Mühendis ve Makina / Engineer and Machinery
https://dergipark.org.tr/tr/pub/muhendismakina

AN OVERVIEW OF TÜRKİYE'S RENEWABLE ENERGY OUTLOOK

Zafer ÇAKMAK*
İstanbul Üniversitesi, İşletme Fakültesi, İşletme Yönetimi ve Organizasyon Ana Bilim Dalı, İstanbul
ORCID No : https://orcid.org/0000-0002-23890179

Keywords

Türkiye energy profile, renewable energy, clean energy, carbon emissions

Abstract

A critical outcome of climate change and energy security concerns is the need to diversify energy sources. In this context, renewable energy emerges as a significant opportunity. Türkiye has significant potential in terms of renewable energy resources. In particular, the widespread use of wind and solar energy sources has gained momentum since 2011. In recent years, Türkiye's renewable energy sector has experienced rapid growth and is poised to become a prominent player among European countries in this field. This article provides a comprehensive overview of the renewable energy sector in Türkiye. The study was conducted using the document analysis method. The information presented in this article was taken from national and international reports, national energy plans, international agreements, energy company statistics and research papers. The results show that the renewable energy sector in Türkiye has experienced radical growth in the last fifteen years. Hydropower has been used for many years and Türkiye is one of the leading countries in terms of installed capacity. However, the development of installed wind and solar capacity is particularly noteworthy. Between 2010 and 2024, installed wind power capacity increased about sevenfold. Between 2015 and 2024, installed solar power capacity grew by about fifty times.

* zaferbcakmak@gmail.com
doi : 10.46399/muhendismakina.14225654

TÜRKİYE'NİN YENİLENEBİLİR ENERJİ GÖRÜNÜMÜNE GENEL BAKIŞ

Anahtar Kelimeler

Türkiye enerji profili, yenilenebilir enerji, temiz enerji, karbon emisyonu

Öz

İklim değişikliğinin ve enerji güvenliği kaygısının kritik sonuçlarından biri de enerji kaynaklarının çeşitlendirilmesi zorunluluğudur. Bu bağlamda, yenilenebilir enerji önemli bir fırsat olarak ortaya çıkmaktadır. Türkiye yenilenebilir enerji kaynakları açısından önemli bir potansiyele sahiptir. Özellikle rüzgâr ve güneş enerjisi kaynaklarının yaygın olarak benimsenmesi 2011 yılından sonra ivme kazanmıştır. Son yıllarda Türkiye'nin yenilenebilir enerji sektörü hızlı bir büyüme kaydetmiştir ve bu alanda Avrupa ülkeleri arasında önde gelen bir oyuncu olmaya hazırlanmaktadır. Bu makale, Türkiye'nin yenilenebilir enerji sektörüne kapsamlı bir genel bakış sunmaktadır. Araştırma doküman analizi yöntemine göre dizayn edilmiştir. Bu çalışmada sunulan bilgiler ulusal ve uluslararası raporlardan, ulusal enerji planlarından, uluslararası anlaşmalardan, enerji şirketi istatistiklerinden ve araştırma makalelerinden alınmıştır. Bulgular, Türkiye yenilenebilir enerji sektörünün son on beş yılda radikal bir büyüme yaşadığını göstermektedir. Hidroelektrik enerji uzun yıllardır kullanılmakta olup, Türkiye kurulu kapasite açısından önde gelen ülkelerden biridir. Bununla birlikte, özellikle kurulu rüzgâr ve güneş enerjisi kapasitesindeki gelişme dikkat çekicidir. 2010-2024 yılları arasında rüzgâr enerjisi kurulu gücü yaklaşık yedi katına çıkmıştır. Güneş enerjisi kurulu gücü ise 2015-2024 yılları arasında yaklaşık elli kat artmıştır.

Derleme Makalesi
Başvuru Tarihi : 25.01.2024
Kabul Tarihi : 10.07.2024

Review Article
Submission Date : 25.01.2024
Accepted Date : 10.07.2024

1. Introduction

A significant part of the current climate crisis is attributed to greenhouse gas emissions resulting from the burning of fossil fuels, including coal, oil, and natural gas. Using these fuels contributes to global warming and leads to air pollution, health issues, and geopolitical conflicts (Caineng et al., 2021). Global population growth and the industrialization race between nations are increasing energy consumption and further deepening the climate change crisis (Begum, Sohag, Abdullah and Jaafar, 2015). In response to this challenge, the Paris Climate Agreement was established in 2015 to mitigate climate change, foster adaptation, and ensure financial support. After this accord, countries committed to achieving their zero-emission targets (European Commission, n.d.-a). Concurrently, the Russian-Ukrainian conflict that erupted in 2022 introduced a distinct energy crisis (International Energy Agency, n.d.). Especially in energy-intensive European nations, this crisis's repercussions manifest in energy supply constraints, a persistent and prominently discussed issue.

Renewable energy is a common solution for addressing the climate crisis caused by energy consumption and the energy supply issues triggered by the Russia-Ukraine conflict. It drives the global shift towards a more sustainable and environmentally conscious energy paradigm (Adams and Acheampong, 2019). Renewable energy helps countries reduce their carbon emissions and ensure energy security. Offering a sustainable, clean, and secure alternative to fossil fuels, renewable energy sources such as wind, solar, geothermal, hydropower, and bioenergy emit minimal or no greenhouse gases. Moreover, they diminish reliance on imported fuels, foster job creation, economic prospects, and fortify energy security. The transition to renewable energy empowers countries to mitigate the impact of climate change, abate air pollution, and kindle innovation and progress (Adjei-Mantey and Adams, 2023; Sarkodie and Adams, 2018)

Türkiye, a developing country with an 85 million population and a burgeoning industrial sector (Turkish Statistical Institute, 2023), witnesses a substantial annual escalation in energy consumption. Türkiye's geographical location between Asia and Europe highlights its importance in terms of energy security. Türkiye is committed to the Paris Climate Agreement and aspires to achieve zero emissions by 2053 (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). This ambitious objective underscores the promise of renewable energy sources within Türkiye and reflects the nation's dedication to an environmentally sustainable energy mix. While historically reliant on fossil fuels, Türkiye has markedly amplified its investment in renewable energy during the past 15 years. Long accustomed to hydroelectric power, Türkiye began harnessing wind power in the early 2000s and solar power in 2015 (Yilmaz, 2012). Notably, enacting the

Renewable Energy Law in 2011 (Official Journal of Türkiye, 2011) bolstered investment incentives, leading to cultivating a robust renewable energy ecosystem based on five sources: wind, solar, hydro, geothermal, and biomass. Presently, energy generated from this relatively nascent sector constitutes around 16% of the total energy output. According to Türkiye's National Energy Plan (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a) targets, this proportion is projected to surpass 40% by 2035.

This article provides a comprehensive overview of renewable energy sector in Türkiye. It looks at existing renewable energy sources and their development. Based on data from national and international sources, the progress of Türkiye in the field of renewable energy is presented. It also compares Türkiye's renewable energy resources with those of leading clean energy countries.

2. Conceptual Framework

2.1 Energy Structure in World

Energy plays a crucial role in nearly all human activities, and its utilization is steadily increasing (BP, 2022). Energy usage revolves around two primary aspects: production and consumption. Certain countries wield significant influence over production, often rooted in dependence on traditional energy sources (IRENA, 2022). Notable examples include Russia, the USA, Saudi Arabia, and Venezuela, countries blessed with substantial natural gas or oil reserves (BP, 2022). Conversely, nations characterized by advanced industrialization, such as Germany, China, the USA, the UK, France, and Japan, also lead energy consumption (European Commission, 2022). Within this framework, energy flows from producing to industrialized countries unable to fulfill their energy demands domestically. Nevertheless, energy consumption has witnessed a marked surge due to rapid technological advancements and population growth. While some nations reap economic benefits from this surge, others grapple with associated challenges.

Figure 1 shows that energy consumption, which was about 43,308 terawatt-hours in 1965, has shown a continuous upward trend, reaching about 167,788 terawatt-hours in 2022. This figure represents a significant increase in global energy consumption during this period. Within each 5-year period, there is a consistent upward trend. This trend signals a continued increase in the coming years.

The escalation of total energy consumption has two major potential consequences. The first is the risk of an imbalance between production and consumption. Such an imbalance could disrupt energy transfers and adversely affect industries that require greater energy inputs (Michaelides, 2012). In scenarios where developed or developing countries with significant energy needs do not have access

to sufficient resources, economic growth could be hindered (Omri, 2014). Moreover, this imbalance could lead to fundamental challenges, including energy insecurity and disproportionate increases in energy prices (Armaroli and Balzani, 2007). The second consequence is the climate crisis. The increase in energy consumption exacerbates the problem of climate change. Since a significant portion of energy still comes from fossil fuels, continued reliance on these sources will inevitably lead to increased carbon dioxide emissions (Begum et al., 2015; Caineng et al., 2021). Given these significant challenges, it might be expected that countries would seek to reduce their energy consumption. However, as shown in figure 1, energy consumption continues to increase on an annual basis. As a result, countries are turning to alternative energy sources to mitigate the impact of these negative outcomes and meet their energy needs. These alternative sources are commonly known as renewable energy sources, which include solar, wind, hydropower, geothermal, biomass, and ocean energy (Kothari, Tyagi, and Pathak, 2010).

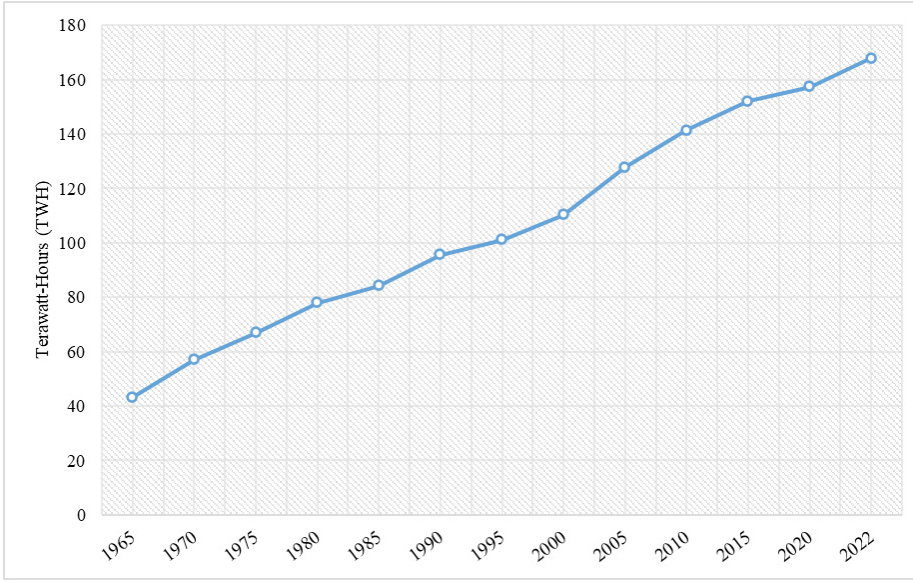

Figure 1. Total primary energy consumption by year (Ritchie, Rosado, and Roser, 2020, last revised in January 2024)

Developed countries, faced with limited energy resources such as natural gas and oil, have gradually shown increased interest in renewable energy sources. This strategic shift aims to reduce dependence on external energy suppliers by

utilizing energy from renewable sources (Kaygusuz, 2012). The 1973 oil crisis (Issawi, 1978) marked a significant turning point (Warlouzet, 2017). Triggered by OPEC countries restricting oil supply, this crisis led to a significant increase in oil prices, with particularly pronounced negative effects in the United States and European countries (Mitchell, 2010). This event triggered a transformational process, with Germany and the United States emerging as central actors in this transition (Balassa, 1981; Warlouzet, 2017). Germany embarked on a primary transformation strategy known as the "Energiewende", a long-term energy and climate policy aimed at meeting energy needs from alternative sources and cultivating an environmentally conscious energy approach (Morris et al., 2012). Similarly, the United States of America has positioned itself as an early advocate and investor in renewable energy sources (Muhammed and Tekbiyik-Ersoy, 2020). In particular, it has laid out plans to meet a portion of its energy needs from alternative sources, particularly through the expansion of wind energy capacity. The aftermath of the Russia-Ukraine conflict in 2022 resulted in another energy crisis (International Energy Agency, n.d.). This crisis, which significantly affected the developed economies of Europe (European Council, 2022), once again underscored the critical importance of alternative energy sources. Over the past four decades, the energy landscape has undergone significant changes, driven by energy crises and climate change. Figure 2 shows energy consumption by resource use over the years. Notably, the use of renewable energy sources such as solar and wind has increased significantly since 2000.

