KADIR HAS UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF ENERGY AND SUSTAINABLE DEVELOPMENT

DECARBONIZATION POTENTIALS IN THE TURKISH ENERGY INTENSIVE INDUSTRIES

BEGÜM ÜNLÜ
ADVISOR: PROF. DR. GÖKHAN KİRKİL

MASTER'S DEGREE THESIS

ISTANBUL, JUNE, 2021

Begüm Ünlü

Master's Degree Thesis

2021

DECARBONIZATION POTENTIALS IN THE TURKISH ENERGY INTENSIVE INDUSTRIES

BEGÜM ÜNLÜ
ADVISOR: ASSOC. PROF. DR. GÖKHAN KİRKİL

MASTER'S DEGREE THESIS

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
WITH THE AIM TO MEET THE PARTIAL REQUIREMENTS REQUIRED TO
RECEIVE A MASTER'S DEGREE IN THE DEPARTMENT OF ENERGY AND
SUSTAINABLE DEVELOPMENT.

ISTANBUL, JUNE, 2021

NOTICE ON RESEARCH ETHICS AND
PUBLISHING METHODS

I, BEGÜM ÜNLÜ;

- Thereby acknowledge, agree and undertake that this Master’s Degree Thesis that I have prepared is entirely my own work and I have declared the citations from other studies in the bibliography in accordance with the rules;
- that this Master’s Degree Thesis does not contain any material from any research submitted or accepted to obtain a degree or diploma at another educational institution;
- and that I commit and undertake to follow the "Kadir Has University Academic Codes of Conduct" prepared in accordance with the "Higher Education Council Codes of Conduct".

In addition, I acknowledge that any claim of irregularity that may arise in relation to this work will result in a disciplinary action in accordance with the university legislation.

BEGÜM ÜNLÜ

____

28 JUNE 2021

ACCEPTANCE AND APPROVAL (For Master's Degree Thesis)

This study, titled **DECARBONIZATION POTENTIALS IN THE TURKISH ENERGY INTENSIVE INDUSTRIES**, prepared by the **BEGÜM ÜNLÜ**, was deemed successful with the **UNANIMOUS/MAJORITY VOTING** as a result of the thesis defense examination held on the **28/07/2021** and approved as a **MASTER'S DEGREE THESIS** by our jury.

JURY:		SIGNATURE:
(Assoc. Prof. Dr. Gökhan Kirkil) (Advisor)	(Kadir Has University)	____________
(Prof. Dr. Volkan Ş. Ediger)	(Kadir Has University)	_______________
(Asst. Prof. Dr. Emre Çelebi)	(Yeditepe University)	_______________

I confirm that the signatures above belong to the aforementioned faculty members.

____

(Title, Name and Surname)

Director of the School of Graduate Studies

APPROVAL DATE: Day/Month/Year

TABLE of CONTENTS

DECARBONIZATION POTENTIALS
IN THE TURKISH ENERGY INTENSIVE INDUSTRIES

ABSTRACT

In the fight against biodiversity and climate crises, a series of measures are taken to keep global warming to a minimum under the leadership of international organizations. In order to reduce greenhouse gas emissions, which is one of the measures, first of all, in the energy sector, a transition from high-carbon sources to low-carbon ones is provided. However, it is known that energy transition alone is not enough to reduce emissions. For this reason, decarbonization methods are emphasized in the industry sector, which ranks second after energy in global emissions. In the studies of developed countries, specific decarbonization proposals for the sub-sectors classified as Energy Intensive Industries consume high energy in the production process and cause intense emissions discussed in detail. On the other hand, The Turkish Industry carries out technological research and development by focusing on energy efficiency. The Turkish Industry should also adopt decarbonization options, as they offer a wide range of options, including energy efficiency. This study aimed to present the potential of decarbonization in energy-intensive industries producing in Turkey. In the study, the concept of decarbonization and the perspective of international organizations, which are at the forefront in the fight against the climate crisis, are examined. Then, decarbonization options that applied globally were investigated, and specific solutions for energy-intensive industries were determined. At the end of the study, the energy-intensive industries in Turkey were examined on a sub-sector basis, and appropriate decarbonization proposals were presented. For these proposals to be implemented, the government, organizations and industrialists should adopt a common approach in line with global targets to fight against the climate crises. Only in this way will it be possible to evaluate decarbonization options in the industry.

Keywords: Decarbonization, Energy Intensive Industries, Alternative Clean Fuel, Energy Efficiency, Direct Carbon Emissions

TÜRKİYE'NİN ENERJİ YOĞUN ENDÜSTRİLERİNDE DEKARBONİZASYON POTANSİYELLERİ

ÖZET

Biyoçeşitlilik ve iklim krizi ile mücadelede uluslararası kuruluşların önderliğinde küresel ısınmayı minimumda tutmak üzere bir dizi önlem alınmaktadır. Önlemlerden biri olan sera gazı emisyonlarının azaltılması için öncelikle enerji sektöründe yoğun karbonlu kaynaklardan düşük karbonlulara geçiş sağlanmaktadır. Lakin sadece enerji geçişinin emisyonları azaltmak için yeterli olmadığı bilinmektedir. Bu nedenle küresel emisyon salınımında enerjiden sonra ikinci sırada gelen sanayi sektöründe karbonsuzlaştırma yöntemlerine ağırlık verilmektedir. Çoğu gelişmiş ülkenin çalışmalarında Enerji Yoğun Endüstri olarak sınıflandırılan, üretim sürecinde yoğun enerji harcayan ve yoğun emisyona sebep olan alt sektörlere özel karbonsuzlaştırma önerileri kapsamlı bir şekilde ele alınmaktadır. Türkiye Sanayisi ise teknolojik araştırma ve geliştirmeleri enerji verimliliğine odaklanarak gerçekleştirmektedir. Karbonsuzlaştırma seçenekleri enerji verimliliğini de içine alan geniş bir yelpaze sunduğu için Türk Sanayisi tarafından da benimsenmelidir. Bu çalışma Türkiye'de üretim yapan enerji yoğun endüstrilerde karbonsuzlaştırma potansiyelini sunmayı amaçlamıştır. Çalışmada öncelikle karbonsuzlaştırma kavramı ve iklim krizi ile mücadalede ön saflarda yer alan uluslarası kuruluşların karbonsuzlaştırmaya bakış açısı incelenmiştir. Ardından küresel çapta uygulanan karbonsuzlaştırma seçenekleri araştırılıp enerji yoğun endüstrilere özel çözümler saptanmıştır. Daha sonra Türkiye'de enerji yoğun endüstriler alt sektör bazında incelenmiş ve uygun olan karbonsuzlaştırma önerileri sunulmuştur. Bu önerilerin hayata geçmesi için hükümetin, kuruluş ve sanayicilerin iklim krizi ile mücadelede küresel hedeflere uygun, ortak bir yaklaşım benimsemesi gerekmektedir. Ancak bu sayede sanayide karbonsuzlaştırma seçeneklerinin değerlendirilmesi mümkün olabilecektir.

Anahtar Sözcükler: Karbonsuzlaştırma, Enerji Yoğun Endüstriler, Alternatif Temiz Enerji Kaynakları, Enerji Verimliliği, Dekarbonizasyon, Direkt Karbon Emisyonları

ACKNOWLEDGEMENT

I would first like to express my gratitude to my supervisor Prof. Gökhan Kirkil who has a great contribution with useful comments, remarks and suggestions to writing this thesis, and to Prof. Volkan Ş. Ediger accepted me as a MA student at the Energy and Sustainable Development Master Program of Kadir Has University. I would also like to thank Dear Dr. Uygar Özesmi, who helped me discover new horizons through their lessons and to making me believe in my journey.

My sincere appreciation also goes to Sinan Tekin for supported me with his positive comments during the completion of my thesis and to my cousin Ebrar Arslan for her help in correcting the grammar.

Finally, I would like to express my endless thanks to my beloved family members my mother Gülhan Ünlü, my father Yılmaz Ünlü, my brother Ahmet E. Ünlü, and my sister Berna Ö. Altun who supported me in every decision I made.

LIST of TABLES

LIST of FIGURES

LIST of ABBREVIATIONS

BF	Blast Furnaces
BOF	Basic Oxygen Furnaces
^oC	The degree Celsius
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CE	Circular Economy
CHP	Combined Heat and Power
COP	Conferences of the Parties
CO_2	Carbone Dioxide
CRF	Common Reporting Format
DRI	Direct Reduced Iron
EAF	Electric Arc Furnaces
EIA	Energy Information Administration
EII	Energy Intensive Industry
EU	European Union
GHG	Green House Gas
IEA	International Energy Agency
IF	Induction Furnaces
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Process and Product Use
kt	Kilotons
MENR	Ministry of Energy and Natural Resources
NIR	National Inventory Report
SDGs	Sustainable Development Goals
SDS	Sustainable Development Scenario
Turkstat	The Turkish Statistical Institute
UN	United Nations
UNDP	The United Nations Development Program
UNFCCC	The United Nations Framework Convention on Climate Change

1. INTRODUCTION

The world has evolved into different habitats where many creatures can live by experiencing the existing climate change numerous times. Nowadays, while the population in the world is increasing, wildlife areas are decreasing due to consumption, and the increase of greenhouse gases in the atmosphere are more than normal since the industrial revolution, has sped up climate change and turned the situation into a climate crisis.

With the Paris agreement, countries aimed to reach peaking of the greenhouse gas (GHG) emissions by limiting global warming to well below 2 degrees Celsius (^{o} C), preferably to 1.5 ^{o}C, compared to pre-industrial levels (United Nations, 2015). Countries have begun to achieve these goals and accelerated the transition from fossil fuel to renewable resources in the energy sector, which causes the most emissions. However, it was understood that energy transition would not be sufficient to reduce GHG emissions alone. In addition, the economy, based on business models that increase consumption, had to be redefined. The industry which consumes the most energy and GHG emissions globally after the energy sector was included in the economic change process as a priority.

Today, industrial products are used in almost all areas of human life. Every product is used, ranging from furniture to mobile phones, from cleaning products to paper, going through an industrial production process. Although it is predicted that fossil energy resources will no longer be used in the new age called the ‘green age,’ we cannot be deprived of using the products of the industries that spend these resources the most. For this reason, we need to put the industries that will continue to produce to meet our needs in an environmentally friendly order. Changing the use of fossil-based resources to renewable ones, optimizing production processes to consume less energy and increasing efficiency by using new technologies, including hydrogen, are the steps to be taken. In order to take these steps, it is essential to have policies and financial support mechanism.

Developed countries focus on revising their existing economic models to reach the carbon-free target by applying similar steps. However, underdeveloped and developing countries with intense resource and energy consumption during industrial production are one step behind in this adaptation process. Nevertheless, International Organizations such as the United Nations (UN) and European Union (EU) seem determined to act globally for a climate-neutral future.

The UN was established to ensure peace between countries in the world in 1945, and over time, it has created various organizations and programs covering children and employees in distress, human rights, and environmental problems on a global scale, besides peacekeeping (United Nations, n.d.-a). The Paris Climate Agreement and the Sustainable Development Goals (SDGs), which were taken into account in the fight against the climate crisis, come into existence with the initiatives of the UN. Turkey signed the Paris Agreement on 22 April 2016, although not a party to the Paris Agreement; according to Turkey's national contribution, declaration of greenhouse gas emissions by 2030 in the reference scenario to reduce by up to 21% is foreseen (Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı, n.d.). SDGs entered into force in January 2016 and are supported to be implemented in more than 170 countries and regions by The United Nations Development Program (UNDP), a program that conducts development studies in cooperation with governments, non-governmental organizations, academia and business circles (UNDP, n.d.). UNDP Turkey works on inclusive and sustainable growth, inclusive and democratic governance, climate change and environmental issues also attach great importance to the role of women, the private sector, capacity building, and Information and Communication Technology in policies and projects (UNDP Türkiye, n.d.).

The EU is another organization that was established to ensure peace and started to produce solutions to environmental problems over time. The European Commission, which implements the decision of the EU and European Parliament, publishes overall targets and reports about energy, climate change and the environment (European Union, n.d.). ‘A Clean Planet for all’ was one of them, which was presented in 2018 as the EU's strategic long-term vision for climate neutrality by 2050 (European Commission &

Climate Action DG, 2019). However, it also became the heart of the European Green Deal.

The European Green Deal that was published in 2019 was designed with a set of deeply transformative policies for clean energy supply across the economy and all the sectors, and Figure 1.1 shows its elements. (European Commission, 2019). The EU also states that the countries which it will business partner in the future will also evaluate due to how they take action against the climate crisis. Countries like Turkey, which are trade partners with the EU and did not approve the Paris Agreement yet, should reconsider their decisions in the circumstances.

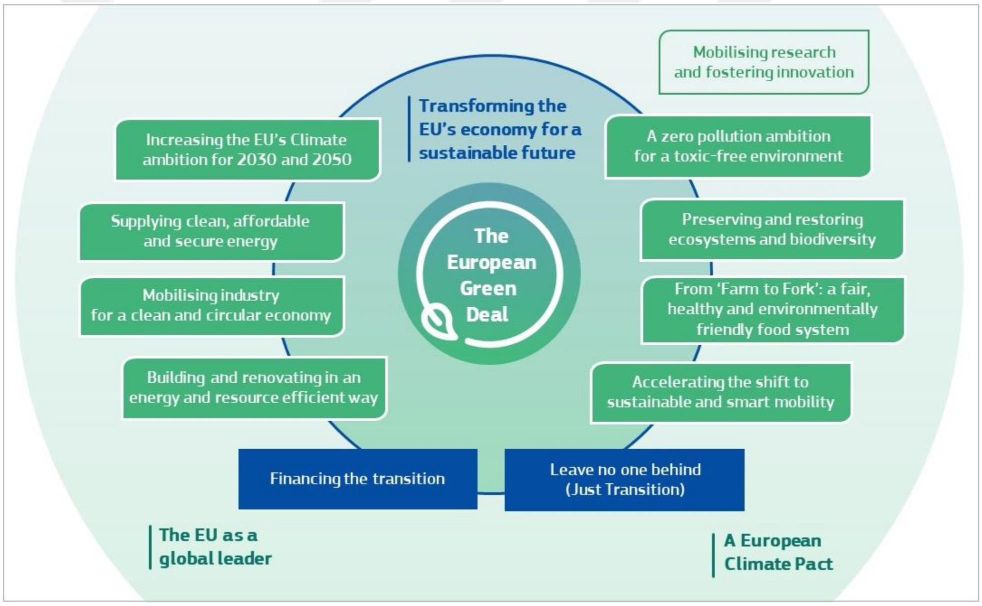


Figure 1.1 The various elements of the Green Deal. (European Commission, 2019)

Most countries in the movement to combat the Climate Crises collectively worldwide expect and sometimes obligate the other countries to be in this effort. Reducing CO_2 emissions, which make up a large part of GHG emissions, is amongst priorities. Carbon Border Adjustment Mechanism (CBAM) supports the EU's climate targets by preventing the risk of carbon leakage explained as part of the July 2021 package (European Commission, n.d.) . Within the CBAM, the EU is scheduled to start a reporting system from 2023 that applied to electricity, cement, aluminum, fertilizer and iron-steel productions and planning to begin to collect carbon taxes of these products from importers in the EU onwards 2026 (European Commission, n.d.) While developed countries focus on many projects and studies to ensure the decarbonization of manufacturing industries, it has been observed that there is a deficiency in this area in Turkey. The manufacturing industry, especially the cement and iron and steel sectors with have a high export share, constitutes the cornerstones of the Turkish economy. Although developing strategies to reduce carbon emissions of the manufacturing industry have importance, there has been no comprehensive study that can guide the government and industrialists in this area. This thesis aims to present a situational assessment in the Turkish manufacturing industry and a guiding study on what can be done to ensure decarbonization soon. Energy-intensive industries have been focused on since the manufacturing industry has a high share in CO_2 emissions and includes the sectors within the scope of the CBAM. The most energy-intensive industries are determined as iron and steel, nonferrous metals, chemicals, minerals (cement, lime, glass and ceramics) and pulp and paper regarding manufacturing production (IPCC, 2007, 2014).The main research question in this study, in which a bottom-up approach is adopted, is “What are the decarbonization options for Turkish Energy Intensive Industries?”. The sub-questions are listed below: “What is decarbonization?”; “why decarbonizing the EIIs is an important issue?”; “what are the current decarbonization applications for EIIs in the world?"; "which decarbonization technologies could be applied in Turkey?"; and “how much CO_2 emission reduction could be achieved with these applications in Turkey?”.

