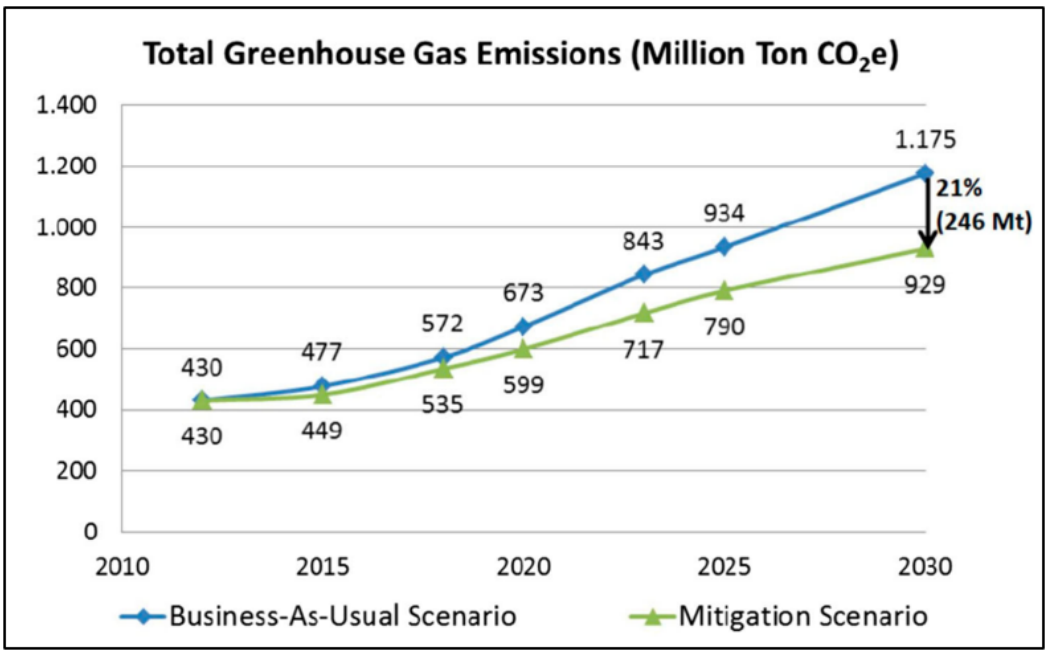


Figure 2.15. The emission reductions to be achieved by INDC and business as-usual scenario (Republic of Turkiye, 2015).

According to the Karapınar *et al.*'s (2019) study, which is analyzing Turkiye's NDC and determining which carbon pricing mechanism is most appropriate for the country, Turkiye's INDC was based on extremely optimistic GDP growth projections and the assumption that GDP growth will be through highly carbon-intensive development. Therefore, the authors envisage that an NDC prepared with such assumptions would be quite redundant in emission reductions (Karapınar *et al.*, 2019).

According to Turkiye's net zero emissions target in 2053, a linear emissions path to emissions neutrality from 2022 to 2053 would require a 28% reduction in greenhouse gases relative to 2021 levels, equivalent to 292 million tons in 2030 compared to, Turkiye committed in its INDC to limit emissions to 929 million tons in 2030, representing a 21% reduction from the government's BAU projection (Teimourzadeh *et al.*, 2023).

In 2022, during the COP27 in Egypt, Turkiye announced its Updated First Nationally Determined Contribution, limiting GHG emissions to around 693 million tons in 2030, with a new reduction target of 41 percent compared to the BAU. According to this plan, Turkiye envisages to reach its emissions peak in 2038 at latest (Teimourzadeh *et al.*, 2023).

Climate Action Tracker, an independent scientific project that monitors governments' climate actions and benchmarks them according to the Paris Agreement targets, rates Turkiye's NDC target as well as its policies and actions as critically insufficient as indicated in Figure 2.16, the worst rating. It even categorizes the world's largest emitters, the USA and China, respectively, as inadequate and highly inadequate. The main reason for Turkiye's low ranking is that the country has set a reduction target from an extreme increase, which would, in any case, lead to an overall increase in emissions relative to today, while other countries have set an absolute reduction target from current emissions (Climate Action Tracker, 2023).

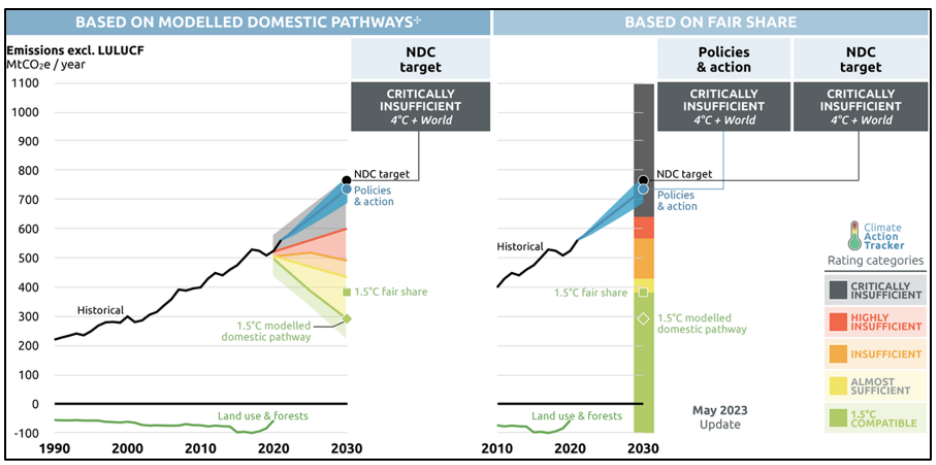


Figure 2.16. Turkiye's overall rating according to its NDC target and current policies based on modelled domestic pathway and fair share (Climate Action Tracker, 2023).

According to the Paris Agreement, NDCs must be updated every five years by increasing the targets. Therefore, Turkiye must submit its second NDC before the COP30, which will be held in Brazil at the end of 2025, with a aimed year of 2035 (Teimourzadeh *et al.*, 2023).

2.4.3. International Agreements

In 1989, Turkiye took the first step to join the participate climate policy process with the Noordwijk Ministerial Conference held in the Netherlands (Yeldan and Voyvoda, 2015). After this conference, Turkiye actively participated in global climate change conferences and became party to global agreements intended to reduce greenhouse gas emissions, Figure 2.17 shows the timeline of international agreements and decisions taken as a country, which will be discussed in detail in this section.

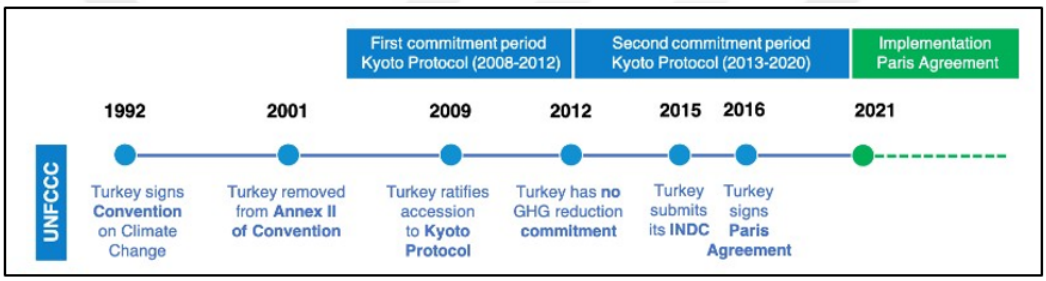


Figure 2.17. Turkiye's climate policy developments timeline (Carbon Markets in Turkey, 2021).

One of the most significant steps taken globally to address climate change was the signing of the United Nations Framework Convention on Climate Change (UNFCCC), which was launched for signature at the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992. Turkiye was initially included in both Annex I and Annex II of the UNFCCC, as the country has been a member of the OECD since 1961. In the agreement, Annex I countries are primarily responsible for reducing greenhouse gas emissions, while Annex II countries are obliged to provide financial and technical assistance to less developed countries to reduce their emissions. Therefore, as a country that historically has not been as responsible as developed countries, it did not ratify the agreement for a long time due to its emission reduction and financial responsibility. At the 7th Conference of the Parties (COP7) held in Marrakech in 2001, Turkiye was subtracted from Annex II, and recognized as an Annex I country "with special conditions". Upon this development, Turkiye became a participant to the UNFCCC on May 24, 2004, as the 189th accession, and after the ratification, the

country became more actively involved in climate policies (Telli *et al.*, 2008; Yeldan *et al.*, 2015).

After becoming a party to the Agreement, Turkiye's first annual Greenhouse Gas Inventories was submitted to the UNFCCC in 2006, and the First National Communication on Climate Change was published in 2007. In the same year, the Turkish Grand National Assembly established a Global Warming Research Commission (Yeldan and Voyvoda, 2015).

As Turkiye's request to be excluded from both annexes of the UNFCCC was declined at the Conference of the Parties III (COP 3) held in Kyoto in 1997, the country participated in the Kyoto Protocol negotiations only as an observeR & Did not become a party. Coming the entry into force of the Kyoto Protocol in 2005, public debate on Turkiye's accession to the Protocol increased. In addition, negotiations for Turkiye's EU membership started in the same year. Subsequently, the country became a party to the Kyoto Protocol in 2009. Since it only participated in the negotiations as an observer in 1997, it was not among the Annex B countries required to make emission reductions. It did not make any reduction promises from 2008 to 2012, which was the first stage of the Protocol. Turkiye's only specific responsibility was to monitor and report GHG emissions from all sources during this stage. Following this, Turkiye also did not participate in the second obligation period of the Kyoto Protocol, which was opened for signature in Doha in 2012. This, unfortunately, caused restriction progress in combating climate change (Mercan and Karakaya, 2015; Uyduranoglu and Ozturk, 2020).

At the 19th UNFCCC COP19 in Warsaw in 2013, Turkiye announced that it would become a party to the new agreement with a flexible goal to be decided by itself if critical mass is met, and Turkiye's climate policies entered a new era with this announcement (Yeldan and Voyvoda ,2015).

The Paris Agreement, which was embraced at the UNFCCC COP21 in Paris in 2015, is a breakthrough as it is the first legally binding climate change agreement. The agreement envisages that global emissions should be reduced by peaking as soon as possible and that a balance should be established between emissions emitted by human activities and emissions removed by sinks in the second half of the century. The concept of Net Zero Emissions is applied explain this balance point. Before adopting the Paris Agreement, Parties submitted their Intended Nationally Determined Contributions (INDCs) to the UNFCCC Secretariat, including their targets and the roadmap for limiting greenhouse gases. Turkiye also submitted its INDC in 2015 for the UNFCCC (Şahin *et al.*, 2021).

Turkiye signed the Paris Agreement on 22 April 2016 but did not ratify it until the 2021. When the ratification of the Paris Agreement in 2021, Turkiye declared that it would apply the Agreement as an emerging country and within the framework of its national contribution declarations only if the Agreement and its mechanisms do not prejudice its right to economic and social development (Republic of Turkiye, 2023a).

Under the Paris Agreement, each party is obliged to prepare, communicate and submit its Nationally Determined Contribution (NDC) at the end of each five-year period. Turkiye submitted its first updated NDC to the UNFCCC in 2022 with revised targets (Alkan *et al.*, 2018).

In summary, Turkiye ratified the UNFCCC, the Kyoto Protocol and the Paris Agreement, respectively, in 2004, 2009, and 2021. As Turkiye is under the Annex-1 countries of the UNFCCC, it publishes annual GHG emission inventories according to IPCC standards. All emission and removal sources included in the inventory are calculated according to the methodology of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Turkish Greenhouse Gas Inventory, 2023).

2.4.4. National Legislations

Turkiye has accelerated its climate-related actions after becoming one of the parties to the Paris Agreement. The Ministry of Environment and Urbanization was reshaped as the Ministry of Environment, Urbanization and Climate Change (MoEUCC) on October 29, 2021. Additionally, the Directorate of Climate Change (DoCC) was established under the Ministry (Republic of Turkiye, 2023a).

Turkiye has also established a National Climate Council, an inter-ministerial coordination function to accelerate its formal arrangements for climate change arguments. MoEUCC is the national focal point for the climate change action plan. It is authorized to monitor, coordinate, and evaluate international and domestic climate actions such as emission reporting and tracking, regulation and preparation of legislation, information dissemination, and awareness raising. It also serves as the secretariat of the Coordination Board on Climate Change and Adaptation (CBCC), a horizontal governmental institution that brings together relevant institutions and organizations to regulate climate change actions and national decision-making at the political level (World Bank Group, 2022).

Turkiye's first Climate Council happened in Konya between 21-25 February 2022, organized by the MoEUCC. The Council consisted of approximately 1,500 stakeholders from different areas, such as the private sector, public sector, NGOs, representatives from youth, and research institutions. The Council formed two subcommittees on reducing greenhouse gas emissions, seven on science and technology, green finance and carbon pricing, climate change adaptation, local governments, migration, just transition, and social policies. Some climate-related issues, such as just transition, climate change's effect on immigration, were discussed for the first time. As a result of the Council, 217 decisions were accepted to create a mission and vision for Turkiye's net zero targets in 2053. Out of all decisions, 76 were prioritized and shared with the public (Republic of Turkiye, 2023a).

Combating climate change was addressed in strategies and action plans developed in various fields in the country. Targets set in the National Climate Change Strategy and Action Plan, measures on green development in the Industrial Strategy and Action Plan, electricity tax scheme in the Energy Efficiency National Action Plan, and so forth can be considered as some examples in this scope. In addition, incentives for electricity generation from renewable sources, including wind and solar energy systems, are already in place (feed-in tariff systems) in Turkiye (TUSIAD, 2016).

Climate change issues are coordinated by different legislations, containing Law on Agricultural Insurance, Law on Catastrophe Insurance, Law on the Protection of Nature and Biological Diversity, Law on Energy Efficiency, By-Law on Energy Performance in Buildings and By-Law on Spatial Plans Construction. The principal climate policy documents are as follows (World Bank Group, 2022; Republic of Turkiye, 2023a):

- 12th Development Plan (2024-2028)
- Environment Law (1983)
- Energy Efficiency Law (2007)
- By-law on Fluorinated Gases (2022)
- By-law on Substances that Deplete the Ozone Layer (2017)
- By-law on Monitoring of GHG emissions (2014)
- Strategic Environmental Assessment By-law (2017)
- Communiqué on Monitoring and Reporting Greenhouse Gas Emissions (2014)
- Communiqué on Verification of Greenhouse Gas Emission Reports and Accreditation of Verification Bodies (2017)
- Türkiye's Green Deal Action Plan (2021)
- Climate Council Final Recommendations (2022)
- Hydrogen Technologies Roadmap and Implementation Plan of Türkiye (2023)
- Low Carbon Roadmap for the Steel, Aluminum, and Cement Sectors (2024)
- Climate Change Action Plan (2024)
- Climate Change Mitigation Strategy and Action Plan (2024-2030)
- Climate Change Adaptation Strategy and Action Plan (2024)

- Climate Change Adaptation Strategy and Action Plan (2024-2030)
- Türkiye National Energy Plan (2020 - 2035)
- Medium Term Program (2023-2025)
- Energy Efficiency Strategy and National Energy Efficiency Action Plan (2024-2030)
- National Transport and Logistics Master Plan (2053)

Upon the completion of the application interval of the 2011-2023 Climate Change Strategy and Action Plan developed by the MoEUCC, a new strategy and action plan was prepared in line with the 2053 Net Zero Emission Target, 12th Development Plan, Medium Term Program, and Climate Council Decisions. To accomplish the declared NDC targets, two separate strategies and action plans covering the 2024-2030 period were prepared under the coordination of the Department of Climate Change and Turkiye's climate change mitigation and adaptation road maps were presented (DoCC,2024a). Climate Change Action Plan and the Mitigation and Adaptation Strategies that are covering 2024-2030 period are the fundamental documents that the shaping the green transformation of Turkiye.

On July 16, 2021, Turkiye's "Green Deal Action Plan" (GDAP) was published. The action plan consists of nine main headings with 32 main targets and 18 actions concentrating on the green transformation of industries in Turkiye. It emphasizes the adoption of GHG reduction preventions, particularly in the areas related to trade and industry. GDAP contains actions in severe fields such as Combating Climate Change, Green and Circular Economy, Green Finance Border Carbon Regulations, Clean, Accessible and Secure Energy Supply, Sustainable Agriculture, Sustainable Smart Transport, and Diplomacy to facilitate the green transformation towards a low-carbon, resource-efficient and circular economy (Republic of Turkiye, 2023a).

To construct the infrastructure for future carbon pricing policies under the direction of global trends, Turkiye has established a monitoring, reporting and verification (MRV) system. In 2012, the first policy was announced regarding the MRV infrastruc-

ture, the "Regulation on the Monitoring of Greenhouse Gas Emissions" and revised in 2014. After that, Communiqué on Monitoring and Reporting of Greenhouse Gas Emissions" entered force in 2014 and was revised in 2021. Then, the "Communiqué on Verification of Greenhouse Gas Emission Reports and Authorization of Verification Bodies" was published in 2017 and revised in 2022. As part of Turkiye's potential accession to the EU and its close trade relations, all regulations have been prepared in line with the European ETS (Republic of Turkiye, 2023a; TUSIAD, 2016).

As shown in Figure 2.18, following the approval of the MRV legislation, the 4-year MRV Pilot phase started, and the implementation of MRV in the sector started in 2016. Since 2016, over 700 facilities responsible for around 50% of Turkiye's total GHG emissions have been monitored under the MRV system. The regulation includes Turkiye's greenhouse gas emissions from key industries such as refining petroleum products, ferrous and non-ferrous metal production, fossil fuel use, iron and steel, cement, chemical industry, primary aluminum production, paper production, and acid production. (Republic of Turkiye, 2023a; Karapınar *et al.*,2019). Almost ten years of emission monitoring experience and know-how provide many advantages in setting up a carbon pricing system for Turkiye, especially regarding emission allowances.

In 2011, the MoEUCC published the Turkish National Action Plan on Climate Change, which encloses priorities and targets across all industries to focus on climate change. The Action Plan also underlined establishing a national emissions trading system (ETS) by 2015 and its connection to other operating regional and global carbon markets. Unfortunately, the foundation of the national ETS market was not realized as planned. However, the Ministry of Environment and Urbanization, in cooperation with the Partnership for Market Readiness (PMR) and the World Bank Group, put an intensive effort to accelerate the establishment of the ETS in Turkiye (Uyduranoglu and Ozturk, 2020).

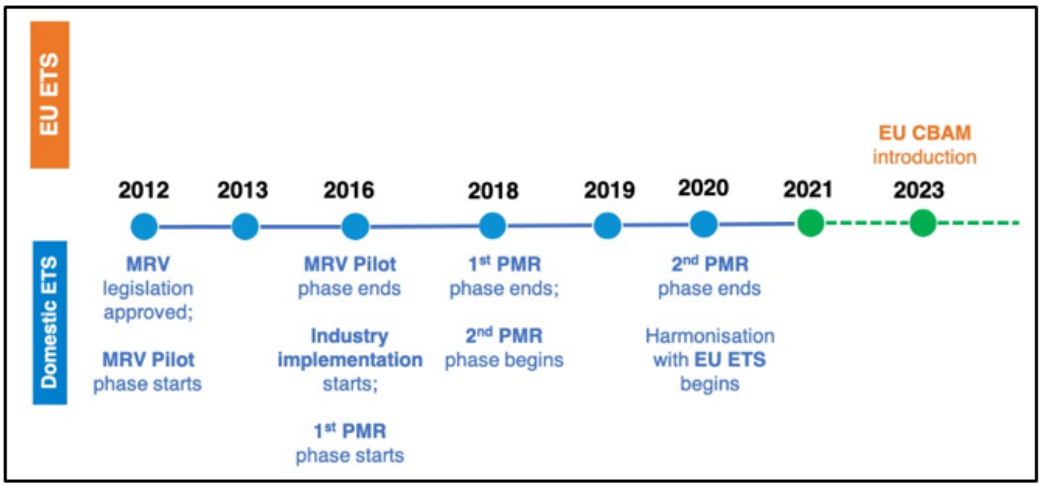


Figure 2.18. The basis of Turkiye's emissions trading system (Carbon Markets in Turkey, 2021).

In 2011, the World Bank launched the Partnership for Market Readiness (PMR), a technical assistance program to support efforts to reduce greenhouse gas emissions in developing countries and ensure the effective use of market-based emission reduction mechanisms. Turkiye was the first country to sign the grant agreement with the World Bank. In 2013, Turkiye officially joined the program, along with 18 other implementing countries. Parallel to the establishment of the MRV system, the PMR project was also launched, and the 1st phase of the Project, which includes capacity building and awareness raising on carbon pricing and the use of carbon pricing mechanisms, started in 2016 and was completed in 2018. Right after the 1st phase, 2nd phase of the PMR started which aimed to determine the most appropriate carbon pricing mechanism and completed in 2021. According to the results of the project, the most suitable market-based mechanism for the country is the Emissions Trading Scheme (PMR Turkiye, 2019; PMR Turkiye, 2016; Karapınar *et al.*, 2019).

ETS provides flexibility for regulated entities to reach the cap more efficiently. Similarly, international linkages of different ETSs can reduce the cost of meeting global emission reduction targets under the Paris Agreement (ERCST, 2020).

Following the successful completion of PMI's predecessor initiative, the PMR, in Turkiye in 2021, PMI came into effect in January,2024 to assist the country in designing, piloting and implementing pricing instruments aligned with its development priorities. The PMI mainly supports the Turkish government's implementation of a national emissions trading system (ETS), which could start as soon as 2025-2026. The project duration is five years, and the World Bank has allocated a grant of approximately USD 5 million. To ensure the achievement of the project's target, the following outcomes are planned to be achieved (World Bank, 2023b, World Bank 2023c):

- ETS design (cap, scope, allocation of allowances, etc.)
- Modeling studies on the economic impacts of ETS
- Pilot and Phase 1 implementation of the ETS
- Just transition in carbon pricing instruments
- Determination of GHG emission benchmarks for ETS/MRV sectors
- Secondary Legislation for ETS

In October 2022, Turkiye announced its first draft climate law, which consists of 17 Articles and 3 Provisional Articles. The Law explains the missions of each ministry in detail. To combat climate change with the green development vision and net zero targets, the Law aims to regulate the reduction of GHG emissions according to the countries' NDC, adjust to climate change and integrate related tools. Action plans are systematically coordinated with the Climate Change Presidency. Local states must develop Local Climate Change Action Plans for each district, consisting of GHG emissions inventory, mitigation aims and functions, sensitivity analysis and climate change adaptation actions within the scope of the Law (Republic of Turkiye, 2022).

Several municipalities and cities have announced climate change action procedures locally to empower flexibility to climate change, whereas some industrial arrangements and plans integrate features or materials of climate change. 27 Turkish municipalities and cities have entered the Global Covenant of Mayors for Climate and Energy, which was defined as the most significant global community for state climate

initiatives, with more than 10,000 city and local government members. 16 of them have promised a climate change reduction aim, 10 of them are still working on their reduction targets; none has a transformation procedure; only one city, Izmir, has adopted a climate change action plan and Green Cities Action Plan (World Bank Group, 2022).

Multi-stakeholder arbitrations were made on the draft of the Climate Change Law. As a result of these discussions, the draft was submitted to the Turkish Grand National Assembly to be arbitrated and completed by the Member of Parliament. The main objective of the draft policy is to construct the legal basis for GHG emission reduction and adaptation plan, support green growth, establish a national emission trading system, planning and implementation tools in line with the net zero targets in 2053, and optimize the legal basis for efficient climate action in Turkiye (Republic of Turkiye, 2023a).

The carbon pricing instruments under the Climate Law are categorized as taxonomy, Climate Change Financing Mechanism and especially the emission trading system (Republic of Turkiye, 2022).

Many developments have been achieved to level up the green financial ecosystem in Turkiye. In 2020, the "Sustainability Principles Compliance Framework" was published for public enterprises. In 2021, the national "Sustainable Finance Framework", which is for green, social and sustainable debt tools was announced (Republic of Turkiye, 2021). One of the most crucial developments is the "2022-2025 Sustainable Banking Strategic Plan", which determines the main sustainable finance strategy of the country (Banking Regulation and Supervision Agency, 2021). The "Guidelines on Green Debt Instruments, Sustainable Debt Instruments, Green Lease Certificates and Sustainable Lease Certificates" was announced to level up the green and sustainable instruments in the capital market in 2022.

The other main development was the revision of the Turkish Commercial Code, empowering the (Public Oversight, Accounting and Auditing Standards Authority) to

decide and announce Turkish Sustainability Standards compatible with international standards (Republic of Turkiye, 2023). The Turkish Sustainability Reporting Standards, fully compliant with the International Sustainability Standards Board's (ISSB) global S1 and S2 sustainability reporting standards, were published in the Official Gazette on 29 December 2023. As of 2024, Sustainability Reporting with financial information will be mandatory for companies above the thresholds (Official Gazette of the Republic of Turkiye, 2023a).

Turkiye published the Taxonomy Framework Document in 2023 to facilitate the integration of financial resources with green investments and promote the country's green transformation. This document aims to outline the scope of green investments and facilitate matching financing sources and green projects in the country (MoEUCC, 2023).

Turkiye has declared that it will continue to encourage sustainable investments by the private sector through robust green financing frameworks supported by ambitious climate policies (Republic of Turkiye, 2023a).

Key legislation and regulations under preparation listed below will also enable the green transformation of industry and contribute to the consolidation of the circular economy in Turkiye (Republic of Turkiye, 2023a):

- Long-term low emission development strategy (Long-Term Strategy)
- Climate Law (under preparation)
- Local Climate Change Action Plan By-Law
- Long-Term Climate Change Strategy
- Circular Economy Strategy and Action Plan (under preparation)
- Sustainable Consumption and Production Strategy
- Secondary Legislation for ETS

- Carbon Dioxide Capture and Utilization Technologies Roadmap and Implementation Plan for Turkiye (under preparation)
- Offshore Wind Roadmap for Turkiye

According to the IMF's working paper, Climate Mitigation in Turkiye (2023), with the ratification of the Paris Climate Agreement in 2021, potential key elements of Turkiye's strategy are expected to include (Parry *et al.*, 2023):

- Alignment of interim emission goals with long-term net zero targets,
- Emissions pricing, potentially in the form of trading,
- Additional measures to promote the acceptability of emission pricing,
- Supportive policies to amplify the response, such as transition from the coal to renewable energy and electrification of transportation.

2.4.5. Carbon Market and Carbon Policies in Turkiye

Research on potential carbon pricing mechanisms integration is essential for Turkiye, as it is at a critical juncture in its climate change policy. The net increase in Turkiye's carbon emissions could affect its capacity to tackle climate change in the future. As a candidate for European Union (EU) membership, Turkiye is envisioned to accept climate change policies in line with the EU's (Aydın, 2023).

As TUSIAD points out in its study, an effective solution to incentivize emission reductions is to internalize the harms of waste and emissions by reflecting the cost of the externality in the price of an environmentally damaging product or service (TUSIAD, 2016).

In this direction, Turkiye has accelerated its climate efforts, especially after becoming a party to the Paris Agreement, and has made many regulations and legislations in this direction and given authorizations to the relevant institutions. As one of the outputs of the PMI project carried out in cooperation with the World Bank, necessary

groundwork has been put in place for the establishment of a national emissions trading system in Turkiye.

2.4.5.1. Mandatory Carbon Market. According to Turkiye's National Action Plan on Climate Change, published by the MoEUCC in 2011, the country's priority was establishing an ETS system by 2015. However, unfortunately the system was not established that year (Uyduranoglu and Ozturk, 2020). According to TUSIAD's report, the main shortcoming in terms of a possible ETS implementation in 2015 was the lack of detailed carbon emission data at the industrial level, which is essential for setting emission caps. Improving the data inventory in this direction was a prerequisite for ETS implementation. The report underlines that it is essential to implement the ETS after companies gain experience in MRV (TUSIAD, 2016).

Turkiye made the first action towards developing a domestic ETS by establishing an MRV system in 2015. In accordance with the regulation, facilities with a specific capacity in the iron and steel, cement, electricity, aluminum, glass, ceramics, lime, mineral wool, paper, refinery products production, and chemicals sectors must report their emissions to the MoEUCC (Aşçı, 2024). As shown in Table 2.3, the system started in 2015 with 693 facilities; as of 2022, the emissions of 747 facilities were monitored under MRV.

Table 2.3. Greenhouse gas emission monitored under MRV regulation (DoCC, 2024).

Year	**Number of Facilities**	**Total Emission (tCO_2e/yıl)**
2015	693	234,868.82
2016	706	245,083.02
2017	721	264,013.65
2018	729	274,559.52
2019	706	251,432.86
2020	711	260,258.53
2021	734	295,879.08
2022	747	275,416.02

The pilot period of the national ETS will begin on October 15, 2024, with the declaration of sectoral allocations. After a two-year (could be also three years) pilot

period, the first implementation phase will start on October 15, 2026. In the first stage, the system's scope is expected to monitor the same sources as those monitored in the MRV system, and only category C facilities will be subject to the ETS system. As indicated in Figure 2.19, Turkiye's MRV system divides facilities into three groups: Category A facilities which emit lesser than 50 ktCO_2e, Category B facilities which emit between 50-500 ktCO_2e, and finally Category C facilities which produce more than 500 ktCO_2e (Aşçı, 2024).

In 2021, the country's total emissions were 564 million tCO_2e, of which 295 million are monitored by the MRV system. As shown in Figure 2.20, Categories A, B and C represent 2%, 8% and 90% of these 295 million respectively. In this regard, about 45% of the country's total emissions will be subject to the Emissions Trading System, as the ETS will only be applicable to Category C in the first stage. In 2022, there are approximately 133 installations emitting Category C emissions (DoCC, 2024).

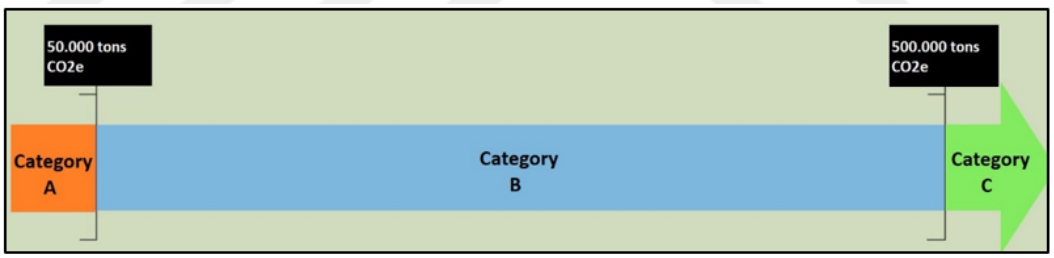


Figure 2.19. MRV system facility categories (DoCC, 2024).

Under the MRV system, only 3 GHGs are monitored (CO_2, PFC, N2O); the others (CH4, HFC, NF3, etc.) are not covered by MRV legislation. The emissions sources monitored are direct emissions from processes and stationery combustion; other direct emissions from mobile combustion and indirect emissions are not within the scope of monitoring. The eight verification bodies accredited by the Turkish Accreditation Agency (TURKAK) undertake the verification mission to verify the facilities' emissions calculations. Facilities submit their verified GHG emissions reports to MoEUCC by April 30 of each year (MoEUCC, 2015).

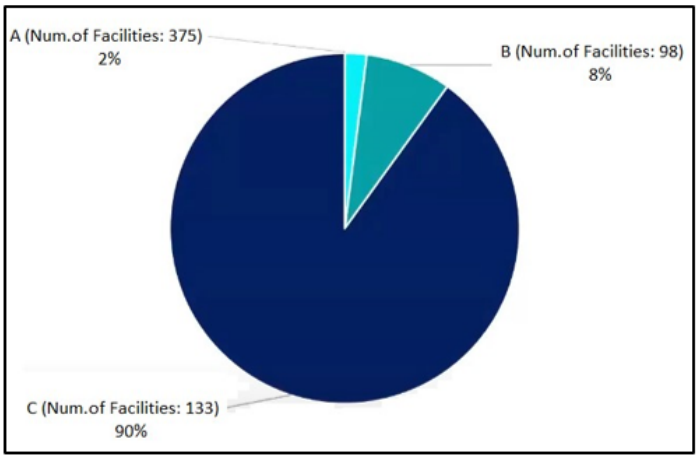


Figure 2.20. MRV system emission scope and facility numbers in 2022 (DoCC, 2024).

The knowledge and experience gained through the MRV system enable Turkiye to determine the average emission levels in the sector accurately, which is one of the most important pillars of a successful ETS (Aşçı, 2024). As TUSIAD (2016) noted in its report, over the last ten years, data inventories have improved, and companies have gained experience in MRV, which has created an optimal environment for a potential ETS implementation (TUSIAD, 2016).

As of July 2024, there are two publicly available official documents on the planned Emissions Trading System in Turkiye: one is the Draft Climate Law prepared in 2022, which has not yet been approved by the parliament, and the other is the Draft Regulation on the Functioning of Carbon Markets published by the Energy Market Regulatory Authority (EMRA) in 2023. The general expectation for the establishment of a carbon market in Turkiye is to first approve the Climate Law, which sets out the framework for establishing the Emissions Trading Scheme, including system revenue and utilization. Following the introduction of Climate Law, the Secondary ETS Legislation expected to be published, which will detail how the system will operate (EPDK, 2023; Republic of Turkiye, 2022).

According to the authorities, the envisaged ETS will cover emission-intensive sectors through a cap-and-trade scheme operating on the polluter pays principle. As

illustrated in Figure 2.21, the ETS's pilot period in will start on October 15, 2024, with the declaration of the national allocation, followed by a two-year transition period, with the first application stage starting on October 15, 2026. In the pilot period, it is planned to apply 80% discounted penalties (DoCC, 2024).

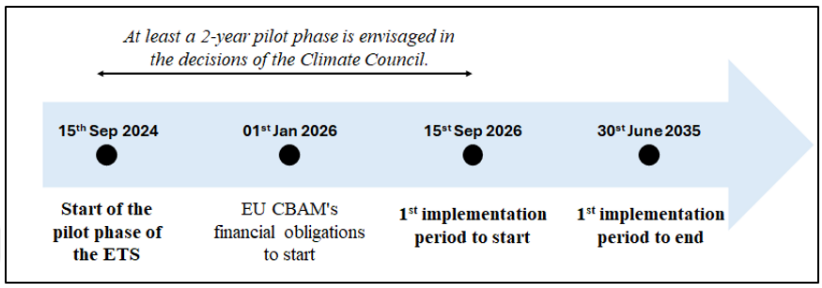


Figure 2.21. Implementation timeline of the planned ETS in Turkiye (DoCC, 2024).

The Draft Climate Law states that a Carbon Market Council will be established to determine the system's plans, policies, strategies, and actions and, most crucially, to develop the plan for allocating allowances, both free allowances and emission caps for the industry. The proposed council consists of the members from different ministries, as listed below (Republic of Turkiye, 2022):

- President: Minister of Environment, Urbanization and Climate Change
- Deputy Minister of Environment, Urbanization and Climate Change
- Deputy Minister of Energy and Natural Resources
- Deputy Minister of Treasury and Finance
- Deputy Minister of Industry and Technology
- Deputy Minister of Trade
- Deputy President of Strategy and Budget
- Chairman of the Capital Markets Board
- President of Department of Climate Change

In the draft Climate Law, Borsa Istanbul is assigned the responsibility of establishing and operating the market, conducting transactions such as clearing, settlement and collateralization, and establishing a transaction registration system, while the Cap-

ital Markets Board is assigned the responsibility of market surveillance and supervision and taking measures against market failures and market fraud (Republic of Turkiye, 2022).

