

Energy and Technology

PhD Onur Yađış



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Contents

Abbreviations	v
Introduction	1
1 The Concept of Energy and Technological Development	3
Energy Concept	3
Energy Resources	5
Energy Economics	6
Primary Energy Sources	11
Secondary Energy Sources	28
Conceptual and Theoretical Framework of Technological Development	29
Technology Indicators	37
2 An Overview of Energy and Technological Developments in the World and in Türkiye	45
Primary Energy Resources in the World	45
Secondary Energy Source in the World	81
Primary Energy Resources in Türkiye	82
Secondary Energy Source in Türkiye	104
Status of Technological Development in the World	106
Status of Technological Development in Türkiye	112
3 Econometric Analysis of the Relationship Between Energy and Technological Development	119
Literature Review	120
Data Set and Model	126
Econometric Method	127
Econometric Application Results	130
Conclusion	133
Bibliography	139

Abbreviations

United Nations Development (UNDP)
Liquefied Petroleum Gas (LPG)
Compressed Natural Gas (CNG).
Standardization/Technical Committee (ISO/TC)
Small hydroelectric power plants (CHPP)
Alternating Current (AC)
Photovoltaic (PV)
Megajoules (MJ)
Research and Development (R&D)
Full-time Equivalent (FTE)
International Energy Agency (IEA)
Three Mile Island (TMI)
Concentrated Solar Power (CSP)
International Hydropower Association (IHA)
Global Market with Regulations on Tariffs (FITs)
Megawatts Thermal (MWth)
Gigawatts (GW)
Power-to-Gas (P2G)
TeraWatt-hours (TWh)
Kilowatts(KW)
Peta Joule(PJ)
Exajoule (EJ)
Billion Cubic Meters(Bcm)
Ocean Thermal Energy Conversion (OTEC)

Standard Cubic Meters (Sm³)
Mega Wat(MW)
Atomic Energy of Canada Limited (AECL)
Kraftwerk Union (KWU)
General Electric (GE)
Nuclear Power Plant (NPP)
Geothermal Power Plants (GPPs)
Biomass Power Plants (BESS)
Energy Market Regulatory Authority (EPDK)
RES Support Mechanism (YEKDEM)
Wind Energy Potential Atlas (REPA)
Solar Energy Potential Atlas (GEPA)
Ministry of Energy and Natural Resources (ETKB)
Türkiye Natural Gas Distributors Association (GAZBİR)
Kilowatt-Mechanical (KW/m)
National Boron Research Institute (BOREN)
Türkiye Electromechanical Industry Inc. (TEMSAN)
Western Black Sea Development Agency (BAKKA)
Türkiye Electricity Authority (TEK)
Türkiye Electricity Distribution Inc. (TEDAŞ)
Türkiye Electricity Production Transmission Inc. (TEAŞ)
Türkiye Electricity Transmission Inc. (TEİAŞ)
Electricity Production Inc. (EÜAŞ)
Türkiye Electricity Trade and Contracting Inc. (TETAŞ)
Gross Domestic Product (GDP)
Fixed Effects (FE)
Random Effects (RE)
Panel Corrected Standard Errors (PCSE)
Organisation for Economic Co-operation and Development (OECD)
Vector Autoregression (VAR)
Panel Least Squares (EKM)
Panel Generalised Least Squares (GEKK)
Autoregressive Distributed Lag Model (ARDL),
Pooled Mean Group (PMG)

Dynamic Fixed Effects (DFE)
Mean Group (MG)
Dynamic Ordinary Least Squares (DOLS)
Fully Modified Ordinary Least Squares (FMOLS)
Environmental Kuznets Curve (EKC)
Communication Technologies (ICT)
Augmented Dickey-Fuller (ADF)
Phillips-Perron(PP)
Final Prediction Error(FPE)
Sequential Modified LR Test Statistic (LR)
Schwarz Information Criterion (SC)
Hannan-Quinn Information Criterion (HQ)
High-Voltage Direct Current (HVDC)
Renewable Energy Resource Area (YEKA)
Scientific and Technological Research Council of Türkiye(TÜBİTAK)