Sun (2005) defines decarbonization from an energy perspective as reducing carbon emissions through fuel consumption. In this study, decarbonization is considered as the reduction of direct CO_2 emissions emitted by energy-intensive industries throughout production. Solutions to reduce the direct CO_2 emissions of the EIIs have been investigated, which emissions from fuel combustion and process emissions usually from the chemical conversion of raw materials.

In the literature review, many studies have been reached on decarbonization applications in energy-intensive industries and determined that are mostly published in the European region, the leader of the world to combat the climate crisis. Some of the studies and reports that were used as sources to determine the decarbonization recommendations are presented below. The report prepared by de Bruyn et al. (2020) includes energy efficiency, electrification, deep geothermal energy, biomass, hydrogen, Carbon Capture, Utilization and Storage (CCUS), process intensification, circular economy and defines the impact of each technology on production processes, products and value chains. The study of Wyns et al. (2018) different from the other reports because it involves sections as industrial symbiosis and synergies with non-industrial sectors and circular economy and materials efficiency besides 11 EIIs. The studies of REINVENT, funded by EU Horizon 2020, were helpful in identifying the decarbonizing options for industrial sectors which REINVENT focuses on: paper, plastic and steel.

Energy Technology Perspectives 2020, published by International Energy Agency (IEA), is another comprehensive report to explain The IEA's Sustainable Development Scenario (SDS), in which the net-zero emission target in the global energy system by 2070. The report specifies that electricity cannot decarbonize entire economies alone and includes technology needs in the industry, transport and buildings sectors besides clean energy technologies (International Energy Agency, 2020). The technology needs for heavy industries that are identified in ETP are taken into consideration in this thesis because in the SDS, the emissions of heavy industry need to decrease 90 % until 2070, as you can see from Figure 1.2 (IEA, 2020; International Energy Agency, 2020).

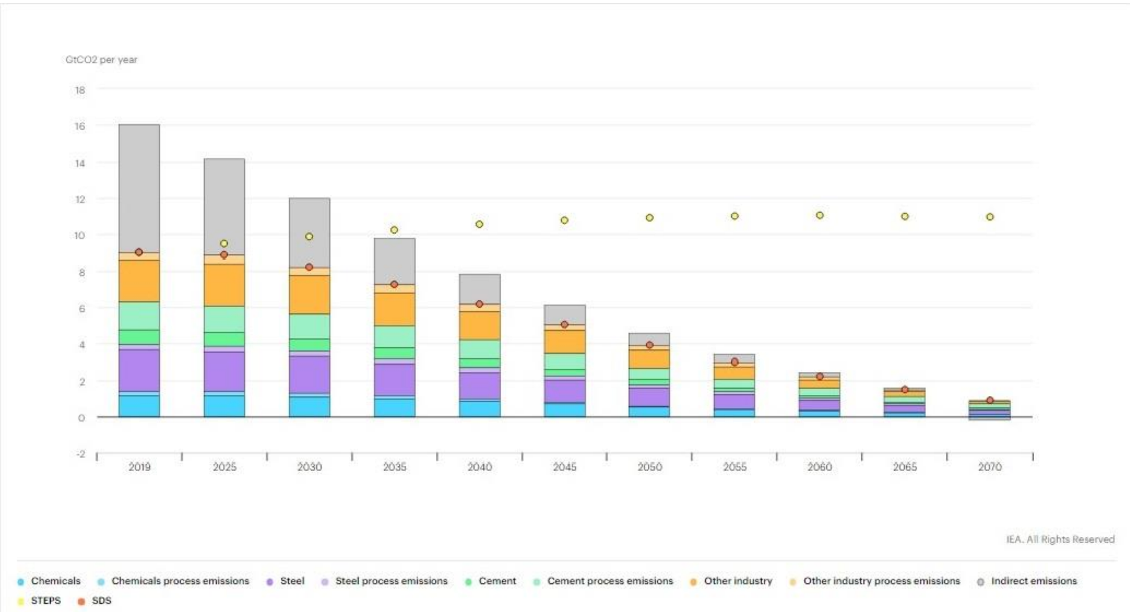


Figure 1.2 Energy consumption and CO_2 emissions changes of the industry globally in the SDS (IEA, 2020).

Apart from institutions and organizations, there are also academicians working on decarbonization. Comprehensive articles authored by the academicians preferred for the technology suggestions in the thesis are as; Gerres et al. (2019) identified areas that decarbonization is possible in EIIs and defined the suggestions with the potentials of the carbon reduction; Napp et al. (2014) published a study by reviewing technologies that enable efficiency and decarbonization for industries; Rehfeldt et al. (2020) calculated that the industries how can reduce carbon release by changing fuel type with already technologies; the study of Rissman et al. (2020) is different from other articles because it defining circular economy approaches such as design, material efficiency, material substitution etc.

With the examination of main publications, technologies for the proposed decarbonization in EIIs were determined, and each one was briefly described. Then EIIs' sub-sectors, which are determined according to the Intergovernmental Panel on Climate Change (IPCC) classification, are explained using the individual sector reports in Turkey. In these explanations, decarbonization technologies suitable for each sector and calculations are also given.

As can be seen in the reviewed paragraphs, there are many studies on the decarbonization of Energy Intensive Industries worldwide. However, there is a lack of comprehensive research on this subject in Turkey. Therefore, this thesis aimed to provide decarbonization options for EIIs in Turkey. For this purpose, focused on both technological and non-technological solutions, which could guide companies and government-affiliated institutions to decarbonize the industry.

The first part of the thesis, the introduction, illustrates why decarbonization in EIIs is an important issue and how it is contextualized. In the second part of the thesis, the definition of decarbonization, its enabler factors and its connection with the industry sector are summarized, and international organizations' publications which are cornerstones of the topic, are mentioned. In the third part, the decarbonization technologies that are reviewed through international literature and scientific articles are classified into two categories as alternative clean fuel and energy sources, and energy efficiency implementations and summarized. Then in the fourth part, the energy-intensive industrial sub-sectors in Turkey are individually defined with the current situation, and decarbonization implementations were recommended. Rough calculated results have given with the extent to which decarbonization applications can reduce emissions has been obtained from the source studies and the 2019 yearly data in the Turkstat report. In the discussion part, all the decarbonization suggestions and calculations are discussed with challenges and solutions. The outcomes of the study and answers to the research questions have given in the conclusion part.

2. CONCEPT OF DECARBONIZATION

This chapter consists of two parts. Firstly, decarbonization definition, its enabler factors and connection with the industry sector are mentioned; after that, extensive publications, which are especially authored by international organizations and made the decarbonization solutions for energy-intensive sectors more important, are summarized.

2.1 DECARBONIZATION DEFINITION AND CONNECTION WITH INDUSTRY SECTOR

Countries are taking measures in the face of the climate crisis to reduce emissions. Controlling CO_2 emission, which has the highest emission among greenhouse gases, is prioritized in order to get faster results. Therefore, decarbonization has become a trend topic, to reaching the targets of the Paris Agreement and the SDGs.

According to Sun (2005), decarbonization states that reducing carbon emissions through fuel consumption since 1990s, in energy projections. Nakićenović (1996) who summarized decarbonization as doing more with less, also argued that it can be has two factors one of them is carbon emissions per unit energy, other one is energy intensity. In this study, decarbonization is considered as the reduction of direct CO_2 emissions emitted by energy-intensive industries throughout production.

Decarbonization is an important issue because reducing CO_2 emissions, which take the largest share of GHG emissions, is a precaution that every country should take in order to keep the air temperature increase low in order to fight the devastating effect of climate change. Various meetings and agreements still be made in order to adopt common goals around the world, and with each passing year, international organizations are increasing their pressure on countries to reduce their environmental impact and carbon emissions, such as the last example in CBAM. In this process, it is important to prevent the economy from being negatively affected and ensuring decarbonization in industries where the economy is closely related, gives a chance to countries for progress in line with these global targets.

Graphics of Turkey's energy related CO_2 emissions by fuel sources, in Figure 2.1 taken from Turkstat (TurkStat, 2021a) statistics, show that there is a continuing increase in CO_2 emissions since 1991. Unfortunately, carbon emissions of the coal have the biggest share with 44% in total fuel emissions in 2019. It is possible to reduce CO_2 emissions due to fuel consumption. The replacement of coal and natural gas, which are mostly consumed for electricity generation, by renewable resources, the design of sustainable transport systems, including using alternative fuels instead of oil, can be listed as just a few of the decarbonization solutions in the energy sector.

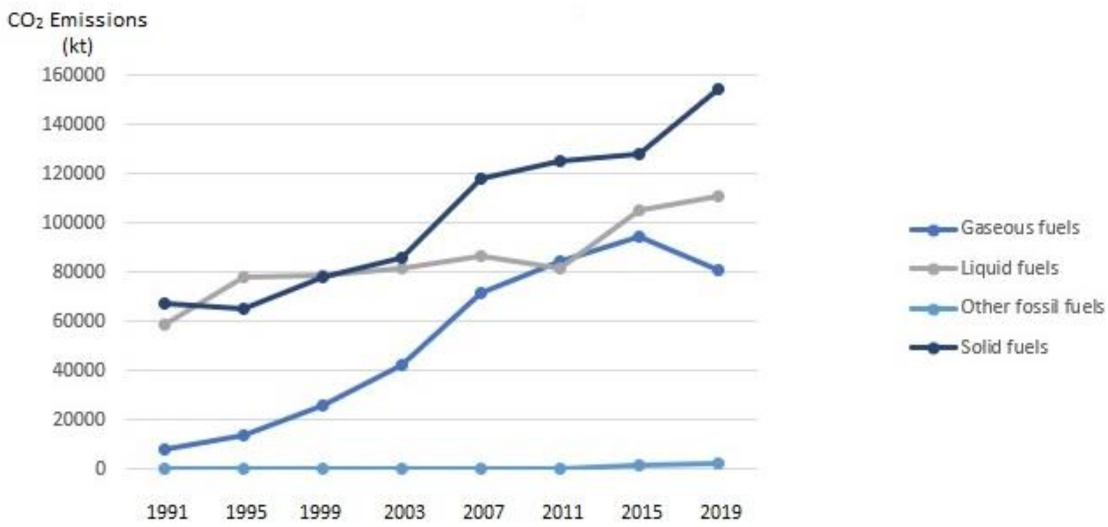


Figure 2.1 Energy related CO_2 emissions by fuel sources of Turkey, 1991-2019. (TurkStat, 2021a)

If we examine the energy consumption in Turkey on a sector basis, energy industry takes the first place with 35%, transportation comes second with 24% and both residential and manufacturing industries come in the third place with 15% as seen in Figure 2.2.

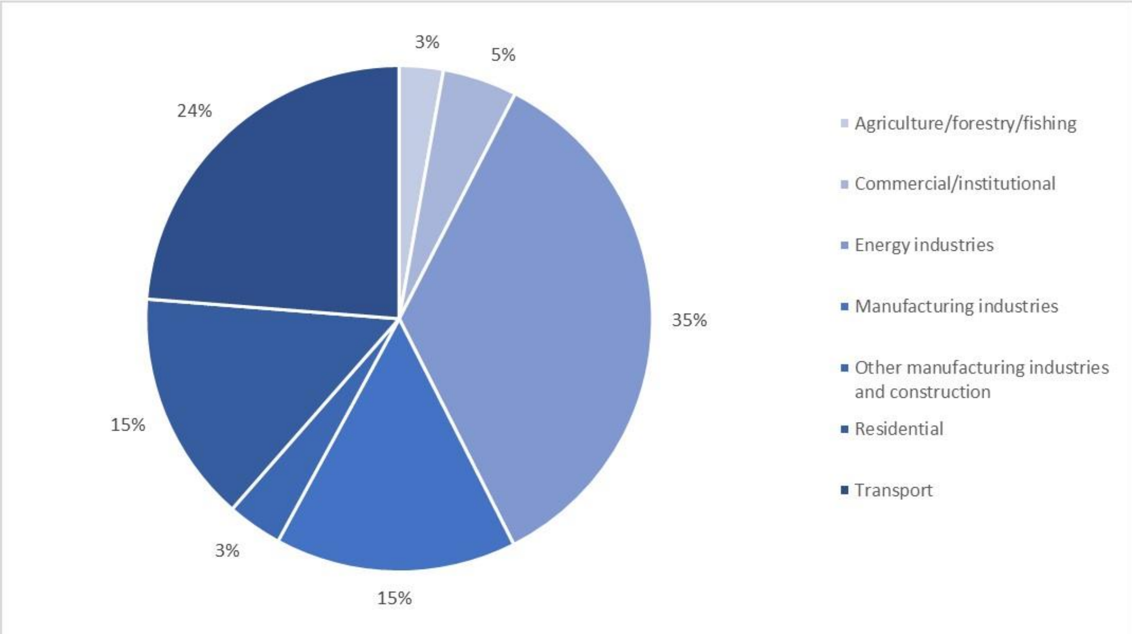


Figure 2.2 Fuel consumption share by sectors in Turkey of the 2019-year. (TurkStat, 2021a)

After energy industries significant amount of carbon reduction could be achieved in both transportation and buildings sectors with increasing the electrification and using electricity produced from renewable energy. However, the same is not true for the manufacturing industry. Because manufacturing industry has numerous sub-sectors and facilities that include diversified equipment with long-term usage to generate a wide range of products. In order to ensure decarbonization, solutions suitable for each production process, equipment and sector must be developed and applied. Therefore, it is necessary to work more on providing decarbonization in the manufacturing industry.

When the manufacturing industry is examined in terms of decarbonization, the sectors where the highest reduction can be achieved are the energy intensive ones. According to Bhattacharyya (2019) energy intensities measure the energy requirement per unit of a driving economic variable. In industries, it can be measured by the ratio of energy use to physical output and it could be reduced by increasing energy efficiency (IPCC, 2014). In this way also decarbonization could be achieved. The most energy-intensive industries in Turkey are determined as iron and steel, nonferrous metals, chemicals, minerals (cement, lime, glass and ceramics) and pulp and paper regarding manufacturing production (IPCC, 2007, 2014). The share of direct CO_2 emission values of these five sectors in all sectors is presented in Figure 2.3.

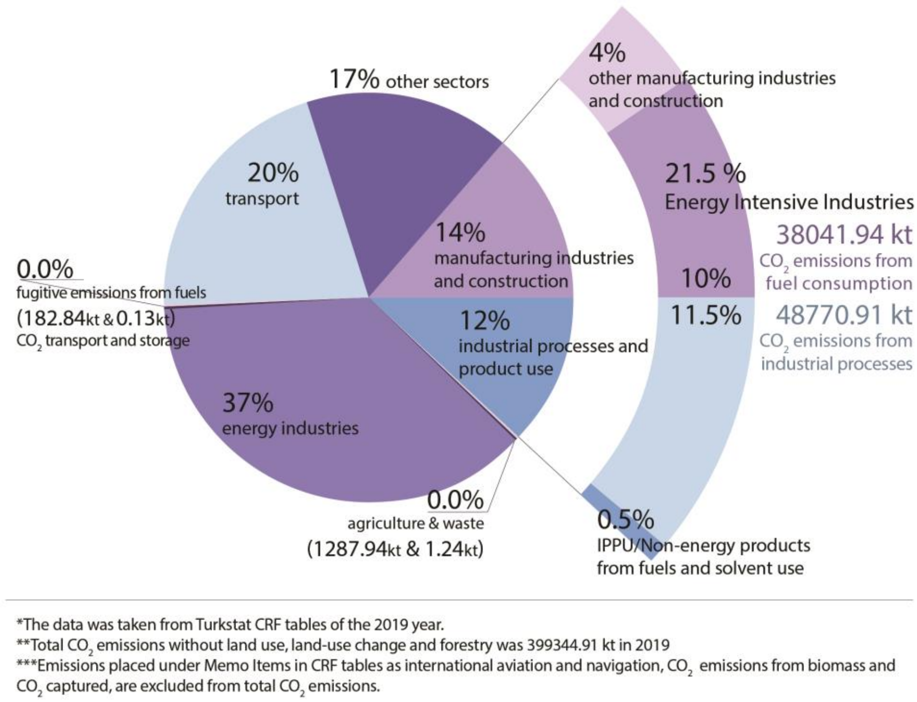


Figure 2.3 The share of the direct CO_2 emissions of the Turkish EIIs of the 2019 year. (TurkStat, 2021a)

Figure 2.3 presents the distribution of all direct CO_2 emissions in Turkey in 2019 and the share of EIIs in this distribution. EIIs are have 21.5% total share that includes both 10% share of fuel consumption from manufacturing industries and constructions and 11.5% share of process emissions from industrial processes and product use. EIIs, which have a high share in CO_2 emissions, are expected to reduce their emissions at a high rate with decarbonization applications. In the literature review, many studies have been reached on decarbonization applications in energy-intensive industries and determined that are mostly published in the European region, the leader of the world to combat the climate crisis.