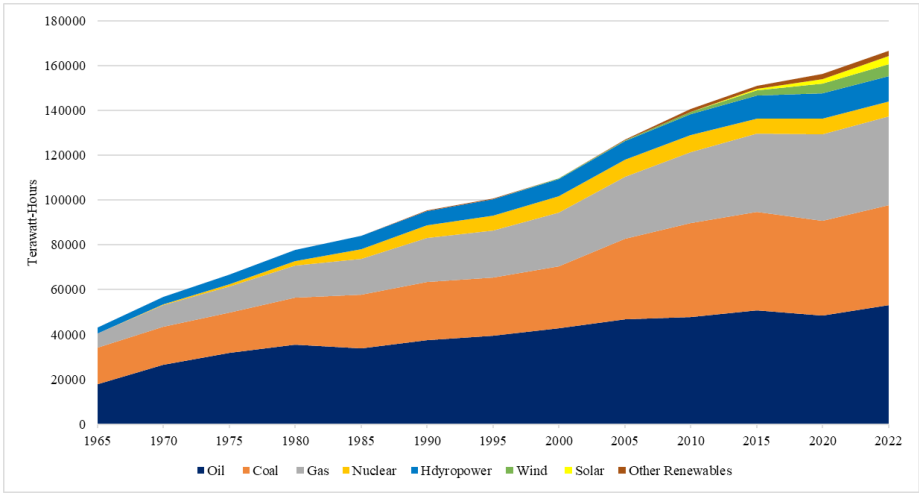

Figure 2. Total energy consumption by sources (Ritchie et al., 2020, last revised in January 2024)

While energy consumption has grown steadily over the years, the range of energy sources has also expanded. In particular, the last two decades have seen a remarkable increase in the use of renewable wind and solar resources. Nevertheless, the use of renewable energy sources remains significantly overshadowed by the prevalence of fossil resources. In 2022, oil, coal and natural gas still accounted for the majority of global energy consumption. As a result, the heavy reliance on fossil fuels contributes to the escalation of energy-related carbon emissions. The magnitude of carbon dioxide emissions has increased significantly over the past half century. In 1920, global carbon dioxide emissions from fossil fuel combustion and industrial processes totaled approximately 3.52 million tons; however, by 2022, this alarming figure had risen to approximately 37.15 million tons (Statista, 2024a). Consequently, heightened concerns regarding carbon emissions and their far-reaching effects are imperative. Given that the sources used to generate energy are a significant driver of this escalation, the need for cleaner energy sources will take center stage in the coming years.

2.2 Energy Structure of Türkiye

The energy sector plays a central role in Türkiye's economic and social development. The relationship between energy consumption and GDP growth is robust, with periods of reduced energy consumption often coinciding with economic slowdowns (Ocal and Aslan, 2013). Türkiye appears to be a country that has recently increased its energy demand. The reasons for this increase include factors such as the growth of the industrial sector, rapid population growth and urbanization (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). Figure 3 shows Türkiye's increasing energy consumption over the years. As the figure shows, Türkiye's energy consumption has tripled in the past two decades. In 1990, it was 51 million tons of oil equivalent (Mtoe), but by 2022, it had risen to 156 Mtoe. Given this significant escalation, the trajectory strongly suggests a continued increase in energy consumption for the foreseeable future.

The National Energy Plan of Türkiye (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a), published by the Ministry of Energy, provides insightful projections of future energy consumption trends in Türkiye, as shown in Figure 4. Projections of future energy use show a discernible trend of increasing energy consumption, primarily driven by the use of current energy sources. The importance of solid fuels, gasoline, and natural gas continues to be emphasized, as these resources will continue to be used intensively. At the same time, the share of renewable energy sources is expected to increase gradually, rising to 48.7 million tons of oil equivalent (Mtoe) in 2035, a significant increase from 24.6 Mtoe in 2020. In line with these developments, Türkiye's ongoing nuclear power

plant construction is scheduled to be commissioned in 2025. As outlined in the National Energy Plan of Türkiye, projections show an increase to 4 Mtoe in 2025, 8 Mtoe in 2030, and a peak of 12 Mtoe in 2035.

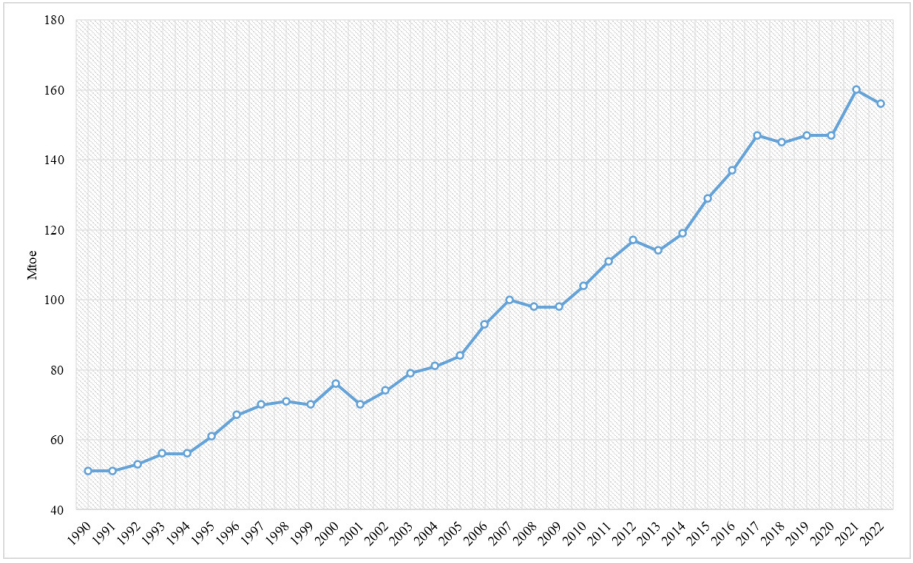

Figure 3. Türkiye's Energy Consumption (Enerdata, 2024)

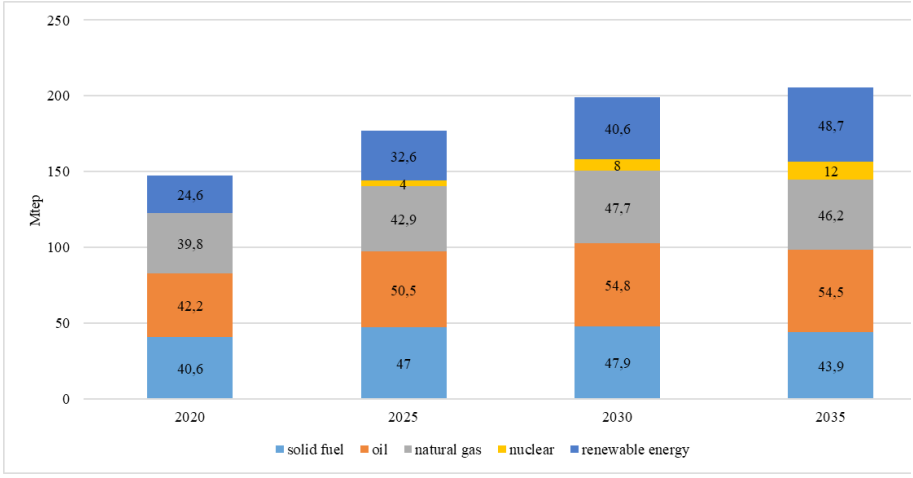

Figure 4. Primary Energy Consumption by Sources-Türkiye (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a)

Increasing energy consumption is central to powering various facets of modern society, including transportation, manufacturing, and residential electricity use (Ozcan, Tzeremes, and Tzeremes, 2020). As the world's population grows and economies develop, energy demand is expected to increase. In this context, it is imperative to find sustainable resources with minimal negative impact on the environment to meet this demand. The provision of reliable and affordable energy plays a pivotal role in promoting economic development and raising living standards, especially in emerging economies (Khan et al., 2021; Omri, 2014). The provision of reliable and affordable energy plays a pivotal role in promoting economic development and raising living standards, especially in emerging economies (Khan et al., 2021; Omri, 2014). Energy is a key driver of industry, transportation systems, households, and essential services such as health care and education. Lack of adequate energy access can hinder economic growth, as businesses and industries face obstacles without reliable electricity (Stern, 2019). Increasing energy consumption in emerging markets is a critical tool for driving economic progress, alleviating poverty, and improving the quality of life for populations (Ozcan et al., 2020).

As energy consumption increases, the origin of these energy sources becomes even more important. Türkiye's escalating energy demand underscores the need to diversify energy sources and increase production capacity (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). In particular, a significant portion of Türkiye's energy resources are imported, making energy security a critical concern (İnançlı and Aylin, 2020). Therefore, Türkiye is actively implementing various measures to reduce its dependence on external energy resources, emphasizing the use of domestic resources and investments in renewable energy sources. Türkiye's energy mix includes a variety of resources, including coal, natural gas, hydroelectric, wind, and solar power (see Figure 5).

Figure 5 shows a diverse mix of energy sources, with a significant share coming from renewable sources (hydropower, solar, wind, and geothermal), which together account for over 54% of Türkiye's installed power capacity. This diversity indicates a balanced approach to the use of both conventional and renewable energy sources. However, a broader perspective requires examining the trajectory of energy supply over the years and closely monitoring the progress of renewable energy development.

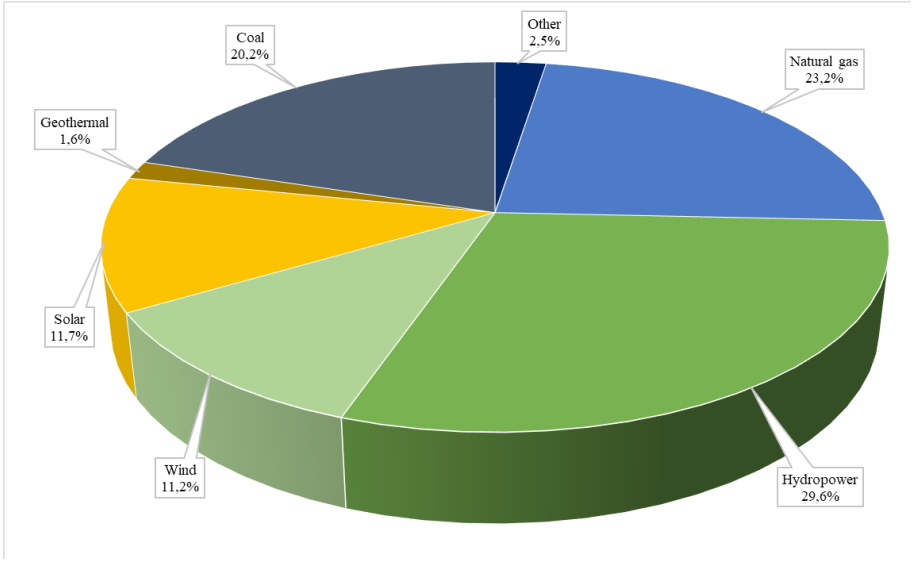

Figure 5. Türkiye's installed power capacity by source, 2024 (March) (Republic of Türkiye Ministry of Energy and Natural Resources, 2024)

Upon examination of figure 6, which depicts Türkiye's energy supply sources over the period from 1990 to 2022, it becomes evident that there have been significant transformations. In 1990, gasoline and coal were the primary energy contributors, collectively accounting for approximately 75% of the total energy supply. By 2000, there had been a notable increase in the prominence of natural gas, a trajectory that persisted through subsequent years. Türkiye's strategic utilization of natural gas as a prominent energy source is grounded in multifaceted reasons, including its unique geographical location. The nation serves as a pivotal conduit connecting the East and the West, facilitating the passage of natural gas pipelines from Russia and Azerbaijan to Europe (Melikoglu, 2013; Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). Furthermore, the bilateral relations and agreements with Russia and Azerbaijan have established natural gas as a vital cornerstone of Türkiye's energy landscape (Petform, n.d.). It is anticipated that natural gas will retain its significance as a pivotal energy source in the forthcoming years. A parallel surge is discernible in the arena of renewable energy sources, specifically wind and solar, which have undergone notable growth over the past three decades. While holding a relatively minor share in 1990, these sources underwent substantial advancement after 2000, culminating in a noteworthy contribution in 2022. This impressive surge can be attributed to a multitude of factors. These will be discussed in greater detail in the subsequent section.