Introduction

Energy is one of the most critical factors for the growth and development of countries. Consumed in every aspect of daily life, even short-term disruptions can cause significant financial losses. The energy planned for annual production is based on statistical results. The statistical results of total energy consumption are examined, and production planning is carried out accordingly. Energy planning has significant geopolitical and strategic importance in terms of the resources it uses. In this context, the use of local resources can eliminate reliance on external sources and help a country become more effective in the energy market. Energy sector management is responsible for meeting energy demand in a high-quality, cost-effective manner. Countries must include new alternative sources in their agendas to ensure the continuity of energy supply security. In recent years, the world has focused on policies such as securing and sustaining energy supply, addressing fluctuations in fossil fuel (e.g., oil) prices, improving the efficient and effective use of energy, reducing the negative effects of greenhouse gases, and transitioning from fossil fuels to renewable energy sources. Global population growth has driven increased urbanisation and industrialisation. This, in turn, has resulted in increased energy demand. Therefore, there is a tendency to turn to alternative renewable energy sources. Consequently, increasing production is necessary to benefit from renewable energy sources. To increase production, this technology must be used effectively. Energy efficiency can be increased and production costs reduced through R&D activities. Energy security can be ensured through the use of renewable energy sources and the development of technological knowledge. Thus, renewable energy sources can compete with fossil fuels such as oil, coal, and natural gas. Technological advancements in the renewable energy field have contributed to the transition to efficient, low-carbon energy systems at minimal cost. R&D supports renewable energy production by facilitating the dissemination of technological knowledge. R&D activities focus on alternative energy sources. Therefore, they also contribute to a country's

economic growth. Renewable energy sources are important both globally and nationally. They have great potential for a sustainable energy future. In the fight against climate change, renewable energy sources help reduce greenhouse gas emissions, mitigating the impacts of climate change and environmental pollution. In terms of economic development and employment, national energy transition projects support economic growth by creating new jobs in the renewable energy sector.

From the perspective of international cooperation and democracy, inter-country energy cooperation contributes to strengthening diplomatic relations through renewable energy projects and technology transfer. In this context, the United Nations Development Programme (UNDP) and other international organisations emphasise the importance of cross-border energy cooperation. Regarding global energy demand and sustainability, efforts to meet it and ensure a sustainable energy transition underscore the global importance of renewable energy. In terms of energy supply security, renewable energy sources make energy supply more secure by reducing countries' energy dependence. Renewable energy technologies encompass systems that generate energy from various natural resources. In renewable energy technologies, solar panels contain photovoltaic cells and are typically mounted on roofs or on the ground. Wind turbines convert the kinetic energy of the wind into mechanical energy, which is then converted into electrical energy. They are usually installed in groups over large areas, typically within wind farms. Distributed energy refers to energy production at the point of consumption, driven by the increasing prevalence of renewable energy sources. Energy storage systems store excess energy and return it to the system when needed, ensuring stable energy supply. These systems are generally preferred by renewable energy sources with variable production profiles. Smart grids are electricity grids that enable more effective communication among energy production, transmission, and consumption, facilitate the integration of renewable energy, and increase energy efficiency. This study consists of three parts. The first part explains the conceptual and theoretical framework of energy and technological development. The second part presents information on World and Türkiye energy and technological development. The third part applies an econometric analysis to the relationship between energy and technological development in Türkiye. In this study, annual data from 1996-2022 were used and causality analysis methodology was applied.

The Concept of Energy and Technological Development

This section provides information on the conceptual and theoretical infrastructure of energy and technological developments. In this context, the concept of energy, energy sources, energy economics, primary and secondary energy sources, technological development, technological indicators, and the channels of technology diffusion will be explained.

1.1. Energy Concept

Energy is an indispensable requirement for humanity. Energy is used in many areas of daily life, from production to consumption and from development to development. Ensuring the continuity of the industrial, residential, and transportation sectors is vital.¹ In ancient times, humanity obtained energy first by using its own muscle strength and later by harnessing the power of various animals. In later times, energy was provided with the help of water, wind, and the sun. While the energy needs of machines were met by steam and coal in the 18th century, hydroelectric power from water was developed in the 20th century. In subsequent years, when oil was used as energy, the need for coal decreased. After World War II, humanity discovered ways to convert atomic energy into heat and electricity. Various energy sources have been developed through wind and solar technologies. Energy has become indispensable for production, consumption, the economy, and human life. In the 21st century, energy has become essential to modern life as industrialisation, population

1 Martin Kaltschmitt, Wolfgang Streicher, Andreas Wiese, (2007) *Renewable Energy: Technology, Economics and Environment*, New York: Springer Berlin Heidelberg, P.2.

growth, urbanisation, and technological development have increased. Thus, energy consumption is closely related to economic growth and development.²