Energy intensive industries became a prevalent working area for countries which aim to reach the Paris Agreement and implement SDGs because decarbonizing the EIIs plays an essential role in reducing the total carbon intensity and energy intensity in countries' economies. There are many studies covering EIIs and prepared by taking international agreements and strategic plans into consideration in order to achieve emission reduction targets. Some of the international agreements and publications as the basis for the preparation of most studies are summarized in the next section.

2.2 INTERNATIONAL ORGANIZATIONS' VIEW

Reducing greenhouse gas emissions is an important measure that international organizations want to take due to the climate crisis, and it can be achieved by taking steps determined in line with the decisions taken together with representatives of countries. On the other hand, decarbonization can be identified shortly as the reduction of carbon emission which has the highest percentage among greenhouse gases released by a set of systems that keep the operation of the economy. Articles in circulars like the Paris Agreement encourage countries to implement decarbonization solutions in sectors such as energy, transportation, building and industry, including areas are controlled resource consumption, material and energy efficiency, and advanced waste management.

In this part of the thesis, agreements, circulars, strategic plans and programs that were published by international organizations and made the decarbonization solutions for EIIs more important are mentioned. While the first part covers the steps taken by the UN, the second part includes EU's.

2.2.1 United Nations

As stated in the first chapter, the UN, which was established to ensure peace in the world, has focused on environmental problems in time. The United Nations Framework Convention on Climate Change (UNFCCC) that is the first intergovernmental agreement on global warming signed under the leadership of the UN, opened for signature in 1992 (United Nations, n.d.-b). After UNFCCC came into force, Conferences of the Parties (COP) have been held 25 times since 1995 (UNFCCC Sites and platforms, n.d.) and COP 21 that was realized in Paris, could be regarded as the most important conference because the Paris Agreement was (United Nations Climate Change, n.d.).

The basic goal of Paris Agreement is to limit global warming to well below 2 degrees Celsius by 2040, compared to pre-industrial levels. (United Nations Climate Change, n.d.). In order to reach this temperature target, sectors which cause the highest emission such as energy, transport, industry and building, should be considered on a preferential basis in countries' long-term strategies to combat climate change through technological development and policy implementation.

The SDG entered into force in January 2016 and is supported by The UNDP, that conducts development studies in cooperation with governments, non-governmental organizations, academia and business circles (UNDP, n.d.). Countries began to prepare their long-term strategic plans to combat climate change with the targets and recommendations of the Paris Agreement and the SDGs. Taking these goals which also include the demands for supporting the developing countries, into consideration by developed countries, will accelerate the global success against the climate crisis, because developing countries need financial support mechanisms to move towards the net - zero emission targets. A Clean Planet for All and The Green Deal which were published by the EU which is another international organization aimed to produce solutions for environmental problems globally, could be agreeable examples of this consideration.

2.2.2 European Union

It is an indisputable fact that the EU leads the world in research, implementation and support in combating the climate crisis. Reports and many interrelated strategy plans which were published by European Commission for sociological, economic and environmental solutions, are followed by the whole world. In addition, the operational and financial support given to non-EU countries, the largest of paramount importance for Turkey as well as other countries. The United States, which re-accepted the Paris Climate Agreement in January 2021 (*Paris Agreement, UNITED STATES OF AMERICA: ACCEPTANCE*, 2021), declared that it decided to work with the EU on the climate crisis (İklim Haber, 2021), which is an indication of how qualified the EU is in this regard.

The EU explained that to the emission reduction rates it has created based on the Paris climate agreement, is increased in The Green Deal which is a guide for many countries to take action against the climate crisis. In addition to this situation besides the targets of EU's to supplying clean energy and supporting low-carbon technologies, announcing strategic plans such as a New Industrial Strategy to reaching the Green Deal objectives, could are proof how it take consider the decarbonization (European Commission, 2019).

In Europe, the industry is evaluated together with all value chains and the focus is on industrial ecosystems rather than sector-based approaches. There are traces of this in A New Industrial Strategy for Europe, while each fundamental for Europe's industrial transformation is announced with all stakeholders have to do, also new strategy plans and guidelines are given under each of them. One of the fundamentals of Europe's industrial transformation is supporting industry towards climate neutrality and under this clause modernizing and decarbonizing energy-intensive industries is seen as a top priority. In order to achieve this, it is reported that the industry will adhere to the principle of 'energy efficiency first'. Also, thanks to circular economy (CE), is another fundamental factor for EU, it may be possible to create new business opportunities in all sectors, as well as to reduce environmental impacts, raw material consumption and production costs due to the radical renewal of design, production, use and waste management. The EU has also published a plan with centering the CE, which includes policy recommendations about waste reduction and creating value from wastes. (European Commission, 2020).

The CE has many definitions by declaring different human and institutions related to implementation or research areas. Kirchherr et al. (2017) defined CE comprehensively by analysis of 114 different CE definitions, as an "A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."

Carbon Border Adjustment Mechanism (CBAM) is one of the latest EU's politics explained as part of the July 2021 package to supports climate targets by preventing the risk of carbon leakage (European Commission, n.d.). Within the CBAM, the EU is scheduled to start a reporting system from 2023 that applied to electricity, cement, aluminum, fertilizer and iron-steel productions and planning to begin to collect carbon taxes of these products from importers in the EU onwards 2026 (European Commission, n.d.). While developed countries focus on many projects and studies to ensure the decarbonization of manufacturing industries, Turkey should keep astride the EU's sustainable development policies closely to not stay outside of this progress. The next part of this study, which was prepared for this purpose, presents a summary of technologies that can provide decarbonization in Turkish EIIs.

3. IMPLEMENTATIONS OF DECARBONIZATION IN ENERGY INTENSIVE INDUSTRIES

The manufacturing industry performs production by consuming high amounts of energy and raw materials through various equipment and devices, causing an increase in CO_2 emissions while providing the products we use to meet our needs, in our daily lives. Bajzelj et al. (2013) presents how the system chains, required to meet human demands, in the global industry sector reveal the GHG emission in the Sankey diagram which is prepared based on all anthropogenic global GHG emissions in 2010 and shown in Figure 3.1.

Each unit in this diagram was created on really data and the thicknesses of the stripes represent the consumption amounts proportionally. The human needs classified on the far left; in second column the sectors which these needs depend on; in the third and fourth place, equipment and devices which the sectors use to production; in the fifth and sixth, energy forms that used by the sectors, and sources of these energies; in the last column GHG emissions which all stages ultimately release, are shown. It is observed that the most dominant gas among GHG emissions is CO_2, which originates mainly from fuel consumption and to a lesser extent from processes.

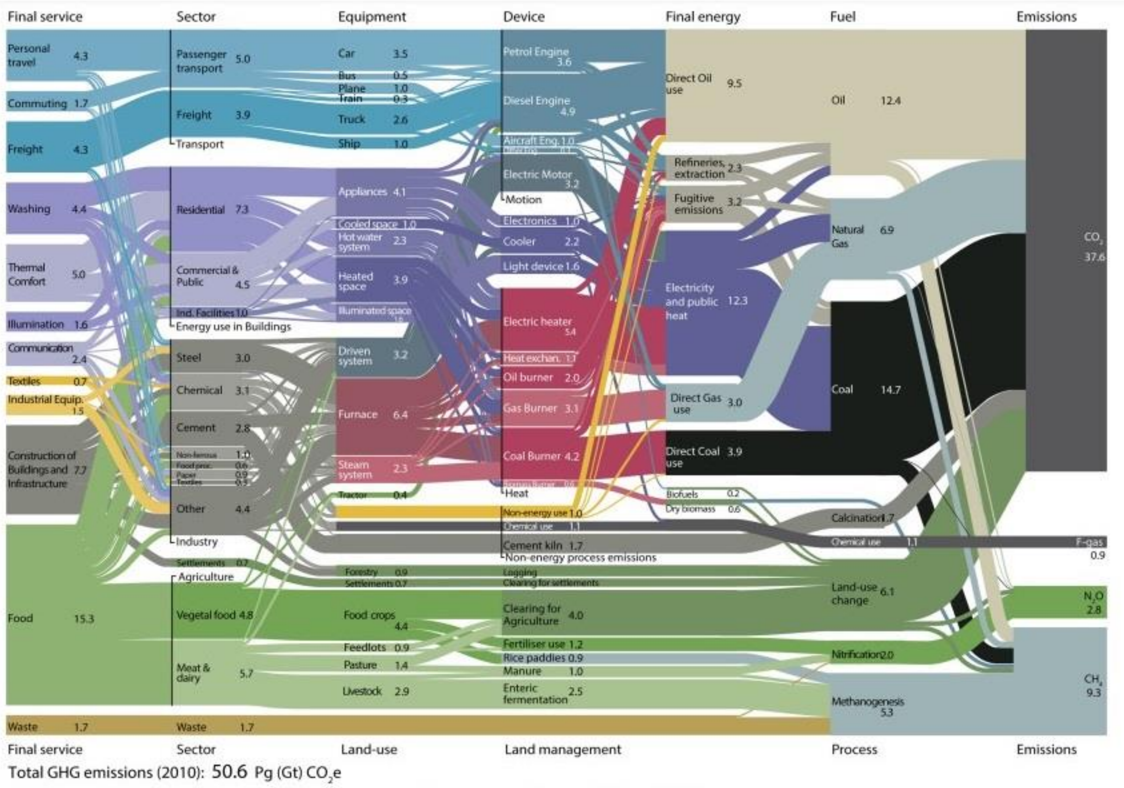


Figure 3.1 A Sankey diagram presents how the system chains reveal the GHG emission, prepared based on all anthropogenic global GHG emissions in 2010. (Bajželj et al., 2013)

As shown in Figure 3.1, industry causes intensive carbon emissions and the way to reduce it is to provide decarbonization in the industry. This study aimed to present suggestions for reducing direct CO_2 emissions from energy-intensive industries. Direct CO_2 emissions are those from sources owned or controlled by the EIIs, consisting of emissions from fuel combustion and process emissions generally from the chemical transformation of raw materials such as iron and steel production, cement and chemical productions (IPCC, 2014). For this reason, in the next section, the recommendations include alternative clean fuels and technological and non-technological solutions that increase the efficiency of the equipment and devices are presented.

3.1 ALTERNATIVE CLEAN FUEL AND ENERGY SOURCES

Today, the Turkish EIIs use approximately 90% of its total fuel demand from fossil fuels (TurkStat, 2021a). This situation indicates that carbon emissions from fuel consumption could be significantly reduced. This can be achieved by switching to low-carbon fuels such as replacing coal with natural gas, waste and biomass. According to the IEA (2020) projections, fossil fuels usage share in the industry will be reduced up to 60% by 2070 in the SDS by increase electricity and bioenergy.

Biomass is an important raw material for paper, silicon, chemicals and refining industries, it is also used as an energy source in most sectors, but at lower levels compared to other energy inputs due to the limited available quantity (Wyns et al., 2018). According to Gerres et al. (2019) and Rehfeldt et al. (2020) biomass has a big potential to decarbonization the EIIs; switching to totally or partially bio-based fuels in the most of the EIIs is possible such as cement, pulp & paper and ceramic industry.

Although electricity is an energy source that we use in every moment of our lives, the production processes of industries mainly use fossil fuels. Carbon reduction can be achieved by revising these production processes to work with electricity, by providing electrification, but the electricity that will be used must be low-carbon, that is, produced from renewable sources. Energy-intensive industries generally use high heat in their production processes. Low temperature demand can be supplied by technologies that work with electricity such as electric arc, infrared, induction, dielectric, direct resistance, microwave and electron beam heating, but for processes which need to generate heat above 1000 ° C it is necessary to develop furnaces adapted with electricity; Wyns et al (2018) also mentioned that most of the innovative processes for further electrification such as steel electrolysis, iron ore reduction with plasma, utilization of electrochemical processes, are in early stage, could be more efficient but further optimization for these processes are required.

There are many studies that offer the electrification options to the EIIs. One of them, prepared by Wiertzema et al. (2020), presents a classification of electrification options for processes where high energy consumption in industry sectors. Another study is prepared by Madeddu et al. (2020) presents the resulting electrification potential of the European industry with their comprehensive bottom-up analysis. As a result of this analysis, technologies that can replace traditional fired systems to electrify industrial heat and cooling demand are summarized together with sub-sectors where they can be applied (Madeddu et al., 2020).

The main studies mentioned in the introduction part of the thesis also include information about electrification of EIIs. Increasing the use of electricity in the industry may reduce emission rates, but since the systems that will enable the cost-effective storage of electricity produced from renewable sources have not yet been developed, the use of electricity becomes difficult especially in EIIs. The technologies recommendation will place in the fourth section.

Hydrogen can be produced with many methods, but it is important to how much CO_2 emitted while producing. The main goal of hydrogen energy transition is based on green hydrogen produced by water electrolysis using renewable energy (Kovač et al., 2021). Biohydrogen is hydrogen produced by a biological process and gives the possibility to use waste sources, it can be included in the green hydrogen class; grey hydrogen is produced from fossil fuels and causes CO_2 emissions (Kovač et al., 2021). The hydrogen production method from coal using gasification is a well-established technology, but it releases CO_2 emissions twice as much as natural gas (blue hydrogen) (IEA, 2019). Transporting hydrogen is another issue that need consider the inflammable matter. Some polyethylene pipes could carry hydrogen but the new infrastructure will be required.

Hydrogen can be used as a feedstock to produce synthetic fuels, or used as a direct product, for example in primary steel making, it can be used as a reducing agent in Direct Reduced Iron (DRI) or smelting processes (Wyns et al., 2018). Even the widest spread industrial hydrogen utilizations are in steel-making, chemical, glass, and electronic industries, there are many potential application of hydrogen is also used; for chemical product synthesis to form ammonia and methanol, for agricultural fertilizing, metal production and fabrication, methanol production, food processing, and cosmetics (Kovač et al., 2021).

3.2 ENERGY EFFICIENCY IMPLEMENTATIONS

Another way to reduce carbon emission in the industry is to increase energy efficiency and this can be achieved by using best available technologies in the production process and opportunities are found within in steam systems, process heating systems and electric motor systems (Fischedick et al., 2014). While developing technology offers new advantages for most processes, following these innovations by both industry-wide companies and the governments will facilitate the adaptation process.

In the industry sector energy efficiency could rise in the period to 2030 with installation of the equipment such as motors, heaters and grinders and processes such as waste heat recovery, however the new technologies like CCUS and electrolysis which have high energy consumption could makes rate of efficiency improvement slows after 2030 according to Net Zero Emission Scenario (IEA, 2021b). In my opinion, as long as technology develops, the issue of energy efficiency will keep up-to-date. It is inevitable in the future to make improvements in the efficiency of technologies that are currently under development and use high energy.

The common feature of energy-intensive industries is that they use heat as input. Low-temperature processes are more suitable for electrification so reaching decarbonization with them could be easier, equipment involved in high-temperature processes have to be improved to ensure energy efficiency.

Heat process is the basic stage that consumes high energy from fossil fuels in EIIs. In the pulp and paper industry, fuel is consumed by boilers up to 30% for steam supply, the emission rate may decrease in parallel when these boilers change to electrically powered ones (Gerres et al., 2019).

Industrial ovens are heat supplying equipment in cooking and drying processes and are used in almost every sub sector of the EIIs. Furnaces which provide temperature up to 200^{o}C are suitable for electrification, and when electrification ensured emission reductions can be achieved in proportion to their fossil fuel uses (Gerres et al., 2019). Another equipment that causes high emission due to the use of high temperature is industrial furnaces. Improving furnaces to reduce energy consumption or to use low-carbon energy sources will reduce the emissions of industrial subsectors.

Iron & Steel industry is most commonly uses blast furnaces (BF) in iron production and basic oxygen furnaces (BOF) in steel production, it also uses electric arc furnaces (EAF) in the production of lower energy-intensive scrap steel (Napp et al., 2014). The EAF consumes lower energy than BF route, but the availability of high-quality scrap can limit production. EAFs can supply with DRI and can replace the BF route in principle, but the consumption of energy does not change much (Rehfeldt et al., 2020). There are also projects that increase productivity by combining production technologies and are still under development for iron & steel. One of them is HIsarna, which combines the BF / BOF steps and produces a concentrated CO_2 waste stream so could equipped with CCS for reducing carbon release (Rissman et al., 2020).