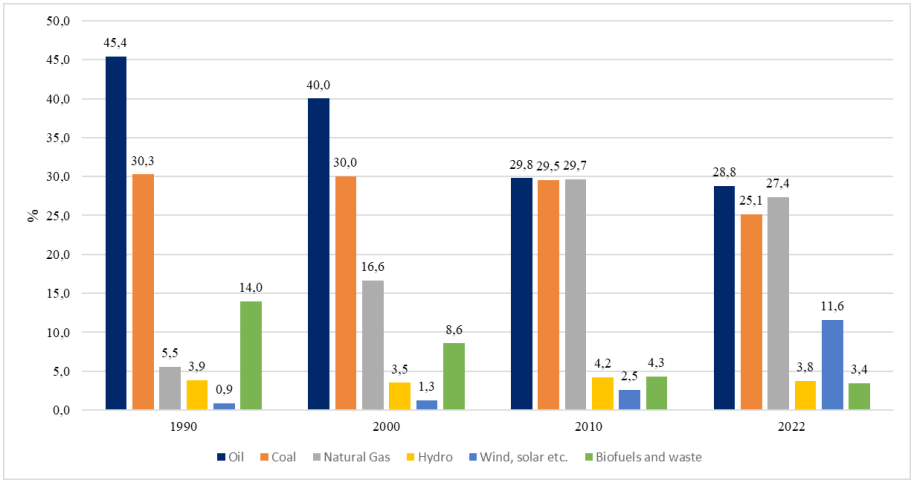

Figure 6. Türkiye's total energy supply by year (%) (International Energy Agency, 2022)

Despite commendable progress in renewable energy, Türkiye's energy landscape remains heavily anchored in fossil fuels (see figure 6), with natural gas in particular playing a significant role in electricity generation. This reliance on fossil fuels can be attributed to escalating energy demand and the need to ensure energy security. However, the country's investments in renewable energy (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-a) and the potential for further expansion in this area (Turkish Statistical Institute, 2023) indicate that the renewable energy sector will flourish in the coming years.

3. Method

The primary objective of this study is to comprehensively analyze and evaluate the current status and development of the renewable energy sector in Türkiye. In line with this objective, the study addresses the changes in the use of various renewable energy sources in Türkiye, such as wind, solar, hydropower, biomass, and geothermal, and compares these changes with other countries. This study is based on a comprehensive literature review focusing on the renewable energy landscape of Türkiye. The data collection process used various sources such as national and international reports, Türkiye's national energy plans, statistics from energy companies, and academic research articles. These sources were selected based on criteria such as timeliness, reliability, and direct relevance to the topic. Document analysis is the primary method used in this study. It involves the systematic examination of existing documents, allowing researchers to collect, analyze, and interpret the data found in these documents. Document analysis is

a process of detailed and systematic examination of written materials (Bowen, 2009). This method considers not only the content of the documents, but also their context, the intent of the authors, and the social and historical context in which they were created, providing researchers with an in-depth understanding (Scott, 1990). This study adheres to research and publication ethics.

4. Findings

The findings section of this research presents the results obtained from the documents analyzed according to the established criteria. These findings are intended to answer the research questions and to clarify the overall purpose of the study. In this study, 42 articles and 27 reports (including nationally and internationally published reports, data-containing website publications) were reviewed. As a result of the analysis, a general structure regarding the outlook of renewable energy in Türkiye has been identified and the findings have been presented under different headings. The identified topics are:

- Renewable Energy in Türkiye
- Wind Energy in Türkiye
- Solar Energy in Türkiye
- Hydropower in Türkiye
- Biomass Energy in Türkiye
- Geothermal Energy in Türkiye

4.1 Renewable Energy in Türkiye

The European Union has been actively engaged in endeavors to curtail greenhouse gas emissions as outlined by the Kyoto Protocol (United Nations, n.d.), concurrently adopting measures to foster the utilization of renewable energy sources (European Commission, 2022). The impetus behind these initiatives lies in the aspiration to curtail environmental pollution and ensure energy security. Notably, the effectiveness of these endeavors within the EU hinges on the synergy of political resolve and the determination exhibited by member states, signifying their pivotal roles in achieving the established objectives. Türkiye, as a nation that has enshrined EU membership as a key tenet of its national policy (Müftüler-Baç, 2018), is resolutely endeavoring to augment the proportion of renewable energy sources in its energy consumption matrix. To this end, the promotion of renewable energy utilization is incentivized, harmonizing international commitments and domestic imperatives, including mitigating energy import reliance (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a; Turkish

Statistical Institute, 2023). The establishment of administrative frameworks is actively underway to facilitate this transition. A good example is the National Program for the Adoption of the EU Acquis (2003) (European Commission, n.d.-b), where increasing the share of renewable energy sources in total energy production is one of the top priorities in the short term. Furthermore, there is a concerted emphasis on the imperative of augmenting the utilization of renewable energy sources, a pivotal component of ensuring energy supply security and an integral facet of the overarching energy policy. In alignment with these objectives, the Türkiye National Energy Plan (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a) explicitly outlines a resolute ambition: attaining a zero-emission target by the year 2053. The pursuit of this ambitious goal necessitates a marked escalation in investments dedicated to the development and expansion of renewable energy sources.

Figure 7 illustrates Türkiye's total CO_2 emissions from 1990 to 2021, expressed in million tons of carbon dioxide equivalent (Mt CO_2). Starting from 128.8 Mt CO_2 in 1990, emissions show a pronounced escalation over time, culminating in a peak of 400.8 Mt CO_2 in 2021. These emissions come primarily from the combustion of fossil fuels, including coal, oil, and gas. This emissions spectrum includes solid, liquid, and gaseous fuel consumption (Saidi and Omri, 2020; Zhang and Cheng, 2009). As one of the primary greenhouse gases, carbon dioxide is responsible for climate change and global warming, which underscores the importance of curbing its excessive emission for the ecological integrity and overall well-being of the planet (Ozturk and Acaravci, 2010). As a result, serious efforts are being made worldwide to mitigate carbon emissions, driven by the promotion of renewable energy sources and energy-efficient technologies and the implementation of sustainable practices. Carbon dioxide emissions are emerging as a significant environmental concern, manifested to varying degrees in different nations (Alkathery and Chaudhuri, 2021).

China is the country with the highest carbon emissions, with about 11.4 billion tons of CO_2 emissions in 2022. The US is also at the top of the list. It ranks second with about 5.06 billion tons of CO_2 emissions. China and the US are followed by India (2.83 billion tons of CO_2), Russia (1.65 billion tons of CO_2), and Japan (1.05 billion tons of CO_2) (Ritchie and Roser, 2020). Although Türkiye is relatively behind, it is very important for Türkiye to take measures in this area and reduce its CO_2 emissions. In this context, Türkiye has strategically increased its commitment to renewable energy in recent years in order to diversify its energy portfolio and reduce its dependence on fossil fuels. One of Türkiye's key goals in this regard is to achieve zero CO_2 emissions by 2053 (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-a). The sustainability of this trajectory and the achievement of these goals depends on maintaining and increasing investment in renewable energy sources.

Figure 8 depicts the projected upward trajectory of new solar and wind capacity installations through 2035. Between 2021 and 2035, 96.9 GW of new capacity is expected to come online, a significant portion of which will be from renewable sources. The goal is for renewables to contribute 74.5% of this new capacity growth, with solar and wind leading the way.

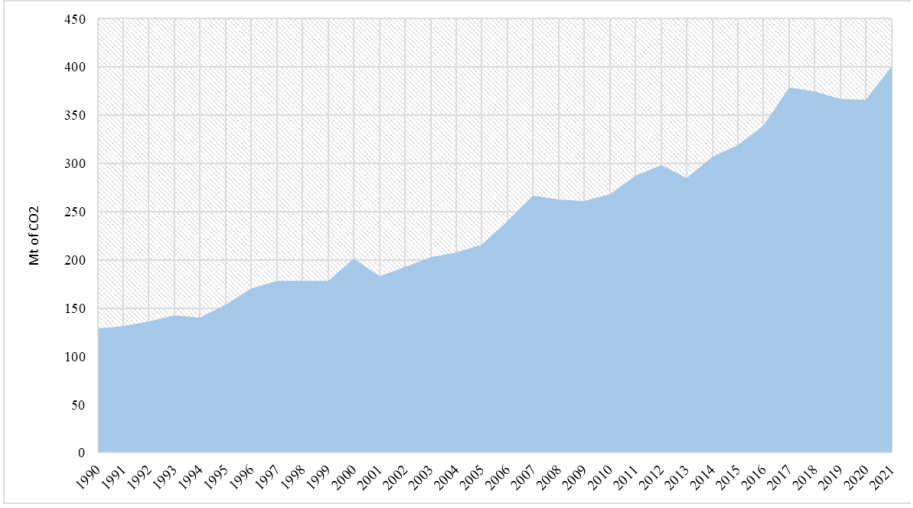

Figure 7. Total CO_2 emissions, Republic of Türkiye 1990-2021 (International Energy Agency, 2022)

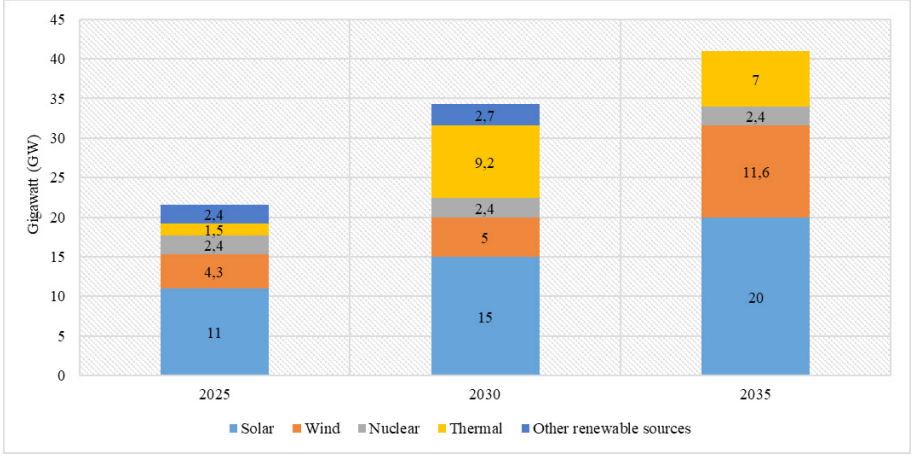

Figure 8. New capacity to be commissioned every five years (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a)

The main renewable energy sources in Türkiye include wind, solar, hydropower, geothermal, and biomass (Erdil and Erbıyık, 2015). Currently, hydropower is the largest contributor, followed by wind, solar, and biomass (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-a). In particular, geothermal energy is rapidly gaining importance in Türkiye due to the country's significant geothermal potential, which is among the largest in the world (MTA, n.d.). Türkiye has significant potential in wind and solar energy resources (Kaya, Aksoy, and Kose, 2017), and over the past decade it has been progressively harnessing this potential (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-a). Following the momentous achievement of establishing its first wind power plant in 1999 (Erdogdu, 2009), Türkiye took another significant step by inaugurating its first solar power plant in 2015 (Turkish Coal Enterprises, 2021). With each passing day, Türkiye is improving its competitive position in the renewable energy sector and joining the ranks of leading nations in this field. Figure 9 shows the distribution of generated energy by source and the changes in this distribution over the years.

As shown in Figure 9, hydropower has consistently maintained its importance as a prominent renewable energy source in Türkiye and has maintained its development trajectory. In 2022, hydropower maintained its status as the leading renewable energy source, generating approximately 67 terawatt-hours (TWh) of energy. At the same time, energy production from wind, solar, and other renewable sources also showed an upward trajectory over the same period, with significant increases observed since 2009. In particular, the rise of solar energy has been particularly notable, with a steady increase since the commissioning of the first plant in 2015. By 2022, energy production from wind reached 35.14 TWh, solar generated 15.91 TWh, and other renewable sources contributed 20.30 TWh to the nation's energy mix.