The term energy refers to the ability of substances to function in physics. In fact, energy is derived from the Greek word “energon.” En-inner refers to the ergonwork.³ Energy that can be converted into different forms includes chemical, magnetic, thermal, mechanical, kinetic, and electrical energy.⁴

The basis of the concept of energy, as in physical science, is that nothing, which is one of the elements in the explanation of matter, can be created or destroyed. They can only be transformed into different types of energy. These forms of energy can develop, differentiate, and add new features through technological development and invention. The forms of energy available today are as follows:

- Kinetic energy: This is the energy of a substance moving from one position to another.
- Potential energy: This is the energy that a substance has under the current conditions.
- Mechanical energy: This consists of the sum of potential and kinetic energies.
- Chemical energy:⁵ Energy is found in the form of storage in substances.
- Heat energy:⁶ This is the energy released by the movement of atoms.
- Electrical energy:⁷ This is the energy produced by electron movement.
- Magnetic energy:⁸ This energy has properties specific to metals and can be converted into attraction or repulsion depending on the arrangement of the atoms.

2 Simeyye AK (2019), An Econometric Analysis of the Sustainability of the Current Account Deficit in Turkey from an Energy Economics Perspective, Aydın Adnan Menderes University, Institute of Social Sciences, PP4-5

3 Aruoba, Ç. ve Alpar, C. (1992). Sectoral Developments in the Turkish Economy. Özyurt Printing House, Ankara, P.89

4 Yamak, T (2006). Turkey's Alternative Energy Sources, Potential and Economic Analyses. Marmara University, Institute of Social Sciences, Master's Thesis, P.3

5 **Matter** or matter is called granular structures that take up space in space and have volume and mass.

6 **An atom** is the smallest building block that carries the chemical and physical properties of all matter in the known universe.

7 **An electron** is a subatomic particle with a negative fundamental electric charge.

8 **Metal is an element** that has high electrical and thermal conductivity, has a unique luster, is prone to shaping, has a high tendency to form cations, and combines with oxygen to give mostly basic oxides.

- Nuclear energy: Energy contained within atoms.
- Light energy: The energy that creates an image by reflecting from the materials.
- Sound energy: This is the energy that living things become aware of, thanks to their hearing organs.

The use of energy resources has increased in the developing world to meet total demand.⁹

1.2. Energy Resources

Today, energy has become an integral part of the economy and social life, with rising consumption and population. This has become an element that determines countries' policies worldwide. Energy resources, which occur in various forms as a result of the natural formation cycle, have geopolitical significance due to their use and availability. It is not possible to distribute the amount and region fairly in a region where the types of energy in the different structures are concentrated. Therefore, energy diversity should be examined in different ways according to its characteristics.¹⁰

Energy resources must be used to meet the energy needs. Energy resources can be classified into two types: use and transformation resources. When classified according to convertibility, they are divided into primary and secondary energy sources. Primary energy resources refer to resources that have not undergone any specific changes or processing and can be used at any time. Secondary energy resources differ according to the processes and changes involved. Secondary energy sources include electricity¹¹, gasoline¹², diesel¹³, diesel, secondary coal, coke, pet coke¹⁴, air gas¹⁵, and liquefied petroleum gas

9 Bilginoglu, MA (1991). Energy Problem and Alternative Energy Policies in Developing Countries. *Erciyes University Faculty of Economics and Administrative Sciences Journal*, 9,122-147.

10 Sümeyye AK (2019), An Econometric Analysis on the Sustainability of the Current Account Deficit in Turkey from the Perspective of Energy Economy, *Aydın Adnan Menderes University Institute of Social Sciences*, p.4-5

11 Electricity is the name given to a series of physical phenomena based on the flow of electrical charges.

12 Gasoline is a type of fuel made from petroleum. Crude gasoline is obtained up to 150 °C, kerosene, kerosene and jet fuel up to 150-250 °C, diesel fuel up to 250-350 °C, and heavy oils after 350 °C.

13 Diesel or diesel oil is one of the distillation products of crude oil used in diesel engines.

14 Petrocoke is a solid fuel, a product of petroleum refining, that has a low ash content and high calorific value, and in some cases provides the same efficiency as natural gas or fuel oil. It is dark gray or black in color.