According to the Draft Climate Law, carbon trading will take place in an organized market, to be operated by Borsa Istanbul. In line with the country's national emission targets, the total capital market instruments to be issued will be set according to the emission cap set by the Carbon Council. Enerji Piyasaları İşletme A.Ş (EPİAŞ), defined as the Market Operator, will be in charge of the operation of the emission trading market. The primary carbon market refers to the market organized and operated by the Market Operator, where transactions are carried out through the auction method to ensure the distribution of allowances among participants. Secondary carbon markets refer to the spot carbon market and physically delivered forward carbon market organized and operated by the Market Operator, where allowances are traded through continuous trading between companies. Operators under the ETS must register in the Transaction Registration System to operate in the markets. The TRS is an electronic data system where the issuance, holding, transfer, cancellation and redemption of allowances are realized and tracked in beneficiary-based accounts (EPDK, 2023; Republic of Turkiye, 2022).

As shown in Figure 2.22, the determined emission cap will be divided into three main segments: one free allowance, two allowances for auctioning and finally allowances for reserves. A portion of the total ETS permits will be allocated to companies as free allowances to ensure a smooth transition to industry and prevent carbon leakage. Free allowances also contribute to public support for the system. In the first pilot phase, the aim is to keep free allowances at the high level (EPDK, 2023; Republic of Turkiye, 2022).

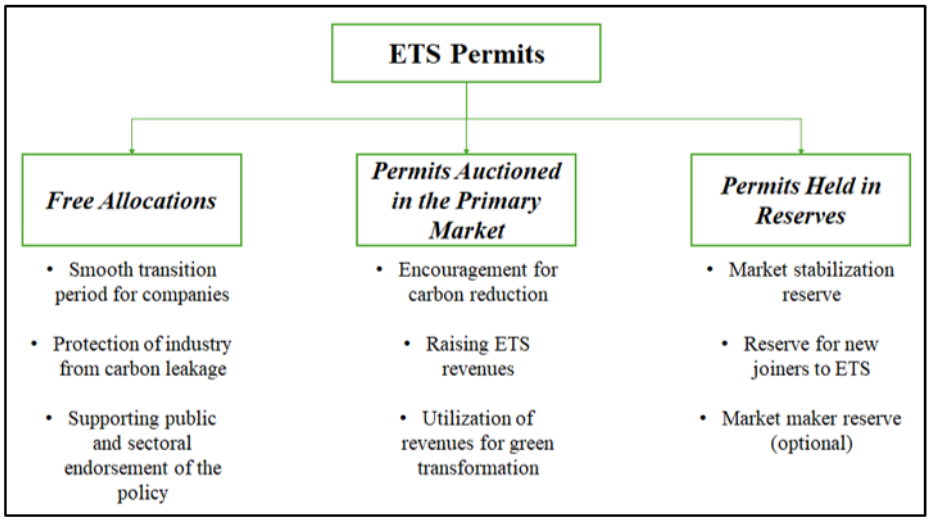


Figure 2.22. The permit allocation system planned in ETS (DoCC, 2024).

Where the companies need more than free allowances for their total emissions, some of the remaining allowances will be auctioned on the primary market so that companies can buy ETS permits. According to the Draft Regulation on the Functioning of Carbon Markets, the minimum offer size in auctions will be one lot and the value of each one-lot bid will 500 allowances. One allowance will match 1 ton of carbon dioxide and equivalent greenhouse gas emission value. In bids, TL/tCO_2 will be used for prices, and lots will be used for quantities. These auctions will incentivize companies to reduce their emissions, while the revenue from the auctions will be used for green transformation and just transition of the (EPDK, 2023; Republic of Turkiye, 2022).

The rest of the permits will be reserved to suppress the market when needed. Permit reserves are held to stabilize the market and prevent extraordinary increases. Reserved permits will also be used for new players joining the ETS system. There will be another market, the spot market, which allows companies to buy and sell their allocations among themselves (EPDK, 2023; Republic of Turkiye, 2022). In general, considering the currently implemented ETSs in the world, prices in the spot market are slightly higher than the primary market.

The ETS will work as follows: following free allocations, the government will issue and auction carbon certificates for sale in the primary market, after which firms can trade their own carbon certificates in secondary markets or spot markets (DoCC, 2024).

According to the Draft Regulation on the Functioning of Carbon Markets, carbon will be purchased and sold in two different markets which are primary and secondary markets, the basic principles are (EPDK, 2023):

- Distributions are offered for sale with auctioning in a quantity decided annually. It is crucial that the total quantity of allocation to be sold to be put to tender within a year be allocated equally between the tenders to be made during the year.
- The minimum offer quantity in auctions is 1 lot. The value of each 1 lot purchase offer is 500 allocations. 1 allocation coincide to 1 ton of carbon dioxide and its equivalent greenhouse gas emission value.
  In the tenders, TL/tCO_2 is used for prices and lot quantity is used for quantities.
- The revenue raised from the auctions is transferred to the relevant accounts opened to build appropriate mechanisms for legal bodies, public foundations, and organizations operating in strategic priority industries, specifically the industries within the scope of ETS, to use green transformation and just transition supports.
- The minimum buys or sell bid size in the spot market is 1 lot. The value of each 1 lot purchase offer is 1000 allocations. 1 allocation corresponds to 1 ton of carbon dioxide and equivalent greenhouse gas emission value. In bids, 0.50 TL and its multiples in TL/tCO_2 are used for prices, and lot units are used for quantities.

Until the Secondary ETS Legislation is published, the DoCC is conducting several public-private meetings to ensure that the private sector has accurate information without any disinformation. In these meetings, it is clearly stated that there are two important strategic approaches behind the national ETS: first, the aim to reach the

2053 net zero target; and second, the protection of Turkish industry from the CBAM, whose financial obligations start in 2026.

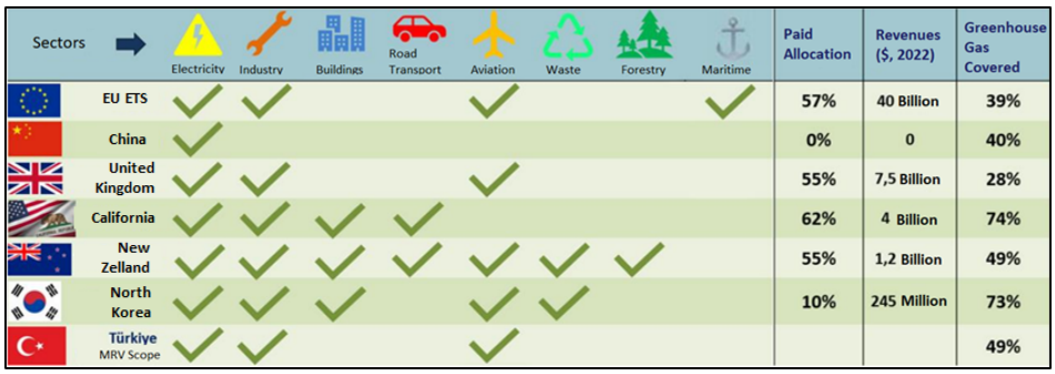
As stated in these meetings, excessive price fluctuations in the market will not be allowed and the market will be stabilized with reserve permits. In addition, it is aimed to provide flexibilities such as offsetting and borrowing from the next year's permits in order to facilitate the implementation in the first period and to minimize the impact on the market.

The world's most comprehensive ETSs cover GHG emissions at varying rates ranging from 28% to 74%. The EU ETS, one of the largest systems in the world, covers the electricity, industry and aviation sectors and generated revenues of USD 40 billion in 2022 with a GHG coverage rate of 39%, while 43% of permits are issued free of charge. The California ETS system's coverage and percentage of paid allowances are very high. However, the revenue is only USD 4 billion because of low carbon prices and the number of participants. Therefore, the revenues from emissions trading systems vary depending on different elements. When comparing Turkiye's MRV coverage with other countries, the percentage of GHG coverage is 49% on average. Also, the sectors covered, such as electricity and industry, are covered by all countries. However, as can be seen in Figure 2.23, the coverage of other countries is more extensive and considers and includes many more sectors (DoCC, 2024).

In the case of the ETS system's integration, the MRV system in Turkiye is almost entirely aligned with the EU ETS in terms of sectors and products, except aviation (Aşçı, 2024).

TUSIAD offered that a dynamic, rather than a static, approach should be undertaken while deciding the upper limit for emissions and that the business industry should be considered while assessing the industrial growth assumptions and sector-specific dynamics (TUSIAD, 2016).

According to the IMF (2023), the eligibility of the system can be raised further by leveraging the revenue raised by pricing and using the revenue to boost economic activities (e.g., by decreasing labor taxes) and to meet distributional concerns (e.g., by allocating a portion of revenues to low-income households) (Parry *et al.*, 2023).



Sectors	Electricity	Industry	Buildings	Road Transport	Aviation	Waste	Forestry	Maritime	Paid Allocation	Revenues ($, 2022)	Greenhouse Gas Covered
EU ETS	✓	✓			✓			✓	57%	40 Billion	39%
China	✓								0%	0	40%
United Kingdom	✓	✓			✓				55%	7,5 Billion	28%
California	✓	✓	✓	✓					62%	4 Billion	74%
New Zelland	✓	✓	✓	✓	✓	✓	✓		55%	1,2 Billion	49%
North Korea	✓	✓	✓		✓	✓			10%	245 Million	73%
Türkiye MRV Scope	✓	✓			✓						49%

Figure 2.23. Sector and emission scope of the world's most comprehensive ETSs (DoCC, 2024).

2.4.5.2. Voluntary Carbon Market. Although Turkiye could not take part in the Kyoto Protocol's flexibility mechanisms, as it is not an Annex-B country, voluntary markets have been paved the way for the country to gain useful experience in carbon markets and trading. Renewable Energy Certificates (REC), emission reduction certificates voluntarily traded in the voluntary carbon market, emerged in 2003 in Turkiye in response to requests from multinational companies for their activities. The voluntary market has accelerated in the last few years, creating a crucial step for Turkiye in developing future emissions trading systems (TUSIAD, 2016; ERCST, 2020).

According to the whitepaper on Voluntary Carbon Markets published by the Department of Climate Change in August 2022, the use of offset credits within the scope of the Emissions Trading System (ETS) is considered important for cost-effective mitigation. In this context, it is stated that a Draft Offset Communiqué is being worked on under the PMR Project. The DoCC states that the Draft ETS Regulation includes the use of carbon certificates from domestic emission reduction projects in the second implementation period of the ETS and limiting offset credits to keep the carbon price

above a certain level in the ETS market. In the first phase of the planned ETS, offsets from credits outside Turkiye are proposed to be used to ensure market liquidity, and in the second phase, offsets from credits generated within the scope of a national system to be established are proposed (DoCC, 2022).

In parallel to the DoCC, according to the study published by PMR Turkiye and conducted by the European Roundtable on Climate Change and Sustainable Transition (ERCST), domestic offsets from existing voluntary registered emission reduction projects up to a certain percentage of the compliance obligation must be used. Offsets should be generated outside the scope of the ETS to avoid double counting (ERCST, 2020).

The first regulation published on the voluntary carbon market in Turkiye is the Voluntary Carbon Market Project Registration Communiqué by the MoEUCC, enacted to regulate the procedures and principles regarding the registration of projects developed in Turkiye to reduce greenhouse gas emissions and obtain carbon certificates (Official Gazette of the Republic of Turkiye, 2013). According to ERCST, although project registration is mandatory, the registry does not apparently function and is not used by either the MoEUCC or project owners/developers. However, some buyers require projects to be registered in the MoEUCC registry, which forces some project owners to submit their projects to the MoEUCC for registration (ERCST, 2020).

In the absence of regulation, alternative certification systems such I-REC have emerged in Turkiye. Following the establishment of the authorized market operator EPİAŞ in September 2015, EPİAŞ started to work on the Regulation of Renewable Energy Resource Guarantee Certificates in the Electricity Market. Taking part in climate change negotiations and following developments in international markets, EPİAŞ published the Regulation on Renewable Energy Resource Guarantee Certificate (YEK-G) in the Electricity Market in November 2020 (Official Gazette of the Republic of Turkiye, 2020).

EPİAŞ provides YEK-G certificates to consumers who consume electricity under the Green Energy Tariff (YETA). YEK-G certificates are electronic documents, each of which corresponds to 1 MWh of electricity generation. The YEK-G Certificate is valid for 12 months starting from the month in which the 1MWh of electricity subject to the relevant certificate is produced (Official Gazette of the Republic of Turkiye, 2020). According to the EPIAŞ transparency platform, the first issuance of YEK-G was made on 21.06.2021, and the total issuance value until July 2024 is USD 157,860.95, corresponding to 42,064,091 MWh (EPİAŞ, 2024). It must be noted that YEK-G is a renewable energy certificate that can be seen as equivalent to I-REC, not an emission reduction certificate such as GS or VCS. YEK-G covers renewable energy sources such as hydroelectric power plants, renewable energy power plants, solar power plants, geothermal power plants and lastly biomass.

In accordance with the World Bank Carbon Pricing Dashboard, Turkiye has been issued 48,747,744 tCO_2e VCS credits cumulatively since 2005; 9,329,137 tCO_2e VCS credits in 2023; and 61,392,701 tCO_2e Gold Standard credits cumulatively since 2003; 8,263,962 tCO_2e Gold Standard credits in 2023 (World Bank, 2024b).

GS and VCS, considered the two largest and most trusted standardization bodies in the voluntary carbon market, have announced that they will no longer accept new renewable energy project applications from countries that are not least developed countries (LDCs) from 2020. Only Gold Standard accepts projects within the scope of waste management. Some standardization bodies that can currently accept renewable energy project applications for the Turkiye market are the Global Carbon Council (GCC), CCB (Climate, Community and Biodiversity) and VOS (Voluntary Offset Standard) (DoCC, 2022).

2.5. Carbon Pricing Literature in Turkiye

A limited number of studies exist on environment-energy-economy modelling in Turkiye. Many of these studies about climate change in Turkiye aimed to measure

the variables that lead to fluctuations in GHG emissions and the influences of these variables benefiting from historical datasets. Research has shown that the most crucial factors that have resulted in the rise in GHG emissions in Turkiye are economic growth, high energy dependency, and population (Mercan and Karakaya, 2015). Some researchers have used a general equilibrium model to study the effect of carbon pricing policies on Turkiye's macroeconomic parameters. However, compared to emerging countries, specific examination on carbon mitigation policies in Turkiye is restricted (Uyduranoğlu and Öztürk, 2020).

The first study, about the mitigation of GHG emissions for Turkiye, belongs to Yeldan *et al.* (1996), which computed the impact of different regulations on emissions with a multi-industry computable general equilibrium (CGE) framework. When the study was conducted, the Kyoto Protocol was not stated, and it was estimated that the energy tax application would increase emissions by approximately 9.3%, by 4.7% emission savings in the 1987-2000 interval (Yeldan *et al.*, 1996).

In 2001, Arıkan and Kumbaroğlu constructed a general equilibrium model, representing the combination of energy, economy, and environment sub-models. The model functioned to decide upper quotas of SO2 and NOx emission levels aligned with the EU environmental standard, and tax quantities based on these limits were decided. As a consequence of the analysis, the GDP loss because of the emission tax was 1.4%. In 2020, it is predicted to be approximately 2.5% (Arıkan and Kumbaroğlu, 2001).

Şahin (2004) studied the influences of energy taxes and emission trading. This study is the first study investigating the implementation of emission trading for Turkiye. The study focused on the impacts of the alternative constraints approach from 2005 to 2008, measured by the 1990 emission level. Based on the study's results, if emission trading was applied in Turkiye, it is estimated that GHG emissions would be roughly 2.34% below the 1990 level in the 2005-2008 interval (Şahin, 2004).

Telli and Voyvoda and Yeldan (2008)'s study states that the burden on the Turkish market from directly implementing carbon limits without backstop functions would be significantly high. According to the findings, introducing a CO_2 limit of 60% in the baseline scenario would require a carbon tax of around 20% to 15% between 2006 and 2020. The resulting GDP loss under this scenario is over 30% by 2020. Such an adjustment would only help to achieve CO_2 reduction targets through employment incentives. Many research illustrate that leveraging such tax revenues to finance cuts in existing taxes on employment, manufacturing, or sales can reach out excellent results by achieving environmental goals at lower costs, perhaps even with a positive net benefit (Telli *et al.*, 2008). Akın-Ölçüm and Yeldan (2013) investigated the welfare effects of various emissions trading system (ETS) scenarios for Turkiye under the EU's 20%-20%-20% aim and its renewed version of 30%. The study constructed a multi-regional and multi-industrial computable general equilibrium (CGE) model and reached out that Turkiye would economically benefit from joining the EU ETS under the 20% cap but would be exposed to significant output losses under the 30% cap (Akın-Ölçüm and Yeldan, 2013).

Yeldan and Voyvoda (2015) carried out one of the leading studies on Turkiye market and explored potential options for emission mitigation. The report "Low Carbon Development Pathways and Priorities for Turkiye" was prepared in partnership with WWF-Turkiye and Istanbul Policy Center (IPC) and published before the Turkiye's INDC. They applied three scenarios to illustrate the effects of policy differences on achieving 2° C ambitions. One is built on Turkiye's political plans and official policies, a highly aggressive growth scenario and carbon emissions. The other scenario, called the baseline scenario, utilizes global growth projection data and has a more conservative carbon emissions pathway. The last scenario is the one that implements the Climate Policy Package, which consists of 3 sub-parts: carbon tax, renewable energy investment fund and energy efficiency improvement. Suppose the regulation tools in this package are applied, the annual CO_2 emissions are simulated to be 506 MtCO_2 in 2030, 23% below the baseline pathway, and a 40% reduction compared to official policies will be achieved (Yeldan and Voyvoda, 2015).

Mercan and Karakaya (2015) conducted a study to determine the economic costs of carbon pricing for the Turkish economy using computable general equilibrium (CGE) analysis and to make suggestions for future economic policies. The study investigated the effects of carbon pricing on welfare, and the results showed that the economic cost of implementation would be high. Since most of the studies in the literature of Turkiye did not focus on carbon pricing and preferred to focus on emission calculations when the study was conducted, different from other studies in the literature, this study put a price on carbon (Mercan and Karakaya, 2015).

Bouzaher, Şahin, and Yeldan (2015) established a CGE model for 12 sectors, including their CO_2 and Particulate Matter (PM10) emissions, solid waste, and wastewater discharges. The study targeted to recognize feasible policies for 2010-2030 to accomplish green development in Turkiye. They suggested a policy of taxing PM10 and CO_2 emissions, taxing solid waste and wastewater discharge, and spending the revenue generated on green job creation and R & D-driven innovation (Bouzaher *et al.*, 2015).

The report, titled "Addressing Climate Change from an Economic Policy Perspective", prepared by the Turkish Industry and Business Association (TUSİAD) following the submission of the INDC in 2015, aims to address policy options for Turkiye after the 2020 period, considering global practices. The authors developed a CGE model to quantify the probable economic impacts of implementing a tax to mitigate emissions in Turkiye with two different alternatives: A baseline scenario with an energy tax to achieve a 21% reduction target and an alternative scenario with an energy tax combined with a mitigation in other taxes such as employment tax. The baseline scenario reduces emissions by 21% but results in an 8.7% reduction in national income; the alternative scenario reduces emissions by 15.5% but a 3.7% reduction in national income (TUSIAD, 2016).

Karapınar *et al.* (2019) evaluated how a carbon tax and a national ETS would influence macroeconomic parameters in Turkiye using Computable General Equilibrium.

The results of the model show that not only the carbon tax but also the ETS can be efficient and effective in decreasing GHG emissions without leading to a crucial negative impact on total macroeconomic parameters such as imports, exports, GDP and growth rate. Nevertheless, compared to the ETS, the carbon tax performs better in terms of carbon reduction. Moreover, the least carbon-efficient scenario is found to be the scenario that only focuses on renewable energy developments in the country, which reveals that without carbon pricing, achieving the desired emission levels is impossible (Karapınar *et al.*,2019).

Uyduranoğlu and Öztürk (2020) analyzed the drivers and barriers to public support for potential carbon pricing by conducting face-to-face surveys with 714 respondents from a representative sample of the Turkish population. By the study, it is crucial to emphasize that the public will be exposed to sudden results of carbon taxation with rising energy prices. At the same time, they cannot suddenly notice the development of environmental benefits of carbon pricing. This situation may prohibit society from noticing the advantages and disadvantages related to carbon taxation. For this reason, since the permanent application of carbon taxation, the usage of a trial interval with the reported sudden co-benefits, such as improved air quality, may empower societies' attitudes toward the efficiency of carbon taxation. In conclusion, when society is entirely aware of the developments related to carbon taxation, they are most likely to start to favor it (Uyduranoğlu and Öztürk, 2020).

To address concerns about loss of competition, the polluting industries with significant energy consumption should be given initial allowances and gradual tax rate rises to allow them to adapt to carbon taxation by moving to cleaner technological structures. The EU ETS applied a similar approach in Phase I and II by granting allowances to enterprises with extensive energy use to focus on possible competition effects (Uyduranoğlu and Öztürk, 2020).

Since 2021, Istanbul Policy Center (IPC), together with its eight experts (Ümit Şahin, Osman Bülent Tör, Bora Kat, Saeed Teimourzadeh, Kemal Demirkol, Arif

Künar, Ebru Voyvoda, Erinç Yeldan) who have contributed to the climate change's effects literature in Turkiye, conducted three studies on Turkiye's climate targets, necessary mitigation methods and what to do for decarbonization of emission-intensive sectors.

The first study, "Turkiye's Decarbonization Roadmap: Net Zero by 2050", was published just before Turkiye's NDC in 2021. The study assesses the net zero goals of the country and creates a roadmap to become net zero in 2050, and outlines what to do in the sub-sectors. Moreover, the methods of mitigating carbon emissions in energy, transportation, buildings, industry, and other industries are presented. In accordance with the net zero scenario in the report, Turkiye can decrease its emissions by 32% until 2030 and 68% until 2050 levels if it complies with the decarbonization roadmap (Şahin *et al.*, 2021).

Secondly, "Turkiye's Decarbonization Roadmap: Sectoral Cost-Benefit Analysis (2020-2030)" was published in 2022. The report shows that the total investment, O and M, and investment cost of the transformation for the net zero scenario is 171 billion dollars between 2020 and 2030. The total benefit of the transition, primarily due to the decrease in fuel use, is 70 billion dollars. This makes the net cost 101 billion dollars, which accounts for around 10 billion dollars per year (Tör *et al.*, 2022).

Thirdly, the report "Turkiye's Decarbonization Roadmap: Transformation Calendar and Geography (2020-2050)", published in 2023, examined the system of decarbonization at 5-year intervals with a specific focus on the electricity sector. In particular, plant-based recommendations were made on when coal-based generation in the electricity sector can be phased out and in which order natural gas and renewable energy plants can be commissioned (Teimourzadeh *et al.*, 2023).

The IMF has conducted a collaborative study for Climate Mitigation Policy in Turkiye, both for baseline assessment and for future steps. In light of the IMF's Working Paper, carbon pricing is the most cost-effective reduction strategy and could

become the keystone of Turkiye's mitigation strategy. Other mitigation instruments, such as emission rate standards and clean technology alternatives, encourage a limited range of behavioral responses (Parry *et al.*, 2023).

In accordance with IMF's study, the price which can be either ETS or a carbon tax begins at $35 per ton in 2023 and climbs steadily to $75 ton in 2030, by this way, it will cover fossil fuel emissions from the manufacturing, transport, construction and power industries. Estimated that, prices of 25,50, and $75 per ton in 2030 will decrease Türkiye's fossil fuel CO_2 emissions by approximately 15, 21, and 26% mentioned below BAU levels in 2030 (Parry *et al.*, 2023).

Apart from the IPC's series of reports titled Turkiye's Decarbonization Roadmap, Aşçı (2024) conducted a study for the preliminary assess of the Turkish emission trading system under the umbrella of IPC. In this study, Aşçı compared the different countries' ETS systems and the emission levels of the industries. Moreover, gathered the information shared by the government authorities about planned ETS also suggested a cap level for the Turkish ETS according to its emission forecasts (Aşçı, 2024).

In all the modelling studies conducted for Turkiye, the cost increase is significant, as the international carbon price is not considered. Especially with the introduction of CBAM, if an ETS system is not established in Turkiye, the export cost will be much higher as the total carbon price in the EU will be paid without any rebate. Moreover, the country's money will not stay within its borders and will fund the EU system rather than itself.

2.6. Construction Industry's Environmental Impact

The construction industry has been the locomotive sector of countries and has contributed to their economic growth. However, it has also caused severe environmental pollution and depletion of natural resources. (Zhou *et al.*, 2021).

One of the main contributors to greenhouse gases is the construction industry, which accounts for over one-third of global carbon emissions, accounting for 37% of global emissions. In addition to that, every year, more than 40% of the energy used globally is utilized for buildings. The production and use of cement and steel, the primary construction materials, have a significant carbon footprint. Despite such a large share, solutions to reduce the embodied carbon emissions of buildings from the design, production and transport of materials such as cement and steel have long been overdue, as the United Nations Environment Program (UNEP) report notes (Cheng *et al.*, 2008; UNEP, 2023).

The UNEP suggested seven methods to help the construction industry minimize the carbon footprint of construction projects in 2009. These are cooperating with governments to establish policies that change emissions perspective, integrating carbon trade mechanisms for buildings, allocating research and development to construct net zero buildings, illustrating technological infrastructure on buildings and rented offices, redesigning buildings to minimize the emissions, heading towards to holistic and systemic solution sets to sustainable buildings, and training the supply chain mechanism (UNEPSBCI 2009).

Despite giving these methods, UNEP did not propose objective evaluations to measure these strategies.

Following the UNEP, Global Reporting Initiatives (GRI) established directives for construction companies to report sustainability performances in 2011. The performance is evaluated by using three critical perspectives: management methodology, strategy, profile and performance indicators. GRI updated this directive as G4 Construction and Real Estate Sector Disclosures in 2014 (GRI, 2014).

The guidelines developed by both GRI and UNEP were not project-specific and functional for assessing a contractor's carbon reduction behavior in a construction project. Due to the nature of construction works, a construction company should be

assessed in terms of not only corporate carbon performance but also project-based carbon performance.

In this manner, the European Network of Construction Companies' (ENCORD) inventory for Research and Development is more suitable for a construction company's evaluation. The inventory assesses both the carbon emitted in construction projects and the corporate emissions of companies. The inventory assesses carbon emissions from twelve perspectives, including reducing emissions through better design, reducing fuel and electricity use at construction sites and offices, reducing process emissions in steel and cement production, and reducing highly embodied CO_2 materials (ENCORD, 2009).

Considering emissions in both construction and operation phases is important for real emission reduction in the construction industry (Zhu *et al.*,2010). In addition to the materialization stage of a building, the operation and destruction phases also cause high amount of carbon emissions (Zhou *et al.*, 2018).

In its fourth evaluation report, the Intergovernmental Panel on Climate Change (IPCC) noted that while the building sector has the most significant potential to significantly reduce GHG emissions, this potential is relatively independent (IPCC, 2007).

Yan *et al.* (2010) identified the main sources of GHG emissions in building construction and studied a high-rise building case study in Hong Kong. The study resulted in GHG emissions of 81.6-86.7% from embodied emissions of building materials, 6.1-8.4% from transportation of building materials, and 6.4-8.6% from equipment energy consumption (Yan *et al.*, 2010).

According to the Turkiye National Inventory Report (2023), the rises in sectoral emissions in Turkiye are driven by growth in the mineral industry, primarily cement manufacturing, and the metal industry, mainly iron and steel manufacturing. As Figure 2.24 shows, emissions from these two sectors are gradually increasing every year,

especially due to industrial developments and rising demand for construction materials (Turkish Greenhouse Gas Inventory, 2023).

Mitigation of emissions at the industrial sector differs from other sectors in some respects, making it a "hard to abate" and leaving the industry behind other sectors in terms of emission reduction. Industrial sub-sectors such as iron and steel, cement and chemicals and petrochemicals are responsible for a significant portion of emissions from the industrial sector. The fact that these sub-sectors (i) are part of an energy-intensive production process and meet this energy need primarily from fossil fuels, and (ii) the presence of process emissions caused by the chemical process that takes place during the production phase makes industrial sector-based mitigation difficult (Hiçyılmaz *et al.*,2022).

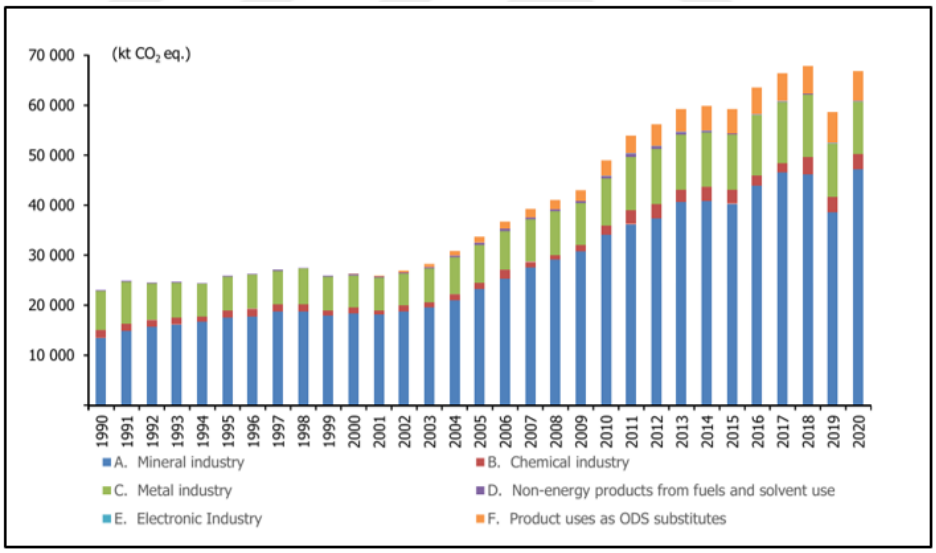


Figure 2.24. Emissions from industrial processes and product use by sub-sector (Turkish Greenhouse Gas Inventory, 2023).

Iron-steel and cement subsectors account for an important portion of total industry emissions globally, and this share has become more significant day-to-day. For instance, in 2000, the portion belonging to these industries equaled 44% of total emissions; in 2010, it became 48%, and in 2020, it grew to 59% (Hiçyılmaz *et al.*,2022).

According to a study by Wu *et al.* (2005), which compared three types of cement and five types of steel, the environmental impact of steel is much higher than that of cement when considering not only CO_2 but also other impacts such as resource use. The reason why is that steel production is a much more complex and energy-consuming process than cement production.

According to the World Bank's Country Climate and Development Report for Turkiye, an investment of 11 billion dollars in the cement, iron, and steel industry, shared 50%-50% by public and private funds, is required to create a resilient and net zero (World Bank Group, 2022).

Kunsch *et al.* (2001) argue that there is a "Willingness to Invest (WTI) cost threshold" for investing in a new technology. They claim that a carbon price that does not exceed this threshold will not encourage producers to invest in new technologies. Therefore, the carbon pricing system established anywhere should be sufficient to provide essential encouragement for investment (Kunsch *et al.*, 2001).

The Istanbul Planning Agency's Turkiye's Decarbonization Roadmap: Sectoral Benefit-Cost Analysis report presents the percentages of Turkiye's producer sectors in total production and exports, their energy intensities and CO_2 emissions in 2018, as seen in Table **??**. The analysis focuses on the types of fuels and emission sources used by the cement, iron and steel sectors as well, which are the two primary materials used in rough construction and account for most of a building's embedded emissions. The analysis shows that the cement sector is responsible for almost half of the country's total producer emissions, with the highest process emissions.

Similarly, the iron and steel sector are liable for around 11% of total emissions, with process emissions almost three times higher than energy (Teimourzadeh *et al.*, 2023).

As the construction sector is liable for 37% of energy-related CO_2 emissions and 40% of primary energy use many countries have introduced carbon pricing for businesses that use energy above a threshold to reduce CO_2 emissions (Ming, 2014).

The proposed ETS system for Turkiye does not include carbon pricing for the construction, operation and demolition phases of buildings. The system covers only the industry for now, so the cement and steel industries will be affected by the ETS system, and the manufacturing costs of these materials will increase. As these two materials are the primary materials used in construction, an increase in these material's manufacturing costs will affect the unit construction cost. Therefore, this study focuses directly on the emissions of the cement and steel industries and the potential manufacturing cost increase through the ETS.

Although the cement and steel industries are responsible for many other GHG emissions, only CO_2 gases, which constitute a large portion of GHGs, are covered by carbon pricing globally and in Turkiye's planned ETS. Therefore, this study only analyzes CO_2 emissions in the cement and steel sectors.

2.6.1. Cement

Cement is the most used man-made material and the fundamental component of concrete. As such, it is of strategic importance to all countries (MoIT and PwC, 2024).

Cement is a non-metallic, inorganic substance with hydraulic binding properties in building materials. It is a fine powder, which could be grey or white, produced by heating a mixture of natural limestone stones and clay at high temperature, grinding and then adding forms of calcium sulfate. It forms a paste when mixed with water, which hardens due to the formation of mineral hydrates. Cement production starts with the pre-calcination of CaCO3. During this process, CaO is formed, and CO_2 is released. Subsequently, CaO reacts with silica, alum and iron oxide at high temperatures (1400-1500 ^oC) to form clinker containing silicates, aluminates and calcium ferrites. The

clinker is then ground with gypsum and other additives to produce cement (MoEUCC, 2020).

Cement emits large amounts of CO_2 throughout the clinker calcination and fuel combustion phases of manufacturing. Therefore, the cement industry is one of the sectors most influenced by environmental regulations (Du *et al.*, 2022).

The cement industry is an energy-intensive industry where energy accounts for 30-40% of production costs. Coal is mainly used as fuel. In addition, waste or waste-derived fuels, such as contaminated waste, end-of-life tyres, etc., can also be used as alternative fuels. Using waste as an alternative fuel also prevents environmental pollution and saves fuel used as primary fuel (MoEUCC, 2020).

Globally, the cement industry which is responsible for almost 7% of energy-based CO_2 emissions has not only strategic importance but also significant features regarding global decarbonization and green transformation aims. In the last decade, it has been observed that Turkiye's geographical location and quickly growing population have triggered a rise in construction projects such as mega projects, therefore demand for cement has been increased and it became a crucial factor in urbanization and economic growth (MoIT and PwC, 2024).

As of 2020, Turkiye is the largest cement producer in Europe, with a production capacity of 77 million tons of clinker. Most of the cement produced in Turkiye is Portland cement. Slag blended cement, pozzolan blended cement and their modifications are also manufactured. As shown in Figure 2.25, CO_2 emissions in the industry rose by 291% from 1990 to 2020. The construction industry and cement exports are the most powerful drivers in the cement production sector. With the exception of some slight decreases in 2001 as a result of economic recessions in Turkiye and in 2015 because of conflicts in Turkiye's southern neighbors, the cement sector continuously grew until 2018. In 2018 and 2019, cement production declined because of a drop in domestic demand. In 2020, clinker manufacturing was 77 539 kt, resulting in CO_2 emissions of

40,813 kt. Despite the negative impacts of COVID-19, Turkiye's construction sector recovered by 2020, and cement production climbed by 26.3% compared to 2019. Total home sales in Turkiye rose by 11.2% compared to 2019, reaching around 150,000 homes (Turkish Greenhouse Gas Inventory, 2023).