Rotary kiln is general kiln in the cement, ceramics and glass sectors and is equipped with multichannel burners and could burn wastes directly, but as long as the wastes used are industrial wastes such as plastic, carbon emission reduction is not achieved (Rehfeldt et al., 2020). New fluidized bed kilns used in the cement industry release less emissions than modern rotary kilns (Gerres et al., 2019).

Cement industry uses around 40% of electricity in granulation period, if the traditional equipment is replaced to modern ones energy could be saved. (Napp et al., 2014). In the ceramics industry, fuel and energy reduction could supply by new furnaces such as intermittent furnaces with continuous furnaces, electrification with microwave-assisted heating are the improvements to could reduce emissions by 3% to 50% (Gerres et al., 2019). Electrification of glass melting process can be achieved more easily than cement. However, electricity prices prevent its application in large facilities, so electrification can be option for small-volume furnaces.

It is also possible to reuse the gas and heat from the furnaces with various equipment, in simple way waste heat from furnaces could use for preheating. Coke furnaces, can generally be classified as recovery and non-recovery furnaces, the coke oven gas from recovery furnaces can be successfully used instead of natural gas in furnaces and boilers; also, can be combined with BF gas to generate electricity in a CHP plant (Napp et al., 2014).

In the combined heat and power (CHP) system the hot air and water dissipated from the energy produced in thermal power plants are used to raise steam or direclty in district heating, so energy saving from 10% to 80% can be achieved (Napp et al., 2014). However, due to the already wide implementation of the CHP system of sub-sectors, the potential for reduction is limited and varies according to the current practice in each sub-sector, although it can be achieved by replacing existing facilities with new CHPs (Gerres et al., 2019).

The petrochemicals industry is different from most other industries because chemicals are generally in liquid and gaseous form, but its heat requirements can minimize by using advanced membranes.

4. TURKEY'S ENERGY INTENSIVE INDUSTRIES WITH DECARBONIZATION SUGGESTIONS

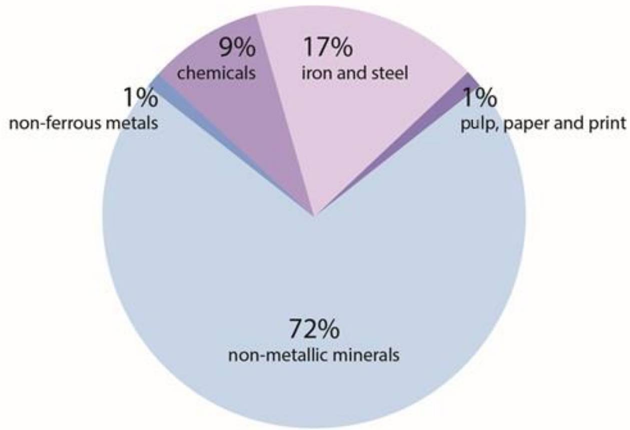
The manufacturing industry, especially the cement and iron and steel sectors with have a high export share, constitutes the cornerstones of the Turkish economy. Nowadays, with the increasing pressure globally, it becomes imperative to provide decarbonization in this sector. This study focused on Energy-intensive industries since the manufacturing industry has a high share in CO_2 emissions. The most energy-intensive industries are determined as non-metallic minerals (cement, lime, glass and ceramics), iron and steel, chemicals, nonferrous metals, and pulp and paper regarding manufacturing production (IPCC, 2014). EIIs' emissions highly depend on energy consumption, however, the reduction of the energy system emission in the industry is lower due to both the focusing on the production of products with low margins in a competitive environment and the long life of the existing installed equipment preventing installing new systems (IEA, 2021). Industrial plants often undergo refurbishment after 25 years of operation to extend their equipment life, during this period, it is important to seize the opportunity to implement decarbonization technologies (IEA, 2021).

The Energy-Intensive Industries, which is significant for the economy in Turkey, had a share of 15% in total fuel consumption with 748743 TJ in 2019 (TurkStat, 2021a). The fuel consumption and direct CO_2 emissions distributions by sub-sectors of the Turkish EIIs are shown in Table 4.1, which is created from the CRF tables published by Turkstat, the sub-sectors are listed descending according to the total direct CO_2 emission values.

Table 4.1 Fuel consumption and direct CO_2 emissions distributions by sub-sectors of Turkey Ells in 2019. (TurkStat, 2021a)

		Direct CO_2 EMISSIONS (kt)		
Energy Intensive Industries	**Fuel Consumption (TJ)**	**From Fuel Combustion**	**Process Emissions**	**Total**
Non-metallic minerals	303022	25292	36827	62119
Iron and steel	90262	4575	10558	15132
Chemicals	81648	6385	1112	7497
Non-ferrous metals	13016	771	275	1046
Pulp, paper and print	14181	1019		1019

As seen in Table 4.1, the sectors with highest CO_2 emissions could be listed as non-metallic minerals, iron & steel, chemicals, non-ferrous metals and pulp & paper. The direct CO_2 emission shares of these sub-sectors in total EIIs are shown in Figure 4.1.



* The data was taken from Turkstat CRF tables of the 2019-year.
** Total direct CO_2 emissions of Energy Intensive Industries were 86813 kt in 2019.
*** Emissions from coke production and indirect emissions are not included in the data for which this graph is prepared.

Figure 4.1 The direct CO_2 emission shares of EIIs' Sub-Sectors. (TurkStat, 2021a)

With this study, it was planned to propose specific decarbonization solutions for each energy-intensive industry. First of all, a general situation assessment was made in each sector, then possible decarbonization applications were included and emission estimates were presented. In addition, technologies that could be applicable in the long term are briefly given in the last paragraph of each sector. Potential emission reductions were presented by making rough calculations in the suggestions that it is possible to reach the required data. Calculation is made using of the 2019-year data from Turkstat (2021a, 2021b) reports generally, if there is not enough information in other reports which were published by Turkish Governmental Organizations. Information that is related suggestions of technology or implementations such as energy efficiency, energy saving, or emission reduction values were taken from different sources given in references. Every estimation was explained under related sector in details. Also, emissions were classified by GHG Protocol Corporate Accounting and Reporting Standard document published by World Business Council for Sustainable Development and World Resources Institute (2004).

4.1 NON-METALLIC MINERALS INDUSTRY

The most carbon-intensive industry in Turkey is non-metallic minerals, and it covers cement, lime, glass, and other process uses of carbonates such as ceramics, soda ash and magnesia. The emission data of the Turkish non-metallic minerals industry, related to fuel consumption, is given under 1.A.2.g category in Turkstat reports. It released 25292 kt CO_2 emission from 303022 TJ fuel consumption in 2019. Fuel consumption and related CO_2 emission values of the Turkish Non-Metallic Minerals industry are given in Table 4.2.

Table 4.2 Fuel consumption and related CO_2 emission values of Turkish Non-Metallic Minerals industry. (TurkStat, 2021a).

	Fuel Consumption (TJ)	CO_2 Emissions (kt)
Non-metallic minerals	303022	25292
Liquid fuels	121782	11738
Solid fuels	83470	8317
Gaseous fuels	63470	3407
Other fossil fuels	13173	1830
Biomass	21129	2117

Mineral industries also cause non-fuel CO_2 emissions from their production processes. Figure 4.2 shows the share of the sub-sector's non-fuel CO_2 emission rate (TurkStat, 2021b). The cement sector had the biggest share with 82.6%, while lime production has 7.6%, other process uses of carbonates have 7.9%, and glass production has 1.9%—the production and CO_2 emission data of the industry also given in Table 4.3.

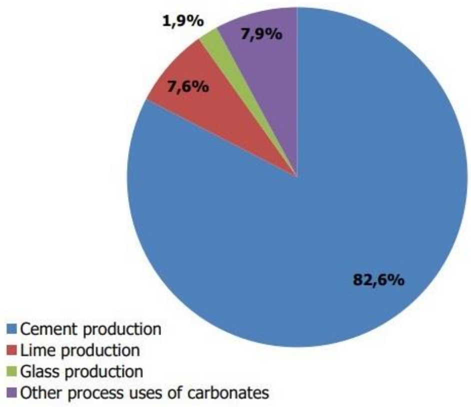


Figure 4.2 The non-fuel CO_2 emission share of the Minerals Industry' Sub-Sectors in 2019 (TurkStat, 2021b).

Table 4.3 Production and CO_2 emission data of Turkey's mineral industry' sub-sectors in 2019. (TurkStat, 2021a).

Mineral industry	Production/Consumption quantity (kt)		Emission CO_2 (kt)
Cement production	Clinker Production	57800	30423
Lime production	Lime Production	4984	2787
Glass production	Glass Production (molten)	4296	717
Other process uses of carbonates			2900
Ceramics	Total Ceramic Production	27302	2526
Other uses of soda ash	Soda Ash Use	386	160
Non-metallurgical magnesium production		410	214

Sub-sectors of the non-metallic minerals industry are examined separately in the sub-headings, as process and related emissions are evaluated separately.

4.1.1 Cement Production

Cement is a primary material used in constructing large structures such as buildings, roads and bridges. Fifty-four facilities are producing in Turkey, the largest cement producer in Europe (TurkStat, 2021b). While slag cement, pozzolan added cement, and modifications made in small quantities, Portland cement are dominant in the sector.

In the cement production process, clinker production is the stage that causes the most carbon-intensive; in 2019, it reached 57800 kt production and caused 30423 kt CO_2 emissions (TurkStat, 2021b). The cement production scheme is shown in figure 4.12.

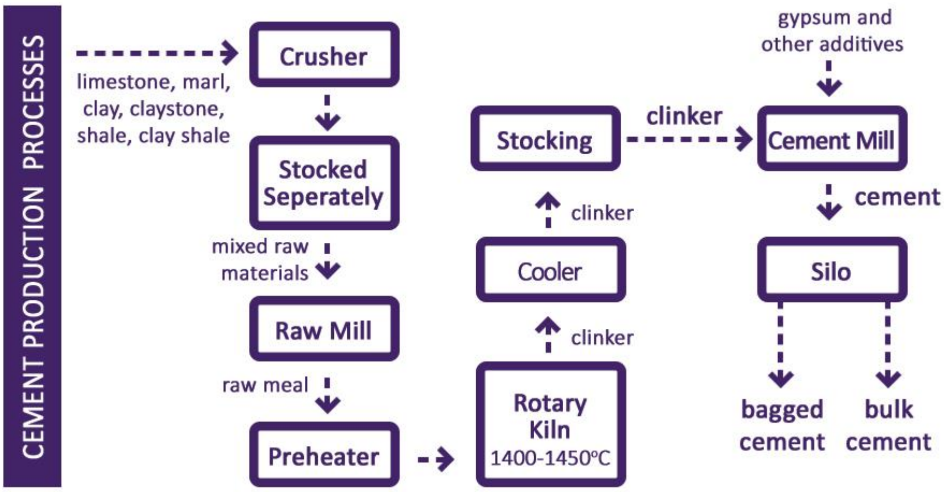


Figure 4.3 Cement Production Processes. (Kapkaç, n.d.)

Blast furnaces are the most energy-consuming equipment in cement production and are generally fed with coal, petroleum coke, and lignite (TurkStat, 2021b). Emission data from fuel consumption are included in the data generated for the mineral sector in general, Table 4.2; other CO_2 emissions related cement production are presented in table 4.3.

The existing energy-efficient technologies in the Turkish cement sector listed as; using a rotary kiln with multi-stage preheater and pre calcination; ensuring good sealing of the rotary kiln; integrating an efficient and modern clinker cooler into the system; reducing the clinker content of cement and cement products; using high-energy vertical roller mills; the establishment of electricity generation from waste heat recovery systems (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, n.d.). However, these efficiency-enhancing technologies are not applied in every facility. For example, there are still 133 facilities using ball mills in Turkey (T.C. Çevre ve Şehircilik Bakanlığı, 2016); replacing these mills with vertical roller mills, roller presses and horizontal mills will reduce the amount of energy consumed (Napp et al., 2014). In cement production, around 40% of the electricity uses for grinding and milling; switching vertical roller mills, roller presses and horizontal mills instead of ball mills could save energy between 30-40% (Napp et al., 2014). However, the emissions of electricity consumption are indirect, and the calculation could not be completed because of the lack of data on electricity consumption and CO_2 emission factor. The energy saving up to 30-40% of grinding and milling process in 133 facilities that use ball mills, by switching modern mills could reduce CO_2 emissions under Scope 2 (indirect emissions).

Biomass can have a significant effect on decarbonization in cement production. In furnaces where electricity is not possible because high heat is required, switching to 100% biomass can significantly reduce emissions caused by fuel consumption (Gerres et al., 2019). Due to the high production amount and high heat requirement, it may not be possible to meet the potential biomass demand. In addition, biomass as a fuel source for Non-Metallic Minerals, has a higher CO_2 emission factor almost than all other fuels in the default factors of Turkstat reports (2021). Therefore, switching to biomass in cement production (in all of the non-metallic minerals) could not be found applicable for Turkey condition.

Many countries around the world are working on kiln designs that increase efficiency. Although it is not a new system that can be applied today, options such as new fluidized bed kilns, which can reduce furnace emissions by 10-20% when commercialized in the future, can be assessed.

However, no matter how much energy efficiency is increased and how much low-carbon sources are placed in fuel consumption, it is impossible to prevent CO_2 emissions from chemical processes in the cement sector. Therefore, CCS technology is seen as the best choice to provide highly efficient results in emission reduction (Gerres et al., 2019). It may be the most critical application for this industry in the future.

4.1.2 Lime Production

Lime is used in wastewater treatment, gas concrete production, agriculture and iron-steel industry etc. According to the Lime Producers Association, ten lime producers receive 80% of the demand in Turkey out of soda, iron & steel and sugar industries, which produce lime for their internal consumption (KİSAD, n.d.). Lime Production is similar to cement production, but it is simpler because it has one raw material, limestone. However, it causes CO_2 emission due to chemical reactions like cement. The lime production process is shown in Figure 4.4.

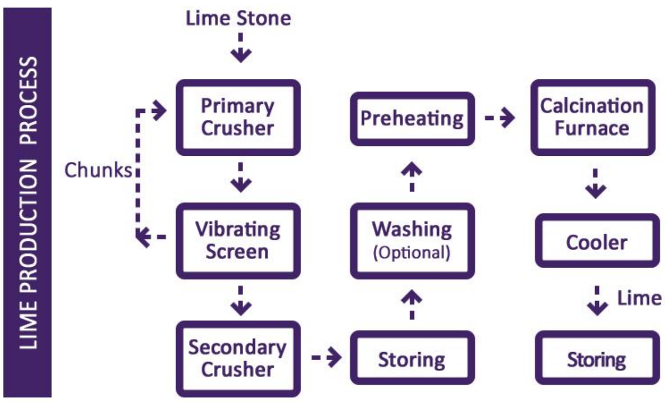


Figure 4.4 Lime Production Processes. (Dokuz Eylül Üniversitesi & T.C. Çevre ve Şehircilik Bakanlığı, n.d.-b)

High-heat furnaces are the most energy-consuming equipment, and most of the kilns in Turkey use fossil fuels in Lime production. Emission data from fuel consumption in the lime production process are involved in emission data of the mineral sector in Table 4.2. Other CO_2 emissions due to calcination reactions during lime production, are presented in table 4.3. In Turkey, 2786 kt of CO_2 emissions were released from 4984 kt of lime production in 2019.

It may be possible to achieve decarbonization in lime production, similar to the cement sector. Still, recommendations are limited as most lime plants are already modified to the best available technologies (TurkStat, 2021b).

4.1.3 Glass Production

The glass industry covers various products with different components and features such as flat glass, fiberglass, packaging, household goods for the needs from construction, automotive, food, beverage, medicine, etc. The Turkish glass industry is ranked 1st in Europe and 5th in the world in flat glass; while it has seven companies that produce the main product, there are over 12.000 small and medium-sized businesses making secondary transactions (T.C. Sanayi ve Teknoloji Bakanlığı, 2020). As in the production of cement and lime, it causes CO_2 emissions due to chemical reactions during production; emissions from fuel consumption are included in the mineral industry data, Table 4.2.

Glass is not dependent on foreign sources because it can obtain sand, soda, dolomite, and quartz from local authorities. Thanks to the glass being 100% recyclable, the waste glass is valuable as raw materials. The glass production process is presented in figure 4.5. The Turkish glass industry has grown from 4.374 kt total glass production in 2019 to 717 kt CO_2 emissions.