15 Air gas is a gas fuel produced from coal to be used for heating and lighting purposes.

(LPG)¹⁶. When classified by use, they are divided into non-renewable and renewable sources. Non-renewable energy resources are those that cannot replenish themselves, and their reserves decrease as consumption increases. They are divided into two categories: fossil origin and nuclear origin. Fossil-based nonrenewable energy sources include coal, oil, and natural gas. The nonrenewable energy sources of nuclear origin are uranium¹⁷ and thorium¹⁸. Renewable energy sources are constantly replenished without processing and are ready for use in nature.¹⁹

In this study, energy resources were examined based on their use. When classified, they are divided into two categories: primary and secondary energy sources. Primary energy sources will be examined in two parts: non-renewable (coal, oil, biomass, and nuclear energy) and renewable (hydroelectric, wind, solar, geothermal, hydrogen, wave, tidal, and current energy). Secondary energy sources were examined under the subheading of electrical energy.

1.3. Energy Economics

In our current age, energy is vital to a country's economic future. Countries at all levels of development worldwide need energy to increase their welfare. Energy accounts for a large share of the production and consumption of goods and services. In this production-consumption network, profits and expenses are involved. Energy economics, also called natural resources economics because energy has become an indispensable need for societies, is examined as a subfield of economics. Economic practices resulting from the extraction and processing of natural resources, along with various studies, have created energy economics.²⁰

Although the energy demand is increasing daily, the energy economy is used to balance resource scarcity. Considering environmental factors, energy economics examines how resources can be extracted at the most affordable cost.

16 Liquefied petroleum gas, or LPG for short, is a colorless, odorless, heavier than air and flammable gas obtained during the distillation of crude oil in refineries or by separating the natural gas found on oil deposits and liquefied under pressure.

17 Uranium is a radioactive chemical element.

18 Thorium. It is a radioactive element with an atomic number of 90, an atomic weight of approximately 232 g/mol, a density of 11.7 g/mL, melting at 1755 °C, lead color, and does not decompose in air. It is used as an atomic energy source.

19 Bilginoğlu, MA (1991). Energy Problem and Alternative Energy Policies in Developing Countries. *Erciyes University Faculty of Economics and Administrative Sciences Journal*, 9,122-147.

20 Field, C.Borry and Martha K.Field (2002); *Environmental Economics*, McGraw-HillNew York. p,24

They also play an essential role in increasing and improving the sustainability of these resources.²¹

1.3.1. Energy Supply and Factors Affecting Energy Supply

The energy available to the market for consumption is called energy supply. In short, it is the process of meeting the energy demand. Energy supply policies are vital for selecting the least-cost, most reliable method. The resources to be used and how energy needs will be supplied are among the leading energy policies of countries. If high-quality energy policies are implemented, they will positively contribute to the growth and development of countries. If opposing policies are implemented, the economy may be negatively affected.²²

The main factors affecting energy supply include countries' geopolitical positions, seasonal conditions, technological and environmental conditions, economic and political factors, and institutional and financial factors. Generally, the general level of prices and the effective use of resources are among the most critical factors affecting energy supply. Economic and political factors, as well as institutional financial conditions, are related to price levels and geopolitical location, while seasonal and environmental conditions are associated with the effective use of resources.²³

Geopolitical locations and seasonal conditions make it easier to access energy resources and obtain information on energy capacity. Extracting energy resources in regions where intense consumption is possible, and preparing them for production, is possible with effective and efficient use of technology. Technology is another factor that affects energy supply. Technology is a mandatory building block at every stage of energy extraction, use, and distribution. Sophistication is essential for the efficient use of technology. Although technology is used more effectively, it should be ensured that its environmental impact is minimised. Another issue affecting energy supply is the financial resources required to extract the energy resource and convert it into energy. If countries' economic resources and technological development cannot be sufficiently increased, energy must be imported. Countries with more energy resources can have a political state and use energy as a means of power.²⁴

21 Yücel, F. Behçet (1994). *Energy Economics*, Febel Publications, Istanbul. P.17

22 Constantini V., Martini C. (2010). "The Causality between Energy Consumption and Economic Growth: A Multi-Sectoral Analysis Using Non-Stationary Cointegrated Panel Data", *Energy Economics*, 32(3), 591-603. PP, 595-596.

23 Biçici, R. (2008). *Energy Economics in Turkey*, (Unpublished Master's Thesis), Zonguldak Karaelmas University, Institute of Social Sciences, Zonguldak.