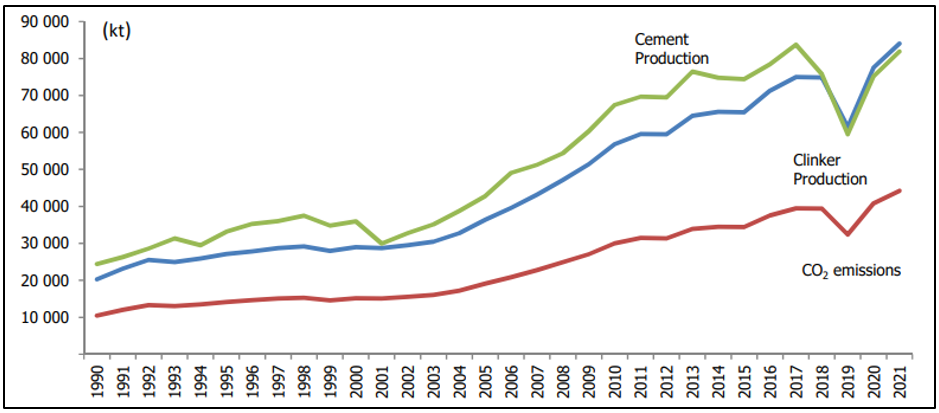


Figure 2.25. Historical trends in clinker and cement production and related CO_2 emissions, 1990-2021 (Turkish Greenhouse Gas Inventory, 2023).

Global cement production was 4.1 billion tons in 2022, and Turkiye's share in total cement production was 1.9%. Turkiye's total clinker and cement production and related CO_2 emissions between 1991 and 2021 showed in Table 2.4. In 2022, Turkiye produced 72.4 million tons of clinker and 77 million tons of cement. In 2019 and 2020, the world's largest cement exporter was Vietnam, while in 2022, Turkiye surpassed Vietnam by exporting 29 million tons in quantity and became the largest exporter with a share of 16.9%. Turkiye was the fifth country in the world with a 2.6% share (44.2 million tons of CO_2) of total emissions related to industrial processes and product use (IPPU) from cement production in 2021 (MoIT and PwC, 2024).

According to Turkiye's National Inventory Report (2023), the most important GHG emission sources of industrial processes and product use (IPPU) in 2021 were cement production with 7.8% and iron and steel production with 2.1% of total national GHG emissions excluding land use, land-use change and forestry (LULUCF) (Turkish Greenhouse Gas Inventory, 2023).

Table 2.4. CO_2 emissions from the cement production between 1990-2021 (Turkish Greenhouse Gas Inventory, 2023).

Year	**Clinker Production (kt)**	**Cement Production (kt)**	**CaO Content (%)**	**CO EF**	**CKD**	**CO Emission (kt)**
1990	20 252	24 416	64.4	0.506	1.02	10 445
1995	27 094	33 140	65.2	0.511	1.02	14 133
2000	28 950	35 953	65.5	0.514	1.02	15 184
2005	36 382	42 787	65.6	0.515	1.02	19 117
2010	56 798	67 447	65.9	0.517	1.02	29 977
2011	59 579	69 643	66.0	0.518	1.02	31 454
2012	59 508	69 466	65.9	0.517	1.02	31 372
2013	64 482	76 484	65.7	0.516	1.02	33 913
2014	65 594	74 768	65.7	0.516	1.02	34 498
2015	65 433	74 401	65.7	0.516	1.02	34 441
2016	71 298	78 437	65.7	0.516	1.02	37 528
2017	74 985	83 735	65.7	0.516	1.02	39 469
2018	74 880	75 746	65.7	0.516	1.02	39 413
2019	61 458	59 511	65.7	0.516	1.02	32 349
2020	77 539	75 172	65.7	0.516	1.02	40 813
2021	84 025	81 881	65.7	0.516	1.02	44 227

As of January 2024, the Turkish cement industry has 56 operating cement plants and 21 grinding facilities, and it manufactures more than 77 million tons of cement. Due to the high transportation costs in the cement sector, production facilities are spread all over the country. (MoIT and PwC, 2024).

2.6.1.1. Primary Sources and Process Emissions. The carbon sources in the cement industry can be summarized in three fundamental categories: clinker calcination emissions, fuel combustion emissions and indirect emissions (Du *et al.*, 2022). Calcination, the primary process in cement production, causes process emissions, while the combustion of fossil fuels causes direct emissions from energy and indirect emissions from electricity consumed and transportation. About half of the cement emissions come from process emissions, 40% from direct fossil fuel combustion, and the rest from electricity purchases and transportation (Hiçyılmaz *et al.*,2022).

Cement production emits high volumes of CO_2 emissions because of the calcination reaction of limestone. In addition to calcination, the production of cement is an

energy-intensive process. The majority of furnaces in Turkiye use fossil fuels such as coal, pet coke and lignite as their primary energy source. Limestone is fed into the cement kiln and heated up to 1400-1500^oC to produce lime. Heating the furnace to such a high temperature with its load is highly energy-consuming.

At this temperature, calcium carbonate (CaCO3) is converted into lime (CaO) and carbon dioxide (CO_2). Silica-containing materials are then integrated with lime to produce clinker. Clinker is the most essential intermediate product and is even traded as a commodity. It is produced by mixing and grinding clinker with other materials, such as gypsum and slag, in small quantities. Almost all CO_2 emissions are emitted from the furnaces during the clinker production phase (Turkish Greenhouse Gas Inventory, 2023).

Carbon dioxide emission during the calcination of limestone in cement plants is the most significant disadvantage for the industry regarding greenhouse gases. Decarbonizing the industry is difficult as the source of emissions is the raw material itself. It is only possible with the use of substitutes for clinker.

For instance, using trass, natural pozzolans, and slags as the cement additive saves the use of clinker and ensures cement production by using less clinker. Thus, reducing carbon dioxide emissions associated with each ton of cement is possible. Therefore, cement production with less clinker, meaning lower emissions, is only possible by using more alternative raw materials (MoEUCC, 2020).

Cement production involves three main stages: extraction and grinding of raw materials, clinker calcination and cement grinding. Cement production and related emission sources are shown as a flow chart in Figure 2.26.

The raw material extraction and grinding process involves crushing, grinding, and homogenizing the limestone. Clinker calcination involves preheating, pre-decomposition, high-temperature calcination and cooling, which produces most of the CO_2. Clinker is

mixed with additives such as gypsum, blast furnace slag or volcanic ash before grinding in the cement grinding process (Du *et al.*, 2022).

Some cement plants in Turkiye have waste incineration licenses issued by the MoEUCC. They utilize waste as alternative fuel and raw material.

The wastes incinerated with the license are waste plastics, end-of-life tyres, waste oils, industrial sludge, tank bottom sludge, sewage sludge, etc. Waste incineration licenses have been issued to the cement industry since 2004 (Turkish Greenhouse Gas Inventory, 2023).

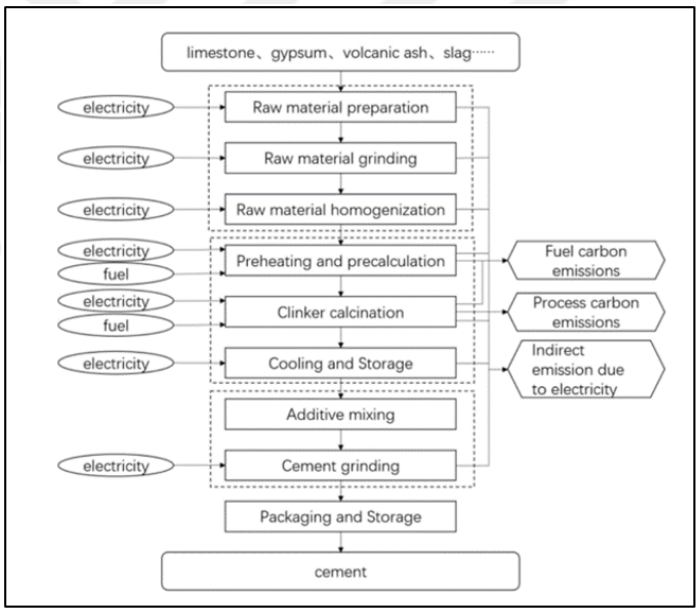


Figure 2.26. Production of cement and emission sources flowchart (Du *et al.*, 2022).

2.6.1.2. Global Best Practices for Emission Reduction. The report titled Low Carbon Roadmap for the Turkish Cement Industry, prepared by the Ministry of Industry and Technology and PwC and supported by the European Bank for Reconstruction and Development (EBRD) and Climate Investment Funds (CIF), draws a decarbonization map for the Turkish cement industry, considering global best practices (MoIT and PwC, 2024).

The policy recommendations identified as a result of all the analysis and discussions were grouped under two main policy themes: first, inputs and technology, and second, policy and market. The policy areas under these themes are summarized as follows (MoIT and PwC, 2024):

- Reducing Clinker Utilization in Cement Production
- Carbon Capture, Utilization and Storage (CCUS) Technologies
- Waste Heat Recovery (WHR)
- Alternative Fuel Use
- Green Energy
- Process Optimization
- Inclusive Employment and Skills
- Material Efficiency in Construction
- Consideration of Recarbonation
- R & D
- ETS
- Trade Model
- National Policy Documents
- Financing Green Transformation
- Collaborations
- Industrial Symbiosis

According to the IPCC's Climate Change Report in 2022, electrified cement kilns can be used to achieve emission mitigation targets for cement and concrete manufacturing. Waste heat to power (WHP) is another currently used option but has yet to be widespread. Research about the cement, glass, and iron industries in China illustrated that the existing technological background provided just 7-13% of waste heat to be utilized for power creation. With more advanced technologies, approximately 40-57% of waste heat with temperatures above 150^oC could be benefited for power generation via heat recovery (IPCC, 2022).

The World Bank Group also highlights that further emission mitigations can be succeed by implementing waste heat recovery systems that meet up to 30% of a cement plant's electricity requirements. Contrary to IPCC, World Bank states that the cement industry is considered hard to electrify with existing technologies, partly due to the high temperatures needed (World Bank Group, 2022).

Biofuels are alternatives to fossil fuels in many forms, including those almost same as fossil fuels but derived from biogenic sources. Although CO_2 emissions are also released during the combustion of biofuels, many global regulations consider biofuels to be zero-emission. Solid biomass, derived directly from wood chips, lignin, or processed pellets, is the industry's most widely used biofuels today (IPCC, 2022). Currently, biofuels are being implemented in the industry; however, due to uncertainty about the sustainable supply of raw materials, companies do not want to rely solely on biofuels.

The International Energy Agency's roadmap for emission reductions in the cement industry to 2050 proposes four key strategies to reduce CO_2 emissions from cement production effectively, and these actions could help reduce emissions from the cement sector by 24% by 2050 (IEA, 2009):

- using thermally and electrically efficient cement production facilities,
- using alternative fuels,
- using supplementary cementitious materials to reduce clinker/cement ratio
- capturing and storing CO_2 before it is released into the atmosphere.

In parallel, according to Du *et al.* (2022), methods to decrease carbon emissions from the cement industry contain alternative fuels, energy-efficient kilns, replacement of clinker with mineral components, carbon capture and utilization, and CO_2 mineralization (Du *et al.*, 2022).

Decarbonisation alternatives include CCUS, one carbon-capturing method is post-combustion, where CO_2 is removed from the exhaust gases, and the other is oxy-

combustion, where the fuel is burned with pure oxygen, thus exhaust gases containing up to 90% CO_2. Post-combustion and oxy-combustion methods reduce emissions by about 55% and 85%, respectively (Parry *et al.*, 2023). CCUS has the potential to capture up to 90% of heat-related emissions from cement manufacturing for $60-170 per t$CO_2$e (World Bank Group, 2022).

The use of green hydrogen in high energy-intensive industries is another alternative on the agenda. However, according to IPM's report, it is assumed predicted that that Green Hydrogen will only start to be used in Turkiye after the 2040s and the share of these industries in total energy consumption will only reach 5% in 2050. In the same report, it is also assumed that the use of Carbon Capture, Utilization and Storage Technologies (CCUS) in high energy-intensive industries will start towards the 2040s and that these technologies will be able to reduce up to 5% of total emissions in these sectors in 2040 and 10% in 2050 (Tör *et al.*, 2022).

The other perspective is to make effective designs in construction projects. Cement and concrete are currently overused since they are cheap, durable and ubiquitous. Basic material effectiveness efforts to use concrete only where needed (e.g. using right-sized, prefabricated components) could mitigate emissions by 24-50% by reducing demand for clinker. Substituting cementitious material with various materials (e.g. ground limestone and calcined clays) can reduce process calcination emissions by up to 50% (IPCC, 2022).

The process, called recarbonation, refers to the process by which some of the CO_2 emitted during cement manufacturing is reabsorbed by the concrete in use via carbonation. It also prevents the release of this carbon over the decades-long lifetime of the products, with predicts of this flux ranging from 15% to 30% of direct emissions. In addition to the lifetime, after demolition of concrete, it should be exposed to atmospheric CO_2 for several months before reuse since the rate of recarbonation will increase as the surface area increases with demolition (VDZ, 2021).

Some concrete producers also implement carbon-cured concrete techniques. In this technique, early-age concrete elements are placed in a room where CO_2 is diffused into the concrete under constant temperature and pressure. The system continues to a carbonation reaction and gains its strength faster. It is an accelerated concrete curing technique. Adding CO_2 strengthens the concrete and, most importantly, reduces the cement required with this technique. The CO_2 sequestered during cement production can also produce carbon-cured concrete. Carbon utilization can be up to 5% in the current technologies, but new technologies can increase it to 25 to 30% (Kazemian and Shafei,2023; IPCC, 2022; TUBITAK, 2023).

In overall, profound mitigation of cement process emissions will depend on cementitious material substitution and the feasibility of CCUS until new chemicals become available (IPCC, 2022).

As a positive precedent from regulations and legislation, the Republic of Turkiye published a new Communiqué in the Official Gazette on March 16, 2024, to promote the use of low-carbon emission cement in public procurement contracts starting in 2025. The use of CEM-I cement is restricted. Between January 1, 2025, and December 31, 2029, the ratio of clinker in cement in public tenders for construction works and procurement of goods containing cement will be a maximum of 80%. As of January 1, 2030, this ratio will be 75% (Official Gazette of the Republic of Turkiye, 2024a).

2.6.2. Steel

Steel is strategically important for all countries as an essential material for infrastructure, manufacturing, and defense industry operations. Apart from its strategic importance, the steel industry is liable for roughly 10% of global energy-related CO_2 emissions and 30% of industrial carbon emissions and is critical for global decarbonization and green transformation goals (MoIT and PwC, 2023).

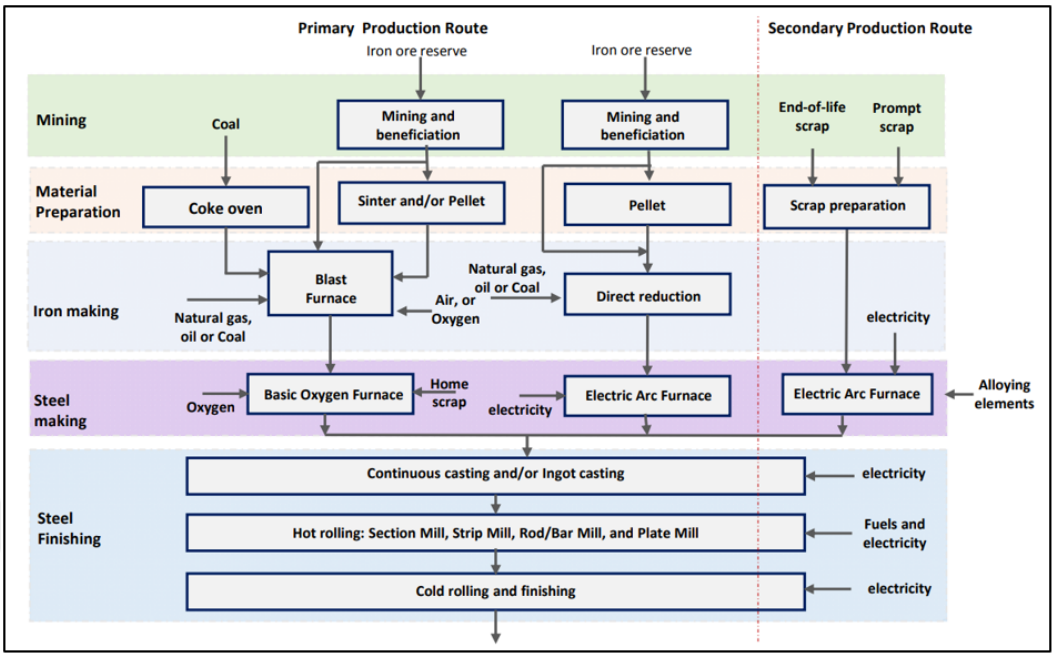


Figure 2.27. Bottom-up flowchart of steel production routes and energy requirements (Ryberg *et al.*, 2018).

There are two main production routes to produce steel: The primary production route, which uses iron ore, and the secondary production route, which uses end-of-life scrap and prompt scrap to produce steel, as shown in Figure 2.27. The primary production route uses both the integrated method, which includes the Blast Furnace (BF) and Basic Oxygen Furnace (BOF), and the Direct Reduced Iron (DRI) method. The DRI method enables iron production by reducing the oxygen content of iron ore without melting it. Although it is relatively new and not yet widely adopted, is considered the future of steel production due to its potential to reduce emissions. The integrated method is the traditional method, which involves several stages, from iron ore to the final product, including the production of intermediate products. It is the most emission-intensive method to produce steel. The second production route is the least emitting as no new raw materials are used; it involves only the melting of scrap and steel finishing as in the other routes (Ryberg *et al.*, 2018).

The breakdown of steel production in Turkiye differs from the world steel production capacity breakdown according to production methods. As can be seen in Fig-

ure 2.28, while world steel production by the BOF method is 72.3%, this rate is 25.2% in Turkiye. This difference also creates an advantage for the Turkish steel industry in terms of emissions, as the EAF production methods emit less emissions compared to the BOF (MoIT, 2022). Even though EAF plants produce the majority of the steel industry's production in Turkiye, as the main emission sources of the steel industry are integrated plants, this study focuses on emissions from integrated steel and iron production plants in Turkiye.

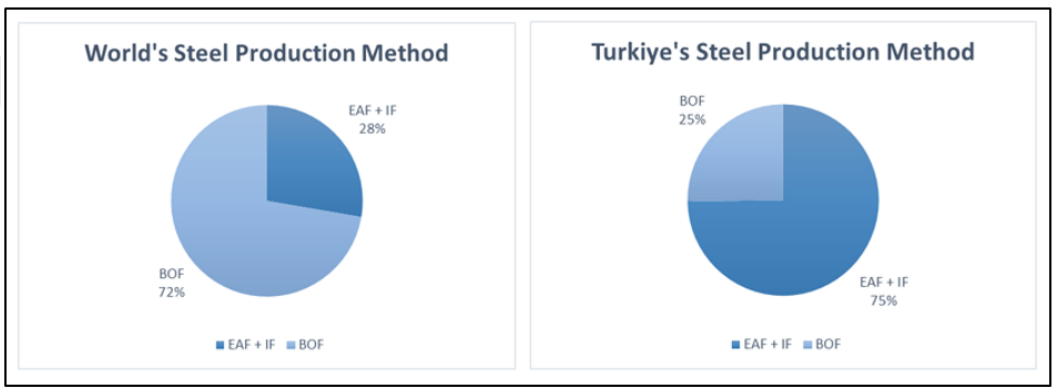


Figure 2.28. Status of the production types of steel in the world and Turkiye (MoIT, 2022).

According to the Steel and Iron Industry Report published by the Ministry of Industry and Technology, as of 2021, world steel production increased by 3.7% compared to 2020, reaching 1.95 billion tons. In 2021, Turkiye's steel production increased by 12.7% to 40.4 million tons, recording an all-time high with these numbers the Turkish steel industry preserved its 7th place in the world and consolidated its 1st place among steel producers in Europe. Production at Electric Arc Furnace (EAF) plants increased by 16.6% to 28.9 million tons and at integrated plants by 3.9% to 11.5 million tons. Accordingly, approximately 72% of total steel production is produced in EAF plants, while the remaining 28% is produced in integrated plants in the country (MoIT, 2022).

In accordance with Turkiye's National Inventory Report (2023), in 2021, the metal industry was responsible for 12,909 kt CO_2e, 17.2% of total emissions from the industrial processes and product usage sector. Most emissions in the metal sector

(92.3%) come from iron and steel manufacturing. Between 1990 (7,620 kt CO_2e) and 2021 (12,909 kt CO_2e), emissions from the metal industry rose by 69.4%, again mainly due to the iron and steel industry. By production methodology and including intermediate products during production, Table 2.5 shows the associated CO_2 emissions of Turkiye's total iron and steel production between 1991 and 2021. Emissions from the iron and steel industry increased by 71.5%, from 6,939 kt CO_2e in 1990 to 11,898 kt CO_2e in 2021 (Turkish Greenhouse Gas Inventory, 2023).

Table 2.5. CO_2 emissions from the iron and steel, sinter, and pellet production between 1990-2021 (Turkish Greenhouse Gas Inventory, 2023).

Year	**Emissions from Iron and Steel Production (integrated plants)**	**Emissions from Steel Productions (EAF plants)**	**Emissions from sinter production**	**Emissions from pellet production**	**Total emissions in 2.C.1 CRF category**
1990	5522	353	1033	31	6939
1995	4048	605	988	26	5668
2000	3800	648	1242	28	5718
2005	4449	1057	1358	34	6898
2010	5858	1488	1480	45	8870
2011	6433	1800	1642	45	9920
2012	6824	1891	1703	46	10464
2013	6892	1760	1867	44	10564
2014	6845	1691	1890	47	10472
2015	7235	1458	1985	46	10725
2016	8140	1555	1961	47	11704
2017	7871	1849	2150	45	11914
2018	7831	1837	2220	45	11933
2019	6857	1629	2067	46	10600
2020	6438	1713	1936	46	10133
2021	7486	2058	2306	47	11898

The energy mix in integrated BOF plants based on iron ore is 80% coal, 10% natural gas, 10% electricity and fuel oil. In comparison, the energy mix in EAO plants where scrap is melted is 65% electricity, 30% natural gas and 5% fuel oil. Accordingly, BOF-type plants in Turkiye emit 1.7 tons of CO_2 per ton of crude steel, while this value is 0.15 tons in EAO-type plants (TUSIAD, 2016).

As of the date of this study, 41 plants are producing liquid steel in Turkiye, of which three are basic oxygen furnaces/blast furnaces, 27 are electric arc furnaces, and 11 are induction furnaces (MoIT, 2022).

Since 1996, Turkiye has been a member of the European Coal and Steel Community and can export iron and steel products to the EU without customs duties. The taxation under the CBAM will be the first taxation that the Turkish steel sector will face in the EU and is essential for the sector's future and the country's climate policies, as 26.8% of Turkish steel exports to Europe (MoIT and PwC, 2023).

2.6.2.1. Carbon Emissions in Steel Production. Similar to cement production, iron and steel production is also emission and energy intensive. The processes require high heat, mainly obtained from the combustion of fossil fuels, and include chemical reactions that cause emissions (Hiçyılmaz *et al.*, 2022). After the chemical and petrochemical sectors, the second largest energy use is in the iron and steel sector globally (TUSIAD, 2016).

Given that EAF plants, which account for 75% of Turkiye's total production capacity, use electricity as energy and scrap as input in production, the Turkish steel sector is in an advantageous position compared to other countries in the world in terms of both current emission levels and future emission reduction efforts. For the steel sector, the availability of scrap steel in international markets and the reduction of electricity-related emissions through additional renewable energy investments will increase in importance in the coming period (MoIT and PwC, 2023).

In most countries, the CO_2 emission intensity of EAF plants is about 0.6 tons of CO_2 per ton of steel, while in Turkiye, it is approximately 0.29 tons of CO_2 per ton of steel, of which 0.04 is Scope 1 and 0.25 is Scope 2 (MoIT and PwC, 2023). Conventionally, steel is manufactured through an integrated flow-through process that includes heating coal to produce coke, feeding coke and iron ore into blast furnace, and purifying the melted iron in an oxygen furnace. This process generates approximately

two tons of CO_2 per ton of steel (Parry *et al.*, 2023). The highest emission route is the integrated Blast Furnace and Basic Oxygen Furnace route; therefore, this study will focus on the integrated route.

Integrated iron and steel plants, being energy-intensive and complex, have several emissions sources. These include emissions from electricity generation in the auto-producer, emissions from heating coke furnaces for coke production, emissions from heating rolling mills and other combustion emissions, all fossil-based fuels emissions used in blast furnaces and sinter production, and emissions from coke used as a reducing agent (Turkish Greenhouse Gas Inventory, 2023).

In overall, the primary emission sources in the integrated steel production facilities could also be grouped into three categories: process emissions, which come directly from the raw materials themselves; combustion emissions, which come from burning fossil-based fuels; and electricity emissions (ISO, 2024).

While in majority of countries, the carbon intensity of BOF plants ranges between 1.8 and 4.0 tons of CO_2 per ton of steel, while Turkiye emits around 2.20 tons of CO_2 per ton of steel, of which 2.17 is Scope 1 and 0.03 is Scope 2, which is higher than the EU average (MoIT and PwC, 2023).

2.6.2.2. Green Steel Technologies and Future Prospects. Improving energy efficiency and developing new processes can reduce GHG emissions from steelmaking. The most promising efforts contain carbon capture and storage, new iron and steelmaking processes such as direct and smelting reduction, hydrogen-based steelmaking, iron ore electrolysis, and biomass-based steelmaking. In addition to new technologies, material efficiency is gaining importance in emission reductions. For example, there are alternatives to increase the supply of end-of-life scrap, which has lower GHG emissions than primary steel production (MoIT and PwC, 2023).

The IPCC's 6th Assessment Report shows that emissions from steel production can be significantly reduced by using electric arc furnaces (EAFs) generated with decarbonized electricity. Waste heat to power (WHP) is another option that is currently being used but is not yet as widespread in the steel industry as is the case in the cement industry. Studies have shown that current technology utilizes only 7-13% of waste heat for power generation in the industry. With more advanced technologies, about 40-57% of waste heat with temperatures above 150^oC can be used for power generation through heat recovery (IPCC, 2022).

According to the World Bank (2022), fully decarbonizing the iron and steel industry, one of Turkiye's carbon-intensive industries, will need new methods such as hydrogen-based steel production and carbon capture and storage. The widespread application of these methods will be more realistic after 2030. It is also emphasized that research and development investments and pilot projects should start immediately so that these technologies are available and cost-competitive by 2030 (World Bank Group, 2022).

IMF's working paper, which suggested climate mitigation actions and policies for Turkiye, also proposes alternative ways to decarbonize the steel industry. These include increasing the capacity of scrap steel in the electric process and implementing emerging technologies, such as CCUS or feeding the electric furnace with iron produced through direct mitigation (e.g., reduced by using natural gas). These alternatives each cause only approximately 0.3-0.4 tons of CO_2 emissions for each one ton of steel (Parry *et al.*, 2023).

Plants with EAF and IF technologies have relatively high Scope 2 emissions due to the high emission intensity of Turkiye's grid electricity. This is one of the critical areas that should be prioritized in the sector's transition to net zero. At this point, Turkiye's goal of rising the share of renewable energy sources in energy generation will play an essential role in decarbonizing the sector (MoIT and PwC, 2023).

The World Bank (2022) also emphasizes that in the long term, hydrogen-based steelmaking is a developing technology that could mitigate emissions in the sector by decreasing the required for coking coal in conventional blast furnaces or as the only decreasing agent in the process of DRI using an electric arc furnace.

Since it is not possible to use just hydrogen in the blast furnace, the electric arc furnace is the most suitable way to reduce emissions. However, this technology is still developing and is forecasted to be available on a commercial scale in 2030. The estimated cost is \$38-77 tCO_2e if it becomes available (World Bank Group, 2022).

In its Climate Change report (IPCC, 2022), the IPCC listed mitigation and mitigation measures in the steel sector:

- Increasing the share of production from the secondary route, from scrap,
- Implementation of CCUS technologies in BF-BOF production types,
- Direct reduced iron (DRI) with methane-based synthesis gas (hydrogen and carbon monoxide) with CCUS implementation,
- Hydrogen-based direct reduced iron (H-DRI),
- The use of aqueous electrolysis to reduce iron ore.

The Ministry of Industry and Technology and PwC prepared a report outlining a Low-Carbon Roadmap for the Turkish Steel Sector, supported by the European Bank for Reconstruction and Development (EBRD) and Climate Investment Funds (CIF) and shaped around global best practices, similar to what they have prepared for the cement sector.

The report organizes policy recommendations under two main policy themes: inputs and technology and policy and market. Key policy areas under these themes are summarized as follows (MoIT and PwC, 2023):

- Optimization of Input Materials: Securing the supply of scrap, increasing the productivity of low-grade ores, promoting technologies using renewable energy sources and using alternative raw material,
- Technologies for Direct Reduction of Iron (DRI),
- Carbon Capture, Utilization and Storage (CCUS) Technologies,
- Process Optimization,
- Green Energy, Including Hydrogen Energy,
- Inclusive Employment and Skills.
- ETS,
- Business Model,
- National Policy Developments,
- Green Transformation Financing,
- Collaborations,
- Industrial Symbiosis.

The scenario study conducted in the report revealed that the net zero target in the steel sector can only be achieved through a combination of green H2 and CCUS technologies. To achieve its sectoral climate targets and increase its competitiveness, policies and supporting decisions at the national level should be prioritized to ensure the necessary H2 supply (MoIT and PwC, 2023).

Moreover, TÜBİTAK's green growth roadmap for the iron and steel industry lists the following future actions for the industry's decarbonization: (TUBITAK, 2023):

- Use of bio coal in coke ovens
- Reduction of coke use in blast furnaces or use of alternative raw materials to coke, injection of waste plastics, pulverized coal injection (PCI), natural gas injection
- Developing continuous lane production operations
- Design of direct reduction (DR) processes and facilities to ensure the most efficient utilization of iron-containing wastes
- Development of processes that can use hydrogen or natural gas as fuel

- Designing special processes for the utilization of low-grade iron ores in our country
- Direct steel production from ore using plasma technology

2.7. Housing Sector in Turkiye

The Central Bank of the Republic of Turkiye regularly publishes the Residential Property Price Index for the whole country and metropolitan cities. According to the latest data published in July 2024, as in Table 2.7, the highest unit residential property price was in Istanbul, at 47,298.9 TRY, while the average price in Turkiye was 33,459.9 TRY in May 2024 (CBRT, 2024).

Table 2.6. The residential property prices for Turkiye and the metropolitan cities (CBRT 2024).

Location	**Unit Residential Property Prices**
Turkiye	33,459.9
Istanbul	47,298.9
Ankara	26,930.3
İzmir	38,874.0

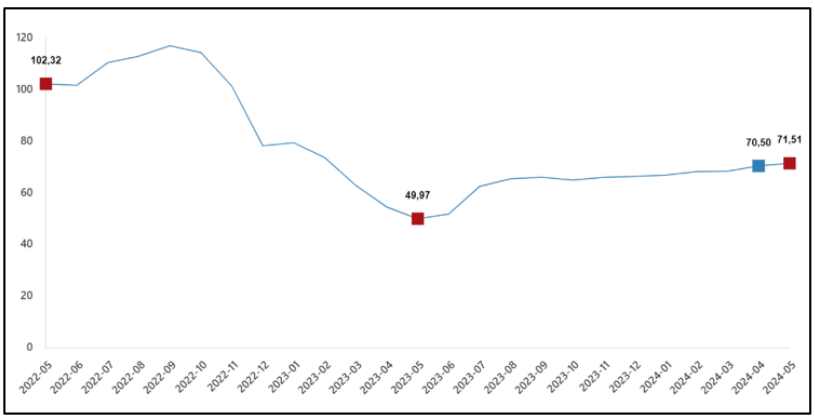


Figure 2.29. Annual rate of change in building construction cost index at May 2024 (Turkish Statistical Institute, 2024c).

According to the Turkish Statistical Institute, the building construction cost index increased by 1.36% compared to the previous month and by 71.51% compared to the same month of the previous year in May 2024, as illustrated in Figure 2.29. The

construction material index increased by 1.69% compared to the previous month, and the labour index increased by 0.75%. Moreover, compared to the same month of the previous year, the construction material index increased by 56.80%, and the labour index increased by 108.25% (Turkish Statistical Institute, 2024c).

REIDIN, a real estate analytics platform, collaborates with reputable Turkish banks such as Yapı Kredi and Garanti BBVA and real estate associations such as the Real Estate Investors Association (GYODER) also offers a database to its subscribers monthly real-time and Turkiye-specific data. Figure 2.30 shows the house sale price trend in Turkiye between 2020 and June 2024, according to REIDIN. House prices have rocketed in the last few years due to high inflation (REIDIN Insights, 2024).



Figure 2.30. Residential house sale price trend in Turkiye between 2020 and June 2024 (REIDIN Insights, 2024).

Due to the high construction costs and thus the increase in housing sales prices, customers are heavily affected by this cost increase, and their income cannot meet it. Figure 2.31 indicates a dramatic decrease in housing affordability for a mean-income family in the last four years. If the housing affordability index is higher than 100, a mean-income family can afford the required money to buy a house in the country; if it is below, they cannot. Even though there have been ups and downs during the last 12 years, it has never been at this low level since 2003 (REIDIN Insights, 2024).

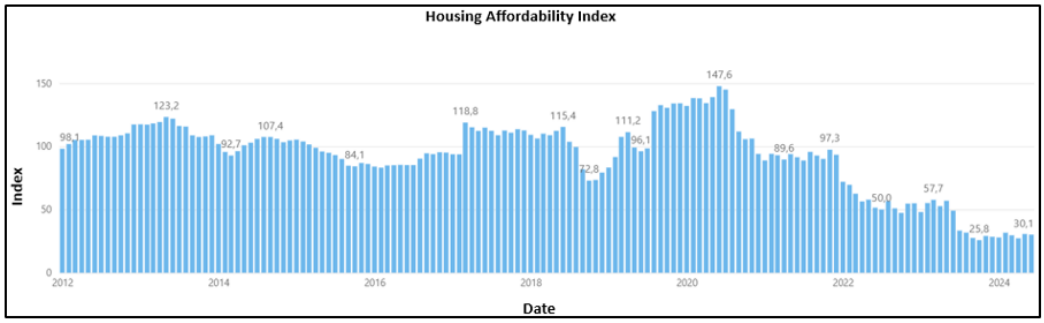


Figure 2.31. Housing affordability index in Turkiye between 2012 and June 2024 (REIDIN Insights, 2024).

2.8. Impact of Carbon Pricing on the Construction and Housing Industry

Carbon emissions are negative externalities affecting the social environment that are not directly involved in construction activities (Ge,2013). The literature includes many studies assessing the impact of carbon pricing on the construction sector, specifically the cement and steel sectors. Countries do not apply carbon pricing instruments directly to the construction sector, i.e., there is no general taxation of the construction phase. Instead, they tax materials and fuels, which ultimately affects the construction sector (Zhu *et al.*,2010).

Kunsch *et al.* (2001) conducted one of the major research projects in literature by evaluating the probable influences of a carbon tax on fossil fuels in the residential sector using Multi-Criteria Decision-Making tools combined with System Dynamics methodology (Kunsch *et al.*, 2001).