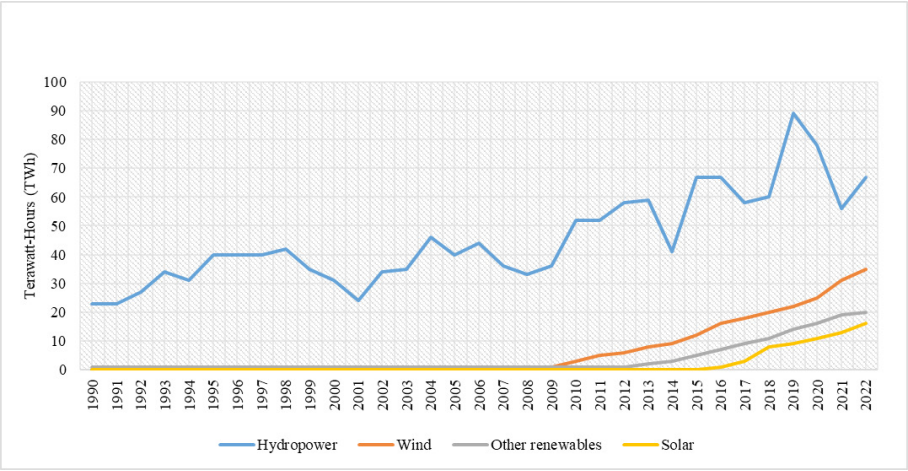

Figure 9. Türkiye's renewable energy generation by source and year (ourworldindata, n.d.)

In assessing Türkiye's progress in renewable energy, a valuable perspective emerges through a comparative lens with countries that embarked on renewable energy investments much earlier, such as Germany, the United States, and China (Balassa, 1981; Peidong et al., 2018; Warlouzet, 2017). Figure 10 illustrates the current status of these countries in terms of the share of renewable energy in their primary energy mix. This representation highlights the extent to which renewable energy contributes to the overall energy matrix in frontier countries.

Figure 10 shows the share of renewable energy sources in primary energy consumption for some countries and regions in 2022. Türkiye obtains 18.85% of its consumed energy from renewable sources. This share is higher than the OECD average, but lower than the EU average. In particular, northern European countries such as Norway and Sweden lead the pack with robust renewable energy penetration. In addition, Brazil is a notable example, with nearly half of its primary energy coming from renewable sources, giving it a prominent position in renewable energy.

The complex interplay of a country's resources, population, spending, and level of industrialization all influence its energy production and consumption patterns. As shown in Figure 10, countries with lower rates (such as China and the United States) may have higher renewable energy capacity. However, countries that get most of their energy from renewables may also have lower capacity. Thus, the total amount of renewable energy used by countries is a key determinant.

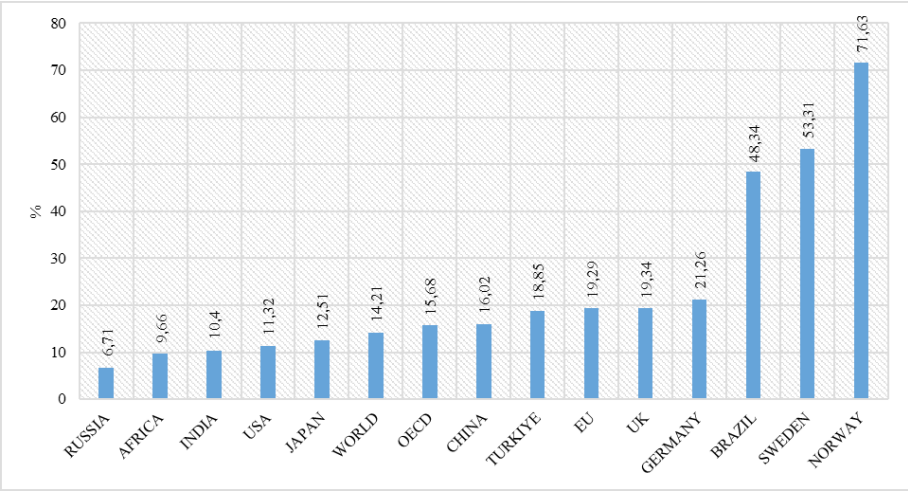

Figure 10. How much of our primary energy comes from renewables (%)? (Ritchie et al., 2020, last revised in January 2024)

Figure 11 shows China's commanding lead in renewable energy capacity (1454 GW). The United States ranks second with 388 gigawatts, followed by Brazil and India with 194 and 176 gigawatts, respectively. Türkiye's renewable energy capacity, at 58 gigawatts, lags significantly behind China and the United States. However, the country's ranking remains notable as it is only slightly behind major energy players such as France and Italy. In comparison, Türkiye's renewable energy capacity lags behind that of Germany, which serves as the vanguard of Europe's renewable energy efforts. This significant gap in capacity underscores the urgency for Türkiye to increase capacity and investment in renewable energy.

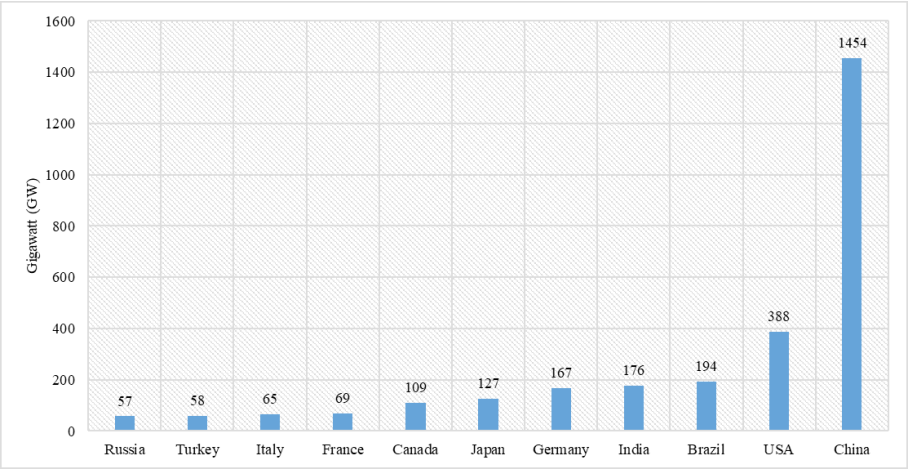

Figure 11. Top 10 countries and Türkiye according to total renewable energy capacity, 2023 (IRENA, 2024)

4.2 Wind Energy in Türkiye

Wind energy is a promising renewable energy source (European Wind Energy Association, 2009). It is a method of energy production that requires minimal transportation and advanced technology. Furthermore, wind energy is naturally abundant in the atmosphere, making it an environmentally friendly option (Erdem and Şenel, 2013; Nazir, Ali, Bilal and Iqbal, 2020). This form of energy is harnessed through wind turbines, and technological advancements have reduced the cost of producing electricity from wind sources. As a result, many countries are actively supporting wind energy initiatives (Nelson, 2009) to make it a competitive alternative to fossil fuels. This strategic approach promotes the adoption of cost-effective and environmentally conscious energy solutions, ultimately supporting sustainable energy production (Sadorsky, 2021).

Türkiye has significant wind energy potential due to its strategic geographical location and diverse topography. The intersection of different climatic zones places the country in an advantageous position for wind energy utilization (Özkan, Yeter, and Gedikli, 2022). Data from the Turkish Ministry of Energy and Natural Resources (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-b) indicate a theoretical wind energy capacity of approximately 48 GW for Türkiye, with an average annual wind speed of 7-8 m/s. As of March 2024, Türkiye's installed wind power capacity is approximately 12 GW, or about 10.81% of total installed capacity (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-b).

The main areas for wind energy development in Türkiye include the Aegean and Mediterranean coasts, as well as mountainous regions in the interior. Notable provinces with high wind energy potential include Izmir, Balikesir, Canakkale, and Manisa (Özkan et al., 2022). The country has introduced several measures to promote the growth of wind energy, including feed-in tariffs, tax exemptions, and investment incentives. With an ambitious goal of reaching 34 GW of installed wind power capacity by 2030, Türkiye is poised to make significant progress toward its renewable energy goals (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-b). Despite a delayed start, Türkiye's considerable wind energy potential (Şenel and Erdem, 2015) has gained momentum. The installation of the first wind turbine in 1999 marked the first foray into electricity generation (Erdogdu, 2009). Subsequent years, especially 2005, witnessed significant progress as concerted efforts were made to promote wind energy. The introduction of the Renewable Energy Law in 2010 catalyzed a significant increase in wind power installations. Recent years have witnessed remarkable progress in the development of wind energy (Official Journal of Türkiye, 2011; Official Legislation of Türkiye, 2005). Figure 12 graphically illustrates the upward trajectory of Türkiye's wind energy capacity, which has been consistently increasing each year. As of March 2024, the installed capacity has remarkably increased to approximately 12 gigawatts, an impressive sixfold increase from the capacity recorded in 2011.

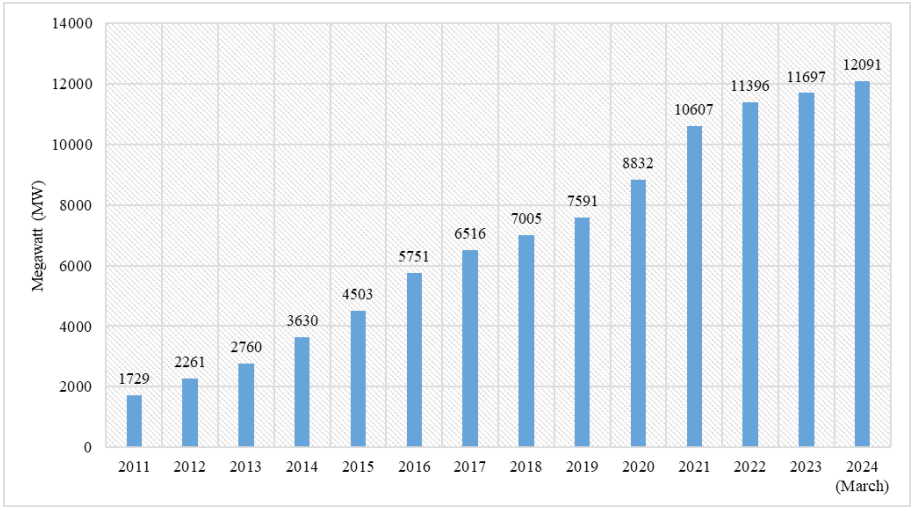

Figure 12. Türkiye's installed power capacity based on wind energy (Republic of Türkiye Ministry of Energy and Natural Resources, n.d-b.; TEİAŞ, 2024)

The wind energy sector is one of the fastest growing areas of the renewable energy

sector on a global scale. According to the Global Wind Energy Council (2022), the cumulative installed wind power capacity worldwide has exceeded 750 GW. As shown in figure 13, China leads the way with more than 365 GW of installed capacity, followed by the United States with more than 140 GW, Germany with a robust 66 GW, India with more than 41 GW, and the United Kingdom with more than 28 GW. Other major contributors to wind capacity include Spain, France, Brazil, Canada, Italy. Türkiye has rightly earned its place in this group of countries, thanks to significant investment in the sector in recent years. In fact, China and the United States currently have significant shares of global installed wind capacity. The upward trajectory of Türkiye's wind energy capacity is promising. As the global renewable energy landscape evolves, Türkiye's commitment to expanding its wind energy sector can undoubtedly contribute to its sustainable energy goals and position within the international renewable energy arena.

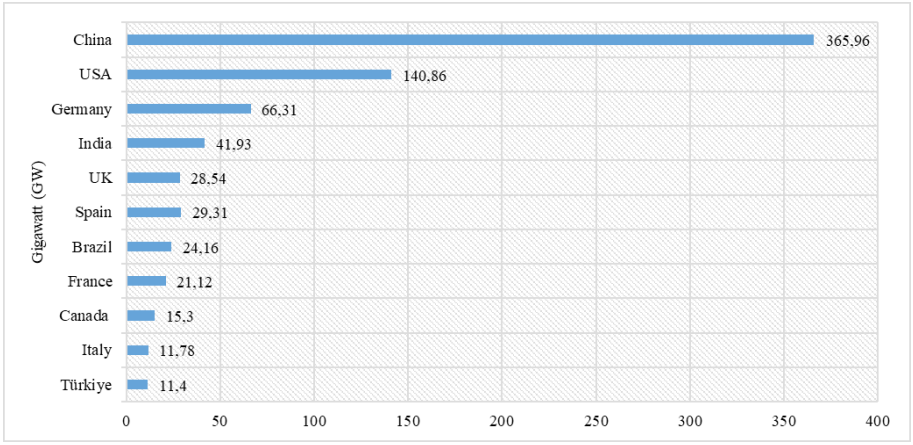

Figure 13. Installed wind power capacity, 2022 (Ritchie, Rosado and Roser, 2023)

4.3 Solar Energy

Solar energy is considered an environmentally clean source in many fields (Rabaia et al., 2021). Since the 1970s, research on solar energy has accelerated, and solar energy systems have developed technologically, leading to a decrease in cost (Güney, 2022). Solar energy is used for various purposes, such as air conditioning and hot water supply in residential and commercial buildings, greenhouse heating, and crop drying in agriculture. In industry, solar ovens, solar cookers, seawater desalination, solar pumps, solar batteries, and heat pipe applications are some examples of solar energy applications. Solar energy has a wide range of applications, from communication devices to automation systems to power generation (Tsoutsos, Frantzeskaki, and Gekas, 2005).