24 Sümeyye AK (2019), *An Econometric Analysis of the Sustainability of the Current Account*

1.3.2. Energy Demand and Factors Affecting Energy Demand

The energy required for human consumption is expressed as the demand for energy. The energy demand is similar to that of the energy supply. The main factors affecting energy demand are population growth, urbanization, economic growth, social development, and technological development.²⁵

Population growth can increase the demand for energy. Additionally, energy demand varies across age groups; individuals with higher levels of education and those participating in production demand more energy.²⁶

Energy demand has increased with urbanization, paralleling population growth. With urbanisation, demand for goods and services has also risen. This increase has increased the energy demand. In this context, energy demand has increased as more goods and services are produced. This increase in production leads to economic growth. Thus, the energy demand will continue to increase. Societies that achieve prosperity may prefer to live more comfortably. Therefore, as social and economic comfort improves, energy demand will increase.

Technological developments affect energy demand in the long term by enabling the use of different energy sources and more efficient resource use.²⁷

1.3.3. Energy Supply and Demand Elasticities

Every good and service that has a price has supply elasticity. Because energy is a product that is supplied and demanded, it has a specific price. Any changes that may occur in energy prices may also affect the amount of energy provided. The elasticity of supply defines the sensitivity of this quantity. According to the energy supply law, assuming all variables that can increase energy prices are ineffective when energy prices rise, the amount of energy produced (i.e., supplied) also increases. In this case, the supply elasticity is positive. Because energy demand is unlimited, countries that cannot meet their demand are forced to import energy from other countries. Thus, dependence on the outside increases.²⁸

Deficit in Turkey from an Energy Economics Perspective, Aydın Adnan Menderes University, Institute of Social Sciences, PP,12-13

- 25 Altuntaşoğlu, Z. (2003). "Sustainable Development-Renewable Energy and Renewable Energy Resources Draft Law", Türkiye VI. Energy Symposium, TMMOB, Ankara.P.196
- 26 Brown, Lester R and Christofer Flavin (2000); *A New Economy for a New Century, The State of the World, 2000*, (Translated by: A.Başçı), TEMA Foundation Publications, İstanbul.p,3-5
- 27 Karadaş, F (2008). *Energy Sector and Policies in Turkey within the Framework of Sustainable Development*, June, Gaziantep University Social Sciences Institute, p. 54
- 28 DEK-TMK, Türkiye Biofuel Potential and Latest Developments, www.dektmk.org.tr/ p.10

Energy was found in all sectors. In this case, it helps us understand the importance of general price levels. There are some consequences of changes in oil prices, which are considered one of the most important non-renewable energy sources. Any increase in oil prices may put economic pressure on the economy. Economies that do not want to be affected by prices and want to reduce their external dependency must turn to alternative energy sources. According to economic theory, changes in the general price level of any good or service may lead to changes in demand, while all other factors remain constant. When the prices of goods and services increase, demand decreases; in the opposite case, demand increases. The price elasticity of demand explains this situation.²⁹

Another factor that affects demand is the individual's income level. Assuming that all factors affecting demand are ineffective, the sensitivity of demand for goods to income is captured by the income elasticity of demand. Income elasticity of demand: For inferior goods, this is possible if it is less than 0. For everyday goods, this is possible if it is between zero and one. If the value exceeds one, it is considered a luxury good.³⁰

1.3.4. General Balance in the Energy Market

Equilibrium in the energy market, as expressed in economic theory, is where supply and demand quantities meet at a certain point. If the demand for energy in the economy increases and the supply cannot meet it, the supply and demand balance shifts. Prices fall. Thus, the amount of energy required to purchase a specific price decreases. To prevent this, the state can implement policies. With the world's growing population, energy prices have risen due to declining fossil fuel reserves.³¹ For this reason, the importance of energy resource policies is rising.

1.3.5. Costs of Energy Production Plants

Production plants are required to deliver energy to places that are in demand. Various costs are incurred in the installation of production plants. The first is unit energy production costs. These costs cover all possible expenses during the entire time the power plant is used; they refer to the costs required to provide unit energy from the power plant. Another type of cost is the initial investment

29 Çermikli, AH and Öztürkler H. (2010). World Energy Consumption: Change in Energy Consumption in the Period 1980–2005. *Economic Approach*, 21 (74), 1-22.P,12

30 Gülcü, Y. (2010). Analysis of Socio-Economic Factors Affecting Natural Gas Usage in Isparta Province (Master's Thesis). Süleyman Demirel University, Isparta..P,14