In Smale *et al.*'s (2006) research, the influence of CO_2 emissions trading on enterprises profits and market prices were evaluated by considering five energy-intensive industries which are cement, newsprint, steel, aluminum, petroleum by implementing the Cournot representation of an oligopoly market (Smale *et al.*, 2006).

In the study of Kunsch and Springael (2008), behavior of end users and the continuous tax-control mechanism depending on several crucial feedback with the sys-

tem dynamics were studied. Fuzzy-reasoning methods consolidated into the system-dynamics model to combine external data based this model and deriving from various resources with various credibility levels (Kunsch and Springael, 2008).

Zhu *et al.* (2010) utilized the USA housing market to conceptualize the emission reductions and sector impact of carbon policies with carbon tax and pricing using Nash-Cournot Equilibrium based on the duopoly market and solved by the Non-linear Complementary Problem (NCP) through GAMS programming (Zhu *et al.*,2010).

According to Zhu *et al.* (2010) and Ming (2014), a carbon tax can decrease emissions in the construction market without crucially affecting the current situation. It can effectively encourage the establishment of renewable energy systems, motivate empowering environmental management implementations, and help build the fundamentals for emerging economies (Zhu *et al.*,2010; Ming, 2014).

Lu *et al.* (2012) conducted a study to assess the effect of different carbon pricing tools based on a duopoly market assumption with the Nash-Cournot equilibrium regression analysis method on the United States construction industry. Overall, carbon taxes in the construction industry can uplift level of energy efficiency, advance the usage of renewable energy sources, and motivate technology and process renovations. Emissions trading could results in the wanted market transition as a market-based methodology, motivating the implementation of energy efficient systems and achieving the emission mitigation goal.

However, people are worried that the lack of public integrity and proper carbon accounting systems in the emissions trading framework might lead to market failures and regulatory gaps in obvious industries (Lu *et al.*, 2012).

Kim *et al.* (2013) designed a system dynamics model for life cycle cost (LCC) based life cycle CO_2 (LCCO_2) emissions assessments covering the whole life cycle of residential buildings in Korea. The model is designed to select the cost and energy-

efficient alternative to reduce LCC and LCCO_2. The study mainly optimizes the carbon/cost impact of construction projects (Kim *et al.*, 2013).

Ge's (2013) research evaluates the impact of introducing a carbon tax on housing affordability in Australia. The link between house prices and construction costs and the impact of carbon taxes on housing affordability are analyzed by applying regression analysis (Ge, 2013). Ming (2014) evaluated the CO_2 emissions during the life cycle of a building project with the life cycle analysis (LCA) method. These calculations directly multiplied the carbon cost and eventually reached the cost of a building's CO_2 emissions in its full life cycle (Ming, 2014).

Karapınar *et al.* (2019) implemented 3 different carbon reduction scenarios in their study, the increased use of Renewable Energy, the use of Carbon Tax, and the establishment of an ETS system. In all three scenarios the change in the sectoral value-added shares in the total value-added in the construction sector are eventually cause the construction sector to lose its share in the range of -0.22% to -0.16% (Karapınar *et al.*,2019).

Du *et al.* (2022) applied a system dynamics model to the Chinese market and analyzed the effects of the benchmark's annual decline factor on the carbon pricing system, the impact of decarbonization investment costs on cement firms' competitiveness, and the effects of carbon limit allocation amounts (Du *et al.*, 2022).

Carbon emissions are negative externalities affecting the social environment that are not directly involved in construction activities (Ge,2013). The literature includes many studies assessing the impact of carbon pricing on the construction sector, specifically the cement and steel sectors. Countries do not apply carbon pricing instruments directly to the construction sector, i.e., there is no general taxation of the construction phase. Instead, they tax materials and fuels, which ultimately affects the construction sector (Zhu *et al.*,2010). The effects of carbon taxation on the construction sector may lead to changes in unit construction costs, which in turn affect unit house prices.

Housing affordability is calculated by unit house prices and household income. If other determinants are constant, the only thing that can significantly affect housing affordability is housing prices.

2.8.1. Construction Costs Considerations and Carbon Reduction

According to Ming (2014), it is a certain fact in the context of carbon tax regulation that the construction industry which emit a lot of carbon dioxide due to energy resources needs to be deal with sharp increase in the total construction costs (Ming, 2014).

Project costs can be analyzed in two divisions: direct and indirect costs. Direct costs consist of materials, labor, and equipment, which are assumed to be approximately 80% of the project's total cost. In recent years, CO_2 emission costs have become critical and one of the significant cost aspects. So, including the CO_2 emission cost, construction costs could cover four aspects: labor, material, equipment, and CO_2 emission costs, by accepting other costs as unchanged fixed costs. To evaluate CO_2 emissions, the LCA methodology has been commonly used in evaluating the environmental costs of products and services during their life cycle. The LCA divides a project into three stages: the design and planning stage, the construction stage, and the maintenance stage (Ming, 2014).

According to Zhu *et al.* (2010), each constructor's cost covers the regular price, carbon emission cost, and technology abatement cost. Residential building costs fluctuate significantly because of material and labor costs. Most USA houses cost around $80 and 200$ per square foot to construct. In their study, varied carbon tax rates from 1 USD/metric ton to 100 USD/metric ton are used to enhance different alternatives and evaluate the contractor's response to the carbon policy. As the carbon tax rate rises from 0 to 100 USD/MMT, the housing market floor areas fall to 2.2%. Small businesses lose a 7% share compared to the tax-free level, while the share of large contractors increases from 68.9% to 70.4%. In terms of gross profit, the small-scale contractor loses

16 per cent of its gross profit, compared to 3 per cent for the large contractor at the tax-free level. Also, it is essential to mention that big contractors are motivated to pay more percentages on research and development, 0.91%, than small companies, 0.32% (Zhu *et al.*,2010).

The carbon price raises the production cost, consequently increasing the house price. The upward change in production costs will be shared between the consumer and producer due to market conditions. If the consumer has more rights in bargaining, the contractor will have to bear most of the carbon cost. As shown in Figure **??**, the scenario where the consumer bears the full carbon costs is illustrated by the upper dashed line; the lower dashed dotted line shows the scenario in which contractors bear all the cost, so the consumer receives the maximum benefit. Under normal dynamics, however, this would be carbon cost sharing, represented by the straight line in the middle (Lu *et al.*, 2012).

Wong and Chan (2013) conducted a study to analyze the Australian market and assessed the impact of carbon tax on construction firms' adoption of carbon reduction plans. According to their results, introducing a carbon tax positively and significantly correlates with adopting carbon mitigation strategies. Moreover, the extra cost resulting from the carbon tax may have an insignificant impact on contractors as they can easily be passed the price (Wong and Chan, 2013).

As indicated in Figure 2.32, contractors and consumers share the cost of carbon policies. Also, it is known that the more expensive the carbon price is, the more cost is transferred to the contractor part. Carbon policies result rise in production costs for producers and customers. If the carbon price is arranged at $22.3 per ton, equivalent to a 17% carbon emission reduction, the actual house price is $100.7 per sq ft, reflecting a 0.4% climb in price. The house price mirrors shared costs between the consumer and producer. It is measured that the consumer carries 54% of the carbon cost while the producer takes the remained part of the increase. This work shows that the housing market is vulnerable to carbon costs, and the contractors must be ready to carry most

of the carbon costs in the case of high carbon prices. Figure 2.32 shows that when the carbon price climbs to $60 per ton, the market situation shows a cost climb of $1.88 per sq ft, just 41% of which consumers share (Lu *et al.*, 2012).

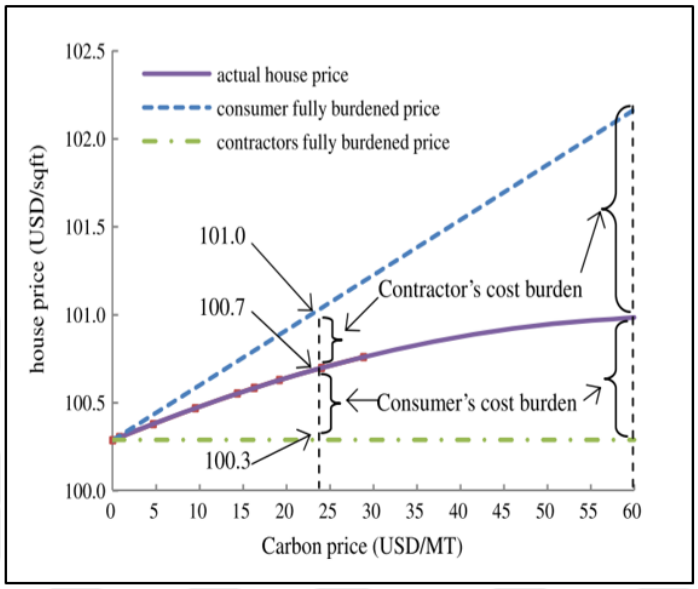


Figure 2.32. Cost burden allocation in carbon pricing between contractor and consumer (Lu *et al.*, 2012).

In terms of the carbon cost pass through to the customers, according to Smale *et al.* (2006), ETS applications result in two possible differences in the marginal cost of production: the direct CO_2 cost and a climb in the cost of electricity. This increment in marginal cost influences enterprises' profits in terms of three outcomes: the level of manufacturing capacity is decreased, the firm carries some costs, and other costs are transferred to customers. Carbon costs, if carried by the customers, increase prices and cause a fall in capacities and revenues. Also, they stated that if the sector transforms into more rival state and the number of entities rises, customer cost-through climbs until it reaches 100%. The more rivalry in the industry, the larger the cost pass-through. It can be stated that when an industry is more competitive, prices will be compatible with costs. The effect size is determined by the demand's sensitivity to price and price elasticity (Smale *et al.*, 2006).

Alexeeva (2010) assessed the carbon pass-through relation based on an oligopoly market assumption with the advanced time series at energy-intensive sectors in Germany. Based on the results, four factors that affect the carbon pass-through rate in strategic oligopoly were discovered:

- market shares of local and foreign firms
- the substitutability between domestic and foreign variations
- relative prices of domestic and foreign firms
- conjectural variation

In terms of cement, producers can pass through an essential fraction of local costs, which is up to approximately 73% of the total expenses to end users in the long-run equilibrium. Domestic companies' potential pass-through will be lower if the interaction with foreign manufacturers increases. Also, the higher the impact of foreign prices, the less ability to pass (Alexeeva, 2010).

Cludius *et al.* (2020) conducted a study to examine how much of the carbon costs associated with the ETS are directly transferred to product prices in EU industry. The result of the study revealed a significant cost transfer for a range of products, with the most robust results for the iron and steel, cement and refinery industries. The estimated cost transfer coefficient is between 20% and 40% for total cement and cement clinker products. For Portland cement the predicted rates are higher at 90-100%. For steel, this cost transfer rate ranges from 55% to 85%. They also examined the relationship between carbon transfer and carbon leakage; industries can be assumed to have a low risk of carbon leakage if there is cost transfer in the market. Limits on these factors identify the share of free allowances given to industries in the EU ETS. Moreover, if companies can get free allowances and at the same time transfer carbon costs, this can create a 'windfall profit' (Cludius *et al.*, 2020).

It is seen that when the tax rate rises, the total emissions certainly decrease. Large enterprises decrease carbon emissions more than small enterprises due to low

unit emissions and more powered R & D infrastructures. The current technological background is another essential factor in lowering carbon emissions. High cost-efficient technology may reduce total emissions because when technology becomes less cost-efficient, contractors are willing to pay tax punishments instead of investments (Zhu *et al.*,2010).

Lu *et al.* (2011) found that market-based approaches perform much better than emission standards in meeting emission targets while maintaining industrial performance as stable. According to their study, the emission standards policy obligates contractors to crucially cut their output and rise housing prices. However, both carbon tax and emissions trading policies would have negligible impact on industrial production and house prices. In the emission standard scenario, it is clear that if the construction sector is obliged to succeed a carbon emission reduction target (CERT) that is 17% lower than the current level, the total amount of output will decrease by almost the same amount, as shown in Figure 2.33. So that, introducing emission standards may not encourage low-carbon-technology investment in the construction sector (Lu *et al.*, 2012).

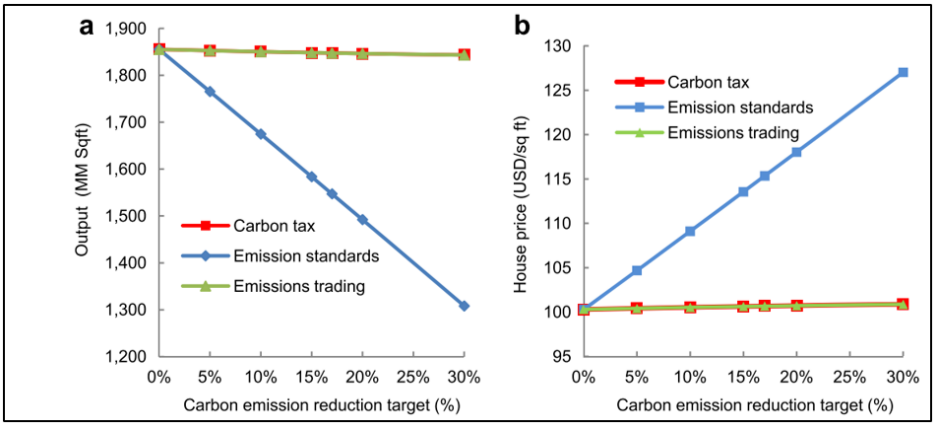


Figure 2.33. Impact of carbon emission targets on output (MM Sqft) and household prices (USD/Sqft) by policy type (Lu *et al.*, 2012).

In terms of the material cost, Smale *et al.* (2006) conducted a study to analyze the effect of the EU ETS on different industries' financial performances in different carbon

pricing scenarios. The scenarios covered alternatives of carbon prices of 15/tCO_2 and 30/tCO_2, which all of them are fully grandfathered. The effect of the carbon prices on the marginal cost of production is shown in Table 2.8. The cement sector showed the highest increase in marginal production costs, by as much as 140%. The increase in prices in the cement sector is directly reflected on the end-users, as the sector is mostly cement export-oriented in the EU market. Steel is the other material that is important for construction costs and the results show a 17% increase in the marginal costs of steel in the highest carbon pricing scenario. Contrary to cement, price increases in the steel sector could not be passed on directly to the customer. Since 80% of the product is supplied in Europe, steel producers could pass on 65% of marginal cost climbs to end-users (Smale *et al.*, 2006).

In addition, there is a reduction in production capacity to subsidize the marginal cost increase of production. For the steel and cement sector, despite production declines of 10% and 5% in the scenario of the highest penalties on carbon emissions, these declines in profits are helped by more significant increases in profits as prices rise, as can be seen in Table 2.7 (Smale *et al.*, 2006).

Table 2.7. Carbon price's effect on emission reduction, marginal cost, production output and EBITDA (Smale *et al.*, 2006).

Metric	**Emissions (%)**		**Marginal Cost (%)**		**Production Output (%)**		**EBITDA (%)**	
Allow. Price	€15/ tCO_2	€30/ tCO_2	€15/ tCO_2	€30/ tCO_2	€15/ tCO_2	€30/ tCO_2	€15/ tCO_2	€30/ tCO_2
Cement	-12	-14	70	144	-1.2	-4.4	13	25
Steel	-14	-21	8	17	-2.1	-10.6	12	18

On the other hand, both carbon tax and emissions trading mechanisms set a price on a contractor's carbon emissions. These methodologies free contractors to obey the policy by reducing output fields, limiting emission intensity, or paying carbon costs. It is almost assured that no contractor can reduce its emission amount, whereas research and development is expensive or unavailable. Therefore, restricting the production amount seems best alternative for construction companies. With these flexible compli-

ance choices, contractors can keep their production output at almost the same level and meet the CERT simultaneously. If the CERT is 17% below the existing level, industrial manufacturing will decline by approximately 8 million sq ft (approximately 0.4% of the current output) under both market-based policies, as can be seen in Figure **??**. Because of a stable market supply, housing prices remain almost constant regardless of other factors, such as inflation. In addition, the analysis stated that approximately 54% of carbon expenditure would be transferred to end customers at this carbon price (Lu *et al.*, 2012).

According to the Zhu *et al.* (2010), if technology is cost-efficient alternative, big contractors are willing to spend more on technology. In terms of small size, they would choose to spend most of the cost on tax penalty rather than R & D (Zhu *et al.*,2010).

According to Ge's study (2013), there is a robust positive correlation between house prices and construction costs. A per cent rise in construction costs will result in a 1.396 per cent rise in house prices of new constructions, if other variables remain same (Ge, 2013). In parallel, Tiwari and Parikh (1995) states that, the construction sector is sensitive to fluctuations in the pricing structure (Tiwari and Parikh, 1995).

2.8.2. Impact on Housing Affordability

Countless factors have an impact on how the real estate market acts. It is an undoubtful fact that supply and demand affect real estate; properties are more expensive when there is a strong demand and a limited supply. However, depending on the size of the project, construction projects may last months or years, delaying supply and demand. Features such as labor, materials, land availability, and financial markets influence the construction industry. Real estate markets have the potential for bubble collapses and calamities. For instance, the 2007 financial crisis harshly affected the USA real estate markets. The theory around housing bubbles is one of the main worries. In overall, real estate markets are unpredictable due to the several factors that affect them (Gasser *et al.*, 2020).

The real estate market is one of the most cyclical and volatile asset groups, with large amplitude cycles spanning five to twenty years. Every nation's overall wealth is mainly derived from real estate, significantly impacting the labor market, finance, and debt levels. The market variables exhibit notable fluctuations due to the inevitable delays in ascertaining the present state of the real estate market and in creating new frameworks. Prices peak when there is so much building that the stock exceeds its aim. This is where the discount on the price starts. This strategy starts a vicious loop in housing supply, construction, and prices (Barlas *et al.*, 2017).

Housing affordability is seen as a significant problem in the 21st century. Housing affordability is measured by house prices and household income. If household incomes are relatively stable in a country, fluctuations in house prices are the primary variable affecting affordability. House prices are also indirectly influenced by the market's demand for and supply of available housing. Therefore, housing demand and supply changes also increases housing prices and affect affordability (Ge, 2013).

According to the World Bank's Country Climate and Development Report for Turkiye, policymakers need to consider housing affordability due to the additional tax burden created by carbon pricing. The report also recommends that revenue from carbon pricing should be used to compensate low-income households for negative impacts, such as higher energy prices (World Bank Group, 2022).

Ge (2013) conducted a study analyzing the housing affordability change in the Australian market almost one year after the entrance of a carbon tax in the country. It is seen that the entrance of the carbon tax rapidly raises the cost of electricity to several industries, such as manufacturing and construction. Households were also influenced by these costs, which have been exposed to the supply chain of the influenced industries. According to the study results, approximately 14.8% of construction expenditures have risen instantly due to the impacts of the carbon tax. As a result of the higher expenditures, relatively half of the enterprises transferred these costs to the end users by rising their prices. Ge's (2013) study's main findings reveal that households

that were previously able to afford loan payments or rent are now struggling after the introduction of carbon pricing. The severity of this effect decreases as household incomes increase. Despite the existence of government subsidy programs to mitigate the impacts of carbon pricing, low and middle-income households bear the heaviest burden (Ge, 2013).

In its study, Ge (2013) have stated that the carbon tax significantly influenced the income of Australia's low-to-moderate-income households. The apparent influence is the rising cost of energy consumption. However, the indirect cost variables have transferred to other materials, with higher costs and the total construction costs. A combination of cost factors has made it difficult for low-middle-income households to achieve housing (Ge, 2013).

A Yale study (Esty and Winston, 2006) shows that only a small public would pay more for green products. Many people want environmentally and socially responsible products but do not want to compromise on price and quality (Esty and Winston, 2006). Similarly, Adaman *et al.* (2011) carried out a survey to evaluate the willingness to pay (WTP) of urban households in Turkiye for CO_2 emission mitigations expected to occur from improvements in energy production. The study also confirmed, as in other studies in the literature, that WTP values stated by young and educated people active in environmental issues have financial security and environmental knowledge are more likely to be high (Adaman *et al.*,2011).

As a result of the comprehensive literature review, a list of studies in the literature on the impact of carbon pricing on the construction and housing sectors is listed in Table 2.8.

Table 2.8. Studies on carbon pricing in the construction and housing sectors.

Reference	**Methodology**	**Region**	**Scope**
Wu, Zhang and Chen	LCA	China	Assessed building materials' environmental profiles, categorized impacts, and considered "green tax" and social willingness to pay (WTP). Results showed thay steel has greater environmental impacts than cement due to its more complex and energy-intensive production.
Smale *et al.*, 2006	Cournot Model	EU ETS	Examined the consequences of the EU ETS for business. Five energy-intensive sectors: cement, newsprint, steel, aluminium and oil are included. Since cement is a local market, it can pass on all cost increases to the consumer, whereas steel, not being a local market, can only pass on 65% of the cost increases.
Sathre and Gustavsson	Analysis	Sweden	Examined the effects of energy and carbon taxes on building material competitiveness, comparing wood and concrete buildings.
Alexeeva, 2010	Advanced Time Series	Germany	Examined the carbon cost pass-through in the energy-intensive sectors, including cement, and identifying the factors that could affect this rate. According to the results producers of cement can up to about 75 per cent of total costs to consumers.
Zhu and Qinbin, 2010	Nash-Cournot Model	United States	The US one-family house market (1999 2008) is taken as an example to predict the construction activities and carbon emissions impacted by carbon tax,. When the tax rate is 100 USD/MT, the carbon price for each land is 3.132 USD per square foot.
Adaman *et al.*, 2011	Survey	Turkiye	Explored Turkish urban households' willingness to pay (WTP) for CO2 emission reductions from improvements in power production. WTP figures are higher among young, educated individuals active in environmental issues, with material security and environmental knowledge.

Table 2.8 Studies on carbon pricing in the construction and housing sectors. (cont.)

Reference	**Methodology**	**Region**	**Scope**
Wong *et al.*, 2012	Literature Review	Australia	The lessons learnt from the EU ETS system were analysed before the introduction of carbon tax in Australia.
Ge *et al.*, 2013	Regression Analysis	Australia	Examined the relationship between construction costs and housing prices. The results indicate a strong positive relationship between construction costs and housing prices. A 1% increase in construction costs leads to a 1.396% increase in new housing prices.
Lu *et al.*, 2012	Nash-Cournot Model	United States	Examined the effectiveness and economic impact of carbon policies on the US construction sector. Focused on changes in industrial output and related house prices under three types of carbon policies. The carbon price increases the production cost therefore drives up the house price.
Ming, 2014	LCA	China	Assessed CO2 emissions throughout the life cycle of the building project, defining three phases-design and planning, construction, and delivery and maintenance-and then derived CO2 emission costs by multiplying the emissions by the relevant tax rate.
Rootzen and Johnsson, 2016	Analysis	Sweden	Evaluated carbon costs on cement price increases and their effect on residential construction, noting that even a near doubling of cement price would raise total construction costs by less than 1%.
Brouwers, Schoubben and Hulle, 2018	Fixed effect instrumental variable (FE-IV) methodology	EU ETS	This study examined if firms' ability to pass through carbon costs affects the link between carbon emissions and financial performance under the EU Emission Trading Scheme. It finds some sectors benefited from windfall profits.
Wang, 2019	Gene expression programming and Genetic Algorithm	Korea	Assessed the impact of carbon pricing on the cost for high-strength concretes with different strength levels.

Table 2.8 Studies on carbon pricing in the construction and housing sectors. (cont.)

Reference	**Methodology**	**Region**	**Scope**
Cadavid-Giraldo *et al.* 2020	Mixed-integer linear programming formulations (MILP)	Columbia	Analyzed the effect of varying carbon emission prices on CO2 reduction decisions in a representative cement supply chain, without specifically focused on unit production cost.
Cludius *et al.*, 2020	Cost-price model	EU ETS	Investigated the extent to which ETS-related carbon costs have been passed through to product prices by EU industries. By examining six industry sectors, it finds significant cost pass-through, especially in the cement, iron and steel, and refineries sectors.
Du *et al.*, 2022	CGE	China	Examined the impact of carbon tax on the construction industry. Analyzed economic (GDP, social welfare) and environmental effects by designing scenarios for tax revenue.
Zhou *et al.*, 2022	Input and Output	China	Assessed the impact of green taxes on the carbon emission efficiency of the construction industry and its underlying mechanisms.
Wang *et al.*, 2022	LCA	China	Assessed carbon emissions during bridge construction, establishing a carbon cost model based on emissions and pricing mechanisms.
Nyahuna and Doorasamy, 2022	Correlation Analysis	South Africa	Examined the relationship between carbon tax and profitability in a cement company. The results show that the carbon tax negatively affects the net profit margin, suggesting it also adversely impacts shareholders' dividends.

3. RESEARCH METHODOLOGY

An event-driven perspective directs to an event-driven approach to problem-solving. Figure 3.1 shows how existing methods generally attempt to solve problems. The current situation is assessed and compared with the goals. The gap between what is desired and what is perceived identifies the problem. With the problem identified, a solution is created. The system then reacts to this solution. Because of this type of event-driven approach, the solutions of the past can become the problems of the day. We don't have the power to influence a system in the direction we want with an external change, as we are embedded in the system (Sterman, 2000).

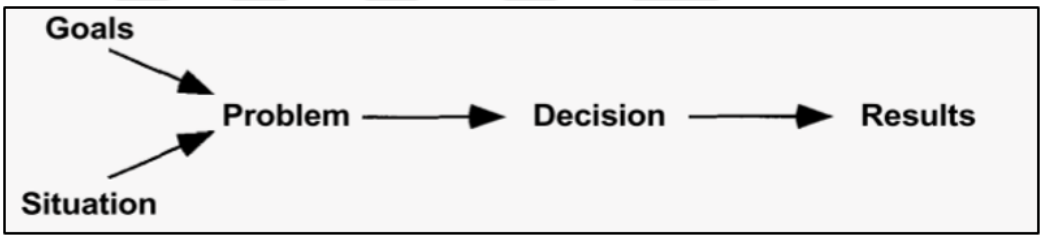


Figure 3.1. An illustration of the event-driven approach (Sterman, 2000).

In contrast to the open-loop perspective in Figure 3.1, real systems respond to our interventions. This means that, as shown in Figure 3.2, systems have feedback; our actions' outcomes shape the situations we will encounter in the future. New situations change our evaluation of the problem and the decisions that we will take in the future. Moreover, as shown in the lower part of Figure 3.2, our actions can provoke side effects that we did not foresee. Other actors, aiming to reach their objectives, respond to re-establish the equilibrium we have disturbed. System resistances, such as policy resistance, occur simply because we do not understand all the feedback that functions in the system (Sterman, 2000). Therefore, it is important to consider systemic thinking rather than event-driven thinking when solving a problem.

There is a strong interconnection between systems thinking and system dynamics. A dynamic problem is not solely due to an external enemy or an executive; no single

person or organization can be responsible for the problem. The source of the dynamic problem lies in a system structure that cannot overcome adverse external conditions. Therefore, to solve a dynamic problem, system dynamics need to be guided by systemic thinking (Barlas, 2002).

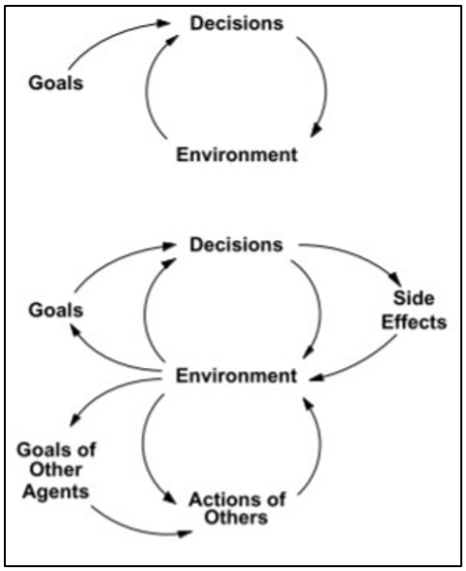


Figure 3.2. Approach to solving a problem with a feedback perspective (Sterman, 2000).

The discipline of system dynamics evolved at the end of the 1950s as an initiative to tackle dynamic, long-term policy challenges in both the public and corporate sectors. A group of researchers from M.I.T., led by Jay Wright Forrester, initiated a new field, which was then called Industrial Dynamics (Barlas, 2002).

Systems thinking is the capability to consider the system as a whole instead of focusing on individual parts. It envisages the whole world as a complex system and fosters an understanding of interdependence and interrelatedness, while System Dynamics measures the impact of these relationships. System Dynamics complements Systems Thinking by measuring interactions and building a time-bounded perspective on system behavior (Sterman, 2000).

As illustrated in Figure 3.3. with a Venn scheme, Richmond (1994) acknowledges that Systems Thinking and System Dynamics are not the same, but they have a substantial overlap. Systems Thinking encompasses all of System Dynamics and adds an "aura" of additional elements (Richmond, 1994).

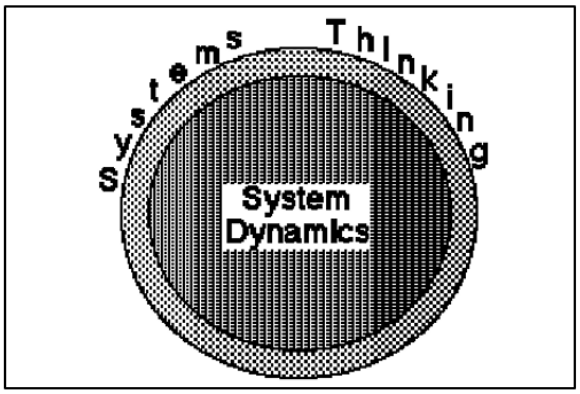


Figure 3.3. Richmond's perspective on the relationship between system dynamics and systems thinking in a Venn diagram (Richmond, 1994).

The domain of system dynamics is designed to provide USA to learn an understanding of the structure and dynamics of the complex systems in which we operate, to help USA design high-leverage policies for continuous improvement, and to foster successful implementation of policies. System dynamics models are often formulated as high-order, nonlinear, stochastic systems of differential equations representing players' decision rules, natural processes and physical structures related to the model's purpose (Sterman, 2002).

Dynamic refers to something that changes with time. Some problems can be challenging to solve, but if their type is static, i.e., the decision is made once and does not need to change over time, this type of problem is not suitable for system dynamics. Consequently, dynamic problems are those of a constant, chronic, and periodic nature. Non-linearity refers to the fact that the cause-and-effect relationships among variables are not proportional. These relationships are tough since a specific effect observed in one domain may not be observed in another. Non-linearity also usually means that there is an effect of the interaction between variables (Barlas, 2002).

According to Sterman (2018), fundamental principles for successful system dynamics modelling include: always model a problem, never a system; the modelling process should involve influencing actors from the very beginning; modelling should be iterative; and the model should be revised and improved after testing (Sterman, 2018).

In general, system dynamics provides a computer-aided method for understanding and studying complex systems, which is helpful in various disciplines, including economics, management, engineering, and the humanities (Zhang, 2023).

The main objective of system dynamics methodology is to identify the reasons for unpleasant dynamics and develop new policies to improve/eliminate them. System dynamics, therefore, focuses on systemic and feedback-informed dynamic problems (Barlas, 2002).

3.1. System Dynamics Principles and Concepts

System dynamics modelling is a strong methodology and technique for understanding and exploring the feedback mechanism in complex systems (Wen *et al.*, 2016). System dynamics involves a top-down approach that begins with an analysis of the high-level behavior of the system (Gasser *et al.*, 2020).

System dynamics is a simulation approach to model long-term, chronic, dynamic management problems. Based on systems thinking, system dynamics analyzes the cause-and-effect relationship between factors affecting the system, allowing quantitative analysis of the dynamic relationship between behavior change and the influence of the feedback system. System dynamics is an important tool for identifying the drivers of problems and analyzing the interactions of subsystems, thus providing a holistic understanding of the whole system and relevant policy responses for the problem. Essentially, the aim of system dynamics studies is to understand how and why dynamic problems occur and then to seek problem-solving policies to further develop system performance (Wen *et al.*, 2016).

The causal relationship y=f(x) indicates that the input variable (x) has a causal effect on the output variable (y). In a system dynamics model, every causal relationship is a "ceteris paribus" statement: "when all other things are equal", causality is expected to produce the specified effect. As there are many variable factors, the ceteris paribus condition generally is not valid, so the representation X $\rightarrow$ Y established in system dynamics means that "when all other things are equal", a change in X causes a change in Y (Barlas, 2002).

Figure 3.4 illustrates the process of solving a problem with system dynamics. The system that needs to be analyzed is identified in the first step. At this step, a hypothesis about how the system creates this problematic behavior is also formulated. The simulation model is created in the next step, which means transforming the system defined in the previous step into a system dynamics model's level and rate equations. By running the first simulations in step 3, a series of questions will arise that will repeatedly return to steps 1 and 2 until the model is satisfactory for the objective in question. Step 4 identifies policy alternatives for further testing, and continuous simulations show which policies have the most promising prospects Step 5 aims to reach a consensus regarding the policy's implementation in the system. In this step, the model shows where problems are encountered in the system and tries to solve them with continuous training. Step 6 applies the new policies. If the model is appropriate and convincing and the training in step 5 has been sufficient, step 6 can proceed more quickly. Yet even so, it can take a very long time to implement a policy. Existing policies will have to be eliminated while new policies will require new sources of know-how and education (Forrester, 1994).

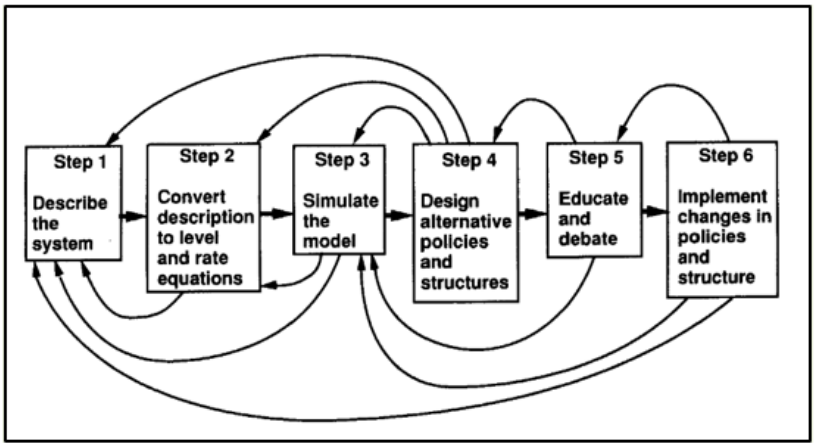


Figure 3.4. System dynamics process (Forrester, 1994).

According to Barlas (2009), the main steps of system dynamics modelling are (Barlas, 2002):

- Problem definition and explanation (objective)
- Building dynamic hypothesis and model conceptualization
- Building an indicative causal loop system to discover possible alternative hypotheses.
- Determine the key stock and flow variables.
- Creating a formal model
- Creating the stock-flow diagram, which is the structure of the model
- Writing mathematical formulations describing cause-effect relationships for all variables
- Predict the numerical values of parameters and starting values of stocks.
- Controlling the consistency of the model within itself and concerning the dynamic hypothesis (validation)
- Model reliability (validity) tests
- Structure: Is the model structure consistent with a meaningful description of the real-life relationships in the problem of interest?
- Behavior: Are the dynamic models produced by the model close enough to the actual dynamic models of interest?

Vensim® and Stella® software are widely used for system dynamics models. They enable a user-friendly interface and enable users to visualize and transmit dynamically how complicated systems and concepts work by building different simulation models from causal loops or stock and flow (Wen *et al.*, 2016). In this study Stella® software will be used.