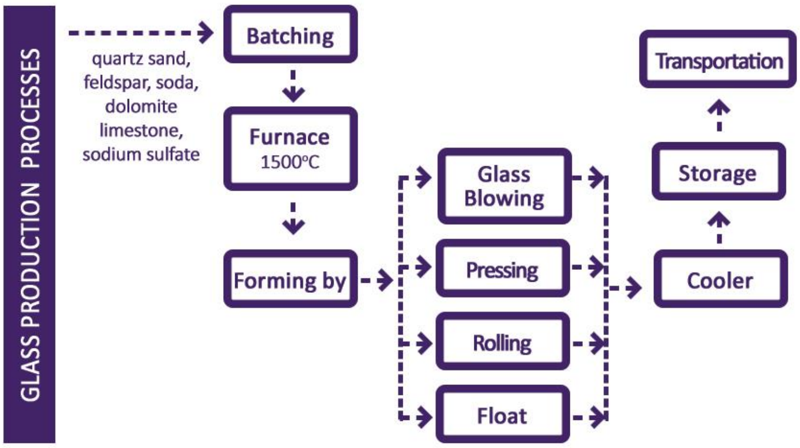


Figure 4.5 Glass Production Processes. (Dokuz Eylül Üniversitesi & T.C. Çevre ve Şehircilik Bakanlığı, n.d.-a)

In the glass industry, energy-efficient technologies such as regenerative furnaces, oxy-fuel melting furnaces, electrical melting with fossil fuel, waste glass recovery, waste heat recovery are applying (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, n.d.) Decarbonization recommendations are limited due to the high temperature used in the glass industry. Studies are carried out on furnace designs that increase efficiency and ensure switching to partial or full electrification. Although it is theoretically foreseen in some publications that full electrification of the glass industry can be achieved, it is not applicable today because there is no commercially available technology (Gerres et al., 2019).

4.1.4 Ceramic Production

The Turkish ceramics industry includes the production of ceramics, sanitary ware, wall and floor tiles, tableware and ornaments, vitrified bricks and tiles. Turkey ranks 3rd in Europe in ceramic tile production and 6th in the world (TurkStat, 2021b). As in the production of cement, lime and glass, it causes CO_2 emissions due to chemical reactions during production. Moreover, most ceramic companies use natural gas because it requires high heat and related emissions are included in the mineral industry data Table 4.12 (TurkStat, 2021b).

Since the raw materials used in ceramic products vary, emission data are calculated based on raw materials. In 2019, a total of 2525.7 kt CO_2 emissions were released from the production of 16094 kt bricks and tile, 6030 kt ceramic tile, 350 kt sanitary ware (TurkStat, 2021b).

The energy-efficient technologies currently used in the Turkish ceramic industry are listed as; switching to a dry grinding system, using continuous mills in the raw material preparation phase, establishing waste heat recovery and cogeneration systems, using microwave-assisted drying and cooking systems, replacing high-emission fuels with low-emission fuels, providing energy in all applications (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, n.d.). In addition to these improvements, the substitution of 80% of natural gas by bio-based syngas in kilns is a decarbonization application without equipment replacement. (Gerres et al., 2019). Depending on the CO_2 emission factor of the syngas to be used, the reductions that can be achieved may vary. The CO_2 reduction potential of this application could not be calculated for the Turkish ceramic industry because the amount of natural gas used in the furnaces and the synthesis gas and their CO_2 emission factors cannot be found.

4.1.5 Soda Ash and Magnesium Production

Soda ash is predominantly used in glass and detergent production; there are facilities that produce soda ash in Turkey, and the emission resulting from the production of these plants was 160 kt in 2019 (TurkStat, 2021b).

Magnesia is used in agriculture and industrial applications, refractory and electrical insulating markets. There are seven companies producing magnesia in Turkey. In 2019, 409 kt magnesia production released 213 kt of CO_2 emission (TurkStat, 2021b).

Decarbonization proposals have not been studied, since soda ash and magnesia production capacities are low.

4.2 IRON & STEEL INDUSTRY

Turkish Iron and Steel industry is the second sector that causes the most CO_2 emissions among the EIIs with a share of 17%, through fuel consumption and process emissions. It has two production routes as primary and secondary. Primary steel production is carried out in integrated iron and steel plants with the BF-BOF route that raw materials are converted into pig iron in BF and pig iron into steel in BOF. Integrated iron and steel plants also include sintering, pelletizing and coal coking plants where raw materials are processed, to increase the performance of the BF (Yılmaz et al., n.d.). Secondary steel production is carried out in EAF with steel scrap instead of hot metal (Yılmaz et al., n.d.), so it emits less carbon because the pig iron production process is not applied, in Turkey EAF facilities comprise 77% of the crude steel production capacity (TSKB, 2018). DRI which usually is produced in chimney furnaces, rotary base or fluidized bed furnaces, is also could be used as a second raw material in EAF (Yılmaz et al., n.d.). This method which could be advantageous when natural gas prices are low and is not used at all in Turkey (TurkStat, 2021b).

Induction furnaces (IF) for melting of scrap metal with electromagnetic eddies by providing highly controllable heat in secondary manufacturing could be more efficient (Rissman et al., 2020). The hot steel obtained as a result of furnaces (BOF, EAF, IF) is cooled by being shaped by ingot or continuous casting in the final stage and finished products which are slab, billet and rod shapes, are obtained to be used in various sectors (Yılmaz et al., n.d.). As of 2017, out of 32 facilities operating in the Turkish iron and steel industry, 25 use systems with electric arc furnaces, 4 with induction furnaces and 3 with blast furnaces (integrated) (T.C. Kalkınma Bakanlığı, 2018) and these production routes summarized in Figure 4.6.

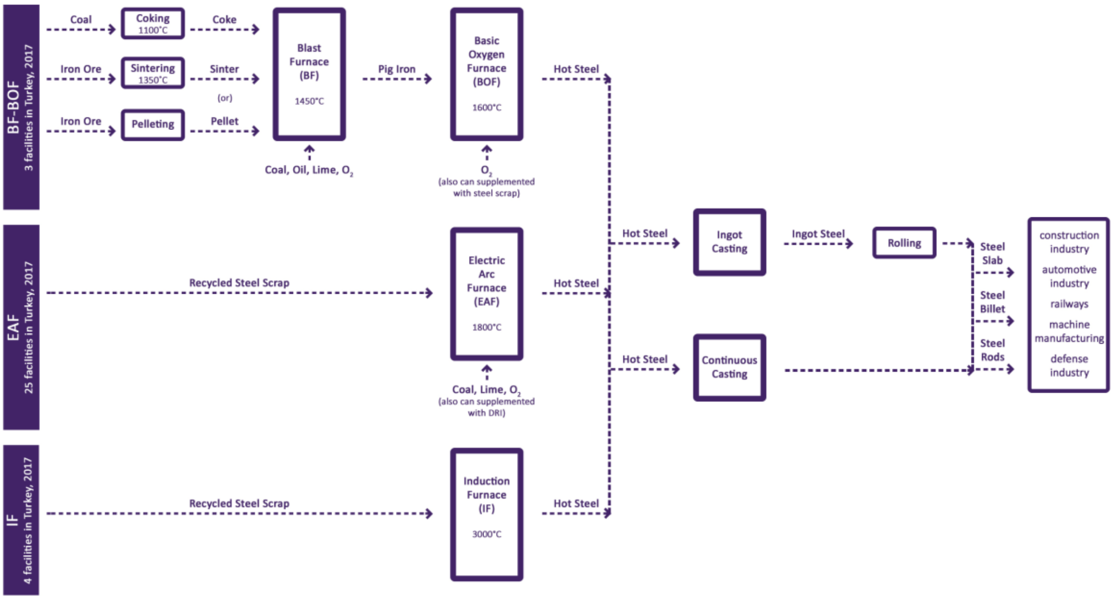


Figure 4.6 Production routes of Turkey' Iron and Steel Industry. (Yılmaz et al., n.d.)

The Iron and Steel industry has an essential position in Turkey both in the domestic market and in exports. Turkey had a share of 1,8% in the world with 33.7 million tons in 2019, ranked 8th and exported 21.2 million tons of steel (Turkish Steel Exporters' Association, 2020). However, in the same year, 14,3 million tons of steel was imported (Turkish Steel Exporters' Association, 2020). Steel importing in Turkey could be due to both the lack of raw materials and the lack of production in accordance with the domestic needs. For example, the need for flat and long steel products in Turkey has the same rate, but according to 2017 data, flat steel were produced at a rate of 33% and long steel were 67%, same year construction and agriculture sectors consumed 18.3 million tons of long steel while automotive, white goods and machinery sectors which are higher added value, consumed 17.7 million tons of flat steel so domestic production did not meet the need for flat steel (TSKB, 2018). Turkey can meet approximately 40% raw material needs from local sources as it is not rich in iron reserves; also mainly imports scrap metal, in 2017 has imported 21 billion tons of scrap metal (TSKB, 2018). Therefore, the variability in raw material prices also affects production capacities. As a result of the faster decline in ore prices compared to scrap steel prices in 2014, the capacity utilization rate in production at EAF facilities decreased to 53% in 2015, while BOF facilities increased to 94% (TSKB, 2018). This situation also affects the carbon emissions of the sector, because the BF-BOF route is more complex and more energy-intensive than the EAF route.

A SWOT analysis was made to clarify the situation of the Turkish iron and steel industry in the face of the progress of the global trend about decarbonization. Table 4.4 presents the opportunities and threats that the industry will face in addition to its current strengths and weaknesses. The sector should evaluate opportunities by using its strengths, eliminate threats by improving its weaknesses. For this, it should start to apply decarbonization technologies that can be added to the existing system in the first place, so that it could reduce the use of fossil fuel, eliminate the risk of reduction in foreign demands and be affected by carbon taxes in a minimum way.

Table 4.4 SWOT analysis of Turkey's Iron and Steel Sector in view of decarbonization.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
▪ high percentage of EAF furnace facilities ▪ having suitable environment for technological applications	▪ foreign dependency in raw material supply ▪ fossil fuels are still in use ▪ unable to prevent the use of coal as a reducing agent	▪ potential to achieving high carbon emission reductions with the decarbonization implementations ▪ support mechanisms	▪ lack of externally dependent resources ▪ imposition of additional taxes, such as carbon taxes ▪ shifting of foreign demands to products with low energy and carbon intensity

In CRF (TurkStat, 2021a) tables, carbon emission data from energy fuel consumed by the iron and steel industry is explained under the Energy - 1.A.2.a category and the data of the 2019 year are presented in Table 4.4. The iron and steel industry released CO_2 emissions 35.10 kt from liquid fuels, 1480.41 kt from solid fuels, 3059.08 kt from gaseous fuels and 14.43 kt from biomass, totaling 4574.59 kt from fuel consumption. In addition to energy consumption, the Iron and Steel industry also causes emissions from processes.

Table 4.5 Fuel consumption and related CO_2 emission values of Iron and Steel Sub-Sector. (TurkStat, 2021a).

	Fuel Consumption (TJ)	CO_2 Emissions (kt)
Iron and steel	90262	4575
Liquid fuels	486	35
Solid fuels	18352	1480
Gaseous fuels	56995	3059
Biomass	14429	14

CO_2 emission data emerging during the production process in the iron and steel industry are determined by Turkstat and experts working in integrated facilities and shared under the relevant category in the CRF tables (2021b). Identified emission sources for the iron and steel sector and production/consumption and CO_2 emissions data in 2019 are shown in Figure 4.7.

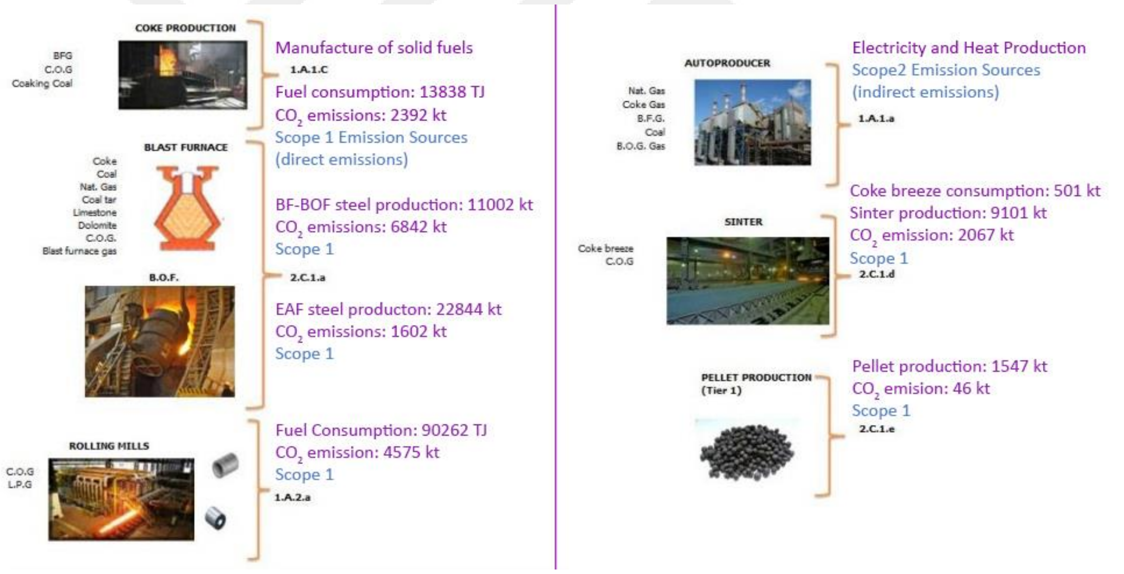


Figure 4.7 CO_2 emission sources of Turkish Iron and Steel Industry with the 2019-year consumption and CO_2 emissions data. (TurkStat, 2021a, 2021b).

Iron & steel production (category 2.C.1), which is under the IPPU category in the CRF tables, presents the emission data released during the production process (TurkStat, 2021b). Turkish iron and steel industry in 2019, released CO_2 emission 6852 kt from Iron and Steel Production (integrated plants), 1602 kt from Steel Production (EAF plants), 2067 kt from sinter production and 46 kt from pellet production, totaling 10558 kt (TurkStat, 2021b). As seen in Figure 4.7, CO_2 emissions arising from the iron and steel production process and resulting from fuel consumption are in Scope 1 emissions source category as direct emissions (WBCSD & WRI, 2004). Fuel consumption and related CO_2 emissions in the coke production process are given in the "Manufacture of solid fuels" category under Energy Industries according to Turkstat data. However, CO_2 emissions of coke production are included in Scope 1 category in this study as direct emissions sources because it is a part of the production process of integrated facilities.

In the report published by the Ministry of Energy and Natural Resources (MENR), the current technologies used in Turkey's Iron and Steel industry are listed as; use of closed charging system and wet quenching process in coke ovens; use of dry quenching technology with heat recovery in coke ovens; waste gas recirculation in sintering; recovery of blast furnace gas; recovery of energy in blast furnace peak pressure; preheating of scrap in EAF; heat recovery in the annealing line; using of Rotary Kiln, Rotary Furnace and Multi-Stage Furnace (Coal fired) (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, n.d.). In addition, technologies that have the potential to reduce more carbon emissions and are applying globally could also be evaluated.

In order to reduce energy-related emissions, biomass or electricity can be used instead of coal and natural gas in some production processes of the iron and steel industry. In blast furnaces, which is one of the most energy-consuming stages, the use of biobased fuels both in coke production and fuel injection options can be offered. According to 2019 data of CRF tables, adding up to 10% of biomass to the coal used in coke production (Rehfeldt et al., 2020) can reduce 238 kt of CO_2 emissions that equivalent to 10% CO_2 emissions from coke production. Rehfeldt et al. (2020) also included the application of biomass substitution instead of pulverized coal, which provides approximately 30% emission reduction, into their work. Turkstat does not provide BF consumption and emission data separately. Therefore, although using biomass instead of pulverized coke in BF application is recommended, emission reduction rate can not be estimated for Turkey.

Scrap steel production route with EAF has lower energy intensity than BF-BOF route, so switching to EAF could make significant energy saving (Napp et al., 2014). Approximately 77% of the facilities in Turkey have EAF furnaces. They are in a position to meet the entire production amount when used at full capacity. If total steel production in 2019 was carried out on the EAF route, 2373 kt of CO_2 emissions would have been emitted instead of 8444 kt for 33846 kt of steel production. It is equivalent to a 40% reduction in all direct emissions of the iron and steel industry (Emissions from coke production and indirect emissions such as electricity consumption of EAF are excluded.). However, the limited access to scrap metal and cheap electricity limits the usage full capacity of the EAF. In order to increase the use of EAF and electrify primary steel production, DRI production which is never used in Turkey, can be started and first quality steel could be produced by DRI-EAF route (Rehfeldt et al., 2020). Nonetheless its energy demand could be closer to the BF-BOF route, and the emission reduction rate could not be high as EAF would provide.