Solar energy has a wide range of applications and its potential performance varies according to the geographical location and climate of different countries (Lehtola and Zahedi, 2019). Due to its geographical location, Türkiye is one of the countries with high solar energy potential. The total sunshine duration in the country has been determined to be 2,737 hours per year, which corresponds to 7.5 hours of daily sunshine (Republic of Türkiye Ministry of Energy and Natural Resources, 2022b; Republic of Türkiye Ministry of Energy and Natural Resources, 2023). Although Türkiye has the potential of solar energy, it started using it relatively late. The first solar energy congress was held in 1975 and studies have been conducted continuously (Çetin, Turan and Bayrakdar, 2019). However, the deployment and production of solar energy started in 2014. Since then, the number of solar power plants has increased every year, and by 2024 (March), the share of solar energy in the installed capacity has reached 11.7% (Republic of Türkiye Ministry of Energy and Natural Resources, 2022b). Figure 14 provides a clear visual representation of Türkiye's remarkable increase in installed solar capacity over the past decade. The growth momentum is striking, escalating from 40 megawatts in 2014 to 12631 megawatts by March 2024. This exponential increase demonstrates Türkiye's strong solar energy potential, which is driving rapid growth.

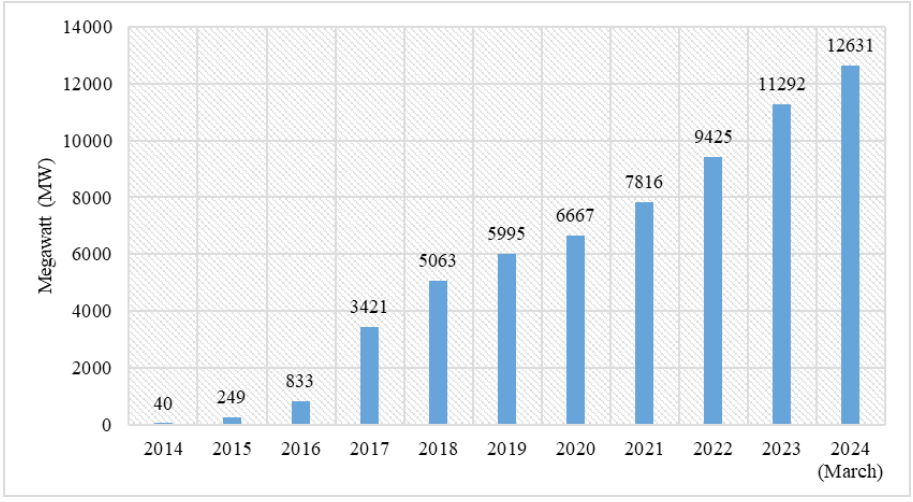

Figure 14. Solar Energy Installed Capacity, Türkiye (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-c; TEİAŞ, 2024)

Globally, solar power stands out as a rapidly expanding renewable energy source. Driven by cost reductions and government incentives, global installed solar

Table 1. Solar energy installed capacity by country [CAP (MW)] (IRENA, 2024)

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
China	28399	43549	77819	130832	175262	204971	253964	306973	393032	609921
USA	17651	23442	34716	43115	51570	60826	75562	95209	114361	139205
Japan	23339	34150	42040	49500	56162	63192	69764	74191	83057	87068
Germany	37900	39224	40679	42293	45158	48914	53721	58461	67479	81739
India	3773	5693	9979	18252	27543	35203	39385	49684	63390	73109
Brazil	21	46	128	1207	2435	4613	7879	13055	25520	37449
Australia	5287	5946	6689	7354	8625	12969	17344	19076	29958	33683
Spain	7001	7008	7017	7027	7068	11143	12589	15952	25615	31016
Italy	18600	18907	19289	19688	20114	20871	21656	22698	24561	29795
Nether-lands	1007	1536	2135	2911	4608	7226	10950	14249	19600	23904
France	6034	7138	7702	8610	9672	10817	12031	14718	17350	20551
UK	5528	9601	11914	12760	13073	13346	13462	13689	14651	15657
Türkiye	40	250	834	3422	5064	5996	6668	7817	9426	11293

power capacity has grown significantly in recent years (Crowe and Li, 2020). This phenomenon is particularly evident in key solar energy players such as China, the United States, and India, where solar energy deployment and capacity have skyrocketed, reaching tens or hundreds of gigawatts (IRENA, 2024). In order to gain a comprehensive perspective of Türkiye's position in the field of solar energy, a comparative analysis with leading European and global nations is essential. Table 1 serves as a valuable reference, illustrating the installed solar energy capacities of these influential countries. This table provides an initial insight into Türkiye's development in the field of solar energy.

Solar energy represents a relatively nascent frontier for numerous countries (Hayat, Ali, Monyake, Alagha, and Ahmed, 2019). Table 1 illustrates the transformative journey within the solar energy landscape. In 2014, Germany and Italy emerged as frontrunners with significant installed capacities, while the solar capacities of the Netherlands, Brazil and Türkiye remained modest. However, the following decade saw a remarkable evolution as these countries expanded their solar power capabilities. By 2023, China had risen to the top of the leaderboard with 609 GW of installed capacity, followed by the United States with 139 GW and Japan with 87 GW. A notable shift is evident in the solar energy landscape of Türkiye, which has seen a significant increase in installed capacity over the past decade. Similarly, the Netherlands and Brazil have made impressive gains in solar capacity over the same period. The table underscores solar's dynamic evolution and growing importance in global energy portfolios.

4.4 Hydropower in Türkiye

Türkiye has significant hydropower potential due to its geographical location and numerous rivers (Akpınar, Kömürcü and Kankal, 2011). The country has been using its hydropower resources for electricity generation since the 1950s (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-d), and hydropower is currently the largest renewable energy source in Türkiye (International Energy Agency, 2022). According to the International Hydropower Association (2022), as of 2021, Türkiye had a total installed hydropower capacity of 31.4 GW, making it the second largest hydropower producer in Europe after Norway.

Most of Türkiye's hydropower plants are located in the eastern and northeastern regions of the country (Sayan, 2019). The largest hydropower plant in Türkiye is the Atatürk Dam, which has an installed capacity of 2,400 MW. Türkiye has also been investing in small hydropower projects. (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-d).

Hydropower has been used for electricity generation for a longer period of time than wind and solar renewable energy sources, which have become more popu-

lar in recent years (Akpınar, Kömürcü and Kankal, 2011). Hydropower, the most important instrument in the renewable energy market of Türkiye, accounts for a significant part of renewable energy (International Energy Agency, 2022). According to the predictions of the international communities in line with the zero-carbon target, hydropower will remain necessary until 2050 (International Hydropower Association, 2022; Nautiyal and Goel, 2020). Figure 15 shows the leading countries in terms of hydropower capacity. China leads with 414.8 GW of installed capacity. It is followed by Brazil (109.8 GW) and the United States (102 GW). Türkiye is also among the top ten countries in terms of installed hydropower capacity.

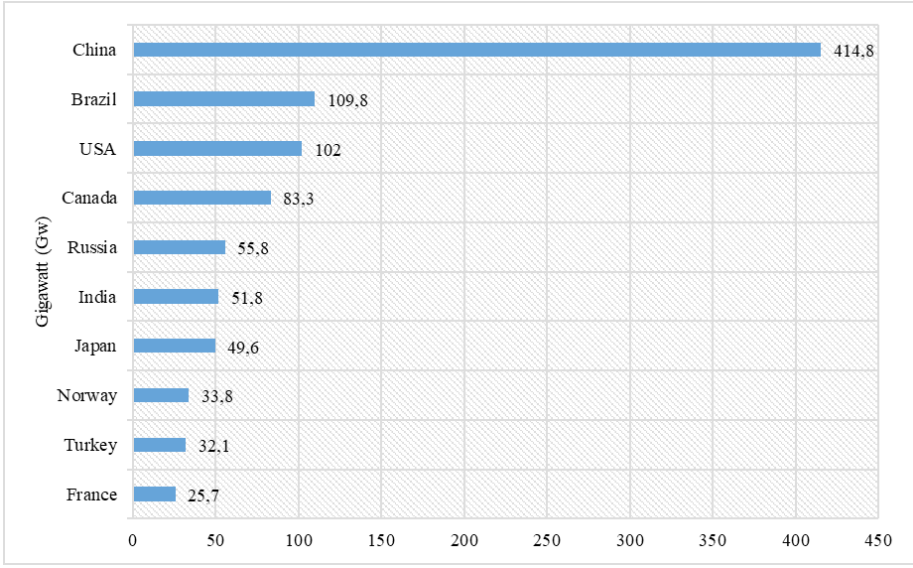

Figure 15. Leading country according to Hydropower installed capacity-2022 (Statista, 2024b)

Hydropower stands out as an important energy source in Türkiye. As of March 2024, hydropower accounts for approximately 29.6 percent of Türkiye's installed capacity (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-d).

4.5 Biomass Energy in Türkiye

Biomass energy is produced from organic matter such as plant matter, agricultural residues, and by-products of forestry activities (Wang, 2019). It is a renewable and sustainable source of energy because the organic matter can be replenished through natural processes (Zafar, Sinha, Ahmed, Qin and Zaidi, 2021). Biomass can be converted into various forms of energy such as electricity, heat or

biofuels through various processes such as combustion, gasification. (Wang, Bui, Zhang and Pham, 2020). Biomass energy is a renewable energy source that is widely used today. It is a sustainable source to meet the rapidly growing demand for energy. In particular, its availability in many places and its ability to reduce energy imports through local sourcing encourage countries to use biomass energy (Magazzino, Mele, Schneider and Shahbaz, 2021; Wang, 2019).

Türkiye has significant potential for biomass energy production due to its abundant agricultural and forestry resources. The main sources of biomass in Türkiye are crop residues, forestry residues, animal waste, and municipal solid waste (Avcıoğlu, Dayıoğlu, and Türker, 2019). In recent years, Türkiye has made efforts to promote the use of biomass energy and increase its share in the country's energy mix. In 2011, a new law was passed to support the development of renewable energy sources, including biomass, and to provide incentives for investments in this sector (Official Journal of Türkiye, 2011). Biomass energy accounts for approximately 1% of total energy consumption in Türkiye (International Energy Agency, 2022). However, the relevant official institutions aim to increase this share to 5% by 2035 as part of the country's renewable energy targets (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). To achieve this goal, Türkiye has launched several initiatives to promote the use of biomass, such as feed-in tariffs, tax exemptions, and subsidies for biomass energy projects (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-e).

Several biomass power plants are already in operation in Türkiye, and new projects are being developed. Overall, biomass energy has the potential to play an important role in Türkiye's energy mix, contributing to energy security, reducing greenhouse gas emissions, and promoting rural development (Gürel, 2020; Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-e). Figure 16 illustrates the changes in Türkiye's installed biomass capacity over the years. The growth from an installed capacity of 115 MW in 2011 to 2,080 MW in March 2024 is compelling and underscores the country's proactive stance on biomass energy deployment. The figure also illustrates Türkiye's position relative to global leaders in bioenergy.