The fundamental components of a system dynamics model are listed and described below, and the representation of the relevant variables in the Stella® software is shown in Figure 3.5.

- Stock: Stocks describe the state or condition of the system at any given time and represent accumulations in the system. Examples of these variables are the population in a city or the water in a reservoir. Stocks are represented by rectangular symbols, as in Figure 3.5 (Bala *et al.*, 2017).
- Flow: Flow variables are the "rate of change" of stocks. Flows are represented by valve symbols, as in Figure 3.5. Examples of these variables are the birth rate (input) and the death rate (output), which affect a city's population. They flow right in and out of stocks, changing their value (Bala *et al.*, 2017; Barlas, 2002).
- Converter: The converter functions to place the input and make the output. It keeps the values of constants, identifies external inputs to the model, calculates mathematical relationships, and acts as a repository for graphical functions. In general, it converts inputs into outputs. Therefore, it is called a 'converter'. Converters are represented by circle symbols, as in Figure 3.5 (Bala *et al.*, 2017; Rudyanto *et al.*, 2018).
- Connector: The connector presents the relation between stock and flow and is represented as an arrow in the system.

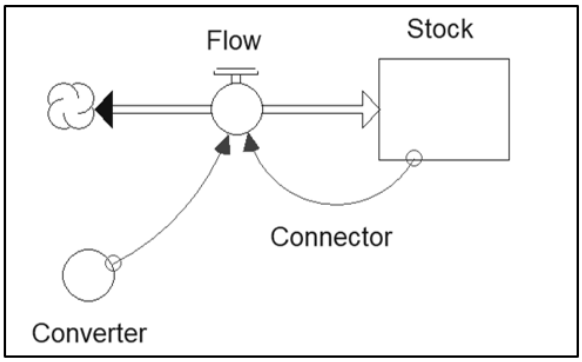


Figure 3.5. System dynamics variables.

In Figure 3.6, a city's population problem will be used as an example to visualize how the system works. The rectangular symbol represents the population stock represents the number of people living in the city. The birth flow feeds the stock as an input, while the death flow reduces the stock as an output. The birth fraction converter feeds the birth flow, and the death fraction converter feeds the death output.

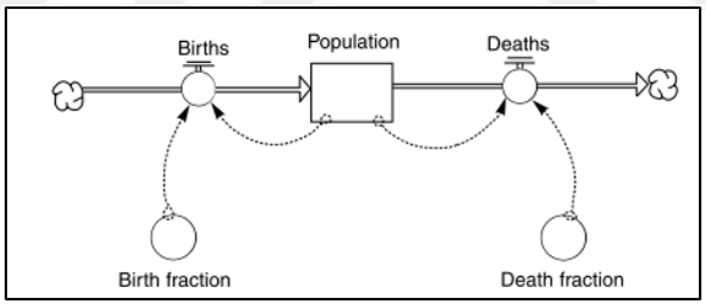


Figure 3.6. Illustration of the population model structure (Barlas, 2002).

The stock equation is a first-order finite difference equation and can be represented as

$$stock(t) = stock(t_0) + \int_{t_0}^{t} (inflow(t) - outflow(t))dt, \tag{3.1}$$

where stock (t) and stock (t_0) represent the accumulation amount at the t and t0 time respectively, the inflow (t) represents the amount of the flow into the stock, and outflow (t) represents the amount of the flow out of stock at the specific t time.

This integral equation can be written in the differential equation form as

$$\frac{d(stock)}{dt} = inflow(t) - outflow(t). \tag{3.2}$$

Equation (3.2) is representing an initial value problem and there are several methodologies to solve this problem. Stella offers 3 different approaches to solve this kind of a problem; these are Euler's method, second order Runge-Kutta method and lastly fourth order Runge-Kutta method. Given the model's straightforward equation structure, the practical and efficient Euler's method is implemented in the model.

3.1.1. Benefits

The System Dynamics approach enables complex problems to be simplified and modelled with transparent causality, identifying the system's underlying structure (Ottoson and Björk, 2004). It helps to understand the background of complex systems better and enables the development of leveraging policies. Moreover, numerous simulations can be run to identify the variables causing the problem. This process educates the model, facilitating the design of the right policies (Sterman, 2002).

Elmahdi *et al.* (2017) stated in their study that system dynamics is well suited to show the step-by-step flow through the model, visualizing the problem processes and the physics of changing these processes, and communicating about the quantification of relationships and units, providing good consistency (Elmahdi *et al.* , 2017).

According to Zhang (2023), the benefits of system dynamics can be categorized into 4 main groups: holistic perspective, scenario analysis, policy analysis and dynamic responses. System dynamics models embrace the complexity and interdependencies of the factors affecting the system and enable a more detailed understanding of market dynamics than traditional analytical methods. It allows to run different scenarios, measuring the potential impact of different changes on the system performance and thus enabling more informed decision-making (Zhang, 2023).

3.1.2. Challenges

Since most system dynamics models complex problems, it can be difficult for non-modelers to understand and track the system (Elmahdi *et al.* , 2017). The other challenge is the difficulty of conducting experimental testing on human systems, which often requires the active participation of individuals who need more technical training (Sterman, 2002).

Barlas (2002) notes that although system dynamics make it possible to model complex systems, these models can also be complex and challenging to understand. Reliable and accurate data may not be easy to find, and future uncertainties may limit the predictive capabilities of system dynamics (Barlas, 2002).

According to Zhang (2023), the challenges of system dynamics can be categorized into 3 main groups: data availability, model complexity, assumptions and uncertainty. The building of accurate and robust system dynamics models requires reach to high quality data, which is often difficult to access. The complexity of system dynamics models can make them difficult to understand and communicate, especially to those stakeholders without a background in modeling research. System dynamics models, as any model, are built on assumptions. Therefore, it is essential that the assumptions underpinning the model are meticulously evaluated and documented and the uncertainty is addressed (Zhang, 2023).

3.1.3. Application Areas

System dynamics is a type of simulation method used to study the non-linear behavior of complicated systems in time. It is often used for techno-economic analysis, such as emissions prediction and policy testing in industry (Du *et al.* , 2022).

System dynamics has been implemented to fields ranging from enterprise planning and policy design to public administration, energy and environmental management,

natural and social sciences theory-making, and supply chain management (Wen *et al.*, 2016).

Some popular implementations of system dynamics include population, food security, commodity price determination, fishery dynamics, reservoir problems, depletion of natural resources, electricity and water supply, global warming and emission models (Bala *et al.* , 2017).

The first implementation of the methodology in the world was in the strategic management of industrial problems, where the main output of this research, Industrial Dynamics, was published (Forrester, 1961). The next flagship project was Urban Dynamics, which presented a dynamic theory of how residential and commercial buildings shapes growth and recession in an urban area (Forrester, 1969). Through this implementation, the industrial dynamics method moved into the broader field of socio-economic problems and was ultimately re-named "system dynamics". World Dynamics (and Limits to Growth) was the next application in the broader socio-economic field. They demonstrated how population increase, and economic growth policies can interact to lead to dynamics of overshoot and collapse when over-crowding and over-industrialization surpass the capacity of the environment (Meadows *et al.* , 1972). System dynamics theory is based on the theory of nonlinear dynamics and feedback control principles developed in mathematics, physics, and engineering. As these instruments applicable to human behavior and both physical and technical systems, they also draw on cognitive and social psychology, economics (Sterman, 2000).

3.1.4. Applications in the Literature and Suitability for the Study

In a closely interconnected system where a change in one causes a change in the others, more than a simple mathematical approach is required to determine the relationship between the parameters. The system dynamics theory and model-building principles provide powerful tools for solving these type of complex and mega-system problems (Du *et al.* , 2022; Guo and Wang, 2021).

Thus, system dynamics is well-suited for analyzing the dynamics of the interactions between the economy, environment and politics in an industry or firm. For instance, in the cement sector, SD has been used to assess the overarching benefits of mitigation technology investments, forecast cement prices over the policy application period, project cement demand, and predict carbon emissions under different cases (Du *et al.* , 2022).

Du *et al.* (2022) studied the effects of the application of carbon quota benchmarks effects on the cement industry specifically with the system dynamics analysis (Du *et al.* , 2022).

Wen *et al.* (2016) conducted a study using system dynamics to estimate and compare industrial carbon emissions in Baoding, China, under different policy focal points and provide emission reduction recommendations (Wen *et al.* , 2016).

Kunsch and Springael (2008) conducted a research study to find an answer to how consumer behavior and the continuous tax control mechanism can be simulated by system dynamics, taking into account the system's feedback that is often ignored in static macroeconomic modelling such as CGE (Kunsch and Springael, 2008). Ding *et al.* (2023) conducted a study using system dynamics to analyze the factors affecting emissions and spatial spillover effects across regions. They also simulated regions' spillover effect and emission reduction potential under different policy schemes (Ding *et al.* ,2023).

Kim *et al.* (2013) conducted a study to determine the optimal cost-effective and carbon-reducing pathway for apartment buildings. A system dynamics model was used to simulate the cost-carbon impact, and an optimization method mixed with LCC analysis was used to optimize the system dynamics (Kim *et al.* , 2013).

Tang *et al.* (2020) analyzed many quantitative studies and determined that the code word "system" in ETS research, which is considered a typical system that includes a variety of interacting factors (Tang *et al.* , 2020).

According to Wen *et al.* (2016), industrial carbon emissions are too complex to be solved only quantitatively or qualitatively. To better understand the system's dynamics, a combination of quantitative and qualitative approaches should be used. Therefore, they have suggested using a mixed approach that combines system dynamics with qualitative analysis (Wen *et al.*, 2016).

Apart from emissions calculations across countries and industries, system dynamics modelling has also been used to investigate fundamental estate-related topics, such as housing supply and demand dynamics, price oscillations, policy interventions, and market stability. These models, which encompass multidimensional interactions between economic, demographic, and regulatory factors, enable critical insights into the functioning of housing markets (Zhang, 2023).

Many factors can affect house prices, and the relationships between them are complex. For this reason, it is clear that adopting a mathematical research methodology from general economic theory is not enough when dealing with housing markets (Guo and Wang, 2021).

Real estate markets are characterized by their high volatility and cyclical nature, with periods lasting 10-20 years. These markets are significantly affected by changes in wealth, banking activity and employment, making it essential to understand and forecast their dynamics (Sterman, 2002).

As can be seen in Table 3.1, a list of System Dynamics studies in the literature shows its application in carbon pricing, sustainability of the construction sector and real estate markets, therefore it was found appropriate to use System Dynamics methodology in this study as these areas overlap.

Table 3.1. System Dynamics applications in the literature.

Reference	**Region**	**Scope**
Kunsch *et al.*, 2011	EU Region	A taxation system based on the fossil-fules is applied. Assesed the Willingnes to Invest cost threshold. According to the results the tax must be high enough to represent a significant incentive for investment.
Kunsch and Springael, 2008	Belgium	A continuous tax control mechanism is studied based on the behaviour of end-users and system dynamics and various important feedbacks by implementing system dynamics.
Barlas *et al.*, 2007	Turkiye	Focused on the economic supply-demand dynamics of the real estate market in İstanbul, examining these dynamics from the perspective of a hypothetical construction company.
Kim *et al.*, 2013	Korea	A system dynamics model was designed for life cycle cost (LCC) based life cycle CO_2 (LCCO_2) emission assessments covering the whole life cycle of residential buildings in Korea to optimize the carbon/cost impact of construction projects.
Wen *et al.*, 2016	China	Estimated and compared industrial carbon emissions, under different policy focal points and provides emission reduction recommendations.
Gasser *et al.*, 2020	USA	Combined agent-based modeling with system dynamics to model housing demand in the USA market.
Guo and Wang, 2021	China	Analyzed the main factors affecting commercial housing prices and the relationship between these factors by using system dynamics.

Table 3.1 System Dynamics applications in the literature. (cont.)

Reference	**Region**	**Scope**
Zhou *et al.*, 2021	China	Compared conventional and green construction methods in terms of costs and carbon emissions using LCA in System Dynamics.
Du *et al.*, 2022	China	Applied a system dynamics model to the Chinese market and analyzed the effects of the annual decline factor of the benchmark on the carbon pricing system. Also assessed the competitiveness level of a company, annual profits and sales.
Ding *et al.*, 2023	China	Analyzed the factors affecting emissions and spatial spillover effects across regions. Also simulated regions' spillover effect and emission reduction potential under different policy schemes.
Zhang, 2023	USA	Analyzed the dynamics of the US real estate market in terms of demand, household income, interest rates, and affordability.

3.2. Analysis Structure

The model is structured to investigate the potential impact of the planned ETS system in Turkiye on construction costs and housing affordability. ETS is expected to impose additional costs on the cement and steel industries, which are the primary materials used in construction.

From a system thinking perspective, after identifying the problem, it is necessary to examine each individual that feeds the problem and determine their behavior within the system. In this study, the systems thinking approach allows to observe the impact of even the type of fuel used in a cement factory on housing affordability.

The model can be classified into three sub-models: cement industry emissions, steel industry emissions and construction and housing industry dynamics. Integrated plants are considered in the model for both steel and cement industries as they cause higher emissions. In the cement sector, integrated plants refer to plants that can produce cement from clinker in a single plant, while in the steel sector, they refer to steel production from iron ore in a single plant. Numerous expert consultations with industry-specific experts were conducted to verify the relationships between the variables during and after the model development to establish real-world dynamics. The list of experts, including their level of experience, graduation degrees and titles in the relevant sector, is listed in Table 3.2.

Table 3.2. List of experts in the expert consultation by sector.

Number	**Sector**	**Experience Level**	**Graduation Degree**	**Expert's Title**
1	Cement	30 years	BSc	Deputy General Manager
2	Cement	10 years	MSc	Sustainability and Environmental Manager
3	Cement	9 years	MSc	Sustainability and Environmental Executive
4	Cement	26 years	PhD	University Professor
5	Steel	28 years	PhD	General Manager
6	Steel	20 years	BSc	Environmental Manager
7	Green Buildings	23 years	PhD	Partner, Advisory Services
8	Construction	10 years	MSc	Project Control Engineer
9	Construction	5 years	MSc	Cost Control Engineer

Table 3.2 List of experts in the expert consultation by sector. (cont.)

Number	Sector	Experience Level	Graduation Degree	Expert's Title
10	Real Estate Development	26 years	BSc	Company Owner, Advisory Services
11	Real Estate Development	22 years	PhD	Company Owner, Advisory Services
12	ESG Advisory	21 years	PhD	General Manager
13	Finance	15 years	MSc	Finance Expert

One of the main decisions to be made in the model was the methodology for quantifying emissions, as three different emission calculation methods can be followed. The first method is the GHG Protocol, which was developed by the World Resources Initiative (WRI) and the World Business Council for Sustainable Development (WBCSD) and is widely used in emission declarations by companies worldwide. The second one is the ISO 14064 standard, which was developed by ISO 14064 and is also widely used.

The last one is the CBAM calculation methodology published by the EU Commission, which is a new and modified type of EU ETS emission calculation method. The comparison of the scope of GHG emission calculation methods is listed in Table 3.3. Mainly, emissions are classified into three main categories: first, direct emissions from production; second, upstream indirect emissions, which represent emissions of energy used during production; emissions from transportation or precursor emissions (if any); and finally, downstream indirect emissions, such as emissions from the use of products or at the end of their useful life.

Table 3.3. Comparison of GHG methods (EU Commission, 2023).

Parameter	**ISO 14064-1**	**GHG protocol**	**EU ETS**	**CBAM**
Direct Emissions				
Direct Emissions (stationary)	Category 1	Scope 1	Subject to System boundaries of each facility	All emissions from the production processes of goods, including emissions from heating and cooling consumed during production,
				independently of the place of production.
Direct Emissions (mobile)			Out of scope	Out of scope
Indirect Emissions (upstream)				
heating/ cooling imported	Category 2	Scope 2	In scope if produced in the facility	Included in direct emissions
Electricity imported			In scope if produced in the facility	Indirect emissions are defined as direct electricity emissions and include electricity generated both on-site and off-site.
fuels imported	Category 3	Scope 3	Out of scope	Out of scope
transport			Out of scope	Out of scope
precursors	Category 4		In scope if produced	Specified in the act

Table 3.3 Comparison of GHG methods (EU Commission, 2023). (cont.)

Parameter	**ISO 14064-1**	**GHG protocol**	**EU ETS**	**CBAM**
			in the facility	
Indirect Emissions (downstream)	Category 5		Out Of scope	Out of scope

One of the main reasons for the introduction of the ETS in Turkiye is to reduce the CBAM tax to the extent of the carbon price in the country's ETS and to preserve the money in the national economy. Therefore, in consultation with Experts 1 and 6, the CBAM emission calculation methodology was chosen.

In the MRV system, where emissions have been monitored in Turkiye since 2015, only combustion and process emissions are monitored on a facility basis, and indirect emissions such as electricity are not monitored on a facility basis. Emissions from electricity generation are monitored within the scope of electricity producers. The planned ETS system will probably have the same scope as the MRV system in the first phase due to the ease of implementation and availability of historical data. It should be noted that emissions monitored in the MRV system are fully aligned with the EU ETS, except for the aviation sector. In addition, given the possibility of merging with the EU ETS to be fully exempt from taxes such as CBAM, while Turkiye's candidacy to the EU continues, it is reasonable to choose the CBAM methodology as it is the most similar methodology to the EU ETS. Carbon emissions can be monitored and measured mainly using calculation-based methodology and measurement-based methodology, as shown in a scheme in Figure 3.7. The measurement-based methodology requires many experiments to determine the accurate value of total carbon emissions. Although its accuracy is higher than calculation-based methodology, the methodology itself is complex and time-consuming (MoEUCC, 2014). Therefore, most emission monitoring standards allow companies to measure their carbon emissions based on calculation-based methodology.

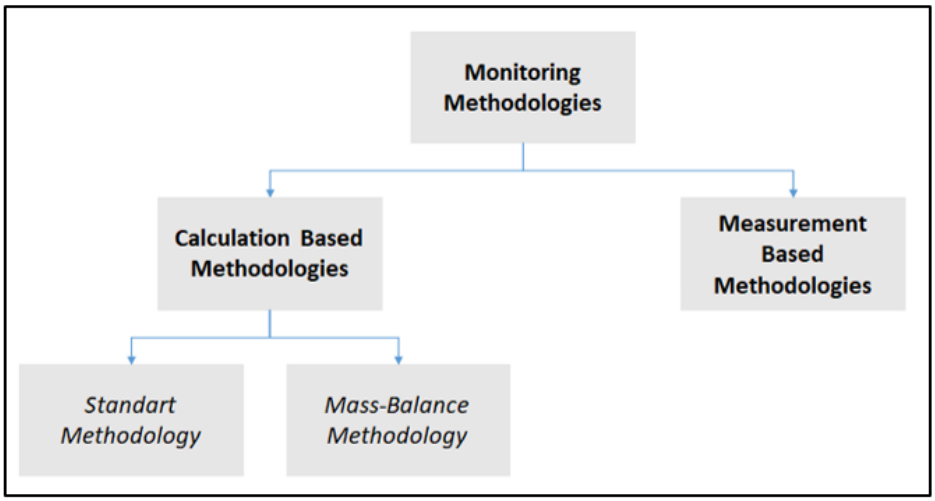


Figure 3.7. Scheme of monitoring methods for monitoring greenhouse gas emissions (MoEUCC, 2014).

Both CBAM Guidance Document for Installation Operations Outside of The EU (EU Commission, 2023) and the MoEUCC's Monitoring and Reporting Communiqué Monitoring Plan Guide (MoEUCC, 2014) recommend the use of the Standard Method for the cement industry and the Mass-Balance Method for the steel industry among calculation-based methodologies. Since steel products contain a certain amount of carbon, the mass-balance method, which analyzes carbon output versus carbon input, is recommended for the steel industry. The standard method is suitable for the cement industry since cement products do not contain carbon like steel.

In plants using the Standard Methodology, the fuel or material used in operations is usually directly linked to emissions (e.g. cement). However, in some facilities (e.g. integrated iron and steel plants), it can be difficult to link emissions to input materials. In these cases, the Mass-Balance Methodology is used. All source streams covered should be considered when using the Mass-Balance Methodology (MoEUCC, 2014).

The standard method approach calculates GHG emissions from activities by multiplying activity data (e.g. amount of fuel consumed or process input material) by a calculation factor (emission factor, NKD) and other factors (e.g. oxidation factor for combustion emissions and conversion factor for process emissions). In the calculation

of emissions by the standard method, CO_2 emissions from the combustion of fuels are analyzed under the heading "Combustion Emissions"; CO_2 emissions from the process are analyzed under the heading "Process Emissions".

In the standard method, GHG emissions from fuel combustion are calculated as

$$Combustion\ Emission = AD * NCV * EF * OF, \tag{3.3}$$

where AD represents the activity data meaning the amount of fuel burned, NCV is the net calorific value per unit quantity of fuel, EF is the relevant emission factor and OF is the oxidation factor used for carbon not emitted. For simplification, the oxidation factor will be considered as 1 in this study.

In the standard method, the company determines GHG emissions from process emissions per source stream as follows

$$Process\ Emission = AD * EF * CF, \tag{3.4}$$

where AD is material consumption, raw material quantity or production output, EF is relevant emission factor and CF is conversion factor. In this study, CF is taken as 1 as a conservative approach.

In the Mass Balance Methodology, the total plant emission quantity is calculated based on carbon in and carbon out as

$$Emission = (Total\ Carbon\ Input - Total\ Carbon\ Output) * f, \tag{3.5}$$

where Total Carbon Input corresponding to the amount of carbon entering the unit boundaries and Total Carbon Output corresponding to the amount of carbon leaving the unit boundaries, where f represents the constant value of 3.664 tCO_2/tC. f is the molar factor that converts carbon content to carbon dioxide (CO_2) emissions. Since the molar mass of carbon (C) is 12 g/mol and the molar mass of carbon dioxide (CO_2) is 44 g/mol, the molar factor for conversion is $44/12 = 3.664$ (MoEUCC, 2014).

The emission quantity is calculated for each input and output source stream as

$$Emission = (f * FVi * Ci), \tag{3.6}$$

where FVi represents each source's activity data regarding tons, Ci represents the activity's carbon content, and f represents the molar factor, as explained in Equation (3.5).

According to the CBAM regulation (EU Commission, 2023)., direct emissions attributed to the process are defined as

$$AttrEm_{Dir} = DirEm + Em_{H,imp} - Em_{H,exp} + WG_{corr,imp} - WG_{corr,exp} - Em_{el,prod}, \quad (3.7)$$

where, $AttrEm_{Dir}$ is the direct attributed emissions of the process in tCO_2e, $DirEm$ is directly related emissions from production such as process emissions, $Em_{H,imp}$ is the heat related emissions imported into the process, EmH, is the heat related emissions exported from the process, $WG_{corr,imp}$ is the consumed waste gas emissions imported into the process, $WG_{corr,exp}$ is the consumed waste gas emissions exported from the process, $Em_{el,prod}$ is the emissions equal to the amount of electricity generated in the process.

As per CBAM regulation the attributed indirect emissions in the process as

$$AttrEm_{indir} = Em_{el,cons} = E_{el} x EF_{el}, \quad (3.8)$$

where, $AttrEm_{indir}$ is the attributed indirect emissions of the process in tCO_2, Em_{el} is the related emissions to the electricity produced or consumed, E_{el} is the amount of electricity consumed in MWh or TJ, EF_{el} is the emission factor for the electricity in tCO_2/MWh or tCO_2/TJ.

3.2.1. Cement Production Processes and Emission Modeling

CBAM's scope of goods in the cement sector includes cement clinker and cement, as listed in Table 3.4. Therefore, both goods are included in the model. An integrated cement plant that produces cement from clinker has been selected for modelling. Since Portland cement is one of the most common types of cement worldwide and in Turkiye, the plant is assumed to produce entirely grey Portland cement corresponding to CN 2523 29 00 (EU Commission, 2023).

Table 3.4. CBAM's scope of goods in the cement industry (EU Commission, 2023).

Aggregated goods category	**CN Code**	**Description**
Calcined clay	2507 00 80	Other kaolinic clays
Cement clinker	2523 10 00	Cement clinkers
Cement	2523 21 00	White Portland cement, whetever
	2523 29 00	Other Portland cement
	2523 90 00	Other hydraulic cements
Aluminous cement	2523 30 00	Aluminous cement

Other auxiliary materials used in cement production, such as blast furnace slag, fly ash and natural pozzolana, are not included in the calculation scope under the CBAM, assuming they do not have any embedded emissions (EU Commission, 2023).

Cement production starts with the production of clinker, which is the precursor of cement, as shown in Figure 3.8. Fossil-based fuels or waste-derived fuels can be used for the heat required to calcinate limestone (calcium carbonate, CaCO), and some alternative raw materials, such as bauxite or iron ore, can also be used as alternative raw materials in the clinker production process. Clinker production results in both process and combustion emissions. Limestone as a raw material causes process emissions in clinker production, and there is no effective substitute for it yet, so the primary way to reduce process emissions from clinker production is Carbon Capture and Storage (CCS)/Carbon Capture and Utilization, which is still under development.

The calcination reaction of limestone is as follows,

$$CalciumCarbonate(CaCO_3) = CalciumOxide(CaO) + CarbonDioxide(CO_2), \quad (3.9)$$

with the influence of high temperature, calcium carbonate ($CaCO_3$) decomposes to form calcium oxide (CaO) and carbon dioxide (CO_2).

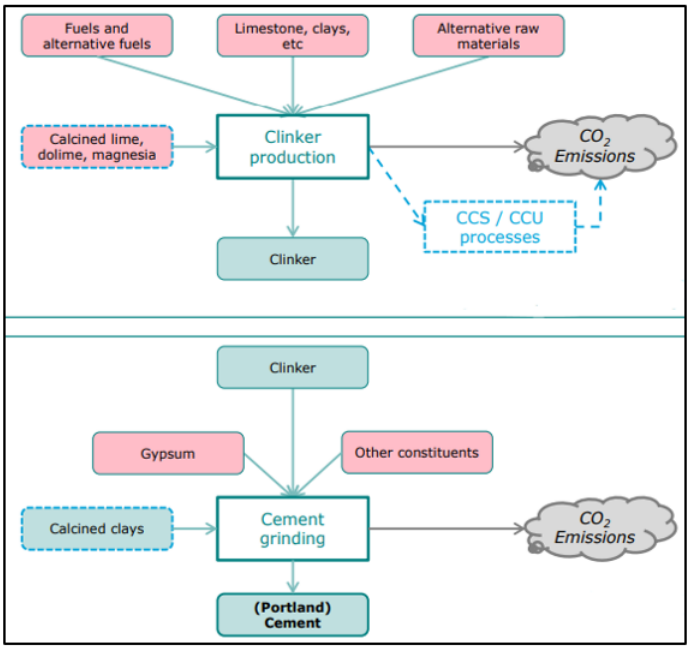


Figure 3.8. Clinker and cement production's scheme (EU Commission, 2023).

For the sake of simplicity of the calculations, in consultation with cement experts, it is assumed that all clinker produced in the cement plant is used in the cement production process and that no sales are made to external parties. Since the clinker produced is used entirely in the cement production process, the bubble approach, by which all production processes are treated as a single process, can be applied. The system boundaries of the bubble approach and the required elements whose emissions need to be monitored are drawn in red in Figure 3.9.

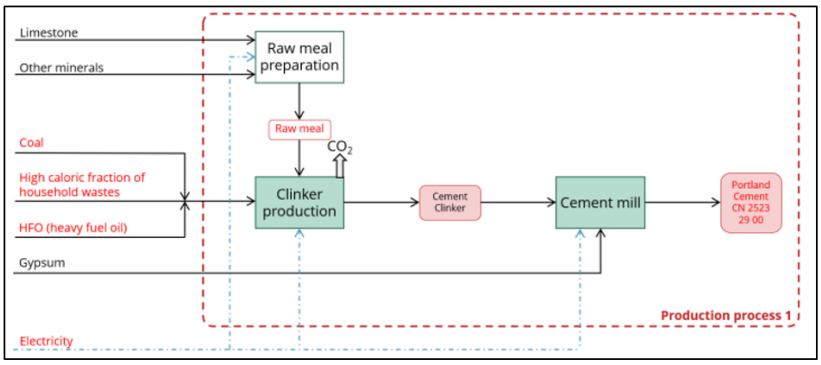


Figure 3.9. Bubble approach for monitoring emissions in the cement industry (EU Commission, 2023).

The emission sources of the cement production can be listed as follow:

- Direct emissions from the combustion of fuel, including that from fossil fuels such as coal, HFO, and alternative fuels derived from waste
- Direct process emissions resulting from the thermo-chemical reactions of carbonates in the input raw materials, such as limestone
- Indirect emissions generated using electricity.

3.2.2. Steel Production Processes and Emission Modeling

Table 3.5 lists CBAM's scope of goods in the iron and steel sector, which ranges from ore to crude steel. The combined category of iron and steel products includes products in CN codes 7205, 7208-7217, 7219-7223, 7225-7229, 7301-7311, 7318, and 7326. Reinforcing steel rebars fall under category 7214, meaning they are a CBAM good (EU Commission, 2023).

The main product produced in the integrated iron and steel plants is crude steel. Crude steel can be converted into the relevant products by hot rolling according to the desired specifications. For instance, it can be transformed into plate steel for household goods and cars or reinforcing steel bars for construction. For this reason, the process up to crude steel production is modelled in the model, and the following processes are not included.

There are different crude steel production routes, such as integrated routes covering blast furnace and basic oxygen furnace routes, smelting reduction routes, electric arc furnaces routes using scrap, electric arc furnaces routes using direct reduced iron, electric arc furnaces routes using high alloy steel or nickel pig iron route using high alloy steel.

Although the most common production route in Turkiye is the electric arc furnaces route using scrap, with the consultation of experts, it has been decided to use

the integrated route, which is the most emission-intensive route, covering the blast furnace and the basic oxygen furnace. In Turkiye, there are only three companies in steelmaking with the integrated route: Kardemir, Erdemir and İsdemir.

Table 3.5. CBAM's scope of goods in the iron and steel.

Aggregated Goods Category **Production route**	**Relevant precursors**
Sintered Ore	None
Ferro alloys (FeMn, FeCr, FeNi) Pig iron Blast furnace route	Sintered ore, if used in the process. Hyrdogen, sintered one, ferro alloys, pig iron/DRI (the later if obtained from other
Smelting reduction	installations or production processes and used in the process).
Direct Reduced Iron (DRI)	Hyrdogen, sintered one, ferro alloys, pig iron/DRI (the later if obtained from other installations or production processes and used in the process).
Crude steel Basic oxygen Steelmaking Electric arc furnace	Ferro alloys, pig iron, DRI, crude stell (the later if obtained from other installations or production processes and used in the process).
Iron or steel products	Ferro alloys, pig iron, DRI, crude steel, iron or steel products (if used in the process).

As illustrated in the Figure 3.10, the crude steel production from iron ore includes a number of essential processes. The process starts by cooking iron ore in a sintering furnace with coal, lime, and other materials. The produced sinter is fed into a blast furnace (BF) and layered with coke and lime. Hot air is blown into the BF to burn the coke and produce pig iron. Pig iron is purified from carbon and other impurities by blowing oxygen in a basic oxygen converter (BOF), producing crude steel. Finally,

the obtained crude steel is hardened by casting methods and transformed into various steel products.

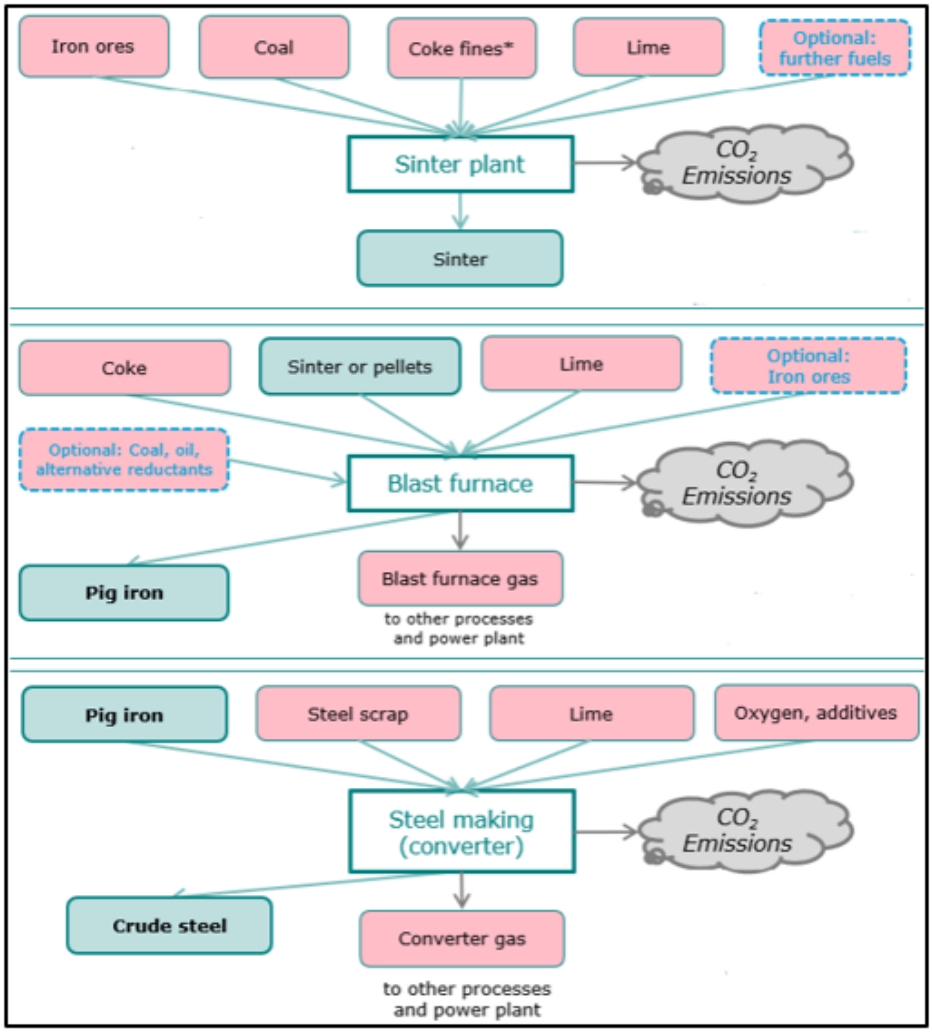


Figure 3.10. System boundaries of crude steel manufacturing with blast furnace and basic oxygen processes (EU Commission, 2023).

The integrated blast furnace/base oxygen furnace (BF/BOF) steelmaking process is the most complex route. It is characterized by interdependent material and energy flow networks between the various production units. It should be noted that CBAM calculations assume that there are no embedded emissions of coke. The CBAM regulation also states that if the BOF process uses all the pig iron produced in the blast furnace to produce crude steel, the whole plant's emissions can be monitored as a single system using a bubble approach, as shown in Figure 3.11.

The emission sources of steel production can be listed as follows:

- Direct emissions from the combustion of fossil fuels and waste gases.
- Direct emissions from the process such as thermal decomposition of carbonates and coke and the carbon content of iron and steel materials, including scrap.
- Indirect emissions from consumed electrical energy.

Most integrated steel plants collect process gases and generate electricity for self-consumption. Emissions from electricity generation by waste gases are accounted under indirect emissions. Therefore, to avoid double counting, waste gas emissions are deducted from direct emissions, as recommended by CBAM (EU Commission, 2023).