The reuse of waste gas and heat generated from the Iron and Steel production process is also important for decarbonization. Waste gas recirculation in sintering is already used in Turkey, but achieving heat recovery from sintering is also significant. This gained heat can be used to produce high pressure steam to generate electricity or directly for district heating (Napp et al., 2014). In addition, it is possible to increase efficiency by including digital applications such as programmed heating in coke ovens, automation of hot-blast stove, using a Multi-Gas Analyzer with online feedback in BOF, improved process control in EAF, into production processes (Napp et al., 2014). In order to obtain the final steel product, it is shaped by cold or hot rolling after casting, instead near net shape casting will be more efficient as it does not require rolling (Napp et al., 2014). Turkish iron and steel industry could start to use near net shape casting according to the demand in their casting process.

Technologies that cannot be implemented today but can be commercialized in 10 years should also be followed. Hisarna project is one of them that iron ore and coal can be added directly into the furnace without sintering and coking; in this way, it could provide CO_2 emission reduction compared to the BF-BOF route (TATA Steel, 2020). In addition, the use of coal as a reducing agent in Iron and Steel production is the biggest obstacle to reducing process emissions, so it will be essential to apply CCUS technologies in the future to reach more CO_2 emissions reduction.

4.3 CHEMICALS INDUSTRY

The chemical industry is a sector where thousands of product types are produced and has primary which released more emission during production, and secondary production. Emissions are released both from energy consumption and chemical reactions of processes. This section describes five different sub-categories.

In CRF tables, CO_2 emission data from energy consumption by the chemicals industry is explained under the Energy - 1.A.2.c category. The data of Turkish chemical industry in 2019 are presented in Table 4.8.

Table 4.6 Fuel consumption and related CO_2 emissions of Chemicals Sub-Sector. (TurkStat, 2021a)

	Fuel Consumption (TJ)	CO_2 Emissions (kt)
Chemicals	81648	6385
Liquid fuels	601	43
Solid fuels	0.20	2003
Gaseous fuels	80589	4325
Other fossil fuels	99	13
Biomass	359	36

Chemical industry (category 2.B), which is under the IPPU category in the CRF tables, also released 1112 kt CO_2 emissions in 2019 from production processes (TurkStat, 2021b). The emission share of chemical industry's sub-sectors shown in Figure 4.8, Nitric Acid production has the biggest rate with 51.7% and followed by ammonia production with 23.7% and soda ash production with 24.2% (TurkStat, 2021b). Carbide use with 0.4% and petrochemical production with 0.1% are much smaller contributors to emissions (TurkStat, 2021b). However, since this study focuses on reducing CO_2 emissions, the production of Nitric Acid, which does not release CO_2 emissions from processes, will not be discussed separately.

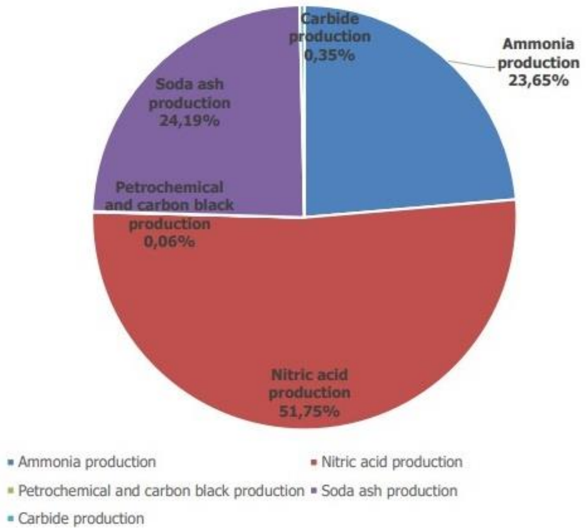


Figure 4.8 The emission share of Chemical Industry' Sub-Sectors in 2019. (TurkStat, 2021b).

The decarbonization solutions that can be applied vary according to the production process, therefore the recommendations are presented under the product-based categories which are mentioned in the Turkstat report in order below. This study only focuses on the production process of industries, so the sub-sectors of the chemicals industry, which do not produce in Turkey, include adipic acid, caprolactam, glyoxal and glyoxylic acid, carbide titanium dioxide, and fluorochemical, are excluded in this section.

4.3.1 Ammonia production

Ammonia has a wide range application as a major industrial chemical and could use directly as a fertilizer. There are two ammonia producers which use the same process and utilize natural gas to produce ammonia in Turkey. The ammonia production process is shown in Figure 4.9.

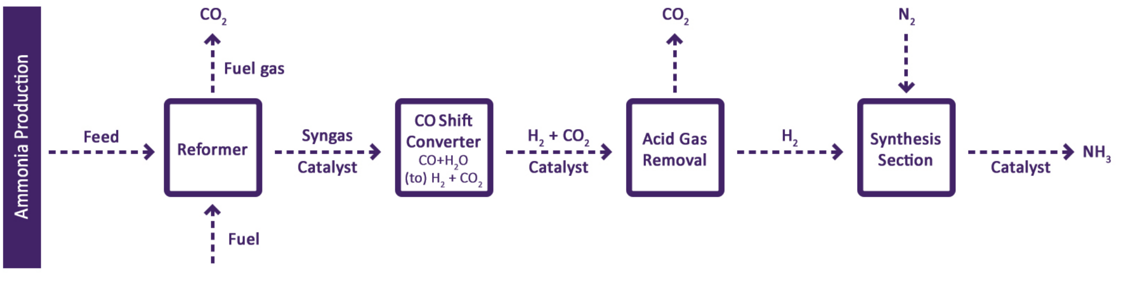


Figure 4.9 The ammonia production process. (Material Economics, 2019)

In the production of ammonia, natural gas is used both as a raw material and as a fuel; CO_2 emissions from fuel consumption and process emissions are included in same category (TurkStat, 2021b). The CO_2 removal was 333 kt from total emission and made net CO_2 emission value 545 kt in 2019.

Table 4.7 Ammonia production and related CO_2 emissions, in Turkey, 2019 (TurkStat, 2021b).

Ammonia Production	Urea Production	CO_2 Emissions	CO_2 Removal	Net CO_2 Emissions
		(kt)		
128	68	878	333	545

Ammonia also is a feedstock for hydrogen-based fuels, its usage could increase in the future by the transportation sector, indicating that it is a valuable substance as an alternative clean fuel (International Energy Agency, 2020). The relationship of ammonia with hydrogen is not limited to this, it is possible to produce low carbon ammonia if the hydrogen is integrated in chemical processes (Wyns et al., 2018).

In the future CCUS technologies could be included in every production process where carbon is released, but in ammonia sector some of the process carbon is used for urea production (Material Economics, 2019), in 2019 about 37% of the CO_2 originating from ammonia production was used in urea production in Turkey. However, this CO_2 is released back into the air during urea-based fertilizers application in agriculture, so it is discussed to integrate CCUS into the ammonia production as long as urea production continues (Material Economics, 2019).

4.3.2 Soda Ash Production

Turkish chemical industry has 3 soda ash facilities, one of them uses sodium sesquicarbonate (trona) production while the other ones use Solvay process which do not release emission because it uses all of the wastes as a resource. Therefore, the emission data of soda ash production, category 2.B.7, just related with Trona utilization and it was 557 kt in 2019 from 2278 kt soda ash production.

4.3.3 Petrochemical and Carbon Black Production

As the name suggests, the petrochemical industry uses primary fossil fuels. Plastics, which cause the biggest waste problem of our age, is also the product of this sector. There is a single petrochemicals producer in Turkey, PETKİM. The emission of fuel gas combustion is included in energy sector however the emission of the fuel gas which is combusted in the flare stacks, include in IPPU category as category 2.B.8, CO_2 emissions from flaring which represent total CO_2 emissions in petrochemical industry, were 1.35 kt in 2019 (TurkStat, 2021b).

PETKİM collects processed gases and uses them as fuel gas and because it is the only company producing petrochemicals, the amount of fuel gas burned is kept secret. Therefore, it cannot be determined exactly how much emission is caused by this fuel gas, but it can be said that it has a share in the increase of energy-related emission data in the chemical industry. The use of process gases as fuel gas is not the only solution in the petrochemical industry because it will eventually cause emissions indispensably. Therefore, we can say that the use of low-carbon fuels is more effective in providing decarbonization.

Biomass and hydrocarbons could use in petrochemical industry and electrification could be applied to reduce CO_2 emission, with increasing share usage of carbon free electricity. However, the equipment transition is required to use electricity as an energy source. Also, the shifting to low-carbon sources has limited area because most chemical plants use self-produced or derived gases from the production process (Rehfeldt et al., 2020). Using the heat potential to achieve decarbonization in the industry is also possible, some studies show the Chemicals and Petrochemicals industry are particularly well suited to CHP (Napp et al., 2014). Also waste heat recovery is another option for the chemical industry (Gerres et al., 2019). Another improvement that will provide decarbonization can be achieved in membranes. Advanced membranes could be used instead of utilizing catalysts for reducing heat needs to a minimum in liquid separation methods that are used in the petrochemical sector (Gerres et al., 2019). Also shifting from to mechanical separation processes via membranes, energy needs could decrease by 90% (Sholl & Lively, 2016), but this technology is still in research phase.

4.4 NON-FERROUS METALS INDUSTRY

The most general grouping in non-ferrous metals is divided into casting alloys and wrought alloys, all alloys that do not contain significant amounts of iron are considered non-ferrous metals (KARTES, 2020). Although ferro-alloys are containing iron, it place in the category of non-ferrous metals in this thesis like work of Cusano et al. (2017).

There are no specific analyzes for the Non-Ferrous Metals sub-sector in Turkey, the ferroalloys, aluminum, lead and copper productions are discussed one by one. In CRF tables, CO_2 emission data from fuel consumption by the non-ferrous metal industry is explained under the Energy - 1.A.2.b category and the data of Turkey in 2019 are presented in Table 4.10. The non-ferrous metal industry has the lowest fuel consumption and related emissions in the EIIs in 2019. It released CO_2 emissions 24.48 kt from liquid fuels, 141.03 kt from solid fuels, 605.73 kt from gaseous fuels, totaling 771.24 kt which is equal to almost one sixth of iron and steel industry (TurkStat, 2021a, 2021b). Copper sector is not taking place in the scope of Turkstat reports.

Table 4.8 Fuel consumption and related CO_2 emission values of Non-Ferrous Sub-Sector. (TurkStat, 2021a).

	Fuel Consumption (TJ)	**CO_2 Emissions (kt)**
Non-ferrous metals	13016	771
Liquid fuels	290	24
Solid fuels	1440	141
Gaseous fuels	11286	606

According to Turkstat reports, CO_2 emission data from the production process of ferroalloys, aluminum, lead and zinc production sectors which are under the IPPU category, are presented in table 4.11. This study only focuses on the production process of industries, so the sub-sectors of the non-ferrous metals industry, which do not produce in Turkey, include magnesium and zinc production are excluded in this section.

Table 4.9 Production and CO_2 emission data of Turkey's Non-Ferrous Metals' Sub-Sectors in 2019 (TurkStat, 2021a).

	Production (kt)	**CO_2 Emissions (kt)**
Ferroalloys Production	118	154
Primary Aluminum Production	78	112
Lead Production	44	9

4.4.1 Ferroalloys Production

Ferroalloys cause significant CO_2 emissions due to the metallurgical reduction process (TurkStat, 2021b). Due to high production costs, there are only two ferrochrome producers in Turkey that provide ferroalloy production on an industrial scale. Ferroalloys production's data, category 2.C.2, was gathered directly from these plants by Turkstat, they released 153.69 kt CO_2 emission in 2019 (TurkStat, 2021b). Emission reduction in this sector could be achieved by recovering the energy used. CCUS application is not recommended in the future, as the technology will bring high investment costs and production of ferroalloys is low.

4.4.2 Aluminum Production

Aluminum, which is the most produced metal in the world after iron and steel, is used in the construction industry, automotive, aircraft and wagon construction, electricity, packaging and metallurgy (TOBB, 2011). Aluminum sector involves enterprises that produce primary or secondary aluminum, and produce goods from aluminum by casting, forming, rolling, drawing and forging processes, and processing aluminum to the final product by alloying it with various methods (T.C. Kalkınma Bakanlığı, 2018).

Eti Aluminum, the only facility that fulfills every process requirement from raw ore to finished product and produces primary aluminum in Turkey, has production process consists of five main stages listed in Figure 4.10. Emissions data of Turkey's primary aluminum production were given under IPPU category, 2.C.3, and were calculated by Turkstat with the data collected from Eti Aluminum plant. It caused 112 kt CO_2 emissions in 2019 with 7.8 kt production. However, since it is a sector that highly consumes heat and electricity, it still needs decarbonization solutions. The primary and secondary aluminum production scheme in Turkey is presented in Figure 4.10.

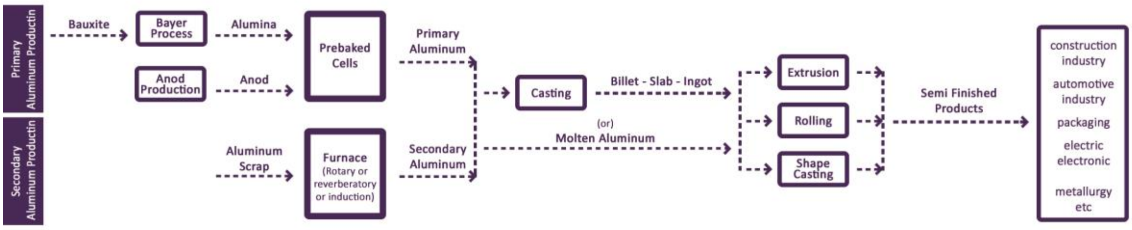


Figure 4.10 Primary and secondary aluminum production routes in Turkey. (TMMOB Metalurji Mühendisleri Odası, n.d.)

Secondary aluminum production is carried out with high efficiency, as it is a material with a high recycling rate and the first section of primary aluminum manufacturing that anod production and bayer process are not required. In secondary aluminum production requires only 5% of the energy consumed in primary aluminum production (Eroğlu & Şahiner, 2018; Haraldsson & Johansson, 2018; TMMOB Metalurji Mühendisleri Odası, n.d.) However, in April 2021 data, while 27 kt of aluminum scrap was imported, 1 kt was exported (Dinçer, 2021), in this case, it can be said that waste recycling in Turkey does not work efficiently.

The SWOT analysis made to clarify the situation of the Turkish aluminum industry in terms of decarbonization is presented in Table 4.12. The sector should increase the secondary aluminum production firstly in this way energy requirement could decrease at the rate of 95%. In addition, it should increase its production volume to meet the domestic market demand by consuming its bauxite reserves for primary aluminum production in a controlled manner. Regular data collection and calculation of emission values from small and medium-sized enterprises are also important for presenting decarbonization improvements in these enterprises.

Table 4.10 SWOT analysis of Turkey' Aluminum Sector in terms of decarbonization.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
▪ wide range of uses ▪ high recycling rate	▪ foreign dependency on raw materials ▪ poor management of the recycling process ▪ consuming high electricity ▪ lack of information about small and medium-sized businesses	▪ the domestic market needs can be met by increasing the primary aluminum production capacity ▪ secondary production can be increased by improving the scrap aluminum collection system	▪ high electricity prices may limit generation ▪ bauxite reserves may be depleted due to increased consumption if the recycling system is not enhanced

As in the iron and steel industry, it is possible to reduce carbon emissions by switching to the secondary route in aluminum production. However, there is not enough information about secondary production in Turkstat reports. Estimates have been made by taking the most recent data from the Eleventh Development Plan: Basic Metal Industry Working Group Report published by the Ministry of Development (2018). Turkey's primary aluminum production in 2017 was 7.5 kt while consumption was 111 kt (T.C. Kalkınma Bakanlığı, 2018). Since aluminum producers reuse production wastes internally, net secondary production amounts are not certain. Also, the productions of medium and small-scale producers could not be followed exactly, even it does not fully reflect the actual situation, the secondary aluminum production was reported as 9 kt in 2017 (T.C. Kalkınma Bakanlığı, 2018). According to the Ministry of Development predictions, primary aluminum production will reach 10 kt, and secondary aluminum production to 12 kt in 2023, also estimated that the average consumption per person, which is 12 kg today, will be 14.5 kg (T.C. Kalkınma Bakanlığı, 2018).