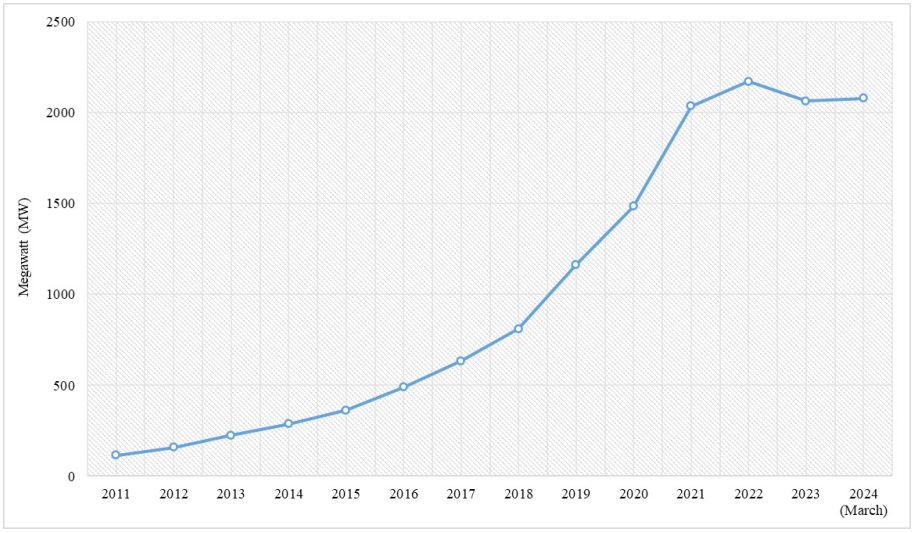

Figure 16. Türkiye's installed biomass power capacity (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-e; TEİAŞ, 2024)

Türkiye has made significant progress in the field of bioenergy and has significantly increased its installed capacity over the past decade. However, there is still a gap with the leading countries in the field. Figure 17 shows the leading countries in terms of installed bioenergy capacity. China leads with approximately 31 GW of installed capacity, followed by Brazil (17.5 GW), the United States (11 GW), India (10.7 GW), and Germany (10 GW).

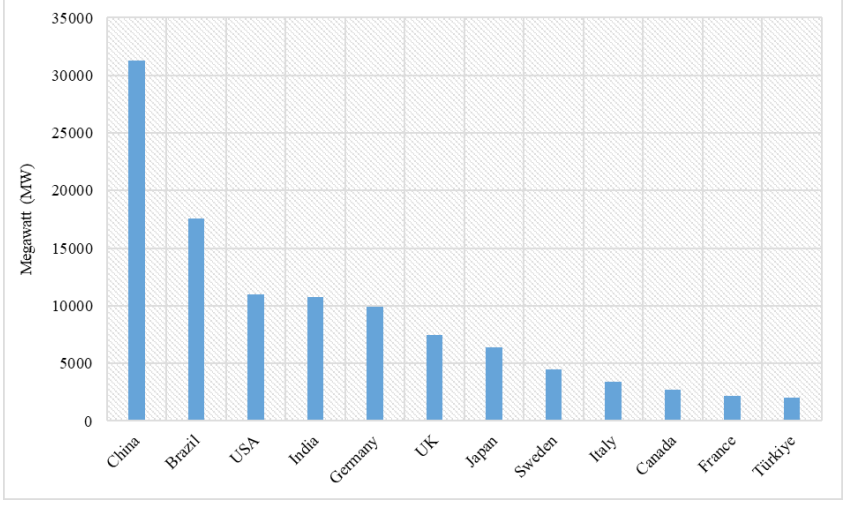

Figure 17. Leading countries by bioenergy installed capacity-2023 (IRENA, 2024)

4.6 Geothermal Energy in Türkiye

Geothermal energy, harnessed from the Earth's internal heat, is a potent energy source. This substantial reservoir of thermal energy resides in underground rocks and fluids (Lund and Toth, 2021). Geothermal power plants convert this heat into electricity through a complex process. Deep wells are drilled into hot rock formations and water is pumped up. The heated water is then converted to steam, which drives electric turbines (Archer, 2020). The intrinsic virtue of geothermal energy lies in its renewability and sustainability, as it leaves no harmful emissions or pollutants in its wake. Its diverse applications range from heating and cooling buildings to powering industrial processes (Wang, Liu, Dou, Li, and Zeng, 2020). This resource is primarily used in areas of high volcanic activity, such as Iceland, the Philippines, and certain regions of the United States. However, its applicability extends to various locations around the world, depending on geological conditions (Archer, 2020; Lund and Toth, 2021).

Türkiye has a rich geothermal potential. Geothermal resource areas are mainly located in the western Anadolu region of the country. About 85% of the geothermal resources are located in this region. Other important regions in terms of geothermal energy are Central Anatolia, Marmara and Eastern Anatolia (MTA, n.d.). The beginnings of geothermal energy in Türkiye date back to 1975, when the Kizildere power plant began generating electricity with a capacity of 0.5 MWe. Geothermal energy, which was used before the prominence of wind and solar energy, has experienced a significant increase in installed capacity since 2011 (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-f). Figure 18 shows the changes in installed geothermal capacity in Türkiye over the years. The last decade has seen a remarkable increase in installed geothermal capacity. This capacity increased from 114 MW in 2011 to 1727 MW in March 2024. While there was a significant acceleration between 2012 and 2019, the growth rate has slowed down in recent years.

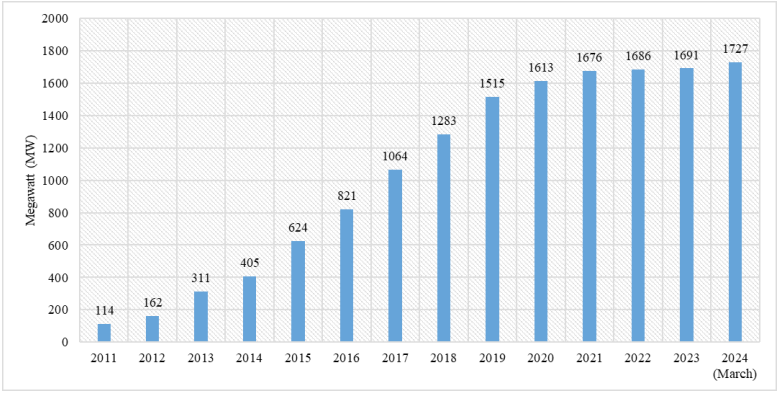

Figure 18. Geothermal energy installed capacity in Türkiye (Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-f; TEİAŞ, 2024)

The installed capacity of geothermal energy remains relatively small compared to other renewable energy sources. In addition, on a global scale, the use of geothermal energy is relatively modest compared to other renewable alternatives. According to IRENA's 2024 Renewable Energy Capacity Statistics, the global installed capacity of geothermal energy is about 15 GW. Figure 19 shows the change in capacity over the years for the top four countries in the sector. Türkiye stands out as one of the leading countries with an installed capacity of 1676 MW.

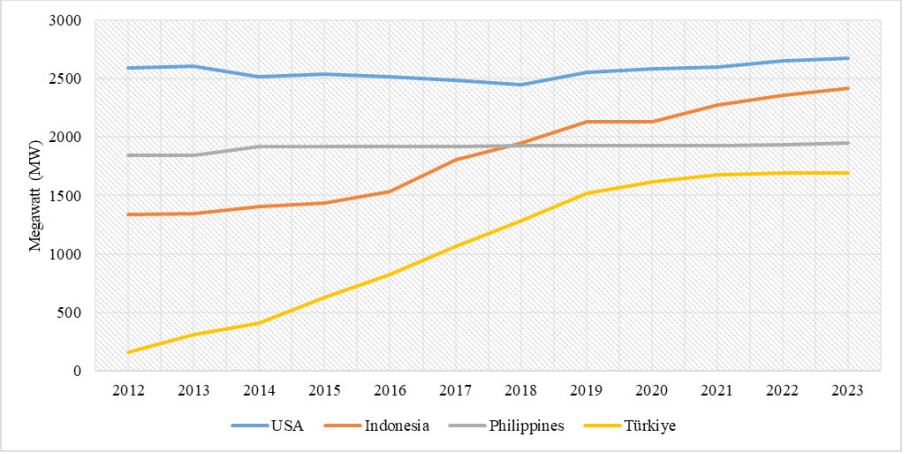

Figure 19. Top 4 countries by Geothermal Energy Installed Capacity (IRENA, 2024)

5. Discussion: Challenges and Opportunities for Türkiye's Renewable Energy Sector

In the field of renewable energy, wind and solar energy are important and popular sources. Although Türkiye started investing in wind and solar energy later than other leading countries, the development in the last fifteen years is quite significant (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a; Yilmaz, 2012). As the renewable energy landscape changes, Türkiye has become a major player in Europe with significant installed capacity (European Commission, 2022; European Union, 2021; International Energy Agency, 2022). Indicators point to a more prominent role for renewables in the energy mix, which brings challenges and opportunities (Özgül, Koçar and Eryaşar, 2020).

Türkiye's central focus is to align energy production with growing consumption and import dependency (Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). While renewable energy can mitigate this dependence, ensuring an adequate energy supply remains paramount. Türkiye's energy structure, dominated by oil, coal, and natural gas (as shown in figure 5), is particularly inf-

luenced by natural gas agreements, suggesting a significant gas-based supply for the foreseeable future (Petform, n.d.). This, together with established fossil fuel dependencies, poses a transition challenge. In addition, the nascent renewable energy sector struggles with costly materials, including imported energy panels (Levenda, Behrsin and Disano, 2021). However, recent investments have promoted localized production, signaling a critical step forward (IRENA, 2022; Republic of Türkiye Ministry of Energy and Natural Resources, n.d.-a). The dominance of the private sector in renewable energy underscores the indispensability of government incentives (Akdoğan and Kovancılar, 2022). However, sporadic disruptions to these incentives warrant comprehensive, long-term strategies to ensure sustainable progress and minimize risk.

Although Türkiye renewable energy sector faces some challenges, it also offers many opportunities. In particular, the country's high potential for renewable resources encourages development (Özgul et al., 2020). As witnessed over the past decade (International Energy Agency, 2022; Republic of Türkiye Ministry of Energy and Natural Resources, 2022a; Ritchie, Roser, and Rosado, 2020), further harnessing this potential can position Türkiye among Europe's renewable energy leaders. International commitments (European Commission, n.d.-a; Kırlı and Fahrioğlu, 2019) encourage Türkiye to move towards carbon reduction targets. While limited skilled labor has historically hindered progress (Sinsel, Riemke, and Hoffmann, 2020), Türkiye's two-decade journey has enriched human capital (Mukhtarov, Yüksel, and Dinçer, 2022; Republic of Türkiye Ministry of Energy and Natural Resources, 2022a). Maintaining this workforce is critical to the desired growth of the sector.

Türkiye has been using hydropower as a renewable energy source for many years. However, both local and global developments make it necessary to use wind and solar energy in renewable energy. As the use of renewable energy sources increases, it will make important contributions from several perspectives. First, Türkiye's dependence on fossil fuels such as natural gas requires the import of these resources from other countries. This situation can lead to the unsustainability of the current status in case of possible delays in the transfer. In addition, energy imports create a significant trade deficit. By diversifying renewable energy sources, important steps can be taken to achieve energy independence. Locally produced energy has the potential to make a significant contribution to the balance of trade. Second, the issue of energy security has become more important, especially with the Russia-Ukraine conflict. In particular, European countries with strong industries have suffered considerable damage. This period has once again highlighted the importance of energy routes and the need for countries to diversify their energy sources. Renewable energy is one of the most important tools for diversification. As a developing country striving to further

strengthen its industry, Türkiye needs to diversify its energy sources as much as possible to avoid potential damage from future conflicts. Third, fossil fuel pollution is becoming increasingly visible, and climate change is becoming more of an issue over time. In this context, every country has its own responsibilities, and Türkiye also has specific obligations. Investments in renewable energy can provide decisive benefits in addressing environmental issues.

The renewable energy sector, which is growing rapidly with investments and incentives from many countries, is a great opportunity for developing countries such as Türkiye, which has a high potential due to its geographical location. Wind and solar energy sources, which are classified as clean energy, stand out as the most popular energy sources today. Based on these two sources, Türkiye has a high potential. The return on investment is lower than in European countries of similar size. Therefore, investments in renewable energy sources have increased significantly, especially in the last decade. As can be seen from the data in the article, the installed capacity of wind and solar power has increased radically since 2010. At this stage, it is crucial to maintain this growth. As stated in the national energy plans, critical targets have been set for 2025, 2030 and 2035. Progress towards these targets can pave the way for Türkiye to become a major renewable energy hub in Europe, alongside Germany, France, the UK and Italy. On a global scale, particularly under the leadership of China and the US, the most notable countries in the advancing renewable energy sector are Brazil and Türkiye. For these two countries, which started to increase their investments in renewable energy much later than other leading countries, the next ten to fifteen years seem to be quite crucial.