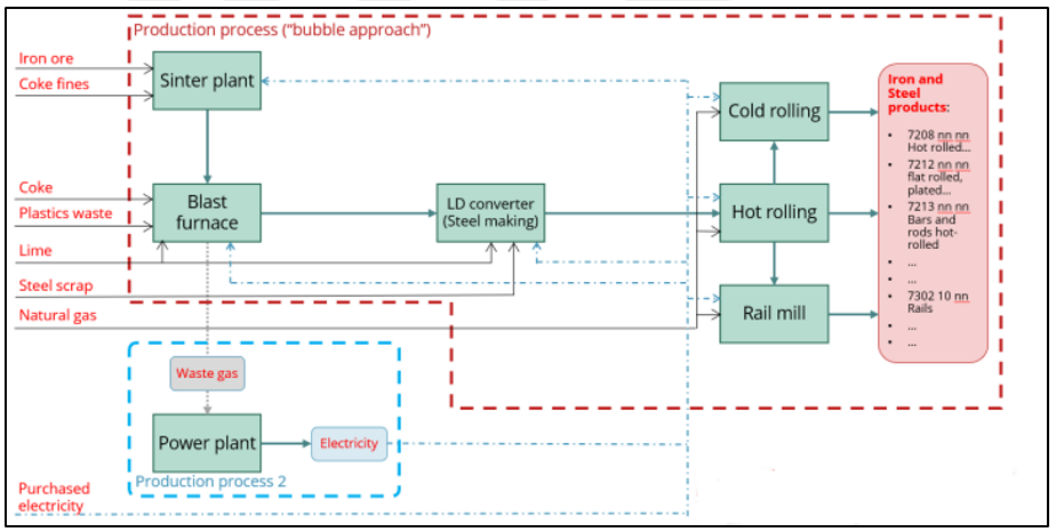


Figure 3.11. Bubble approach for monitoring emissions in the iron and steel industry (EU Commission, 2023). (EU Commission, 2023).

3.2.3. Construction Cost and Housing Affordability Modelling

The study aims to assess the impact of the increased steel and cement prices due to the carbon pricing system construction costs and, thus, housing affordability and the structure of the model is designed to analyze this.

Every year, MoEUCC publishes the Unit Construction Costs with the relevant building types and the Construction General Cost Analysis, which includes all kinds of activity costs, including labor and transportation costs. The department responsible for publishing these cost analyses is the Higher Technical Board, established in 1934. Unlike previous years, the Ministry published the Construction General Cost Analysis twice in both 2022 and 2023, as the first shared prices could not preserve their place due to the effect of inflation. However, no second publication was made in 2024 as of August. This year, Construction General Cost Analysis was published on 23 January 2024, and Unit Construction Costs were published on 20 February 2024.

Since the study is not a macroeconomic study and the objective is solely to assess the impact of carbon pricing, during the model life, the price changes have been made only with the inflation rate, and other macroeconomic changes have not been considered. Unit cement manufacturing, unit concrete manufacturing and unit steel manufacturing costs are taken directly from the 2024 Construction General Cost Analysis of the MoEUCC, which is usually published for the price calculation of public tenders. With the expert's consultation, it is decided to make 65% uplift to these costs to present real life dynamics.

In order to verify the base prices published by the MoEUCC with the real market dynamics, the construction cost analysis software developed by Çevik Proje Yazılım A.Ş., "inşaat hesabı" one of the most well-known cost analysis platforms in Turkiye, was also benefitted in this study. In this study, REIDIN Insights was used to collect real-time and Turkiye-specific data. The TurkStat was the primary source of country-specific economic data, such as average family income, used in the study.

To eliminate the high and uncertain effects of inflation in the Turkiye market, especially in recent years, the study was conducted in USA Dollars (USD) and converted using the indicative exchange rates published by the Central Bank of the Republic of Türkiye (CBRT) daily. Therefore, the Construction General Cost Analysis and Unit Construction Costs have been converted into USA Dollars at the indicative exchange

rates of the Central Bank of the Republic of Turkiye (CBRT) on the day preceding the day of publication.

In consultation with the Finance Expert, as construction costs are converted into USA dollars, macro-economic values such as interest and inflation rates are also taken from the USA dollar perspective to ensure accuracy and avoid overpricing. Current and projected inflation rates are taken from the OECD's database, and the GDP rates are from the World Bank's Global Economic Prospects report published in June 2024 (World Bank, 2024c).

The housing affordability index (HAI) measures, based on the economic perspective and the housing sales prices, whether an average family living in the country would be able to afford a mortgage loan for an average house with their family income.

The value of 100 means that a family with a median income in the country has just enough money to afford a mortgage loan for an average house. If it is above 100, a family earning a median income in the country has more than the income to afford a mortgage loan with an 80% loan of the house price.

For instance, if the HAI is 120, a family with a median family income has 120 per cent of the income needed to qualify for a loan, equivalent to 80 per cent of an average home. The increase in HAI indicates that the family can afford an average-priced home. If it is below 100, it means that a family in the country with a median family income has not enough income to afford a median-priced house. It should be noted that HAI assumes that only 25 per cent of family income goes towards monthly mortgage payments.

Housing affordability index (HAI) is calculated as

$$HAI = \frac{MedianIncome}{QualifyingIncome} * 100, \tag{3.10}$$

where the HAI represents the housing affordability index, median income is the median family income in the country, and qualifying income is calculated as the monthly

principal and interest payment on the mortgage interest rate of the median-priced house.

Qualifying income is the family income required to be eligible for a mortgage loan for a median-priced home and is calculated as follows

$$Qualifying\ Income = PMT * 12 * 4, \tag{3.11}$$

where PMT represents the monthly principal payment of a mortgage loan, the coefficient 12 represents the conversion of the monthly payment into an annual payment and the coefficient 4 represents that the loan payment should be only 25 per cent of the family income.

The monthly principal and interest payment (PMT) is calculated as follows

$$PMT = MEDHOUSEPRICE * 0.80 * (\frac{IR/12}{(1 - \frac{1}{1+IR/12})^{360}}), \tag{3.12}$$

where medhouseprice is the median priced family house price in the country, the coefficient of 0.80 indicates that 80 per cent of total house prices are financed from the loan and IR is the annual interest rate. As the median family house price and median family income data are not available for Turkiye, the mean family income and mean family house prices are used in the study.

3.3. Stock and Flow Diagram

The system dynamics model is built under three sub-models, as described in the previous sections. The cement sub-model represents the process and related emissions of an integrated cement plant, while the steel sub-model represents the process and related emissions of an integrated steel plant. In the third sub-model, the construction cost and housing affordability sub-model, carbon tax inputs from the cement and steel sub-models feed into the construction cost, which affects housing sales costs. The impact on housing affordability due to these cost increases is investigated. The STELLA, a well-known system dynamics programming tool from the isee system, developed by Barry Richmond, a Systems Thinking practitioner, is used for system dynamics modelling.

3.3.1. Cement Sub-Model's Stock and Flow Diagram

The production processes of an integrated cement company and the associated emissions from clinker to cement production are modelled in the stock and flow diagram of the cement sub-model, the company named Cement Company X as a representative. An overview of the stock and flow diagram of the cement sub-model is shown in Figure 2.4. For the cement industry, emission calculations for all processes are conducted with Standard Methodology as recommended in CBAM's Guidance Document (EU Commission, 2023) and the MoEUCC's Monitoring Plan Guide (MoEUCC, 2014).

In consultation with cement industry experts, it was decided to model cement and clinker emissions separately, as both cement and clinker are products themselves, and neither is a by-product. The "Carbon Emissions from Clinker Production" converter is fed from the "Indirect Emissions from CLNKR" converter and the "Direct Emissions from CLNKR" converters, as clinker production has both indirect emissions from electricity use and direct emissions from process emissions and combustion emissions. "Carbon Emissions from Cement Production" has only one feeder, "Indirect Emissions CMNT" since cement production has only a clinker grinding process, as shown in Figure 3.12, the only emission source is the use of electricity.

In the cement sub-model, the carbon emission sources that feed the "Direct Emissions CLNKR" converter are as listed:

- Process Emissions CLNKR
- Combustion Emissions CLNKR
- Coal Emissions CLNKR
- RDF Emissions CLNKR
- TDF Emissions CLNKR
- HFO Emissions CLNKR

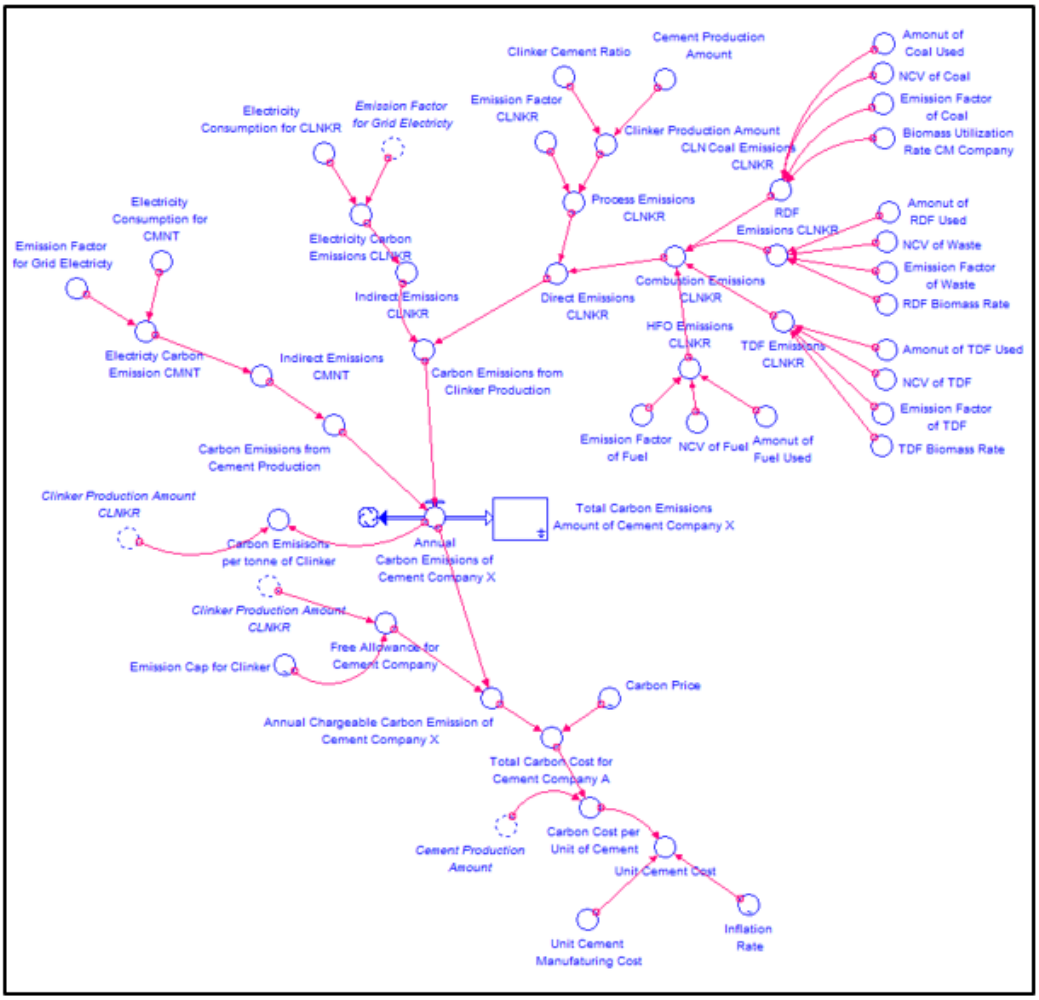


Figure 3.12. Cement sub-model's stock and flow diagram.

3.3.2. Steel Sub-Model's Stock and Flow Diagram

As detailed in Section 3.3.3.2 (Steel Production Processes and Emissions), the processes and emissions involved in the production of crude steel from iron ore are modeled for a representative Steel Company Y and Figure 3.13 shows a holistic representation of the stock and flow diagram of the steel sub-model.

For the iron and steel industry, as suggested in both the CBAM Guidance Document (EU Commission, 2023) and the MoEUCC's Monitoring Plan Guide (MoEUCC, 2014), the Mass-Balance Methodology is being used to calculate direct emissions, while indirect emissions are calculated using the Standard Methodology. Therefore, the "Car-

bon Input of STEEL" and "Carbon Output of STEEL" converters feeding the "Direct Emissions of STEEL" converter calculate direct emissions by Mass-Balance Methodology, while the "Emissions from Grid Electricity production STEEL" and "Emissions from Waste Gas Electricity Production STEEL" converters feeding the "Indirect Emissions of STEEL" converter calculate indirect emissions by Standard Methodology.

In the proposed model, the carbon inputs that feed the "Carbon Input of STEEL" converter can be listed below:

- Emissions from Coal STEEL,
- Emissions from Iron Ore STEEL,
- Emissions from Coke STEEL,
- Emissions from Oil STEEL,
- Emissions from Scrap STEEL,
- Emissions from Natural Gas STEEL.

The process outputs are divided into two: steel and slag. As both contain carbon in specific proportions, they feed the "STEEL Carbon Output" converter. Steel is a universal material that finds applications in numerous industries. Slag, a by-product of the process, is used as the raw material in industries such as cement. The scrap produced during the process is fed back into the following production process, so they do not contribute to the carbon content of the output products. The feeds to the "Carbon Output of STEEL" converter are as follows:

- Steel Carbon Output,
- Slag Carbon Output.

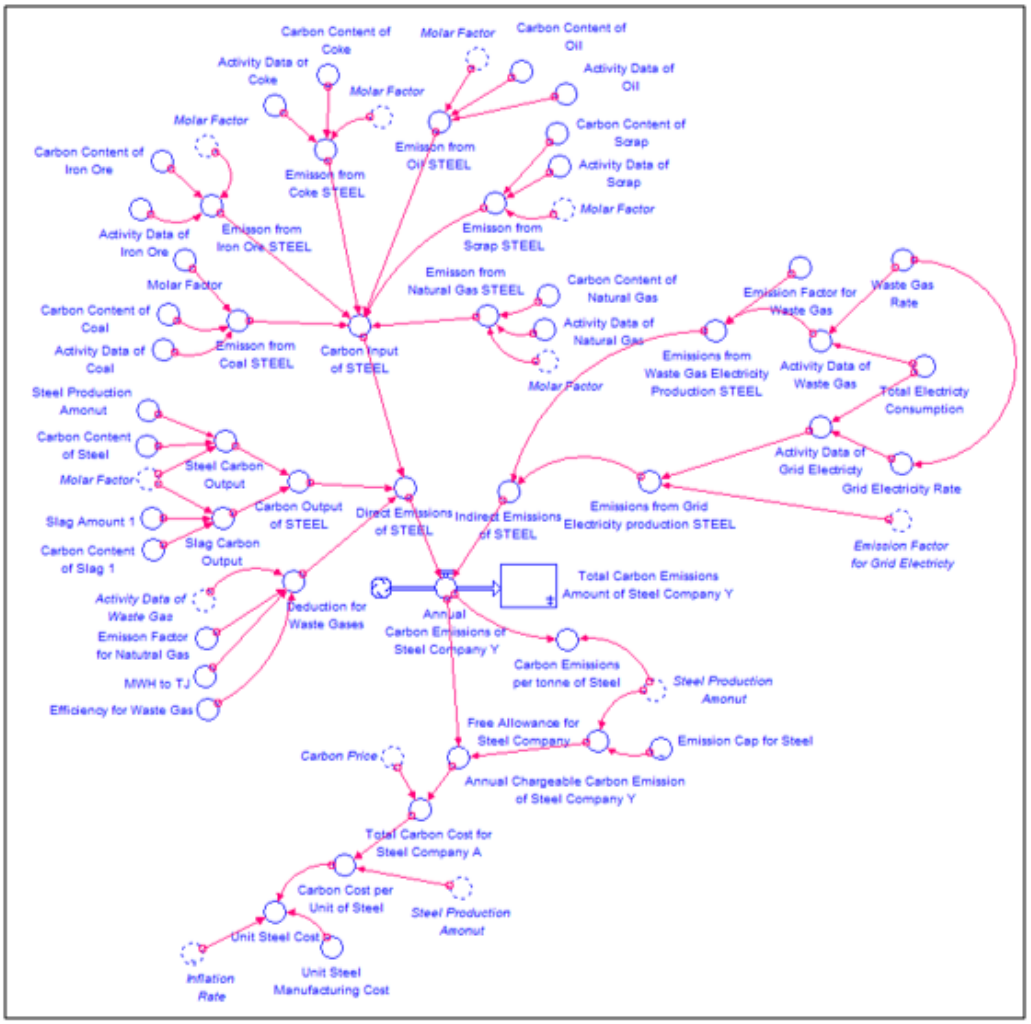


Figure 3.13. Steel sub-model's stock and flow diagram.

As mentioned before, Standard Methodology is used to calculate indirect emissions in the steel sector. There are two feeder converters for indirect emissions:

- Emissions from Waste Gas Electricity Generation,
- Emissions from Grid Generation.

3.3.3. Construction and Housing Affordability Sub-Model's Stock and Flow Diagram

This sub-model focuses on the impact of carbon pricing on cement and steel prices and, ultimately, on construction costs, as illustrated in Figure 3.14. Changes in construction costs will directly affect house sale prices, and as house sale prices are affected, housing affordability will also change.

The main driver of the model is carbon pricing in the sector; a company's annual chargeable carbon emissions are determined by deducting the companies' allowance levels from their respective emissions in the relevant year. The total carbon cost for the company is calculated by multiplying the annual chargeable emissions by the carbon price of the relevant years. Dividing this by the total amount of production gives the carbon cost per unit product. In this way, the total cost increase resulting from carbon pricing per unit product is determined. This approach has been applied to both cement and steel sectors.

Since cement prices do not directly affect construction prices but rather concrete prices, there is a price transfer from cement to concrete. In contrast, steel directly affects construction prices as it is not an intermediate product; steel rebars such as S420 are produced directly in steel production facilities.

Unit concrete and steel costs contribute to the unit material cost for construction. In contrast, other costs contributing to the unit material costs are assumed to change only with inflation and no other impact on them is considered. Unit construction costs consist of unit material costs, unit labour costs, project development costs, overhead costs and profit margin.

The factors that make up housing prices are the construction cost, land cost, VAT depending on the type of construction, and the profit margin if the contractor and the housing seller are different. In addition to all these, the inflation rate also

affects housing sales prices. Based on expert consultation and REIDIN data, the mean family house size is assumed 100 m^2 and the average family house price is calculated by multiplying this size by the unit sales price.

Using the mean family house price, with a loan rate of 80%, and the corresponding mortgage interest rate, the PMT value is calculated using Equation (3.12). Based on the calculated PMT value, qualifying income is calculated using Equation (3.11). Since TurkStat publishes the average family income every year, it is taken directly. The base mean income value is increased for future years by the GDP growth rate. Eventually, housing affordability is calculated using mean and qualified family incomes.

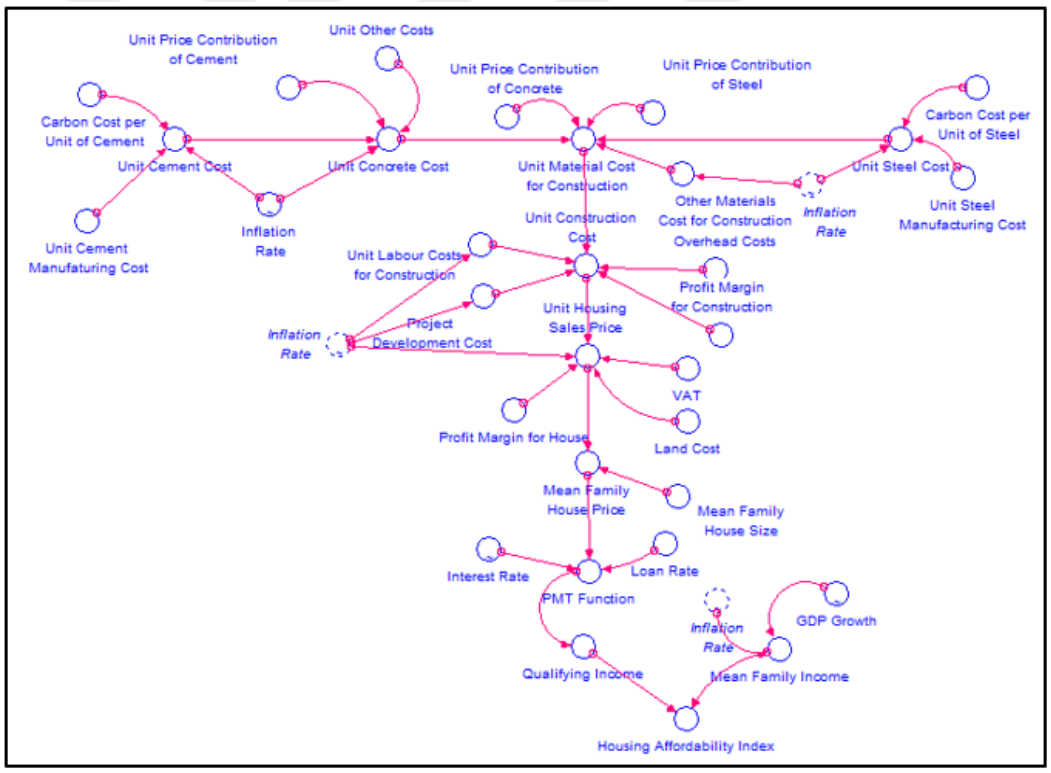


Figure 3.14. Construction cost and housing affordability sub-model's stock and flow diagram.

3.4. Data Collection

During the consultation meetings conducted with cement, steel and construction companies, they were unwilling to share their company data for use in this study. For instance, the cement and steel companies have been reporting their emissions to the MoEUCC since 2015 under the MRV scheme. However, they did not share their company's emission data directly due to high-level confidentiality. Rather, they have guided the study with Turkish sector-specific data, mostly from associations such as the Turkish Cement Manufacturers' Association and the Turkish Iron and Steel Producers Association.

The primary sources for data collection were Turkiye's National Inventory Report, MRV default values, CBAM default values, IPCC default, and best available technique documents, as well as sector reports published by MoIT and MoEUCC.

It should be noted that the model assumes that the production capacities of both steel and cement companies remain at the same level throughout the model's time frame; in other words, no investments are made to increase capacity.

3.4.1. Data collection in Cement Sub-Model

Table 3.6 shows the amount of each variable in the cement sub-model and their corresponding references. As previously indicated in section 3.3.1, Cement Production Processes and Emission Modeling, the facility is assumed only to produce grey Portland cement, the most common type of cement used worldwide, as it sets faster than other types. Since the Republic of Turkiye restricted the use of CEM I in public tenders, CEM II is used in the model, and the average clinker-to-cement ratio for CEM II is taken as 0.85. This decision was also taken in consultation with cement industry experts.

The Cement Company X's annual cement production is accepted as 2,000,000 tons, therefore with the 0.85 cement/clinker ratio, the clinker production is calculated as 1,700,000 tons.

According to the IEA (2021), the world average thermal specific energy consumption per ton of clinker is 3.3 GJ/t, compared to 3.7 GJ/t in the EU and 3.3 GJ/t in the Middle East. In parallel, based on the experts' suggestion, the thermal specific energy consumption per ton of clinker is taken as 720 kcal/ kg, which is 3.01 GJ/t for the Turkish cement industry.

When thermal specific energy consumption per ton of clinker is multiplied by the total annual clinker production capacity, the total thermal energy consumption for clinker production is calculated as 1,224,000,000,000 kcal. Corresponding to this energy calculation, it is assumed that the energy needs 30% is covered by alternative fuels as equal by Refuse-Derived Fuel (RDF), Tire-Derived Fuel (TDF) and biomass, while 70% of energy is covered by fossil-based fuels such as coal.

Table 3.6. Variables in the cement sub-model.

Variable Name	**Amount**	**Unit**	**Reference**
Total Cement Production	2,000,000	ton	Cement Industry Experts
Clinker/Cement Ratio	0.85	%	Cement Industry Experts
Total Clinker Production	1,700,000	ton	Calculation
Thermal Energy Consumption per Ton of Clinker	720,000	kcal/ton	Cement Industry Experts
Total Thermal Energy Consumption for Clinker	1,224,000,000,000	kcal	Calculation
Alternative Fuel Percentage	0.30	%	Cement Industry Experts
Total Thermal Energy from Alternative Fuel	367,200,000,000	kcal	Calculation
Total Thermal Energy from TDF	122,400,000,000	kcal	Cement Industry Experts
TDF's Energy Density	7,265,77	kcal/ton	DUKES 2023
Total TDF Amount	16,846	ton	Calculation
Total Thermal Energy from RDF	122,400,000,000	kcal	Cement Industry Experts

Table 3.6 Variables in the cement sub-model. (cont.)

Variable Name	**Amount**	**Unit**	**Reference**
RDF's Energy Density	3,632,887	kcal/ton	DUKES 2023
Total RDF Amount	33,692	ton	Calculation
Total Thermal Energy from Biomass	122,400,000,000	kcal	Cement Industry Experts
Biomass's Energy Density	2,500,00	kcal/ton	Turkish National GHG Emission Report
Total Biomass Amount	48,960	ton	Calculation
Coal Percentage	70	%	Cement Industry Experts
Total Thermal Energy from Coal	856,800,000,000	kcal	Calculation
Coal's Energy Density	7,705,545	kcal/ton	NIR 2023
Total Coal Amount	111,193	ton	Calculation
Electric Energy Consumption per Ton of Clinker	0.0656	MWh/t	Cement Industry Experts
Total Electricity Consumption in Clinker Production	111,520	MWh	Calculation
Electric Energy Consumption per Ton of Cement	0.0372	MWh/t	Cement Industry Experts
Total Electricity Consumption in Cement Production	74,400	MWh	Calculation

As shown in Table 3.6, the energy intensities of fuels are taken from the Turkish National Greenhouse Gas Emission Report, if available, or from the UK Digest of Energy Statistics (DUKES) 2018, if not available. The total thermal energy requirement of the fuels was divided by their energy densities to calculate the amount of fuel required. In terms of electricity consumption, based on expert opinion, the electricity required per ton of clinker production is assumed to be 0.0656 MWh and 0.0372 MWh per ton of cement. When those unit consumption amounts are multiplied by the total production quantities, the total required electricity consumptions are calculated and listed in Table 3.6.

It has been determined that Standard Methodology will be used for emission calculation in cement and clinker processes. In this context, Equation (3.3) was used for combustion emissions and Equation (3.4) for process emissions. The variables in the equations are given in Table 3.7, together with their references and the relevant

activity data, emission factors, and net calorific values. It should be noted that detailed calculations for activity data are given in Table 3.6.

Table 3.7. Activity data, emission factors and net calorific values of raw materials, fuels and electricity in the cement sub-model.

Emission Type	**Name**	**Activity Data (AD)**	**Emission Factor (EF)**	**Reference**	**Net Calorific Value (NCV)**	**Reference**
Process	Clinker	1,700,000 t	0.525 tCO_2/t	EU CBAM	-	-
Combustion	Coal	111,193 t	97.4 tCO_2/TJ	NIR 2023	32.24 TJ/kton	NIR 2023
Combustion	RDF	33,692 t	143 tCO_2/TJ	MRV Annex-5	15.2 TJ/kton	DUKES 2018
Combustion	TDF	16,846 t	85 tCO_2/TJ	MRV Annex-5	30.4 TJ/kton	DUKES 2018
Combustion	Biomass	48,960 t	-	-	-	-
Combustion	Heavy Fuel Oil	100 t	77 tCO_2/TJ	NIR 2023	39.39 TJ/kton	NIR 2023
Indirect	Electricity – Clinker	111,520 MWh	0.439 tCO_2/MWh	MoENR	-	-
Indirect	Electricity – Cement	74,400 MWh	0.439 tCO_2/MWh	MoENR	-	-

Under both CBAM and MRV regulations, biomass is considered to have zero emissions. Therefore, a biomass utilization rate converter is added to the system. If the fuel is 100% biomass, the biomass utilization rate is written as 100% and zero emissions are calculated. If the fuel contains some biomass, e.g. TDF is considered to have 27% biomass content under MRV regulations, then the fuel is considered to have zero emissions up to the biomass content.

3.4.2. Data collection in Steel Sub-Model

The Ministry of Industry and Technology publishes sector reports every year, which assess the sector's annual performance, including financial and energy performance. The last sector report for the steel industry was published for 2021 (MoIT, 2022). According to this report, the energy required to produce 1 ton of crude steel in

BF/BOF plants is 5450 Mcal, which is equal to 22.803 GJ. The percentage breakdown of this energy consumption is listed in Table 3.8.

Table 3.8. Energy consumption of a BF/BOF steel plant (MoIT, 2022).

Energy Consumption	**BF/BOF Plants (per 1 tons of crude steel)**
Electricity (%)	5
Natural Gas (%)	15
Coal (%)	75
Oil (%)	5
Total (GJ)	**22.803**

Table 3.9 shows the quantity of each variable in the steel sub-model and their corresponding references. As explained in detail in Section 3.4.2, a steelmaking process has two outputs: one is steel, and the other is slag. The Steel Company Y's annual crude steel production is considered to be 2,000,000 tons based on the consultations of steel industry experts. When the Sustainability Reports of Kardemir, Erdemir and İsdemir were analyzed, it was determined that slag production is approximately 20% of total steel production. Therefore, 20% was taken as the sector average, which accounted for 400,000 tons of slag production.

According to the MoIT, the required amount of iron ore per ton of crude steel is 1.5 tons. Since the MoIT does not consider using scrap in the BF/BOF route, however, the industry widely uses it. Therefore, 1.5 tons is considered the required amount of iron ore plus scrap per ton of crude steel; based on expert consultation, the scrap percentage is considered 22%. Accordingly, the amount of scrap is 440,000 tons, and iron ore is calculated as 2,560,000 tons.

Table 3.9. Variables in the steel sub-model.

Variable Name	**Amount**	**Unit**	**Reference**
Total Crude Steel Production	2,000,000	ton	Steel Industry Experts
Slag Percentage	0.20	%	Steel Industry Experts
Slag Amount	400,000	ton	Calculation
Iron Ore + Scrap percentage per ton of Crude Steel	1.50	ton/ton	MoIT, 2022
Total Iron Ore + Scrap Amount	3,000,000	ton	Calculation
Scrap Percentage	0.22	%	Steel Industry Experts
Scrap Amount	440,000	ton	Calculation
Iron Ore Amount	2,560,000	ton	Calculation
Energy Need per ton of Crude Steel	22.803	GJ/ton	MoIT, 2022
Total Energy Need	45,638,000	GJ	Calculation
Natural Gas Percentage	0.15	%	MoIT, 2022
Total Natural Gas Energy Consumption	6,840,900	GJ	Calculation
Natural Gas's Energy Density	34.54	GJ/m^3	NIR 2023
Total Natural Gas Energy Amount	198,057	m^3	Calculation
Total Natural Gas Amount	138,640	ton	Calculation
Coal Percentage	0.75	%	MoIT, 2022
Total Coal Energy Consumption	34,204,500	GJ	Calculation
Coal's Energy Density	26.03	GJ/ton	NIR 2023
Total Coal Amount	1,314,041	ton	Calculation
Hard Coal Percentage	0.25	%	Steel Industry Experts
Hard Coal Amount	328,510	ton	Calculation
Coke Percentage	0.75	%	Steel Industry Experts

Table 3.9 Variables in the steel sub-model. (cont.)

Variable Name	**Amount**	**Unit**	**Reference**
Coke Amount	985,531	ton	Calculation
Oil Percentage	0.05	%	MoIT, 2022
Total Oil Energy Consumption	2,280,300	GJ	Calculation
Oil's Energy Density	43.96	GJ/ton	NIR 2023
Total Oil Amount	51,872	tons	Calculation
Energy Consumption per Ton of Crude Steel	22.803	GJ/ton	MoIT, 2022
Total Energy Consumption	45,606,000	GJ	Calculation
Electricity Percentage	0.05	%	MoIT, 2022
Total Electricity Energy Consumption	2,280,300	GJ	Calculation
Total Electricity Consumption	633,417	MWh	Calculation
Electricity Generation from Waste Gas Percentage	0.54	%	Steel Industry Experts
Electricity Generation from Waste Gas Amount	342,045	MWh	Calculation
Electricity Consumption from Grid	291,372	MWh	Calculation
Waste Gas Efficiency	0.35	%	Steel Industry Experts
Waste Gas Amount	3,518	TJ	Calculation

Based on energy consumption data from the MoIT and energy densities obtained from the 2023 National Inventory Report, the required amount of natural gas was calculated as 138,640 tons, coal as 1,314,041 tons, and oil as 51,872 tons. According to expert opinion, 25% of the coal is considered hard coal, and the rest is coke.

It is assumed that 54% of the electrical energy is generated from the waste gases collected during the processes, and the remaining is consumed from the grid. Based on expert opinion, the efficiency of the waste gas was assumed to be 35%, and therefore, the total amount of waste gas required was calculated as 3,518 TJ. Based on this amount, waste gas emissions were then deducted from the carbon input of steel production to

avoid double counting, as its emissions are mainly calculated in the indirect emissions of steel.

It was determined that the mass balance methodology should be used for direct emission calculations and the standard methodology for indirect emissions in steel production. The relevant emission input and output sources are fuels, electricity, raw materials, products and by-products listed in Table 3.10.

Table 3.10. Activity data, carbon content, and emission factors of raw materials, fuels and electricity in the steel sub-model.

Emission Type	**Name**	**Activity Data (AD)**	**Carbon Content (%)**	**References**	**Emission Factor (EF)**	**Reference**
Carbon Input	Hard Coal	328,510 t	86.2	EU CBAM	-	-
Carbon Input	Iron Ores	2,560,000 t	0.023	EU CBAM	-	-
Carbon Input	Coke	985,531 t	87.06	MRV Annex-5	-	-
Carbon Input	Scrap	440,000 t	4.09	MRV Annex-5	-	-
Carbon Input	Natural Gas	138,640 t	75	EU CBAM	-	-
Carbon Input	Oil	51,872 t	84	EU CBAM	-	-
Carbon Output	Steel	-2,000,000 t	1.09	MRV Annex-5	-	-
Carbon Output	Slags	-400,000 t	0.03	EU CBAM	-	-
Indirect Emission	Electricity generated from waste gas	342,045 MWh	-	-	0.576 tCO_2/MWh	EU CBAM
Indirect Emission	Electricity from grid	291,372 MWh	-	-	0.439 tCO_2/MWh	MoENR, 2024
Carbon Output	Deduction from waste gas	3,518 TJ	-	-	55,43 tCO_2/TJ	NIR, 2023

Carbon inputs are mainly fuels such as hard coal, coke, natural gas, and oil and raw materials such as iron ore and scraps, while carbon outputs are steel and slags.

Their activity data were previously calculated in Table 3.9. The carbon content and references for each material are listed in Table 3.8. Since the Mass-Balance Methodology is applied, the formulation of Equation (3.6) is used to calculate how much carbon emissions enter and exit the process.

Regarding indirect emissions, there are two types of electricity sources: electricity generation from waste gases collected in the steelmaking process and electricity use directly from the grid. Indirect emissions are calculated using the Standard methodology; therefore, Equation (3.3) is used for the calculation. The emission factor for waste gas is taken directly from the EU CBAM Guidance Document, while the emission value for grid electricity is taken from MoENR as it is specific to the country's grid electricity energy source distribution.

In addition, as waste gas emissions are considered indirect emissions, they need to be deducted from the carbon input to avoid double counting as they are collected from the process. As recommended in the CBAM guidance, the emission factor for waste gas was taken equal to natural gases and the relevant data was collected from the 2023 National Inventory Report.