There are more than 2000 companies producing semi-finished products or casting products from primary or secondary aluminum in Turkey, while continuous casting technology is used by all rolled flat products plants, however this method does not offer a wide product portfolio so investments are required such as direct chill casting and hot strip rolling plants (T.C. Kalkınma Bakanlığı, 2018). The aluminum must be in the liquid phase in the casting process, the melting process occurred in furnaces, it is recommended to prefer electric furnaces such as induction furnace for decarbonization. According to Ministry of Development report (2018) cast aluminum production was 38 kt in 2017, data of the fuel consumption and furnace properties could not be found. If aluminum is melt by tower-furnace for all cast aluminum production, switching to induction furnaces could save 37% energy (Beyond Zero Emissions, 2018). CO_2 emissions from gas-fired tower furnaces for melting process of cast aluminum can be reduced 100% in Scope 1, but the emissions from electricity consumption of induction furnaces will increase in Scope 2. Induction furnaces are also should preferred by facilities that perform secondary aluminum production, as they offer higher recovery rates for all scrap types than rotary or reverberatory furnaces (TMMOB Metalurji Mühendisleri Odası, n.d.)

There are also technologies that are still undergoing R&D studies such as the development of carbon anodes and cathodes in the primary aluminum melting process which constitutes 40% of the emissions, or the usage of multipolar cells, the establishment of adjustable heat exchangers in electrolytic cells to meet the electricity need (International Energy Agency, 2020; Wyns et al., 2018) The Turkish aluminum industry could follow these developments closely and include them in their own R&D processes.

4.4.3 Lead Production

Lead is generally used in accumulator manufacturing, also is used in areas such as lead oxide paints that prevent corrosion, coating of cables, as a compound in gasoline, protection from x-rays because it is the metal that transmits radiation the least, ammunition production (MTA Genel Müdürlüğü, n.d.). Lead is only produced by recycling of old vehicle accumulator in Turkey. There are large amounts of vehicle accumulator to be recycled each year from over 20 million registered road vehicles, so there are many Waste Accumulator Recovery Plants (TurkStat, 2021b). Old batteries are classified as hazardous waste and statistically inspected, emission values of lead production, category 2.C.5 in NIR report, listed under IPPU category. 44 kt lead produced from 73 kt waste accumulator and caused 8.8 kt CO_2 emissions in 2019 (TurkStat, 2021b).

Lead recycling from batteries is provided as follows; accumulators are broken into pieces, these pieces separated by floating, in next step lead is melted in a furnace containing some reducing agent, silica and iron, during this process CO_2 is released from the furnace (TurkStat, 2021b). The main environmental problems associated with secondary lead production come from the exhaust gases from the furnaces (Cusano et al., 2017).

Although the secondary lead production process is explained simply, melting could be achieved by using various processes such as blast furnaces, rotary kilns, reverberatory furnaces, kaldo method, electrothermic furnaces with the pyrometallurgical method and RSR process, USBM Process, engitec process, ginatta process, AAS process, direct electrolyte methods, placid process, plint process with the hydrometallurgical method (Malayoğlu, 2011). There is no information on how many establishments in Turkey produce with which method and there is no carbon emission data specific to these processes. Therefore, decarbonization recommendations are presented in a limited way.

CCUS technology would reduce carbon emissions from the furnace in secondary lead production, but it will not be realistic to implement the technology recommendations as many and small enterprises provide production.

4.4.4 Copper Production

Copper metal, which is widely used in the industry, has a wide usage area such as electricity and electronics, energy, transportation, automotive, construction, jewelry, ornaments, chemistry sectors and is used in voltage power cables, generators, transformers thanks to its high conductivity feature (T.C. Kalkınma Bakanlığı, 2018). With the increase of electrification while the need for fossil fuels is decreasing the demand for copper will increase and it will be at the center of the energy transition time. (International Energy Agency, 2020).

There are 1961 companies operating in the copper industry in Turkey and the annual copper consumption amount is 50 kt, the raw material cost is high as a result of foreign dependency and in the production phase energy cost is high too (T.C. Kalkınma Bakanlığı, 2018). As with aluminum, copper is obtained by primary and secondary production routes. In primary production, copper concentrates are obtained by enriching the sulfide ores with the flotation method, blister copper is produced from these concentrates by smelting methods which are reverberatory and converter or by flash and converter, then electrolyte copper is produced from blister copper by refining process (Ünal et al., 2016). Although there is no data on the production method of copper producers in Turkey, emission data have not been generated either. As electrification increases in future, production is likely to increase with the need for copper, so production and emissions data need to be monitored. There is only one plant, Eti Bakır Samsun, that produces copper from ore in Turkey and it produces 42000 kt of electrolytic copper annually (Eti Bakır, n.d.).

Secondary copper production amount and methods in Turkey are not known. According to estimates copper scrap recycling rate is very high, almost 100% of new copper scrap and almost 95% old copper scrap can be recycled (Cusano et al., 2017). It is predicted that CO_2 emissions from secondary production will be lower than primary like as iron and steel and aluminum production.

4.5 PULP, PAPER AND PRINT INDUSTRY

Paper, which is the primary material of the products frequently used in daily life, is divided into two classes: cultural papers covering writing and newsprint in the sector and industrial papers covering wrapping, cleaning, kraft bags, and corrugated cardboard and cigarette papers (Bayrak et al., 2020). Cellulose, the raw material of paper products, is generally obtained from trees, annual plants, or recycling waste paper; therefore, the paper industry is directly related to the forest products industry and the waste paper industry. Products we use every day, such as packaging, cleaning papers, and books, are classified according to their usage areas and are produced in related sectors.

Cellulose is obtained from specially grown industrial woods and annual plants to prevent desertification. The paper industry consumes 20% of the industrial wood produced in Turkey; this rate equaled 38 kt of wood in 2018 and approximately 16 kt of paper (Bayrak et al., 2020). This figure is far below the consumption because industrial forests are not enough; it is more expensive to produce cellulose from wood, so cellulose is mainly importing.

Production from recycled paper in the paper industry is an essential factor in providing decarbonization. While waste paper prevents the consumption of forest products, it also increases production efficiency as it needs less water and energy in the production process. According to a report prepared by Bayrak et al. (2020), it stated that by bringing 1 ton of waste paper into production could prevent to cut down 17 mature pine trees, 36 tons of CO_2 emission, 267 kg of pollutant gas emission, consumption of 4100 kWh electricity, 1750 lt fuel oil and 38.8 tons of water. For this reason, recycling paper is significant for the environment and preferred by facilities as it has high efficiency. Still, since the paper recycling rate is low in Turkey, the production demand cannot be met by domestic sources, and waste paper is also importing.

Production processes of paper are showing in Figure 4.7 The number of enterprises in Turkey's pulp and paper sector was 3479 in 2017 (İstanbul Sanayi Odası, 2018), and none of them produces cellulose. It is estimated that the number of enterprises that use industrial wood to make paper in integrated facilities is low. The rest of the enterprises that produce from waste paper or imported cellulose are the majority.

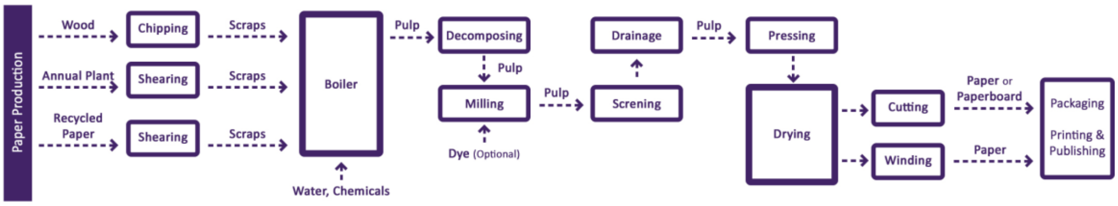


Figure 4.11 Pulp and Paper Industry' production routes. (Bayrak et al., 2020; Hasanbeigi et al., 2021)

In the reports of Turkstat, the Turkish Pulp and Paper Industry fuel consumption was 14181 TJ and related CO_2 emissions was 1019 kt in 2019. The data of the fuel consumption and related CO_2 emissions are giving in Table 4.13.

Table 4.11 Fuel consumption and related CO_2 emissions of Pulp, Paper and Print Sub Sector. (TurkStat, 2021a)

	Fuel Consumption (TJ)	**CO_2 Emissions (kt)**
Pulp, paper and print	14181	1019
Liquid fuels	220	19
Solid fuels	5169	534
Gaseous fuels	8697	467
Biomass	95	10

The most energy consumption processes in paper production are in the stages where heat is provided, as in other sectors. It is possible to achieve energy savings by improved heat recovery for multi-cylinder dryers (Laurijssen, De Gram, et al., 2010; Utlu & Kincay, 2013) and using closed heat in preheating equipment (Laurijssen, Marsidi, et al., 2010). Applying improved heat recovery for multi-cylinder dryers could reduce 15% primary energy consumption (Laurijssen, De Gram, et al., 2010). If it was assumed that multi-cylinder dryers are used in 90% of paper production plants (Gerres et al., 2019) in Turkey, and also if it was assumed that the reduction of 15% energy consumption has occurred in total fuel consumption; CO_2 emission reduction would be 137 kt according to the 2019 Turkstat data. It equals a 13% reduction from total CO_2 emissions from fuel consumption from the Turkish Pulp and Paper Industry. In addition, although CHP is not a new technology, it is well-suited for the Pulp and Paper industry (Napp et al., 2014). The evaluation of the steam generated in the drying process for electricity generation facilities, a method primarily used in the Turkish paper industry, can be given as an example to CHP (Dokuz Eylül Üniversitesi, n.d.).

5. DISCUSSION

Ensuring decarbonization in Turkey's energy-intensive industries is one of the steps to be taken in facing the global climate crisis. Agreements and policies prepared under the leadership of international organizations also support decarbonization. Many international studies focus on providing decarbonization in energy-intensive industries. However, no study summarizes the situation in Turkey and introduces new measures that can be taken today. The primary purpose of the thesis is to fill this gap.

The common feature of energy-intensive industries is the need for high heat and, accordingly, high energy expenditure. Therefore, decarbonization recommendations are given to increase the efficiency of the equipment providing the heat, increase the use of energy sources with lower carbon content, and reduce the amount of lost energy such as waste heat. Many studies published internationally include new technologies to provide more decarbonization. Since this thesis aims to provide solutions suitable for today, non-commercialized proposals are not included. Some of the efficiency-enhancing solutions are already implemented in energy-intensive industries so were not recommended again. At the same time, decarbonization proposals have been restricted as the focus is on direct emissions reductions resulting from industries' fuel consumption and processes. The suggestions of technology and application are presented to the energy-intensive industries' five sub-sectors are summarized in Table 5.1.

The energy-saving or CO_2 emission reduction rates stated in the studies where decarbonization recommendations were taken, and the consumption, production and CO_2 emission values obtained from the reports published by Turkish organizations specific to EIIs were used to make rough calculations. Since the information that is required for accounting for some recommendations could not be reached, the CO_2 emission reduction amounts could not be determined.

Table 5.1 Suggestions of decarbonization technologies and implementations with calculations.

Sector	Technology / Implementation	Process Applied	Benefits of Suggestion	Emissions Reductions	Comments	Sources
Cement Production	Switching Modern Mills	Using vertical roller mills, roller presses and horizontal mills instead of ball mills	30-40% energy saving	30-40% energy saving from electricity usage for grinding and milling which has share 40% from all electricity consumption in cement production.	There are 133 facilities in Turkey that appropriate this implementation. However, emissions from electricity consumption of grinding and milling is indirect and evaluated under Scope 2.	Ministry of Environment and Urbanisation (2016) and Napp et al. (2014).
Ceramic Production	Syngas Substitution	Adding up to 80% syngas to natural gas in kilns	CO_2 emission reduction	The amount of CO_2 emission reduction from fuel consumption is changes depends on Syngas CO_2 emission factor.	It could not be calculated because the amount of natural gas used in the furnaces and the synthesis gas CO_2 emission factor could not be reached.	(Gerres et al., 2019)
Iron and Steel	Biomass Substitution	Adding up to %10 biomass to the coal used in coke production	10% CO_2 emission reduction	238 kt of CO_2 emissions from coke production. (Scope 1)	It is equivalent to 10% CO_2 emissions from coke production.	Calculation is made using of the 2019 year data from Turkstat tables (2021) and information from Rehfeldt et al. (2020).
Iron and Steel	Biomass Substitution	Adding biomass instead of pulverized coal in BF	30% CO_2 emission reduction	30% CO_2 emission reduction from BF. (Scope 1)	It could not be calculated because BF consumption and emission data could not be reached.	Rehfeldt et al. (2020).
Iron and Steel	Switching to EAF	Secondary steel production	40% CO_2 emission reduction	6071 kt from direct CO_2 emissions of iron & steel industry. (Scope 1)	It was assumed that total steel production in 2019 was carried out on the EAF route. 6071 kt is equivalent to a 40% of all direct emissions by the iron and steel industry without emissions from coke production and indirect emissions such as electricity consumption of EAF.	Calculation is made using of the 2019 year data from Turkstat tables (2021) and information from Napp et al. (2014).
Iron and Steel	Heat Recovery	Heat recovery from sintering	energy saving	Gained heat can be used to produce high pressure steam to generate electricity. (Scope 1)		(Napp et al., 2014)
Aluminum	Induction Furnaces	Melting process for cast aluminum production by tower furnace	37% energy saving	100% from tower furnace gas consumption. (Scope 1.)	Emissions from electricity consumption of induction furnaces should be added in Scope 2.	Calculation is made using of the 2017 year data from Ministry of Development report (2018) and information from Beyond Zero Emissions (2018.)
Pulp and Paper	Improved Heat Recovery	Multi-cylinder dryers	15% energy saving	137 kt from primary fuel consumption. (Scope 1.)	It was assumed that multi-cylinder dryers are used in 90% of paper production plants in Turkey. 137 kt is equivalent to 13% of primary fuel consumption by pulp and paper industry.	Calculation is made using of the 2019 year data from Turkstat tables (2021) and information from Laurijssen et al. (2010) and Gerres et al. (2019).

The total direct emissions caused by EIIs in Turkey in 2019 were 86812 kt. In this study, eight implementation proposals are given in the table, and only 3 have CO_2 emission reduction calculations. Total CO_2 emission reduction is calculated as 6446 kt, corresponding to 7% of the total direct emissions of EIIs in 2019. 238 kt reduction by adding up to 10% biomass to the coal used in coke production; 6071 kt reduction by switching to EAF in Iron and Steel production; 137 kt reduction by Improved Heat Recovery from multi-cylinder dryers in pulp and paper industry were calculated.

EIIs can reduce CO_2 emissions from fuel consumption by choosing low-carbon energy sources, updating equipment to increase efficiency, and reusing waste heat. However, new technologies are needed to reduce process emissions generally from the chemical transformation of raw materials such as iron and steel production, cement and chemical productions. Industrialists and government can apply the current developments and recommendations presented in this study until new technologies are commercialized.

Decarbonization is like energy efficiency, solutions for more decarbonization will be updated as time goes on. Turkey Energy Intensive Industries should be aware of these updates until it has a high technologic structure. Decarbonization suggestions which could apply in the long term, including indirect emissions, could be a subject to be studied in the next step.

6. CONCLUSION

Decarbonization could define as; doing the same work with less energy; emitting less carbon per unit of energy consumed; reducing energy, material or carbon density; reducing carbon emissions through decreasing fuel, energy or material consumption. This study focuses on decarbonization potentials in the Turkish Energy-Intensive Industries and suggests decarbonization implementations to reduce direct CO_2 emissions of EIIs. Providing decarbonization in EIIs is an essential issue because international organizations' putting the trade of energy-intensive products on the agenda, puts the economy of Turkey which has a high export share in these products, at risk. For example, the Carbon Border Adjustment Mechanism published by the EU, it is planned to applied additional taxes to importers in Europe from 2026. Until this time, it is a necessity for Turkey to take action to decarbonize its industry.

Decarbonization solutions to reduce direct CO_2 emission, which can be implemented as soon as possible in Turkey, can be listed as follows if summarized on the basis of all EIIs.

1- Providing the energy requirements from sources that have low density than the current source,
2- Increasing the efficiency of existing equipment to save energy and materials,
3- Finding solutions with in-plant for high recovery of heat, water, steam, chemicals, or other materials generated as waste in existing systems,
4- Reducing process CO_2 emissions by developing the current devices and equipment,
5- Increasing the rates of secondary production, which are generally less carbon-intensive.

The calculation that 10% biomass substitution to the coal that used in coke production, provides 238 kt of CO_2 emissions reduction from coke production, shows the potential of the transition to low carbon fuel. The calculation that improved heat recovery from multi-cylinder dryers reduce 137 kt CO_2 emissions from pulp and paper industry' primary fuel consumption, shows the potential of in-plant recovery systems. The 6071 kt direct CO_2

emissions reduction that provided by switching to EAF in iron and steel industry, is proof of how increasing secondary production could increase decarbonization.