In essence, Türkiye's renewable energy story is one of accelerated progress. While challenges remain, the country is on the cusp of harnessing its rich potential, embracing transformative technologies, and cultivating a workforce ready to drive sustainable energy development in the years ahead.

6. Conclusion

Türkiye's energy structure has been dominated by fossil fuels for many years. In particular, coal and natural gas have been used at high rates. Today, however, an important change is taking place. As a signatory to the Paris Climate Agreement, Türkiye is designing its national energy plans in line with its zero-emissions target for 2053. In this context, it has taken steps to facilitate the transition to renewable energy, especially in the last decade. Investments in renewable energy sources are increasing as an alternative to fossil fuels. Although the share of fossil fuels is still significant, the share of renewable energy sources is gradually increasing. Türkiye uses hydropower, wind, solar, biomass, geothermal, wind, solar, biomass and geothermal resources as renewable energy sources. However,

among these sources, especially wind and solar energy have started to come to the forefront. Türkiye, which started using these two clean energy sources later than other leading countries, has made rapid progress. It has become one of the leading countries in Europe in this field.

Energy consumed worldwide is expected to continue to grow in the coming years. Given the environmental and geopolitical risks in the energy sector, there will be difficulties in meeting the growing demand for energy. Interest in renewable energy will inevitably grow. The information contained in the relevant documents shows that the renewable energy sector will continue to grow in the coming years. In this context, it can be said that Türkiye has a very important opportunity. If investments can be directed correctly and effectively, the country can become one of the leading clean energy countries in the world in the short and medium term. Continued incentives, strategic planning, and increased social support are the cornerstones for realizing this goal.

List of abbreviations

CO_2	:	Carbon Dioxide
EU	:	European Union
GDP	:	Gross Domestic Product
GW	:	Gigawatt
Mt of CO_2	:	Million Metric Tons of Carbon Dioxide Equivalent
Mtep	:	Million-Ton Equivalent of Petroleum
Mtoe	:	Million Tons of Oil Equivalent
MW	:	Megawatt
OPEC	:	Organization of the Petroleum Exporting Countries
TWh	:	Terawatt Hour

Conflict of Interest

The author has declared no conflict of interest

References

Adams, S., & Acheampong, A. O. (2019). Reducing carbon emissions: the role of renewable energy and democracy. *Journal of Cleaner Production,* 240, 118245. Doi: https://doi.org/10.1016/j.jclepro.2019.118245

Adjei-Mantey, K., & Adams, S. (2023). Renewable energy, foreign direct investment and carbon dioxide emissions: Do sectoral value additions and policy uncertainty matter? *Energy Nexus,* 10, 100193. Doi: https://doi.org/10.1016/j.nexus.2023.100193

Akdoğan, İ., & Kovancılar, B. (2022). Avrupa Birliği ve Türkiye'de çevre dostu yenilenebilir enerji politikalarının teşvik türleri açısından değerlendirilmesi. *Yönetim ve Ekonomi Dergisi,* 29(1), 69-91. Doi: https://doi.org/10.18657/yonveek.1004872

Akpınar, A., Kömürcü, M. İ., & Kankal, M. (2011). Development of hydropower energy in Turkey: the case of Coruh river basin. *Renewable and Sustainable Energy Reviews*, 15(2), 1201-1209. Doi: https://doi.org/10.1016/j.rser.2010.10.001

Alkathery, M. A., & Chaudhuri, K. (2021). Co-movement between oil price, CO2 emission, renewable energy and energy equities: evidence from GCC countries. *Journal of Environmental Management,* 297, 113350. Doi: https://doi.org/10.1016/j.jenvman.2021.113350

Archer, R. (2020). Geothermal Energy. (pp. 431-445). Editor(s): Trevor M. Letcher, Future Energy (Third Edition), *Elsevier.* Doi: https://doi.org/10.1016/B978-0-08-102886-5.00020-7

Armaroli, N., & Balzani, V. (2007). The future of energy supply: challenges and opportunities. *Angewandte Chemie International Edition,* 46(1-2), 52-66. Doi: https://doi.org/10.1002/anie.200602373

Avcıoğlu, A. O., Dayıoğlu, M. A., & Türker, U. J. R. E. (2019). Assessment of the energy potential of agricultural biomass residues in Turkey. *Renewable Energy,* 138, 610-619. Doi: https://doi.org/10.1016/j.renene.2019.01.053

Balassa, B. (1981). The newly-industrializing developing countries after the oil crisis. *Weltwirtschaftliches Archiv,* (H. 1), 142-194.

Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015). CO2 emissions, energy consumption, economic and population growth in Malaysia. *Renewable and Sustainable Energy Reviews,* 41, 594-601. Doi: https://doi.org/10.1016/j.rser.2014.07.205

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative research journal,* 9(2), 27-40. Doi: https://doi.org/10.3316/QRJ0902027

BP (2022). Statistical Review of World Energy. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf (accessed 8 June 2024)

Caineng, Z. O. U., Xiong, B., Huaqing, X. U. E., Zheng, D., Zhixin, G. E., Ying, W. A. N. G., ... & Songtao, W. (2021). The role of new energy in carbon neutral. *Petroleum exploration and development,* 48(2), 480-491. Doi: https://doi.org/10.1016/S1876-3804(21)60039-3

Crowe, J. A., & Li, R. (2020). Is the just transition socially accepted? Energy history, place, and support for coal and solar in Illinois, Texas, and Vermont. *Energy Research & Social Science,* 59, 101309. Doi: https://doi.org/10.1016/j.erss.2019.101309

Çetin, S., Turan, E., & Bayrakdar, E. (2019). Türkiye'nin güneş enerjisi politikaları. *Third Sector Social Economic Review,* 54(2), 949-968.

Enerdata (2024). World Energy & Climate Statistics-Yearbook. https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html (accessed 18 June 2024)

Erdem, K. O. Ç., & Şenel, M. C. (2013). Dünyada ve Türkiye'de enerji durumu-genel değerlendirme. *Mühendis ve Makina,* 32-44.

Erdil, A., & Erbıyık, H. (2015). Renewable energy sources of Turkey and assessment of sustainability. *Procedia-Social and Behavioral Sciences,* 207, 669-679. Doi: https://doi.org/10.1016/j.sbspro.2015.10.137

Erdogdu, E. (2009). On the wind energy in Turkey. *Renewable and Sustainable Energy Reviews,* 13(6-7), 1361-1371.Doi: https://doi.org/10.1016/j.rser.2008.09.003

European Commission (2022). CO_2 emissions of all world countries. https://edgar.jrc.ec.europa.eu/report_2022 (accessed 05 June 2024)

European Commission (n.d.-a). Paris Agreement, https://climate.ec.europa.eu/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_en (accessed 12 June 2024)

European Commission (n.d.-b). European Neighbourhood Policy and Enlargement Negotiations, National Programme. https://neighbourhood-enlargement.ec.europa.eu/enlargement-policy/glossary/national-programme_en (accessed 18 June 2024)

European Council (2022). Impact of Russia's invasion of Ukraine on the markets: EU response. https://www.consilium.europa.eu/en/policies/eu-response-ukraine-invasion/impact-of-russia-s-invasion-of-ukraine-on-the-markets-eu-response/ (accessed 04 June 2024)

European Union (2021). The Eu in 2021. https://op.europa.eu/webpub/com/general-report-2021/en/ (accessed 16 June 2024)

European Wind Energy Association (2009). The economics of wind energy. EWEA. https://www.ewea.org/fileadmin/files/library/publications/reports/Economics_of_Wind_Energy.pdf (accessed 04 June 2024)

Global Wind Energy Council (2022). Global Wind Report. https://gwec.net/global-wind-report-2022/ (accessed 08 June 2024)

Güney, T. (2022). Solar energy, governance and CO_2 emissions. *Renewable Energy,* 184, 791-798. Doi: https://doi.org/10.1016/j.renene.2021.11.124

Gürel, B. (2020). Türkiye'deki Güncel Biyokütle Potansiyelinin Belirlenmesi ve Yakilmasiyla Enerji Üretimi İyi Bir Alternatif Olan Biyokütle Atiklar İçin Sektörel Açidan ve Toplam Yanma Enerji Değerlerinin Hesaplanmasi. *Mühendislik Bilimleri ve Tasarım Dergisi,* 8(2), 407-416. Doi: https://doi.org/10.21923/jesd.671767

Hayat, M. B., Ali, D., Monyake, K. C., Alagha, L., & Ahmed, N. (2019). Solar energy—A look into power generation, challenges, and a solar-powered future. *International Journal of Energy Research,* 43(3), 1049-1067. Doi: https://doi.org/10.1002/er.4252

İnançlı, S., & Aylin, A. K. I. (2020). Türkiye'nin Enerji İthalatı ve Yenilenebilir Enerji Arasındaki İlişkinin Ampirik Olarak İncelenmesi. *Econder International Academic Journal,* 4(2), 551-565. Doi: https://doi.org/10.35342/econder.849015

International Energy Agency (2022). *World Energy Balances.* https://www.iea.org/countries/turkiye (accessed 02 June 2024)

International Energy Agency (n.d.). Russia's War on Ukraine, https://www.iea.org/topics/russias-war-on-ukraine (accessed 05 June 2024)

International Hydropower Association (2022). Hydropower Status Report. https://assets-global.website-files.com/5f749e4b9399c80b5e421384/63a1d6be6c0c9d38e6ab0594_IHA202212-status-report-02.pdf (accessed 06 June 2024)

IRENA (2022). Renewable Capacity Statistics. https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022 (accessed 17 June 2024)

IRENA (2024). Renewable Capacity Statistics. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2024/Mar/IRENA_RE_Capacity_Statistics_2024.pdf?rev=a587503ac9a2435c8d13e40081d2ec34 (accessed 19 June 2024)

Issawi, C. (1978). The 1973 oil crisis and after. *Journal of Post Keynesian Economics,* 1(2), 3-26. Doi: https://doi.org/10.1080/01603477.1978.11489099

Kaya, M. N., Aksoy, M. H., & Kose, F. (2017). Renewable energy in Turkey: potential, current status and future aspects. *Annals of the Faculty of Engineering Hunedoara,* 15(1), 65.

Kaygusuz, K. (2012). Energy for sustainable development: A case of developing

countries. *Renewable and sustainable energy reviews,* 16(2), 1116-1126. Doi: https://doi.org/10.1016/j.rser.2011.11.013

Khan, S. A. R., Godil, D. I., Quddoos, M. U., Yu, Z., Akhtar, M. H., & Liang, Z. (2021). Investigating the nexus between energy, economic growth, and environmental quality: A road map for the sustainable development. *Sustainable Development,* 29(5), 835-846. Doi: https://doi.org/10.1002/sd.2178

Kırlı, M. S., & Fahrioğlu, M. (2019). Sustainable development of Turkey: Deployment of geothermal resources for carbon capture, utilization, and storage. Energy Sources, Part A: Recovery, *Utilization, and Environmental Effects,* 41(14), 1739-1751. Doi: https://doi.org/10.1080/15567036.2018.1549149

Kothari, R., Tyagi, V. V., & Pathak, A. (2010). Waste-to-energy: A way from renewable energy sources to sustainable development. *Renewable and Sustainable Energy Reviews,* 14(9), 3164-3170. Doi: https://doi.org/10.1016/j.rser.2010.05.005

Lehtola, T., & Zahedi, A. (2019). Solar energy and wind power supply supported by storage technology: A review. S*ustainable Energy Technologies and Assessments,* 35, 25-31. Doi: https://doi.org/10.1016/j.seta.2019.05.013

Levenda, A. M., Behrsin, I., & Disano, F. (2021). Renewable energy for whom? A global systematic review of the environmental justice implications of renewable energy technologies. *Energy Research & Social Science,* 71, 101837. Doi: https://doi.org/10.1016/j.erss.2020.101837

Lund, J. W., & Toth, A. N. (2021). Direct utilization of geothermal energy 2020 worldwide review. *Geothermics,* 90, 101915. Doi: https://doi.org/10.1016/j.geothermics.2020.101915

Magazzino, C., Mele, M., Schneider, N., & Shahbaz, M. (2021). Can biomass energy curtail environmental pollution? A quantum model approach to Germany. *Journal of Environmental Management,* 287, 112293. Doi: https://doi.org/10.1016/j.jenvman.2021.112293

Melikoglu, M. (2013). Vision 2023: Forecasting Turkey's natural gas demand between 2013 and 2030. *Renewable and Sustainable Energy Reviews,* 22, 393-400. Doi: https://doi.org/10.1016/j.rser.2013.01.048

Michaelides, E. E. S. (2012). *Alternative energy sources.* New York: Springer Science & Business Media.