3.4.3. Data collection in Construction Cost and Housing Affordability Sub-Model

The primary references for construction cost calculations were the MoEUCC's Unit Construction Costs and Construction General Cost Analysis. As stated in Section 3.4.3, based on the consultation of finance experts, the unit costs published by the MoEUCC were converted into USA dollars using the relevant exchange rate of the CBRT on the day before they were published. The related values and calculations can be found in Table 3.11.

The model was initially structured based on the unit costs of the MoEUCC; however, in consultation meetings with real estate and construction sector experts, it

was stated that the unit construction costs of the MoEUCC were far below the actual price dynamics of the sector. Therefore, applying a 65 per cent increase to each unit cost from the MoUCC was consensually decided. In addition to this, the construction cost calculation software of Çevik Proje Yazılım A.Ş. (Çevik Project Software Inc.), inşaat hesabı, was used to verify these new uplifted prices. The inşaat hesabı software is continuously updating the data from the industry dynamics. According to the latest data, the level of the uplifted costs was found to be adequate and appropriate.

Table 3.11. Variables in the construction cost sub-model.

Variable Name	**Value**	**Units**	**Reference**
USD Currency	TL 32.88	TL/USD	CBRT, 22nd Jan 2024
Unit Cement Cost	TL 2,030	TL/ton	MoEUCC, 2024
Uplift Coefficient	0.65	%	Real Estate and Construction Industry Experts
Revised Unit Cement Cost	TL 3,350	TL/ton	Calculation
Unit Cement Cost	$ 101.87	USD/ton	Calculation
Unit Concrete Cost (C30/37)	TL 2,020	TL/m^3	MoEUCC, 2024
Uplift Coefficient	0.65	%	Real Estate and Construction Industry Experts
Revised Unit Concrete Cost (C30/37)	TL 3,333	TL/m^3	Calculation
Unit Concrete Cost (C30/37)	$ 101.37	USD/m^3	Calculation
Unit Price Contribution of Cement	0.36	%	Cement Industry Expert
Unit Price Contribution of Cement	$ 36.49	USD/m^3	Calculation
Unit Other Costs	$ 64.87	USD/m^3	Calculation
Unit Steel Cost (S420)	TL 20,009	TL/ton	MoEUCC, 2024
Uplift percentage	0.65	%	Real Estate and Construction Industry Experts

Table 3.11 Cost values and related references in the. (cont.)

Variable Name	**Value**	**Units**	**Reference**
Revised Unit Steel Cost	TL 33,015	TL/ton	Calculation
Unit Steel Manufacturing Cost (S420)	$ 1,004	USD/ton	Calculation
USD Currency	TL 30.80	TL/USD	CBRT, 19th Feb 2024
Unit Construction Cost	TL 15,300	TL/m^2	MoEUCC, 2024
Uplift Coefficient	0.65	%	Real Estate and Construction Industry Experts
Revised Square Meter Unit Price	TL 25,245	TL/m^2	Calculation
Unit Construction Cost	$ 819.54	USD/m^2	Calculation
Profit Margin Percentage	0.10	%	MoEUCC, 2024
Profit Margin	$ 81.95	USD/m^2	Calculation
Overhead Costs Percentage	0.15	%	MoEUCC, 2024
Overhead Costs	$ 122.93	USD/m^2	Calculation
Material + Labor + Project Dev. Cost	$ 614.65	USD/m^2	Calculation
Material Cost Percentage	0.65	%	Real Estate and Construction Industry Experts
Unit Material Cost for Construction	$ 399.52	USD/m^2	Calculation
Concrete Cost Percentage	0.10	%	Real Estate and Construction Industry Experts
Concrete Cost	$ 39.95	USD/m^2	Calculation
Steel Cost Percentage	0.07	%	Real Estate and Construction Industry Experts
Steel Cost	$ 27.97	USD/m^2	Calculation
Other Materials Costs for Construction	$ 331.60	USD/m^2	Calculation
Project Dev. Cost Percentage	0.10	%	Real Estate and Construction Industry Experts

Table 3.11 Cost values and related references in the. (cont.)

Variable Name	**Value**	**Units**	**Reference**
Project Dev. Cost	$ 61.47	USD/m^2	Calculation
Labor Cost Percentage	0.25	%	Real Estate and Construction Industry Experts
Labor Cost	$ 153.66	USD/m^2	Calculation

The house was selected as an apartment-type house building (building height less than 30,50 m) in building class IV, sub-class A. According to MoEUCC, the published unit construction cost includes a 10% profit margin and 15% overhead costs. Based on the experts' opinions, the rest of the unit construction cost is considered to consist of 65% material costs, 25% labor costs, and finally, 10% project development costs, including project drawings, real estate development, license and permit fees, and other fees to be paid to the authorities.

Cement type was selected as Portland slag cement, CEMII 42,5 R corresponding to item number 10.130.1205. The concrete type was selected as C30/37 corresponding to item number 10.130.1506 in the general cost analysis list of the MoEUCC.

The steel type was selected in the range of Ø 14 - Ø 32 mm ribbed concrete steel rebar of S420 strength steel, corresponding to item number 10.130.1705 in the MoEUCC's general cost analysis list.

The US dollar inflation rate is taken from the World Bank's Global Economic Prospects report, as in Table 3.12, published in June 2024 with projections until 2029 (World Bank, 2024). After 2029, the inflation rate is expected to remain at the same level, as the US dollar inflation rate does not fluctuate much above or below the 2% in historical data, with consultation of finance expert.

Table 3.12. Inflation rate in USD (World Bank, 2024c).

Inflation Rate	**2024**	**2025**	**2029**	**Reference**
United States	2.9	2.0	2.1	World Bank, 2024

The housing affordability part of the model can be seen in Table 3.13. The primary data source for the housing section of the sub-model is REIDIN Insights (2024) data. This database includes price breakdowns by province/district/neighborhood. In consultation with real estate industry experts, it was decided to select the location as Istanbul/Şişli/19 Mayıs to reflect better the situation in Istanbul, one of the most crowded metropolises in Turkiye, which has the highest house prices and therefore the lowest housing affordability index. Istanbul/Şişli/19 Mayıs's housing sales prices between January 2023 - June 2024 can be seen in Figure 3.15.

Table 3.13. Housing sales, affordability values, and relevant references in the housing affordability sub-model.

Variable Name	**Value**	**Units**	**Reference**
USD Currency	TL 30.30	TL/USD	CBRT, 31st Jan 2024
Unit Construction Cost	$ 819.54	USD/m^2	Table 3.9
House Sales Price	TL 47,000	TL/m^2	REIDIN, 01st Feb 2024
House Sales Price	$ 1,551.40	USD/m^2	Calculation
VAT	0.10	%	Official Gazette, 2023b
VAT Excluded House Sales Price	$ 1,396.26	USD/m^2	Calculation
Profit Margin	0.10	%	Real Estate Sector Experts
Profit Margin Excluded House Sales Price	$ 1,256.63	USD/m^2	Calculation
Construction Cost Percentage	0.65	%	Calculation
Land Cost Percentage	0.35	%	Calculation
Land Cost	$ 437.10	USD/m^2	Calculation
Mean Family House Size	100	m^2	Real Estate Sector Experts
Mean Family House Price	$ 155,140	USD	Calculation
Loan Rate	0.80	%	REIDIN, 2024
PMT	$ 662.74	USD	Calculation
Qualifying Income	$ 31,811	USD/year	Calculation
Mean Family Income	TL 167,983	TL/year	TurkStat, 2024b
Average USD Currency for 2023	TL 23.74	TL/USD	CBRT, 2024
Mean Family Income	$ 7,075.95	USD/year	Calculation

It should be noted that prices in districts such as Beşiktaş or Kadıköy are twice as high as Şişli, but this is mainly due to the very high cost of land; high prices are not related to construction costs. The average house sale price in Şişli, 19 Mayıs in

February 2024 is 47,000 TL/m^2, as in Figure 3.15, while it is 86,000 TL/m^2 in Kadıköy. To better represent the effects of the increased construction costs, Şişli was appropriate. Also, as Istanbul's mean housing sales price in Feb 2024 is 42,000 TL/m^2, Şişli reflected more İstanbul's overall (REIDIN Insights, 2024).

The unit house sale price was published on 01.02.2024 for February 2024 and converted to USD with the relevant exchange rate of the CBRT. According to the Revenue Administration of the Ministry of Treasury and Finance, 10% VAT applies to houses with a net area of less than 150 m^2, whether second-hand or first-hand (Official Gazette of the Republic of Turkiye, 2023b). According to consultation with real estate experts, the profit margin for the house seller is set at 10%. In most cases, the building contractor differs from the house seller, so a separate profit margin is envisaged for this segment.

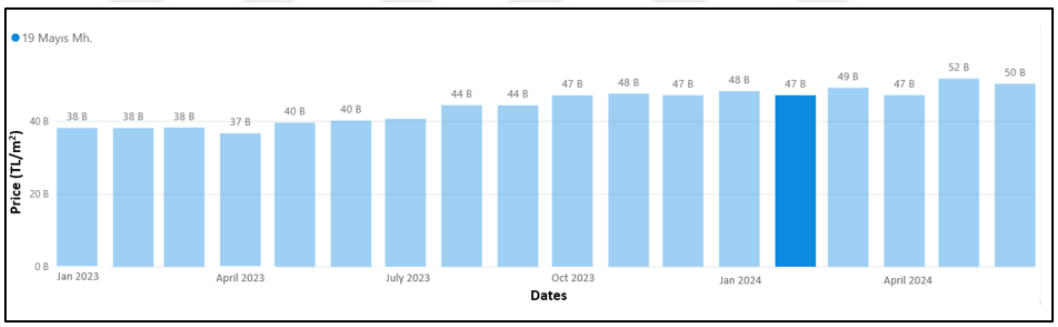


Figure 3.15. Housing sales prices in Istanbul/Şişli/19 May between January 2023 - June 2024 (REIDIN Insights, 2024).

According to the calculations, the percentage of land cost is determined as 35% of the total house sale price, which is reasonable for the Şişli region as mentioned above; if it were a different location such as Beşiktaş or Kadıköy, the percentage of land value could be as high as 60% of the total house sale value.

When calculating housing affordability, it is accepted that a loan covers 80% of the total house price and the rest 20% is covered by equity. The National Association of Realtors, an organization that publishes housing affordability indices monthly in the

United States, also applies an 80% loan rate in its calculations. REIDIN publishes housing affordability indices in Turkiye on a monthly basis and, in line with global practices, assumes a loan utilization of 80% of the total house price in its calculations. According to Equation (3.11), PMT was calculated, and using the PMT value, with an assumption of 30-years of loan maturity, qualified income was calculated by Equation (3.10).

Since TurkStat publishes the average family income in Turkiye every year, the average family income for the year 2023 was taken directly from TurkStat as 167,983 TL and converted to USD with the average USD exchange rate for 2023 (Turkish Statistical Institute, 2024). The GDP growth rate is taken from the World Bank's Global Economic Prospects report until the end of 2026, as shown in Table 3.14. Since Turkiye's average GDP growth rate is 0.35%, it is assumed to remain constant from 2026 until the end of the projections.

Table 3.14. GDP growth rate for Turkiye (World Bank, 2024).

GDP Growth Rate (%)	**2024**	**2025**	**2026**	**Reference**
Turkiye	0.30	0.36	0.43	World Bank, 2024

3.4.4. Data Collection for the Emissions

In the analysis, fuel consumption and utilization rates of abatement technologies such as renewable energy, CCUS, biomass, hydrogen and other technologies are assumed at the same level in 2024. The model represents if companies do not engage in any mitigation efforts to reduce carbon emissions, instead opting to pay for carbon permits. According to IMF projections (Parry *et al.*, 2023), the carbon price in Turkiye will be 35 USD/tCO_2 in 2023 and 75/tCO_2 in 2030. The other study conducted by EBRD, MoEUCC and Climate Focus analyzing the impact of CBAM in Turkiye assumes an ETS system with a carbon price of 20 USD/tCO_2 in 2027 and 50 USD/tCO_2 in 2032.

Since this study adopts a more conservative approach and the report was prepared together with MoEUCC, carbon pricing was determined, as shown in Table 3.15, with a linear estimation based on this report (EBRD and MoEUCC and Climate Focus, 2023).

Table 3.15. Carbon price projections in Turkiye (EBRD and MoEUCC and Climate Focus, 2023).

	2025	**2026**	**2027**	**2030**	**2032**	**2034**	**2040**	**2050**	**2055**
Carbon Price (USD/tCO_2)	7	14	20	38	50	62	98	158	188

According to the study conducted by MoIT and PwC (MoIT and PwC, 2024), the cement industry's average carbon emission level is 0.91 tCO_2 per ton of clinker. By reducing this by 10%, with the assumption that benchmarking methodology is adopted, the upper emission limit for the first year of implementation is 0.819 tCO_2 per ton of clinker.

The emission cap for the cement sector was set using a more conservative approach based on the conferences of the MoEUCC and the opinions of the cement industry experts. The cement industry expert states that they want more allowances as their export level to the EU is well below that of the steel industry. Normally, the cement industry will not pay that much carbon fee in the CBAM system if the ETS does not come into force; however, as one of the biggest markets of the steel industry is the EU, the steel industry will pay the carbon fee in any case. Besides, MoEUCC states that there will be industry-level exemptions in the first years of ETS's implementation. Therefore, the emission cap is reduced by 3% per year from 2026 to 2034 and by 5% from 2034 to 2040 as in Table 3.16; the level of reduction is different from the steel sector, as explained above.

Table 3.16. Emission cap allocations for the cement industry.

Per Ton of Clinker	**2026**	**2030**	**2034**	**2040**	**2050**	**2055**
Emission Cap (tCO_2)	0.819	0.725	0.642	0.472	0	0

To determine the emission cap for the steel industry, the sustainability reports of 3 integrated steel producers in Turkiye were analysed, and it was observed that Kardemir emits 2.61 tCO_2 per ton of crude steel, Erdemir emits 2.45 tCO_2 per ton of crude steel, and finally, İsdemir emits 2.17 tCO_2 per ton of crude steel. With the assumption of the benchmarking methodology used for carbon allocation, the average carbon emissions of the three companies are calculated as 2.41 tCO_2 per ton of crude steel. An emission cap of 2.17 is determined for the steel industry for the first year when a 10% reduction is applied. The carbon cap levels for the steel industry are determined assuming that between 2026 and 2030, the cap will be reduced by 5% each year, after 2030, by 10% each year until 2040, and after 2040, there will be no carbon cap for the industry, as in Table 3.17.

Table 3.17. Emission cap allocations for the steel industry.

Per Ton of Crude Steel	**2026**	**2030**	**2034**	**2040**	**2050**	**2055**
Emission Cap (tCO_2)	2.17	1.77	1.16	0.62	0	0

4. RESEARCH FINDINGS AND DISCUSSION

The study results reveal that the impact of the emissions trading system on the industry will be severe if no subsidy scheme and mitigation efforts is implemented. Even product prices will more than double if the collected ETS revenues do not go towards the green transformation of the industry. The cement and steel industries face significant cost increases that could even create market failure. However, the housing sector will not be affected by this new policy implementation, as the percentage of the cost of cement and steel products in the total construction cost and housing sales is limited to approximately 17%.

4.1. Findings of the Cement Industry Analysis

Cement Company X's annual carbon emissions, free allowances allocated to the company, annual paid emissions and carbon cost per cement unit can be seen in Table 4.1. Since the company has no emission reduction efforts in the model, the emission level of 2024 is preserved until 2055. The annual carbon emission for cement company X is calculated as 1,428,597.65 tCO_2.

With a total annual production of 2.000.000 tons of cement, the cement company's carbon emission per ton of clinker is determined as 0.84 tCO_2/t clinker. Since this is above the emission cap set in section 3.5.4, the cement company starts to pay for its carbon emissions from the point of entry into the emission trading system. In the pilot phase, it is assumed that the carbon price will be zero until 2025, after which it will increase annually, as in Table 3.15. Annual chargeable emissions are calculated as annual carbon emissions minus free allowances for the company with the relevant production and permit rate. With the annual chargeable emission amounts, increase in every year due to the increased carbon price and the decreased carbon allowances, the carbon cost per cement unit reaches 134.29 USD per ton in 2055.

According to the model results, the sector will face a significant cost increase with the free allowance allocations indicated in Table 3.16. Unit cement cost will increase from 101.97 USD/t in 2024 to 238.30 USD/t in 2055, a product cost percentage change of 134%. Unit concrete cost will also increase from 101.64 USD/m^3 in 2024 to 152.02 USD/m^3 in 2055, with a 50% cost rate change.

Table 4.1. Cement company X's carbon emissions & cost increase (2024-2055).

Years	**Annual Carbon Emission (tCO_2)**	**Free Allowance (tCO_2)**	**Annual Chargeable Emission (tCO_2)**	**Carbon Cost per Unit of Cement (USD/t)**	**Unit Cement Cost (USD/t)**	**Unit Concrete Cost (USD/m^3)**
2024	1,428,597.65	1,392,300.00	36,297.65	0	101.97	101.64
2025	1,428,597.65	1,392,300.00	36,297.65	0.13	104.03	103.62
2026	1,428,597.65	1,392,300.00	36,297.65	0.25	104.16	103.67
2027	1,428,597.65	1,352,350.00	76,247.65	0.76	104.7	103.88
2028	1,428,597.65	1,312,400.00	116,197.65	1.51	105.49	104.19
2029	1,428,597.65	1,272,450.00	156,147.65	2.5	106.51	104.58
2030	1,428,597.65	1,232,500.00	196,097.65	3.73	107.74	105.02
2031	1,428,597.65	1,197,225.00	231,372.65	5.09	109.1	105.51
2032	1,428,597.65	1,161,950.00	266,647.65	6.67	110.68	106.08
2033	1,428,597.65	1,126,675.00	301,922.65	8.45	112.46	106.72
2034	1,428,597.65	1,091,400.00	337,197.65	10.45	114.46	107.44
2035	1,428,597.65	1,033,600.00	394,997.65	13.43	117.44	108.51
2036	1,428,597.65	975,800.00	452,797.65	16.75	120.76	109.71
2037	1,428,597.65	918,000.00	510,597.65	20.42	124.43	111.03
2038	1,428,597.65	860,200.00	568,397.65	24.44	128.45	112.47
2039	1,428,597.65	802,400.00	626,197.65	28.81	132.81	114.05

Table 4.1 Cement company X's carbon emissions & cost increase (2024-2055). (cont.)

Years	**Annual Carbon Emission (tCO_2)**	**Free Allowance (tCO_2)**	**Annual Chargeable Emission (tCO_2)**	**Carbon Cost per Unit of Cement (USD/t)**	**Unit Cement Cost (USD/t)**	**Unit Concrete Cost (USD/m^3)**
2040	1,428,597.65	0	1,428,597.65	70	174.01	128.88
2041	1,428,597.65	0	1,428,597.65	74.29	178.3	130.42
2042	1,428,597.65	0	1,428,597.65	78.57	182.58	131.96
2043	1,428,597.65	0	1,428,597.65	82.86	186.87	133.5
2044	1,428,597.65	0	1,428,597.65	87.14	191.15	135.05
2045	1,428,597.65	0	1,428,597.65	91.43	195.44	136.59
2046	1,428,597.65	0	1,428,597.65	95.72	199.73	138.13
2047	1,428,597.65	0	1,428,597.65	100	204.01	139.68
2048	1,428,597.65	0	1,428,597.65	104.29	208.30	141.22
2049	1,428,597.65	0	1,428,597.65	108.57	212.58	142.76
2050	1,428,597.65	0	1,428,597.65	112.86	216.87	144.3
2051	1,428,597.65	0	1,428,597.65	117.15	221.15	145.85
2052	1,428,597.65	0	1,428,597.65	121.43	225.44	147.39
2053	1,428,597.65	0	1,428,597.65	125.72	229.73	148.93
2054	1,428,597.65	0	1,428,597.65	130	234.01	150.48
2055	1,428,597.65	0	1,428,597.65	134.29	238.3	152.02

The model assumes that free allowances will be allocated to the cement industry until 2040, and no free emission allocation will be made after 2040. Therefore, after 2040, all emissions emitted by the company will be charged. As seen in Figure 4.1, after the free allowance period ends in 2040, the costs of both cement and concrete industries skyrocket. This shows that free allocations are important to prevent improper increases in product costs. It shows the importance of the amount of free allocation in terms of protecting producers, especially in the first phase of implementation.

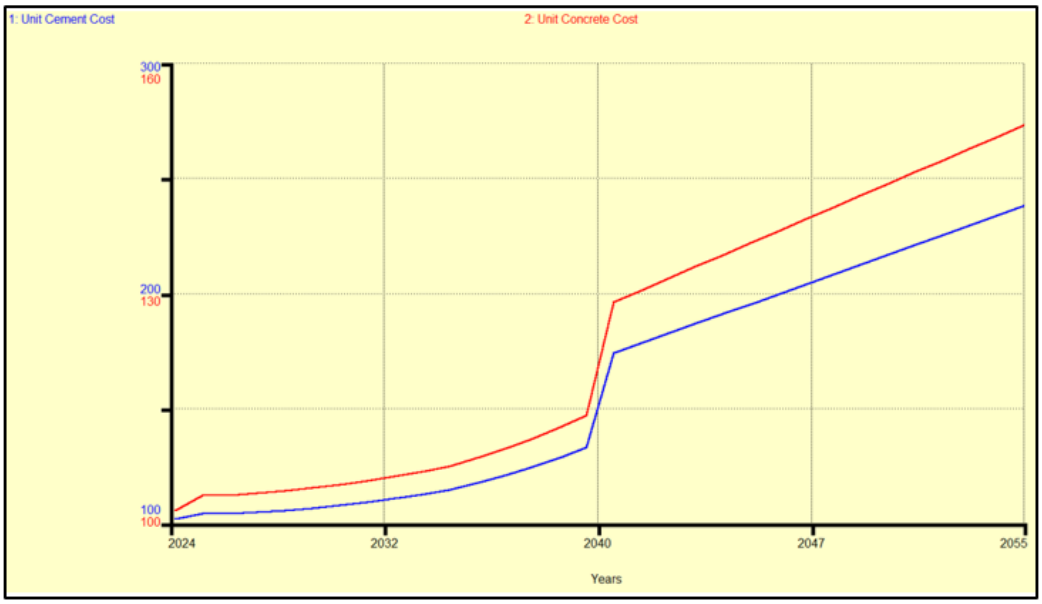


Figure 4.1. Unit cost increases in the cement and concrete industries.

4.2. Findings of the Steel Industry Analysis

Table 4.2 lists Steel Company Y's annual carbon emissions, free allowances allocated to the company, and carbon cost per steel unit. As the model assumes that Steel Company Y is not implementing any mitigation efforts, the company's annual carbon emissions are preserved until 2055, the same as the 2024 level. The annual carbon emission for Steel Company Y is calculated as 4,839,609.23 tCO_2.

The carbon emission per ton of crude steel of a steel company with a total annual production of 2.000.000 tons of crude steel is determined as 2,42 tCO_2/t crude steel. Since this level of carbon emissions per unit product is above the emission cap set in section 3.5.4, the steel company starts to pay for its carbon emissions from the entry point into the emissions trading system. In the pilot phase, it is assumed that the carbon price will be zero until 2025 and increase annually thereafter, as in Table 3.15.

Table 4.2. Steel company Y's carbon emissions & cost increase (2024-2055).

Years	**Annual Carbon Emission (tCO_2)**	**Free Allowance (tCO_2)**	**Annual Chargeable (tCO_2)**	**Carbon Cost per Unit of Steel (USD/t)**	**Unit Steel Cost (USD/t)**
2024	4,839,609.23	4,340,000.00	499,609.23	-	1,005.00
2025	4,839,609.23	4,340,000.00	499,609.23	1.75	1,025.83
2026	4,839,609.23	4,340,000.00	499,609.23	3.50	1,027.58
2027	4,839,609.23	4,140,000.00	699,609.23	7.00	1,031.41
2028	4,839,609.23	3,940,000.00	899,609.23	11.69	1,036.44
2029	4,839,609.23	3,740,000.00	1,099,609.23	17.59	1,042.68
2030	4,839,609.23	3,540,000.00	1,299,609.23	24.69	1,049.78
2031	4,839,609.23	3,235,000.00	1,604,609.23	35.30	1,060.39
2032	4,839,609.23	2,930,000.00	1,909,609.23	47.74	1,072.82
2033	4,839,609.23	2,625,000.00	2,214,609.23	62.01	1,087.09
2034	4,839,609.23	2,320,000.00	2,519,609.23	78.11	1,103.19
2035	4,839,609.23	2,104,000.00	2,735,609.23	93.01	1,118.09
2036	4,839,609.23	1,888,000.00	2,951,609.23	109.21	1,134.29
2037	4,839,609.23	1,672,000.00	3,167,609.23	126.70	1,151.79
2038	4,839,609.23	1,456,000.00	3,383,609.23	145.50	1,170.58
2039	4,839,609.23	1,240,000.00	3,599,609.23	165.58	1,190.67
2040	4,839,609.23	-	4,839,609.23	237.14	1,262.22
2041	4,839,609.23	-	4,839,609.23	251.66	1,276.74
2042	4,839,609.23	-	4,839,609.23	266.18	1,291.26
2043	4,839,609.23	-	4,839,609.23	280.70	1,305.78
2044	4,839,609.23	-	4,839,609.23	295.22	1,320.30
2045	4,839,609.23	-	4,839,609.23	309.73	1,334.82
2046	4,839,609.23	-	4,839,609.23	324.25	1,349.34
2047	4,839,609.23	-	4,839,609.23	338.77	1,363.86

Table 4.2 Steel company Y's carbon emissions & cost increase (2024-2055). (cont.)

Years	Annual Carbon Emission ($tCO-2$)	Free Allowance (tCO_2)	Annual Chargeable (tCO_2)	Carbon Cost per Unit of Steel (USD/t)	Unit Steel Cost (USD/t)
2048	4,839,609.23	-	4,839,609.23	353.29	1,378.38
2049	4,839,609.23	-	4,839,609.23	367.81	1,392.89
2050	4,839,609.23	-	4,839,609.23	382.33	1,407.41
2051	4,839,609.23	-	4,839,609.23	396.85	1,421.93
2052	4,839,609.23	-	4,839,609.23	411.37	1,436.45
2053	4,839,609.23	-	4,839,609.23	425.89	1,450.97
2054	4,839,609.23	-	4,839,609.23	440.40	1,465.49
2055	4,839,609.23	-	4,839,609.23	454.92	1,480.01

Annual chargeable emissions for the steel company Y are calculated based on the company's annual emissions and the related emission allowance for that year with the relevant production and permit rate. Due to the decreased free allowances in every year, and increased carbon cost the carbon cost per steel unit increases every year and reaches 454.92 USD per ton in 2055.

The model results show that if the steel industry does not make any reduction efforts, it will also face a significant cost increase with the free allowance levels indicated in Table 3.17. The unit steel cost will increase from 1,005 USD/t in 2024 to 1,480.01 USD/t in 2055, which will be 47% of the product cost percentage change.

The model assumes that free allowances will be allocated to the steel industry until 2040. However, after 2040, there will be no free emission allocations, leading to a significant increase in costs for the steel industry. As shown in Figure 4.2, the end of the free allowance period in 2040 results in a steep rise in industry costs. This highlights the importance of free allowances in preventing unwanted increases in product costs.

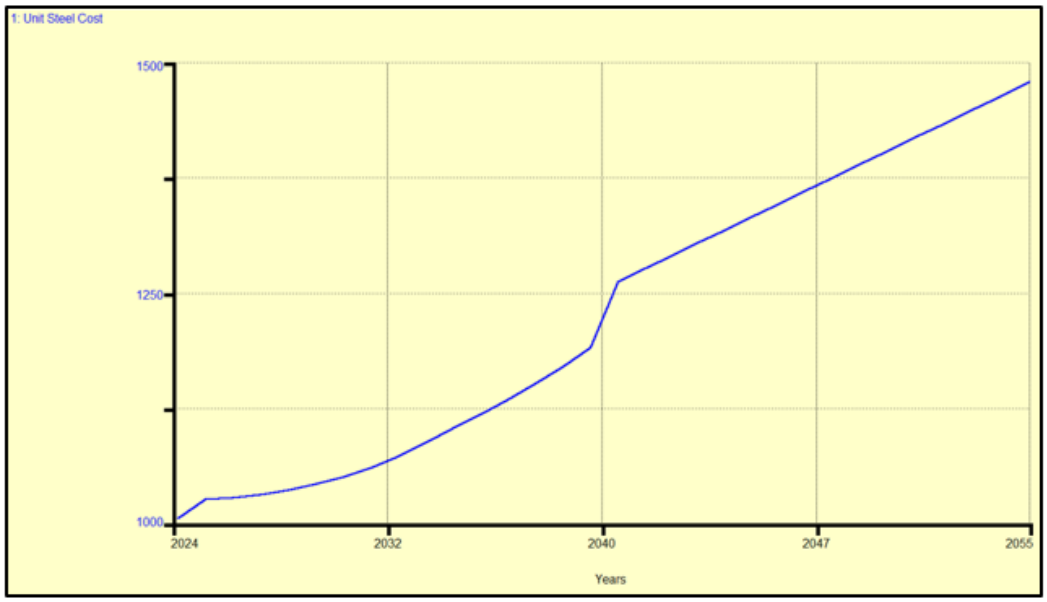


Figure 4.2. Unit cost increase in the steel industry.

4.3. Findings of the Construction Cost and Housing Affordability Analysis

As indicated above, the cement, concrete, and steel industries will be heavily affected by the ETS if they do not implement mitigation efforts. The study aims to determine these cost-increase effects on the construction industry and, ultimately, on housing affordability.

Table 4.3. Changes in unit costs and house prices (2024-2055).

Years	**Unit Cement Cost (USD/t)**	**Unit Concrete Cost (USD/m^3)**	**Unit Steel Cost (USD/t)**	**Unit Construction Cost (USD/m^2)**	**Unit Housing Sales Price (USD/m^2)**
2024	101.97	101.64	1,005.00	820.76	1,496.98
2025	104.03	103.62	1,025.83	836.42	1,525.50
2026	104.16	103.67	1,027.58	836.51	1,525.61

Table 4.3 Changes in unit costs and house prices (2024-2055). (cont.)

Years	Unit Cement Cost (USD/t)	Unit Concrete Cost (USD/m^3)	Unit Steel Cost (USD/t)	Unit Construction Cost (USD/m^2)	Unit Housing Sales Price (USD/m^2)
2027	104.70	103.88	1,031.41	837.01	1,526.38
2028	105.49	104.19	1,036.44	837.60	1,527.26
2029	106.51	104.58	1,042.68	838.29	1,528.26
2030	107.74	105.02	1,049.78	838.78	1,528.86
2031	109.10	105.51	1,060.39	839.44	1,529.65
2032	110.68	106.08	1,072.82	840.20	1,530.58
2033	112.46	106.72	1,087.09	841.08	1,531.63
2034	114.46	107.44	1,103.19	842.06	1,532.82
2035	117.44	108.51	1,118.09	843.18	1,534.18
2036	120.76	109.71	1,134.29	844.42	1,535.67
2037	124.43	111.03	1,151.79	845.77	1,537.31
2038	128.45	112.47	1,170.58	847.23	1,539.08
2039	132.81	114.05	1,190.67	848.81	1,540.99
2040	174.01	128.88	1,262.22	859.28	1,553.66
2041	178.30	130.42	1,276.74	860.63	1,555.29
2042	182.58	131.96	1,291.26	861.99	1,556.93
2043	186.87	133.50	1,305.78	863.34	1,558.57
2044	191.15	135.05	1,320.30	864.69	1,560.21
2045	195.44	136.59	1,334.82	866.05	1,561.85
2046	199.73	138.13	1,349.34	867.40	1,563.49
2047	204.01	139.68	1,363.86	868.76	1,565.13
2048	208.30	141.22	1,378.38	870.11	1,566.77
2049	212.58	142.76	1,392.89	871.47	1,568.41
2050	216.87	144.30	1,407.41	872.82	1,570.04

Table 4.3 Changes in unit costs and house prices (2024-2055). (cont.)

Years	Unit Cement Cost (USD/t)	Unit Concrete Cost (USD/m^3)	Unit Steel Cost (USD/t)	Unit Construction Cost (USD/m^2)	Unit Housing Sales Price (USD/m^2)
2051	221.15	145.85	1,421.93	874.18	1,571.68
2052	225.44	147.39	1,436.45	875.53	1,573.32
2053	229.73	148.93	1,450.97	876.88	1,574.96
2054	234.01	150.48	1,465.49	878.24	1,576.60
2055	238.30	152.02	1,480.01	879.59	1,578.24

Despite these high material cost increases in the cement, steel, and concrete industries, construction costs increased by only 7% from 820.76 USD/m^2 to 879.59 USD/m^2. With a decreasing impact, house sale prices increased by only 5% from 1,496.98 USD/m^2 to 1,578.24 USD/m^2, as in Table 4.3. The model's results clearly show that the impact of the ETS on construction and housing can be negligible, but the ETS creates a real burden on producers and manufacturers.

This result is mainly driven by the fact that the construction and housing industries depend on different factors, such as labor costs and land costs. Therefore, since concrete and steel cover only a limited percentage of construction costs, they do not affect the costs of the construction sector as much as the sectors themselves. In addition, as the main determinant of housing prices is the land cost in Turkiye, ETS's effects on the housing industry are less powerful than those of the industry itself.

Housing affordability, which is determined by average family income and house prices, is projected to rise from 23.37 in 2024 to 29.64 in 2055. It is expected to exceed 30 between 2027 and 2045. The changes are not mainly due to house prices, but to changes in average family income through GDP growth rates. However, it should be noted that this increase does not mean that the houses are affordable for a mean-income

family as they are still well below the threshold of 100; houses are still not affordable for an average-income household to buy a house in Turkiye.

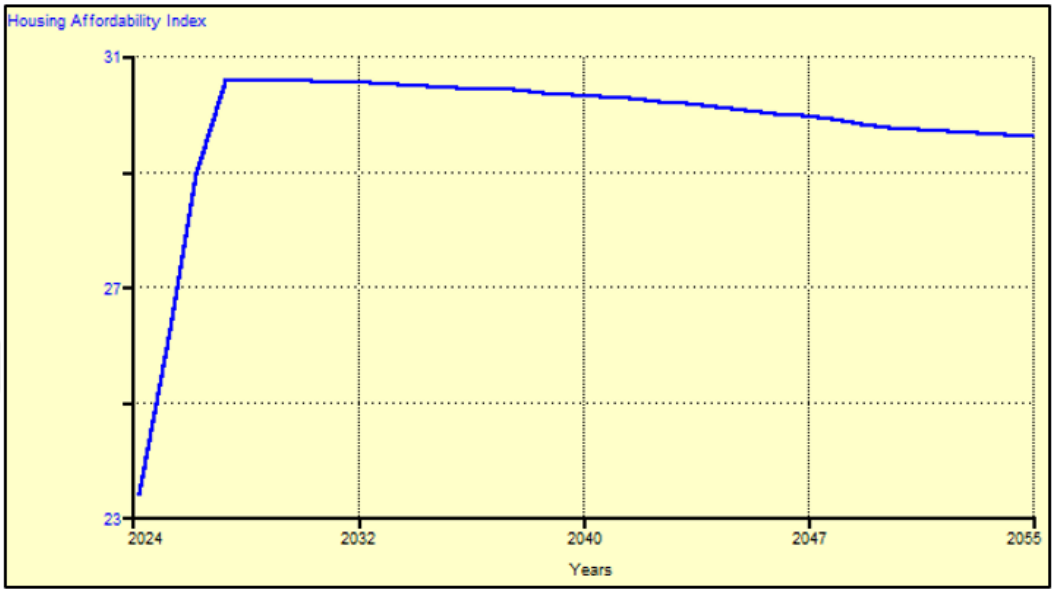


Figure 4.3. Change in housing affordability index through the years.