The potential examples presented above may not be sufficient to increase decarbonization applications. Turkey should develop supportive and deterrent policies to increase decarbonization practices in EIIs. Policy recommendations are shared below.

1- Carbon tax mechanism should be implemented quickly.
2- With the revenues obtained from carbon tax, new technological research or projects that will provide decarbonization technologies can be funded.
3- In order to increase the secondary production, where waste materials are used as raw materials in general, a comprehensive mechanism can be designed in the field of waste management, involving companies, municipalities and the public.
4- Laws can be enacted requiring EIIs to reuse lost energies such as waste heat and steam from their processes.

Apart from these policy implementations, it is also important for Turkey to act together with other countries against the climate crisis. First of all, accepting the Paris Agreement and becoming a party can strengthen its communication and business relations with other countries.

BIBLIOGRAPHY

Bajželj, B., Allwood, J. M., & Cullen, J. M. (2013). Designing Climate Change Mitigation Plans That Add Up. *Environmental Science & Technology*, *47*(14), 8062–8069. https://doi.org/10.1021/es400399h

Bayrak, H., Bayrak, C., & Güvendikler, M. E. (2020). *Doğu Marmara Kağıt Sektör Raporu* (p. 140). Doğu Marmara Kalkınma Ajansı. https://www.kalkinmakutuphanesi.gov.tr/assets/upload/dosyalar/kagit-raporu.pdf

Beyond Zero Emissions. (2018). *Zero Carbon Industry Plan: Electrifying Industry*. https://bze.org.au/wp-content/uploads/2020/12/electrifying-industry-bze-report-2018.pdf

Bhattacharyya, S. C. (2019). *Energy Economics: Concepts, Issues, Markets and Governance*. Springer London. https://doi.org/10.1007/978-1-4471-7468-4

Cusano, G., Gonzalo, M. R., Farrell, F., Remus, R., Roudier, S., & Sancho, L. D. (2017). *Best available techniques (BAT) reference document for the non-ferrous metals industries*. Publications Office. https://data.europa.eu/doi/10.2760/8224

de Bruyn, S., Jongsma, C., Kampman, B., Görlach, B., & Thie, J.-E. (2020). *Energy-intensive industries*. 93.

Dinçer, D. (2021). *ALÜMİNYUM SEKTÖRÜ Mayıs 2021 DEĞERLENDİRMESİ*. İDDMİB. https://www.turkishmetals.org/storage/files/ihracat_files/1623060672.pdf

Dokuz Eylül Üniversitesi. (n.d.). *Kâğıt Üretimi: Sektörel Uygulama Kılavuzu (Taslak)*. T.C. Çevre ve Şehircilik Bakanlığı. Retrieved June 20, 2021, from https://webdosya.csb.gov.tr/db/sanayihavarehberi/icerikler//18_k-git-uret-m--20200103075114.pdf

Dokuz Eylül Üniversitesi, & T.C. Çevre ve Şehircilik Bakanlığı. (n.d.-a). *Sektörel Uygulama Kılavuzu: Cam Üretimi*. Retrieved August 23, 2021, from https://webdosya.csb.gov.tr/db/sanayihavarehberi/icerikler/06_cam-uret-m--20200103075113.pdf

Dokuz Eylül Üniversitesi, & T.C. Çevre ve Şehircilik Bakanlığı. (n.d.-b). *Sektörel Uygulama Kılavuzu: Kireç Üretimi*. Retrieved August 23, 2021, from https://webdosya.csb.gov.tr/db/sanayihavarehberi/icerikler//20_k-rec-uret-m--20200103075114.pdf

Eroğlu, G., & Şahiner, M. (2018). *DÜNYADA VE TÜRKİYE'DE ALÜMİNYUM*. MADEN TETKİK VE ARAMA GENEL MÜDÜRLÜĞÜ. https://www.mta.gov.tr/v3.0/sayfalar/bilgi-merkezi/maden-serisi/aluminyum.pdf

Eti Bakır. (n.d.). *Samsun İzabe ve Elektroliz Tesisi*. Eti Bakır. Retrieved June 21, 2021, from https://etibakir.com.tr/tesisler/samsun-izabe-elektroliz-tesisi/

European Commission. (n.d.). *Carbon Border Adjustment Mechanism* [Text]. European Commission. Retrieved August 19, 2021, from https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661

European Commission. (2019). *The European Green Deal*. https://ec.europa.eu/info/sites/default/files/european-green-deal-communication_en.pdf

European Commission. (2020). *A new Circular Economy Action Plan For a cleaner and more competitive Europe*. European Commission.

https://ec.europa.eu/info/sites/default/files/communication-eu-industrial-strategy-march-2020_en.pdf

European Commission & Climate Action DG. (2019). *Going climate-neutral by 2050: A strategic long-term vision for a prosperous, modern, competitive and climate-neutral EU economy*.

European Union. (n.d.). *European Commission*. Retrieved March 21, 2021, from https://europa.eu/european-union/about-eu/institutions-bodies/european-commission_en

Fischedick, M., Roy, J., Abdel-Aziz, A., Acquaye, A., Allwood, J. M., Ceron, J.-P., Geng, Y., Kheshgi, H., Lanza, A., Perczyk, D., Price, L., Santalla, E., Sheinbaum, C., & Tanaka, K. (2014). Industry. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Gerres, T., Chaves Ávila, J. P., Llamas, P. L., & San Román, T. G. (2019). A review of cross-sector decarbonisation potentials in the European energy intensive industry. *Journal of Cleaner Production*, *210*, 585–601. https://doi.org/10.1016/j.jclepro.2018.11.036

Haraldsson, J., & Johansson, M. T. (2018). Review of measures for improved energy efficiency in production-related processes in the aluminium industry – From electrolysis to recycling. *Renewable and Sustainable Energy Reviews*, *93*, 525–548. https://doi.org/10.1016/j.rser.2018.05.043

Hasanbeigi, A., Kirshbaum, L. A., Collison, B., & Gardiner, D. (2021). *Electrifying U.S. Industry: A Technology- and Process-Based Approach to Decarbonization*. 118.

IEA. (2019). *The Future of Hydrogen*. IEA, Paris. https://www.iea.org/reports/the-future-of-hydrogen

IEA. (2020, September 9). *Global industrial CO2 emissions in the Sustainable Development Scenario, 2019-2070*. https://www.iea.org/data-and-statistics/charts/global-industrial-co2-emissions-in-the-sustainable-development-scenario-2019-2070

IEA. (2021). *Net Zero by 2050*. IEA, Paris. https://www.iea.org/reports/net-zero-by-2050

İklim Haber. (2021, March 10). *ABD ve AB'den İklim Krizi Konusunda Birlikte Çalışma Kararı*. https://www.iklimhaber.org/abd-ve-abden-iklim-krizi-konusunda-birlikte-calisma-karari/

International Energy Agency. (2020). Energy Technology Perspectives 2020. *Energy Technology Perspectives*, 400.

IPCC. (2007). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer, Eds.). Cambridge University Press.

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier,

B. Kriemann, J. Savolainenr, S. Schlömer, C. von Stechow, T. Zwickel, & J. C. Minx, Eds.). Cambridge University Press.

İstanbul Sanayi Odası. (2018). *Kağıt ve Kağıt Ürünleri İmalat Sanayi*. https://www.iso.org.tr/sites/1/upload/files/kagit_sektoru_raporu_web_kasim2018-9076.pdf

Kapkaç, F. (n.d.). *Çimento Çeşitleri, Özellikleri, Hammaddeleri ve Üretim Aşamaları*. 10.

KARTES. (2020, March 11). *Demir Olmayan Metaller Nelerdir? – Ağır Metaller*. https://kar-tes.com.tr/blog/genel-bilgiler/demir-olmayan-metaller-nelerdir-agir-metaller/

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

KİSAD. (n.d.). *Hakkımızda*. Retrieved June 26, 2021, from http://www.kirec.org/tr/1-hakkimizda.html

Kovač, A., Paranos, M., & Marciuš, D. (2021). Hydrogen in energy transition: A review. *International Journal of Hydrogen Energy*, *46*(16), 10016–10035. https://doi.org/10.1016/j.ijhydene.2020.11.256

Laurijssen, J., De Gram, F. J., Worrell, E., & Faaij, A. (2010). Optimizing the energy efficiency of conventional multi-cylinder dryers in the paper industry. *Energy*, *35*(9), 3738–3750. https://doi.org/10.1016/j.energy.2010.05.023

Laurijssen, J., Marsidi, M., Westenbroek, A., Worrell, E., & Faaij, A. (2010). Paper and biomass for energy? *Resources, Conservation and Recycling*, *54*(12), 1208–1218. https://doi.org/10.1016/j.resconrec.2010.03.016

Madeddu, S., Ueckerdt, F., Pehl, M., Peterseim, J., Lord, M., Kumar, K. A., Krüger, C., & Luderer, G. (2020). The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat). *Environmental Research Letters*, *15*(12), 124004. https://doi.org/10.1088/1748-9326/abbd02

Malayoğlu, U. (2011). *ATIK AKÜLERİN GERİ KAZANIM YÖNTEMLERİ VE TEKNOLOJİLERİ*. http://www.haliccevre.com/images/sempozyum/17.pdf

Material Economics. (2019). *Industrial Transformation 2050—Pathways to Net-Zero Emissions from EU Heavy Industry*. https://materialeconomics.com/publications/industrial-transformation-2050

MTA Genel Müdürlüğü. (n.d.). *Kurşun*. Retrieved June 20, 2021, from https://www.mta.gov.tr/v3.0/metalik-madenler/kursun

Nakićenović, N. (1996). Decarbonization: Doing more with less. *Technological Forecasting and Social Change*, *51*(1), 1–17. https://doi.org/10.1016/0040-1625(95)00167-0

Napp, T. A., Gambhir, A., Hills, T. P., Florin, N., & Fennell, P. S. (2014). A review of the technologies, economics and policy instruments for decarbonising energy-intensive manufacturing industries. *Renewable and Sustainable Energy Reviews*, *30*, 616–640. https://doi.org/10.1016/j.rser.2013.10.036

Paris Agreement, UNITED STATES OF AMERICA: ACCEPTANCE. (2021). United Nations; C.N.10.2021.TREATIES-XXVII.7.d. https://treaties.un.org/doc/Publication/CN/2021/CN.10.2021-Eng.pdf

Rehfeldt, M., Worrell, E., Eichhammer, W., & Fleiter, T. (2020). A review of the emission reduction potential of fuel switch towards biomass and electricity in

European basic materials industry until 2030. *Renewable and Sustainable Energy Reviews*, *120*, 109672. https://doi.org/10.1016/j.rser.2019.109672

Rissman, J., Bataille, C., Masanet, E., Aden, N., Morrow, W. R., Zhou, N., Elliott, N., Dell, R., Heeren, N., Huckestein, B., Cresko, J., Miller, S. A., Roy, J., Fennell, P., Cremmins, B., Koch Blank, T., Hone, D., Williams, E. D., de la Rue du Can, S., … Helseth, J. (2020). Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. *Applied Energy*, *266*, 114848. https://doi.org/10.1016/j.apenergy.2020.114848

Sholl, D. S., & Lively, R. P. (2016). Seven chemical separations to change the world. *Nature*, *532*(7600), 435–437. https://doi.org/10.1038/532435a

Sun, J. W. (2005). The decrease of CO2 emission intensity is decarbonization at national and global levels. *Energy Policy*, *33*(8), 975–978. https://doi.org/10.1016/j.enpol.2003.10.023

TATA Steel. (2020). *HISARNA: Building a sustainable steel industry*. https://www.tatasteeleurope.com/ts/sites/default/files/TS%20Factsheet%20Hisarna%20ENG%20jan2020%20Vfinal03%204%20pag%20digital.pdf

T.C. Çevre ve Şehircilik Bakanlığı. (2016). *Çimento Sanayi İçin Mevcut En İyi Teknikler (MET) Ulusal Kılavuzu*. https://webdosya.csb.gov.tr/db/ippc/icerikler/ulusal-met-kilavuzu-20180425132410.pdf

T.C. Enerji ve Tabii Kaynaklar Bakanlığı. (n.d.). *Sanayide Enerji Verimli Teknolojiler*.

T.C. Kalkınma Bakanlığı. (2018). *On Birinci Kalkınma Planı (2019-2023): Ana Metal Sanayi Çalışma Grubu Raporu* (p. 314).

T.C. Sanayi ve Teknoloji Bakanlığı. (2020). *Cam Sektörü Raporu (2020)*. https://www.sanayi.gov.tr/assets/pdf/plan-program/CamSektorRaporu2020.pdf

TMMOB Metalurji Mühendisleri Odası. (n.d.). *Alüminyum Raporu*.

TOBB. (2011). *TÜRKİYE DEMİR VE DEMİR DIŞI METALLER MECLİSİ SEKTÖR RAPORU 2010*. https://www.tobb.org.tr/Documents/yayinlar/Tobb_Demir_Sektor_rapor2011.pdf

TSKB. (2018). *Sektörel Görünüm: Demir Çelik, Mayıs 2018*. https://www.tskb.com.tr/i/assets/document/pdf/sektorel-demir-celik.pdf

Turkish Steel Exporters' Association. (2020). *Çelik İhracatçıları Birliği 2019 Çalışma Raporu*. https://www.cib.org.tr/files/Doc/files/2019_Calisma_Raporu.pdf

Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı. (n.d.). *Paris Anlaşması*. Retrieved March 21, 2021, from https://iklim.csb.gov.tr/paris-anlasmasi-i-98587

TurkStat. (2021a). *2019 Turkey CRF Tables*.

TurkStat. (2021b). *TURKISH GREENHOUSE GAS INVENTORY 1990—2019*.

Ünal, İ. H., Tuncel, S., Yücel, M. B., Yoleri, B., & Arslan, M. (2016). *Türkiye ve Dünyada Bakır*. Maden Tetkik ve Arama Genel Müdürlüğü. https://www.mta.gov.tr/v3.0/sayfalar/bilgi-merkezi/maden-serisi/Bakir.pdf

UNDP. (n.d.). *Sustainable Development Goals*. Retrieved March 21, 2021, from https://www.undp.org/content/undp/en/home/sustainable-development-goals.html

UNDP Türkiye. (n.d.). *Türkiye'de UNDP*. Retrieved March 21, 2021, from https://www.tr.undp.org/content/turkey/tr/home/about-us.html

UNFCCC Sites and platforms. (n.d.). *Conference of the Parties (COP)*. Retrieved March 21, 2021, from https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop

United Nations. (n.d.-a). *History of the United Nations*. Retrieved March 21, 2021, from https://www.un.org/en/about-us/history-of-the-un

United Nations. (n.d.-b). *United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992*. Retrieved March 21, 2021, from https://www.un.org/en/conferences/environment/rio1992

United Nations. (2015). *Paris Agreement*. 3.

United Nations Climate Change. (n.d.). *The Paris Agreement*. Retrieved May 3, 2021, from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Utlu, Z., & Kincay, O. (2013). An assessment of a pulp and paper mill through energy and exergy analyses. *Energy*, *57*, 565–573. https://doi.org/10.1016/j.energy.2013.05.054

WBCSD, & WRI (Eds.). (2004). *The greenhouse gas protocol: A corporate accounting and reporting standard* (Rev. ed). World Business Council for Sustainable Development ; World Resources Institute.

Wiertzema, H., Svensson, E., & Harvey, S. (2020). Bottom–Up Assessment Framework for Electrification Options in Energy-Intensive Process Industries. *Frontiers in Energy Research*, *8*, 192. https://doi.org/10.3389/fenrg.2020.00192

Wyns, T., Khandekar, G., & Robson, I. (2018). *Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe*. https://www.ies.be/node/4758

Yılmaz, Ö., Yetiş, Ü., & Karanfil, T. (n.d.). *Sektörel Atık Kılavuzları: Demir Çelik Sanayi*. T.C. Çevre ve Şehircilik Bakanlığı. Retrieved June 12, 2021, from https://webdosya.csb.gov.tr/db/cygm/editordosya/Demir_celik_Sanayi_Kilavuzu.pdf

CURRICULUM VITAE

Personal Information
Name and surname:
Begüm Ünlü

Academic Background
Bachelor’s Degree Education:
Anadolu University, Faculty of Architecture and Design, Industrial Design - Eskişehir
Foreign Languages: English

Work Experience
February 2017 – Current, 2F Gıda Pazarlama
December 2014 – November 2016, NOBLE Environmentals Technologies Turkey