Mitchell, T. (2010). The Resources Of Economics. *Journal of Cultural Economy,* 3:2, 189-204. Doi: https://doi.org/10.1080/17530350.2010.494123

Morris, C., Pehnt, M., Landgrebe, D., Jungjohann, A., Bertram, R., Glastra, K., &

Franke, A. (2012). Energy Transition. The German Energiewende. https://inis.iaea.org/search/search.aspx?orig_q=RN:50064834. (accessed 16 June 2024)

MTA (n.d.). Geothermal Energy Potential And Exploration Studies In Turkey, https://www.mta.gov.tr/v3.0/arastirmalar/jeotermal-enerji-arastirmalari (03 June 2024)

Müftüler-Baç, M. (2018). Remolding the Turkey-EU relationship. *Turkish policy quarterly,* 17(1), 119-128.

Muhammed, G., & Tekbiyik-Ersoy, N. (2020). Development of renewable energy in China, USA, and Brazil: A comparative study on renewable energy policies. *Sustainability,* 12(21), 9136. Doi: https://doi.org/10.3390/su12219136

Mukhtarov, S., Yüksel, S., & Dinçer, H. (2022). The impact of financial development on renewable energy consumption: Evidence from Turkey. *Renewable Energy,* 187, 169-176. Doi: https://doi.org/10.1016/j.renene.2022.01.061

Nautiyal, H., & Goel, V. (2020). Sustainability assessment of hydropower projects. *Journal of Cleaner Production,* 265, 121661.Doi: https://doi.org/10.1016/j.jclepro.2020.121661

Nazir, M. S., Ali, N., Bilal, M., & Iqbal, H. M. (2020). Potential environmental impacts of wind energy development: A global perspective. C*urrent Opinion in Environmental Science & Health,* 13, 85-90. Doi: https://doi.org/10.1016/j.coesh.2020.01.002

Nelson, V. (2009). *Wind energy: renewable energy and the environment.* Boca Raton: CRC press. Doi: https://doi.org/10.1201/9781420075694

Ocal, O., & Aslan, A. (2013). Renewable energy consumption–economic growth nexus in Turkey. *Renewable and sustainable energy reviews,* 28, 494-499. Doi: https://doi.org/10.1016/j.rser.2013.08.036

Official Journal of Türkiye (2011). Yenilenebilir Enerji Kaynaklarinin Elektrik Enerjisi Üretimi Amaçli Kullanimina İlişkin Kanunda Değişiklik Yapilmasina Dair Kanun. https://www.resmigazete.gov.tr/eskiler/2011/01/20110108-3.htm (accessed 07 June 2024)

Official Legislation of Türkiye (2005). Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımna İlişkin Kanun. https://www.mevzuat.gov.tr/mevzuatmetin/1.5.5346.pdf (accessed 04 June 2024)

Omri, A. (2014). An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. *Renewable and Sustainable Energy Reviews,* 38, 951-959. Doi: https://doi.org/10.1016/j.rser.2014.07.084

Ourworldindata (n.d.). Renewable energy generation, Turkey. https://ourworldindata.org/grapher/renewable-energy-gen?time=1990..latest&country=~TUR (accessed 19 June 2024)

Ozcan, B., Tzeremes, P. G., & Tzeremes, N. G. (2020). Energy consumption, economic growth and environmental degradation in OECD countries. E*conomic Modelling,* 84, 203-213. Doi: https://doi.org/10.1016/j.econmod.2019.04.010

Özgül, S., Koçar, G., & Eryaşar, A. (2020). The progress, challenges, and opportunities of renewable energy cooperatives in Turkey. *Energy for Sustainable Development,* 59, 107-119. Doi: https://doi.org/10.1016/j.esd.2020.09.005

Özkan, A., Yeter, U. S. L. U., & Gedikli, E. (2022). Türkiye'nin yenilenebilir enerji potansiyelinde rüzgâr gücü ve Danimarka örneği. *Akdeniz İİBF Dergisi,* 22(2), 26-35. Doi: https://doi.org/10.25294/auiibfd.1111423

Ozturk, I., & Acaravci, A. (2010). CO2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews,* 14(9), 3220-3225. Doi: https://doi.org/10.1016/j.rser.2010.07.005

Peidong, Z., Yanli, Y., Jin, S., Yonghong, Z., Lisheng, W., & Xinrong, L. (2018). Opportunities and challenges for renewable energy policy in China. *Renewable Energy,* Vol4_486-Vol4_503.

Petform (n.d). Natural Gas Market in Turkey. http://www.petform.org.tr/dogalgaz-piyasasi/turkiye-dogal-gaz-piyasasi/ (accessed 08 June 2024)

Rabaia, M. K. H., Abdelkareem, M. A., Sayed, E. T., Elsaid, K., Chae, K. J., Wilberforce, T., & Olabi, A. G. (2021). Environmental impacts of solar energy systems: A review. *Science of The Total Environment,* 754, 141989. Doi: https://doi.org/10.1016/j.scitotenv.2020.141989

Republic of Türkiye Ministry of Energy and Natural Resources (2022a). Türkiye Ulusal Enerji Planı. https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/TUEP/T%C3%BCrkiye_Ulusal_Enerji_Plan%C4%B1.pdf (accessed 19 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (2022b). Güneş. https://enerji.gov.tr/bilgi-merkezi-enerji-gunes (accessed 06 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (2023). Atlas of solar energy potential. https://gepa.enerji.gov.tr/MyCalculator/ (accessed 03 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (2024). Elektrik. https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik#:~:text=2024%20

y%C4%B1l%C4%B1%20Mart%20ay%C4%B1%20sonu,i%20ise%20di%C4%9Fer%20kaynaklar%20 (accessed 19 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-a). *Enerji.* https://enerji.gov.tr/bilgi-merkezi-enerji (accessed 04 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-b). Rüzgar. https://enerji.gov.tr/eigm-yenilenebilir-enerji-kaynaklar-ruzgar (accessed 04 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-c). Güneş. https://enerji.gov.tr/eigm-yenilenebilir-enerji-kaynaklar-gunes (accessed 06 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-d). Hidrolik. https://enerji.gov.tr/bilgi-merkezi-enerji-hidrolik (05 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-e). Biyokütle. https://enerji.gov.tr/bilgi-merkezi-enerji-biyokutle (accessed 03 June 2024)

Republic of Türkiye Ministry of Energy and Natural Resources (n.d.-f). Jeotermal. https://enerji.gov.tr/eigm-yenilenebilir-enerji-kaynaklar-jeotermal (accessed 07 June 2024)

Ritchie H. and Roser M. (2020). "CO_2 emissions" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-emissions' [Online Resource] (accessed 19 June 2024)

Ritchie H., Rosado P. & Roser M. (2020). "Energy Production and Consumption" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/energy-production-consumption' [Online Resource] (accessed 18 June 2024)

Ritchie H., Roser M. & Rosado P. (2020) . "Renewable Energy" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/renewable-energy' [Online Resource] (accessed 19 June 2024)

Ritchie, H., Rosado P. & Roser M. (2023). "Data Page: Wind energy capacity". "Energy". Data adapted from International Renewable Energy Agency. Retrieved from https://ourworldindata.org/grapher/cumulative-installed-wind-energy-capacity-gigawatts [online resource] (accessed 18 June 2024)

Sadorsky, P. (2021). Wind energy for sustainable development: Driving factors and future outlook. *Journal of Cleaner Production,* 289, 125779.Doi: https://doi.org/10.1016/j.jclepro.2020.125779

Saidi, K., & Omri, A. (2020). The impact of renewable energy on carbon emissions

and economic growth in 15 major renewable energy-consuming countries. *Environmental research,* 186, 109567. Doi: https://doi.org/10.1016/j.envres.2020.109567

Sarkodie, S. A., & Adams, S. (2018). Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa. *Science of the total environment,* 643, 1590-1601. Doi: https://doi.org/10.1016/j.scitotenv.2018.06.320

Sayan, R. C. (2019). Exploring place-based approaches and energy justice: ecology, social movements, and hydropower in Turkey. *Energy Research & Social Science,* 57, 101234. Doi: https://doi.org/10.1016/j.erss.2019.101234

Scott, J. (1990). *A matter of record: Documentary sources in social research.* Cambridge: Polity Press.

Sinsel, S. R., Riemke, R. L., & Hoffmann, V. H. (2020). Challenges and solution technologies for the integration of variable renewable energy sources—a review. *Renewable Energy,* 145, 2271-2285. Doi: https://doi.org/10.1016/j.renene.2019.06.147

Stern, D. I. (2019). *Energy and economic growth.* In Routledge handbook of Energy economics (pp. 28-46). London: Routledge.

Statista (2024a). Historical carbon dioxide emissions from global fossil fuel combustion and industrial processes in selected years from 1750 to 2022. https://www.statista.com/statistics/264699/worldwide-co2-emissions/. (accessed 09 June 2024)

Statista (2024b). Cumulative hydropower capacity worldwide in 2022, by major country. https://www.statista.com/statistics/474652/global-total-hydropower-capacity-in-major-countries/ (accessed 18 June 2024)

Şenel, M. C., & Erdem, K. O. Ç. (2015). Dünyada ve Türkiye'de rüzgar enerjisi durumu-Genel değerlendirme. *Mühendis ve Makina,* 56(663), 46-56.

TEİAŞ (2024). Türkiye Elektrik İstatistikleri. https://ytbsbilgi.teias.gov.tr/ytbsbilgi/frm_istatistikler.jsf (accessed 18 June 2024)

Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. *Energy policy,* 33(3), 289-296. Doi: https://doi.org/10.1016/S0301-4215(03)00241-6

Turkish Coal Enterprises. (2021). Installation of TCE's first solar power plant completed. https://eli.tki.gov.tr/haberler/tkinin-ik-gunes-enerjisi-santrali-kurulumu-tamamlandi (accessed 15 June 2024)

Turkish Statistical Institute (2023). Data Portal, https://data.tuik.gov.tr/ (accessed 07 June 2024)

United Nations (n.d.). What is the Kyoto Protocol? https://unfccc.int/kyoto_protocol (accessed 12 June 2024)

Wang, Y., Liu, Y., Dou, J., Li, M., & Zeng, M. (2020). Geothermal energy in China: Status, challenges, and policy recommendations. *Utilities Policy,* 64, 101020. Doi: https://doi.org/10.1016/j.jup.2020.101020

Wang, Z. (2019). Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Science of the Total Environment,* 670, 1075-1083. Doi: https://doi.org/10.1016/j.scitotenv.2019.03.268

Wang, Z., Bui, Q., Zhang, B., & Pham, T. L. H. (2020). Biomass energy production and its impacts on the ecological footprint: An investigation of the G7 countries. *Science of the Total Environment,* 743, 140741. Doi: https://doi.org/10.1016/j.scitotenv.2020.140741

Warlouzet, L. (2017). *Governing Europe in a globalizing world: neoliberalism and its alternatives following the 1973 oil crisis.* London: Routledge.

Yılmaz, M. (2012). Türkiye'nin enerji potansiyeli ve yenilenebilir enerji kaynaklarının elektrik enerjisi üretimi açısından önemi. *Ankara Üniversitesi Çevrebilimleri Dergisi,* 4(2), 33-54. Doi: https://doi.org/10.1501/Csaum_0000000064

Zafar, M. W., Sinha, A., Ahmed, Z., Qin, Q., & Zaidi, S. A. H. (2021). Effects of biomass energy consumption on environmental quality: the role of education and technology in Asia-Pacific Economic Cooperation countries. *Renewable and Sustainable Energy Reviews,* 142, 110868. Doi: https://doi.org/10.1016/j.rser.2021.110868

Zhang, X. P., & Cheng, X. M. (2009). Energy consumption, carbon emissions, and economic growth in China. *Ecological economics,* 68(10), 2706-2712. Doi: https://doi.org/10.1016/j.ecolecon.2009.05.011