4.4. Discussion of Research Findings

The impact of the ETS on the construction sector and ultimately on housing affordability is assessed through System Dynamics methodology by adopting a bottom-up approach that assesses unit cost increases through firm-level emissions modelling. The findings found that is consistent with the carbon pricing literature and the views of the experts consulted in this study.

However, it should be noted that the comparison with studies in the literature may not be precisely right as such a problem depends on economic and socio-economic dynamics and the time the study is conducted. Since no previous study has been conducted in Turkiye on this topic, and the ETS has not yet been implemented in the country, the results are examined in this section based on the studies conducted in countries that have already implemented carbon pricing and the opinions of the experts consulted.

4.4.1. Cement Industry Findings Discussion

The annual carbon emission of the cement company is calculated as 1,428,597.65 tCO_2, 1,395,936.05 tCO_2 of this is from clinker production, and 32.661,60 tCO_2 is from cement production, as in Table 4.4. This clearly shows that the emission sources in cement production are clinker itself. Therefore, to reduce emissions and thus the amount of carbon tax, cement companies should focus on reducing clinker/cement ratios as much as possible within the framework of maintaining durability. The recent development regarding the restriction of the use of CEM-I in public tenders, which has the highest clinker/cement ratio, is a positive development in terms of directing the sector towards a lower clinker/cement ratio. (Official Gazette of the Republic of Turkiye, 2024a).

Table 4.4. Carbon emission sources in the cement production.

Annual Carbon Emission from Cement Production (tCO_2)	**Annual Carbon Emission from Clinker Production (tCO_2)**	**Annual Carbon Emission of Cement Company X (tCO_2)**
32,661.60	1,395,936.05	1,428,597.65

With the 2,000,000 tons of annual cement production, the carbon emission per clinker is calculated as 0.84, which is according to the study conducted by the MoIT and PwC (2024), it is in the level of the industry.

As per the study results the biggest unit cost increase between the materials of cement, steel and concrete is in the cement industry with the 134% cost increase from 101.97 to 238.30 USD/t. According to the Smale *et al.* (2006), which analyzed the effect of the EU ETS on industries' financial performances under carbon pricing scenarios of 15 EUR/tCO_2 and 30 EUR/tCO_2, with full grandfathering, the cement sector saw the highest increase in marginal production costs, up to 140%, which is in line with the results of the study.

While the cost increase in the cement sector was 134%, the concrete sector experienced a cost increase of 50%, mainly due to the relative financial impact of cement on the cost of concrete. Since concrete has other raw materials such as aggregate, water, and additives, the price contribution of cement is only 36%, according to experts consulted in the construction industry. Therefore, the 134% cost increase in the cement sector led to only a 50% increase in concrete costs. According to one of the cement experts consulted, an environmental tax on aggregates could also come into force in the coming years due to their high environmental impact during production, which could lead to higher environmental costs in concrete.

According to Rootzén and Johnsson (2016) for the cement sector, it is stated that if a high carbon tax is applied, cement production costs will increase by approximately 90%, in the level of 100 EUR/tCO_2. The same study determined that due to the limited use of cement in concrete, concrete cost increases would be approximately 16%, and the impact on construction costs would be limited to 1%. The difference in the cement sector would be mainly due to the specific carbon emissions in the Australian industry, which is considered as 0.7 tCO_2/t, which is well below 0.84.

Stede *et al.* (2021) discussed the impact of carbon pricing on basic materials such as cement and steel along the value chain. The study's results revealed that even at a carbon price of 30 EUR/tCO_2 in the EU ETS, the cost increase in the cement industry would be 50%. The result of the study is relatively low compared to the results of the thesis, but it should be taken into account that the carbon pricing level assumption is much higher than 30 EUR/tCO_2 in this thesis.

During the expert consultations, cement industry experts stated that they are not supporting the establishment of an ETS in Turkiye. The main reason is that without a national ETS system, the cement industry would be subject to taxation on the amount imported into the EU, which is only 10% of total production. However, if a system is established in Turkiye, they would be subject to taxation on the entire amount they produce. During these consultation meetings, it was clear that it would be better to

apply for sector-specific exemptions during the implementation phase of the ETS to incentivize the industry.

4.4.2. Steel Industry Findings Discussion

The annual carbon emission for Y Steel Company is calculated as 4,839,609.23 tCO_2. Since carbon output cannot be increased, the carbon input is analyzed in detail. It is seen that the primary source of emission is coke, which is mainly used to reduce iron ore, as in Table 4.5. The only way to minimize the amount of coke is the use of direct reduced steel. In this way, the main emission reduction in the steel industry can be achieved by reducing the amount of coke needed. The following emission sources of steel production are coal, natural gas and oil, respectively, and these can be effectively reduced by using clean energy technologies. Therefore, the steel industry should adopt clean energy technologies soon.

Table 4.5. Carbon emissions breakdown in the steel industry.

Emission from Coke (tCO_2)	**Emission from Coal (tCO_2)**	**Emission from Natural Gas (tCO_2)**	**Emission from Oil (tCO_2)**	**Emission from Scrap (tCO_2)**	**Emission from Iron Ore (tCO_2**	**Carbon Input of Steel (tCO_2)**
3,143,724.05	1,037,555.47	380,982.72	159,649.57	65,937.34	2,157.36	4,790,006.52

With the production amount of 2,000,000 tons of annual crude steel production, the carbon emission per ton of crude steel is calculated as 2,42 tCO_2/t crude steel, which is in line with the industry level, according to the Kardemir, Erdemir and İsdemir's Sustainability Reports.

The analysis results show that, the unit steel cost will increase from 1,005 USD/t in 2024 to 1,480.01 USD/t in 2055, which will be 47% of the product cost percentage change. According to the Smale *et al.* (2006) which is making an analysis in the EU

ETS, in the steel sector, marginal costs increased by 17%, which is not aligned with the study. This difference may be due to the fact that this study focuses on a time period rather than an instantaneous increase and assumes the steel production route to be BF/BOF, which is the most emissive.

Riccardi (2015) analysed the impact of the EU-ETS implementation on the steel industry and found that without carbon abatement, the industry would face a 60% cost increase at a carbon price level of 70 EUR/tCO_2. Since this study also assumes no carbon abatement, it is logical to compare the results, and the results of both studies are in the same direction.

According to Stede et al.'s (2021) study, a carbon price of 30 EUR/tCO_2 in the EU ETS would lead to a 25% increase in steel costs. As indicated in the cement section, the difference between this study's results is mainly due to the different carbon price levels.

Consultations with steel industry experts revealed that the Turkish steel industry welcomed the establishment of an ETS in Turkiye as it would allow them to reduce the fees they would pay to Europe as one of their largest markets is the EU market. This is quite a different perspective gained in the cement industry. This situation clearly shows once again that some exemptions are necessary in the first implementation period, taking into account the dynamics of each sector.

4.4.3. Construction Cost and Housing Affordability Analysis Findings Discussion

Even though the material costs increased significantly, the construction costs increased only by 7%, from 820.76 USD/m^2 to 879.59 USD/m^2. According to the experts consulted, this is mainly because concrete and steel costs account for only 17% of construction costs.

Other costs, such as fine construction and labor costs, which can vary depending on the desired level of luxury, have a more significant impact than concrete and steel costs on construction costs.

Similar to the expert's comments, according to Rootzén and Johnsson (2016), cement and concrete make up a small portion of total construction costs. Therefore, shifting carbon mitigation costs to end-users would minimally impact project costs. Even if cement prices nearly doubled, total construction costs would rise by less than 1%.

When the impact on house sale prices is analyzed, it is seen that it is even lower than the construction cost, with only a 5% increase from 1,496.98 USD/m^2 to 1,578.24 USD/m^2. Regarding housing costs, according to the experts consulted and REIDIN Insights, the primary determinant is the cost of land, which can vary greatly depending on the house's location. Overall, according to the study results, the impact of ETS on construction and house sale prices is minimal.

According to Lu *et al.* (2012), since emissions trading and carbon taxes give producers the flexibility to make low-carbon cost investments or pay the carbon price, the level of output and house prices are not much affected by these policies. It increases by only 1.7% and developers and consumers will share this increase. The results of the study is parallel of the findings, the ETS does not affect the house prices strongly, as it finded 5% affects in the study. The number is slightly high compared to the Lu *et al.* (2012), it may be mainly due to the higher material costs due to the Turkiye's dynamics compared to the United States.

As per, Zhu *et al.* (2010)'s study, which conducted a study to measure the carbon tax impact on house price for USA market, an increase of % 2.55 was observed for USD/sq ft of houses is found with an implementation of the carbon tax. The results of Zhu *et al.* (2010) are significantly similar with the study, %2.55 and %5 respectively.

In terms of the housing affordability nothing changed in the current status, as the houses was not affordable before the carbon pricing with an housing affordability index of 23.37, it is still not affordable after the introduction of the carbon pricing with an housing affordability index of 29.64.

The most similar study in the literature is conducted in the Australia by Ge (2013), main findings reveal that households that were previously able to afford loan payments or rent are now struggling after the introduction of carbon pricing. The severity of this effect decreases as household incomes increase. Despite the existence of government subsidy programs to mitigate the impacts of carbon pricing, it is clear that low and middle-income households bear the heaviest burden. However, the introduction of the ETS did not change Turkiye's situation in terms of housing affordability, as Turkiye's housing affordability was well below the affordability index before the ETS.

5. CONCLUSIONS

As climate change continues to have many adverse effects with the increased greenhouse gases, it is crucial to explore measures to limit them. Emission Trading is one of the measures to limit the effects of greenhouse gases and, thus, climate change. Many countries adopt Emission Trading as it provides flexibility in emission reduction. Since the establishment of an Emissions Trading System is also planned in Turkiye, this study focuses on the potential impact of the establishment of an Emissions Trading System on construction costs and, ultimately, housing affordability, considering the gap in the literature on carbon pricing in construction and housing affordability.

In order to assess the impact of establishing an ETS, a firm-level emission modelling was developed in the cement and steel sectors and the unit cost increases in these sectors; hence, construction costs were analyzed. With the increased construction cost, the effect on the house sales prices and housing affordability is assessed. During the model development, several expert consultation meetings were conducted, and the data was sourced from both the expert's knowledge and the industry reports prepared by the international organizations or ministries. The System Dynamics methodology was used by Stella® software to analyze the effects. Through the analysis, many research findings were acquired.

5.1. Summary of Findings

In consultation with 13 experts from different sectors, using system dynamics methodology, a comprehensive conceptual model of carbon pricing and its impact on the construction sector in Turkiye was developed for the first time in the literature. This model sets out the relationship between emission pricing and product cost increases in the cement and steel sectors, construction cost increases, house sale price increases, and, finally, the housing affordability index.

Key findings of the study show that while implementing an emission trading system in a country, one of the most important things is the proper level of determining the free emission allowances to the companies. It should be at the level that encourages the industry to transition to green sources to reduce their emission levels rather than paying carbon fees. Therefore, determining the proper level of the emission caps and the actual level of the carbon price is essential. If the emission caps and carbon prices are not determined appropriately, the industry cost could double itself, eventually leading to market failure.

Comparing the industry's cost increases with the effect of the ETS, the cement industry faces the highest unit cost increase, with 134%. The concrete and steel industries also face a high level of increase in their unit costs, respectively 50% and 47%.

The study's findings show that the ETS's effect on construction costs, house sales costs, and housing affordability is limited to 7% and 5% cost increases, respectively. The labor and other material costs for fine construction have a more significant effect on the construction cost. In terms of house costs, the most important determinant is the land cost, as stated. Even in the same city, the house price can be more than doubled.

As seen in the projection results, increased cement and steel costs will not cause a fluctuation in construction costs and housing affordability. Also, housing affordability has already been less than 100 in Turkiye due to low mean-family income, which is the threshold for housing affordability. Moreover, according to the World Bank's projections, there will be no exceptional growth in GDP in the following decades; therefore, the housing affordability index will not change extremely.

To make a house affordable for a mean-income family, the family income should be increased well, and the high house prices compared to the income mainly due to the land costs and the high material costs should be decreased. Otherwise, according

to the GDP forecasts of global banks and the rising costs due to emissions trading, houses will not be affordable for families even in 2055.

5.2. Contributions to the Body of Knowledge

The literature currently lacks a comprehensive model that analyzes the effects of carbon pricing on the construction sector and housing affordability in both global and Turkish literature. Existing studies focus on emission projections or the macroeconomic effects of carbon pricing. However, there is a significant gap in the literature regarding representing a holistic perspective with a bottom-up approach at the industry level, especially in the Turkish literature. This study, therefore, takes a different approach by building a bottom-up study from the company to the customer level using System Dynamics analysis. By combining the application of System Dynamics in both the real estate market and emissions modelling, this study aims to create a conceptual model that reveals the effects of carbon pricing in the real estate market and provides valuable insights for policymakers, industry professionals, and academic researchers.

For the first time, the possible orientations and impacts of the sectors with the ETS planned to be established at the level of manufacturing companies in Turkiye have been evaluated from the perspective of the construction sector. This study evaluates which sector players will be affected by the additional costs arising from the ETS and to what extent.

5.3. Contribution to Practice and Recommendations

The study's results clearly show that the industry plays a pivotal role in the green transformation. If it does not initiate this transformation, it will face significant carbon fees in Turkiye and other countries due to the carbon border taxes. Therefore, the industry's focus on its decarbonization roadmap to reduce emissions becomes more crucial than ever.

It is important to collaborate closely with the industry while developing low-carbon technologies. Therefore, the sector, professional chambers, and associations must take the initiative to develop these technologies and conduct feasibility assessments in the country.

The steel industry has different alternatives to producing steel, such as DRI, green hydrogen steel, and many other low-carbon production technologies. However, implementing these technologies is currently only available on a small scale. In the long term, having different alternative production methods and starting to transform their facilities to low-carbon technologies would be an alternative.

The cement industry's emission source is mainly the materials themselves, such as clinker. Therefore, the most crucial aspect to consider is decreasing the clinker/cement ratio as much as possible without decreasing the product's strength. Unlike the steel industry, the cement industry has no other production methodology. Therefore, the most important technology for reducing emissions in the cement industry is CCUS. The cement industry should collaborate with the government and the associations to implement CCUS technologies as soon as possible.

While the industry is making green transformation investments, such as renewable energy, biofuel, and carbon-capturing investments, it should not be only with companies by their own equity. Otherwise, companies will not be willing to invest in new technologies to mitigate their emissions and prefer to pay carbon fees.

For all industries, working closely with the government authorities to make a significant change in their industry is essential since the aim is not achievable by one entity alone; it should be a collaborative effort. Defining the carbon price level and the emission cap are two critical points that can determine the success or failure of the ETS. As Turkiye has about ten years of experience in MRV, it will be advantageous to utilize this experience when implementing the ETS.

Government authorities cooperate closely with development banks such as the World Bank, EBRD, and AFD. They publish guidance documents for sectoral decarbonization roadmaps and, most importantly, work closely to develop the ETS. However, these institutions are not decision-makers but only advisors. Since the decision-making part belongs to the government, it is essential to implement global best practices.

The upcoming ETS will heavily affect the steel and cement industries; therefore, the government must subsidize green investments and transformation. If the government does not act, this will burden manufacturers and trigger market failure in the following years. However, if the government subsidizes manufacturers to develop their emission mitigation mechanisms and implement low-carbon technologies, with the mitigation funds as in the EU ETS, the burden on manufacturers will be less in the following years.

Moreover, it has been observed in similar carbon pricing practices around the world that if it is not clearly stated in the implementation phase that the ETS has successfully reduced emission levels, the public may see the system as a "taxation" and may not welcome it. Therefore, during the implementation phase, it should be demonstrated that absolute emissions are reduced even at a low carbon price level.

Based on the extensive literature review and the analysis results, Table 5.1 shows the recommendations for both industry and government.

Table 5.1. Recommendations for the government and the industry.

		Industry	
	Government	**Cement**	**Steel**
Carbon Emissions	-Setting carbon caps and free allowances properly.	-Reducing the clinker/cement ratio as much as	-Initiating the transformation of plants to low-carbon
	- Establishing flexibility mechanisms	possible. -Focusing on the	production routes. -Focusing

Table 5.1 Recommendations for the government and the industry. (cont.)

	Government	Industry	
		Cement	**Steel**
	for the first implementation phase. -Determining exemptions according to the dynamics of each sector to prevent carbon leakage and market failure.	CCUS technologies to decrease Scope 1 emissions. -Implementing low-carbon fuels as maximum.	on the green hydrogen, DRI and CCUS technologies. -Implementing low-carbon fuels as maximum.
Prices	-Setting the carbon price at a level that encourages industry to invest in low carbon technologies without causing market failure.	-Determining the carbon cost pass-through rate accurately according to market dynamics.	
Funding Mechanisms	-Establish a financing mechanism that refinances the industry with ETS revenues generated to invest in low carbon technologies.	-Working closely with the government to determine the real level of funding needs for the green transformation of sectors.	
Collaborations	-Cooperation with international organizations for a smooth implementation of the ETS and benefitting from lessons learnt from previous ETSs. -Making collaboration	-Collaborating with the government, professional chambers and associations for the development and implementation of low-carbon technologies in industry and establishing a decarbonisation roadmap.	

Table 5.1 Recommendations for the government and the industry. (cont.)

		Industry	
	Government	**Cement**	**Steel**
	for the development of decarbonisation roadmaps for sectors with the industry and the professional associations.		
Public Perspective	-Ensuring that the ETS is not seen as an extra "taxation" but as an incentive for decarbonisation by clearly demonstrating emission reduction results.		

5.4. Limitations

The study's main limitation is that this is the first time this policy has been implemented in the country. Therefore, due to the lack of historical data, the accuracy of the analysis is not certain, and many assumptions have been made to build the model. One of the main reasons for the various assumptions is that the government has not yet published the final version of the Emission Trading System Regulation and related implementing by-laws.

Another significant factor contributing to the study's uncertainty is the potential for macro-economic changes over the next 30 years. These changes, which are inherently unpredictable, could significantly change the study's results, either positively or negatively.

The analysis results were compared with the existing studies in the literature. Since there is no direct study in the Turkish literature, comparisons were made with studies conducted in different countries. The dynamics at the time of these studies and the economic and geographical differences in the countries where they were conducted were among the most important constraints of the discussion part.

Regarding construction costs, since the study only investigates the effects of the ETS on the unit costs of the cement and steel industries, other materials such as aluminum and other cement products, i.e. mortars and tile adhesives, are not covered. Considering their cost increases, the unit construction cost may increase further due to the ETS implementation. In addition to that, carbon cost-pass through rate to the customers could be also taken into consideration. Finally, as housing is already unaffordable in the country, the study's results cannot predict any change in the same economic environment.

5.5. Future Research

For further research, the cost of green transformation of industry players can be analyzed in more detail by dipping into new technologies and their utilization rate for the companies. To compensate for the investment cost burden of carbon abatement technologies on firms, the incentives and subsidies to be given by the government could be considered during the implementation journey. Moreover, in the model, only ETS's effect on the concrete and steel industries was taken into account; the level of inclusiveness of the model can be levelled up by including the other sectors, such as aluminum and other cement-based products used in the construction projects.

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APPENDIX A: SYSTEM DYNAMICS MODEL STOCK AND FLOW DIAGRAM

System dynamics model stock and flow diagram

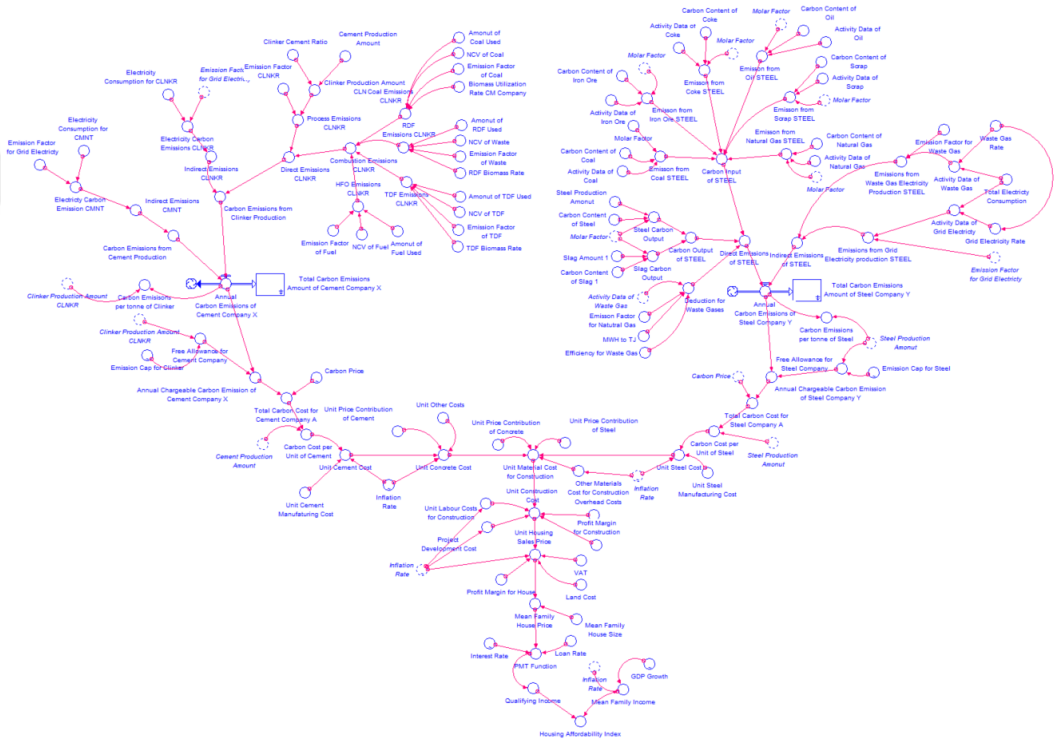

Figure A.1. The System Dynamics Model's Stock and Flow Diagram.

APPENDIX B: SYSTEM DYNAMICS MODEL EQUATIONS

System dynamics model equations.

Total-Carbon-Emissions-Amount-of-Cement-Company-X(t)=

Total-Carbon-Emissions-Amount-of-Cement-Company-X(t-dt) +

(Annual-Carbon-Emissions-of-Cement-Company-X) * dt

INIT Total-Carbon-Emissions-Amount-of-Cement-Company-X = 0

INFLOWS:

Annual-Carbon-Emissions-of-Cement-Company-X=

(Carbon-Emissions-from-Clinker-

Production+Carbon-Emissions-from-Cement-Production)

Total-Carbon-Emissions-Amount-of-Steel-Company-Y(t)=

Total-Carbon-Emissions-Amount-of-Steel-Company-Y(t-dt)+

(Annual-Carbon-Emissions-of-Steel-Company-Y) * dt

INIT Total-Carbon-Emissions-Amount-of-Steel-Company-Y = 0

INFLOWS:

Annual-Carbon-Emissions-of-Steel-Company-Y=

(Indirect-Emissions-of-STEEL+Direct-Emissions-of-STEEL)

Activity-Data-of-Coal = 328510

Activity-Data-of-Coke = 985531

Activity-Data-of-Grid-Electricty=

Grid-Electricity-Rate*Total-Electricty-Consumption

Activity-Data-of-Iron-Ore = 2560000

Activity-Data-of-Natural-Gas = 138640

Activity-Data-of-Scrap = 440000

Activity-Data-of-Waste-Gas =

Total-Electricty-Consumption*Waste-Gas–Rate

Activity-Data-of–Oil = 51872

Amonut-of-TDF-Used = 16846

Amonut-of-Fuel-Used = 100

Amonut-of-RDF-Used = 33692

Amonut-of–Coal-Used = 111193

Annual-Chargeable-Carbon-Emission-of-Cement-Company-X=

Annual-Carbon-Emissions-of-Cement-Company-X-

Free-Allowance-for-Cement-Company

Annual-Chargeable-Carbon-Emission-of-Steel-Company-Y =

Annual-Carbon-Emissions-of-Steel-Company-Y-

Free-Allowance-for-Steel-Company

Carbon-Content-of-Coal = 0.862

Carbon-Content-of-Coke = 0.8706

Carbon-Content-of-Iron-Ore = 0.00023

Carbon-Content-of-Natural-Gas = 0.75

Carbon-Content-of-Scrap = 0.0409

Carbon-Content-of–Oil = 0.84

Carbon-Content-of-Slag = 0.0003

Carbon-Content-of-Steel = 0.0109

Carbon-Cost-per-Unit-of-Cement =

Total-Carbon-Cost-for-Cement-Company-A/Cement-Production-Amount

Carbon-Cost-per-Unit-of-Steel =

Total-Carbon-Cost-for-Steel-Company-A/Steel-Production-Amonut

Carbon-Emisisons-per-tonne-of-Clinker =

Annual-Carbon-Emissions-of-Cement-Company-

X/Clinker-Production-Amount-CLNKR

Carbon-Emissions-from-Cement-Production = Indirect-Emissions-CMNT

Carbon-Emissions-from-Clinker-Production =

Indirect-Emissions-CLNKR+Direct-Emissions-CLNKR

Carbon-Emissions-per-tonne-of-Steel =

Annual-Carbon-Emissions-of-Steel-

Company-Y/Steel-Production-Amonut

Carbon-Input-of-STEEL =

Emisson-from-Coal-STEEL+Emisson-
from-Iron-Ore-STEEL+Emisson-from-Coke
-STEEL+Emisson-from-Scrap-STEEL+Emisson-
from-Natural-Gas-STEEL+Emisson
-from–Oil-STEEL
Carbon-Output-of-STEEL = Steel-Carbon-Output+Slag-Carbon-Output
Carbon-Price = GRAPH(TIME)
(2024, 0.00), (2025, 7.00), (2026, 14.0),
(2027, 20.0), (2030, 38.0), (2032, 50.0), (2034, 62.0),
(2040, 98.0), (2050, 158), (2055, 188)
Cement-Production-Amount = 2000000
Clinker-Cement-Ratio = 0.85
Clinker-Production-Amount-CLNKR =
Cement-Production-Amount*Clinker-Cement-Ratio
Coal-Emissions-CLNKR =
(Emission-Factor-of-Coal*Amonut-of–Coal-Used*NCV-of-Coal)
*(1-Biomass-Utilization-Rate-CM-Company)
Combustion-Emissions-CLNKR =
Coal-Emissions-CLNKR+RDF-Emissions-
CLNKR+HFO-Emissions-CLNKR+TDF-Emissions-CLNKR
Deduction-for-Waste-Gases =
(Activity-Data-of-Waste-Gas/Efficiency-for-Waste-Gas)
*MWH-to-TJ*Emisson-Factor-for-Natutral-Gas
Direct-Emissions-CLNKR =
Process-Emissions-CLNKR+Combustion-Emissions-CLNKR
Direct-Emissions-of-STEEL = Carbon-Input-of-STEEL-
Carbon-Output-of-STEEL-Deduction-for-Waste-Gases
Efficiency-for-Waste-Gas = 0.35
Electricity-Carbon-Emissions-CLNKR =
Electricity-Consumption-for-
CLNKR*Emission-Factor-for-Grid-Electricty

Electricity-Consumption-for-CLNKR = 111520

Electricity-Consumption-for-CMNT = 74400

Electricty-Carbon-Emission-CMNT =

Electricity-Consumption-for-CMNT

*Emission-Factor-for-Grid-Electricty

Emissions-from-Grid-Electricity-production-STEEL =

Activity-Data-of-Grid-Electricty*Emission-Factor-for-Grid-Electricty

Emissions-from-Waste-Gas-Electricity-Production-STEEL =

Activity-Data-of-Waste-Gas*Emission-Factor-for-Waste-Gas

Emission-Cap-for-Clinker = GRAPH(TIME)

(2026, 0.819), (2030, 0.725), (2034, 0.642),

(2039, 0.472), (2040, 0.00), (2050, 0.00),

(2055, 0.00)

Emission-Cap-for-Steel = GRAPH(TIME)

(2026, 2.17), (2030, 1.77), (2034, 1.16), (2039, 0.62),

(2040, 0.00), (2050, 0.00), (2055, 0.00) Emission-Factor-for-Waste-Gas = 0.576

Emission-Factor-CLNKR = 0.525

Emission-Factor-for-Grid-Electricty = 0.439

Emission-Factor-of-Coal = 97.4

Emission-Factor-of-Fuel = 77

Emission-Factor-of-TDF = 85

Emission-Factor-of-Waste = 143

Emisson-Factor-for-Natutral-Gas = 55.43

Emisson-from-Natural-Gas-STEEL =

Activity-Data-of-Natural-Gas*Carbon-Content-

of-Natural-Gas*Molar-Factor

Emisson-from-Coal-STEEL =

Carbon-Content-of-Coal*

Activity-Data-of-Coal*Molar-Factor

Emisson-from-Coke-STEEL =

Activity-Data-of-Coke*Carbon-

Content-of-Coke*Molar-Factor
Emisson-from-Iron-Ore-STEEL =
Activity-Data-of-Iron-Ore*Carbon-
Content-of-Iron-Ore*Molar-Factor
Emisson-from-Scrap-STEEL =
Activity-Data-of-Scrap*Carbon-
Content-of-Scrap*Molar-Factor
Emisson-from–Oil-STEEL =
Activity-Data-of–Oil*Carbon-
Content-of–Oil*Molar-Factor
Free-Allowance-for-Cement-Company =
Clinker-Production-
Amount-CLNKR*Emission-Cap-for-Clinker
Free-Allowance-for-Steel-Company =
Steel-Production-
Amonut*Emission-Cap-for-Steel
GDP-Growth = GRAPH(TIME)
(2024, 0.03), (2025, 0.036), (2026, 0.043), (2027, 0.0345),
(2028, 0.035), (2029, 0.035),
(2030, 0.035), (2040, 0.035),
(2045, 0.035), (2050, 0.035), (2055, 0.035)
Grid-Electricity-Rate = 1-Waste-Gas–Rate
HFO-Emissions-CLNKR =
Amonut-of-Fuel-Used*NCV-of-
Fuel*Emission-Factor-of-Fuel
Housing-Affordability-Index =
(Mean-Family-Income/Qualifying-Income) *100
Indirect-Emissions-CLNKR = Electricity-Carbon-Emissions-CLNKR
Indirect-Emissions-CMNT =
Electricty-Carbon-Emission-CMNT
Indirect-Emissions-of-STEEL =

Emissions-from-Waste-Gas-Electricity-
Production-STEEL+Emissions-from-Grid-El
ectricity-production-STEEL
Inflation-Rate = GRAPH(TIME)
(2024, 0.001), (2025, 0.02), (2026, 0.02), (2029, 0.021),
(2030, 0.021), (2034, 0.021),
(2040, 0.021),
(2045, 0.021), (2050, 0.021), (2055, 0.021)
Interest-Rate = GRAPH(TIME)
(2024, 0.051), (2025, 0.042), (2026, 0.034),
(2027, 0.029), (2028, 0.029), (2030, 0.029),
(2034, 0.029),
(2040, 0.029), (2045, 0.029), (2050, 0.029), (2055, 0.029)
Land-Cost = 416
Loan-Rate = 0.8
Mean-Family-Income = 7075.95*(1+GDP-Growth)
*(1+Inflation-Rate)
Mean-Family-House-Price = Unit-Housing-Sales-
Price*Mean-Family-House-Size
Mean-Family-House-Size = 100
Molar-Factor = 3.664
MWH-to-TJ = 0.0036
NCV-of-Coal = 0.03224
NCV-of-Fuel = 0.03939
NCV-of-TDF = 0.0304
NCV-of-Waste = 0.0152
Other-Materials-Cost-for-Construction =
353.71*(1+Inflation-Rate)
Overhead-Costs = 0.15
PMT-Function = (Mean-Family-House-Price*Loan-Rate)
*(Interest-Rate/12)/(1-(1/(1+Interest-Rate/12) ∧360))

Process-Emissions-CLNKR =
Clinker-Production-Amount-
CLNKR*Emission-Factor-CLNKR
Profit-Margin-for-House = 0.1
Profit-Margin-for-Construction = 0.1
Project-Development-Cost = 65.56*(1+Inflation-Rate)
Qualifying-Income = PMT-Function*4*12
RDF-Emissions-CLNKR =
Amonut-of-RDF-Used*Emission-Factor-of-Waste*NCV-
of-Waste*(1-RDF-Biomass-Rate)
Slag-Amount-1 = 400000
Slag-Carbon-Output = Slag-Amount-1*Carbon-
Content-of-Slag-1*Molar-Factor
Steel-Carbon-Output =
Steel-Production-Amonut*Carbon-
Content-of-Steel*Molar-Factor
Steel-Production-Amonut = 2000000
TDF-Biomass-Rate = 0.27
TDF-Emissions-CLNKR =
(Amonut-of-TDF-Used*NCV-of-
TDF*Emission-Factor-of-TDF) *(1-TDF-Biomass-Rate)
Total-Carbon-Cost-for-Cement-Company-A =
Annual-Chargeable-Carbon-Emission-of-Cement-Company-X*Carbon-Price Total-Carbon-
Cost-for-Steel-Company-A =
Annual-Chargeable-Carbon-Emission-of-Steel-Company-Y*Carbon-Price
Total-Electricty-Consumption = 633417
Unit-Cement-Cost =
Carbon-Cost-per-Unit-of-
Cement+(Unit-Cement–Manufaturing-Cost*(1+Inflation-Rate))
Unit-Cement–Manufaturing-Cost = 101.87
Unit-Concrete-Cost = (Unit-Cement-Cost*Unit-

Price-Contribution-of-Cement)
+(Unit-Other-Costs*(1+Inflation-Rate))
Unit-Construction-Cost =
Unit-Material-Cost-for-Construction+Unit-Labour-
Costs-for-Construction+(Overhead-
Costs*(Unit-Material-Cost-for-Construction+Unit-
Labour-Costs-for-Construction+Proj
ect-Development-Cost))+(Profit-Margin-for-
Construction*(Unit-Material-Cost-for-
Construction+Unit-Labour-Costs-for-Construction+Project-
Development-Cost))+Proje
ct-Development-Cost
Unit-Housing-Sales-Price =
(Unit-Construction-Cost+((Land-Cost)
*(1+Inflation-Rate))) *(1+VAT) *(1+Profit-Margin-for-House)
Unit-Labour-Costs-for-Construction =
163.91*(1+Inflation-Rate)
Unit-Material-Cost-for-Construction =
(Unit-Concrete-Cost*Unit-Price-Contribution-of-Concrete)
+(Unit-Steel-Cost*Unit-Price-Contribution-of-Steel)
+Other-Materials-Cost-for-Construction
Unit-Other-Costs = 64.87
Unit-Price-Contribution-of-Cement = 0.36
Unit-Price-Contribution-of-Concrete = 0.42
Unit-Price-Contribution-of-Steel = 0.03
Unit-Steel-Cost = Carbon-Cost-per-Unit-of-
Steel+((Unit-Steel-Manufacturing-Cost) *(1+Inflation-Rate))
Unit-Steel-Manufacturing-Cost = 1004
VAT = 0.1
Waste-Gas–Rate = 0.54