31 Akan, Y. and Tak. S. (2003). Türkiye Electric Energy Econometric Demand Analysis. *Journal of Economics and Administrative Sciences*, 17 (1-2), 22-49. P,21

cost. These costs are also called operating and maintenance costs. Before the power plant starts the energy production process, the necessary machinery, vehicles, etc., incur such expenses. At the same time, the initial investment costs were among the largest. Other costs include fixed and variable operating costs. Fixed operating costs, workers' wages, and variable operating costs include consumable materials, such as the fuel required to power production plants.³²

1.3.6. Pricing of Energy

Changes in supply and demand for energy are the most important variables in pricing and charging in the energy market. Fees for natural gas, one of the primary energy resources, vary depending on consumers' needs and market structure. Seasons and weather conditions influence resource pricing. When weather conditions become unfavourable, power plant problems may increase energy prices. Factors that affect energy pricing include the amount of energy needed, how long it will take to use it, and the cost of the raw materials required to obtain it. Other factors that determine energy prices are geopolitical locations and political problems.³³

Energy conversion costs are another important element of energy pricing. This can be examined in two ways: through energy and monetary costs. Energy costs are the costs incurred during the conversion from one type to another. This is especially evident in non-renewable energy types, such as oil. Losses occur when the chemical energy contained in oil is converted into electrical energy. However, because oil is less costly for electricity distribution, the acceptability of the losses increases. The transportation sector is less preferred because the efficiency obtained from coal is extremely low. However, it is also possible to convert coal into liquid fuels. Although the liquid chemical fuel produced is half the amount of the coal source, it can be used for transportation. Therefore, the losses in coal are acceptable. Monetary costs include investment costs for establishing and operating production plants.³⁴

1.3.7. Determining Energy Policies

Economic growth and energy consumption play important roles in determining energy policies. This relationship can be explained by the following four hypotheses in the literature: growth, protection, feedback, and neutrality. According to the growth hypothesis, the complementarity between capital

32 Kaya, K. ve Koç, E. (2015). Cost Analysis of Energy Production Plants. *Engineer and Machine*, 56, 61-68. PP,61-62

33 Regnier, E. (2007). Oil and energy price volatility. *Energy Economics*, 29, 405-427. p,405

34 Özil, E. et al. (2013). *Electricity Energy Technologies and Energy Efficiency Volume 1*. İstanbul, Turkey: TESAB. P,250

and labour during production is required to ensure that energy consumption increases economic growth. Thus, energy consumption has led to growth. According to the conservation hypothesis, the possible energy-related savings do not affect growth. In this context, a relationship exists between growth and energy consumption. The feedback hypothesis offers growth-enhancing effects when implementing practices that increase energy consumption. Finally, according to the neutrality hypothesis, there is little to no relationship between energy consumption and economic growth.³⁵

This study first includes definitions of energy concepts and resources, followed by information about the energy economy. Primary and secondary energy sources were included in this study. Primary energy resources are examined under two subheadings: non-renewable and renewable energy resources. Secondary energy sources are discussed under the subheading of electrical energy sources, which are frequently used in the literature.

1.4. Primary Energy Sources

Primary energy resources are examined under two subheadings: non-renewable and renewable. Non-renewable energy sources are examined under subheading coal, oil, natural gas, biomass, and nuclear energy. The energy subheadings will explore renewable energy sources such as hydroelectric, wind, solar, geothermal, hydrogen, wave, tidal, and ocean.

1.4.1. Non-Renewable Energy Sources

Energy demand is increasing daily due to the world's growing population and economic development. For this reason, nonrenewable energy resources are decreasing daily. These sources can cause serious environmental problems. These energy sources have a fossil origin. In this context, they occur in nature as solids, liquids, and gases. These fossil resources are then burned and converted into energy. The main nonrenewable energy sources are coal, oil, natural gas, biomass, and nuclear energy.

1.4.1.1. Coal Energy Source

It is a solid fossil fuel with a black, dark grey, brown-black, shiny, or matte colour.³⁶ Coal also ³⁷ has the features of sedimentary rock. Coal consists of

35 Squalli, J. (2007). Electricity Consumption and Economic growth: Bounds and Causality Analyses of OPEC Countries. *Energy Economics*, 29, 1192–1205. PP.1195-1196

36 Fossil fuel or mineral fuel is a natural energy source containing hydrocarbons and high amounts of carbon.

37 Sedimentary rocks are generally layered and contain the remains of organisms.

50% by weight and more than 70% by volume of charred plant residue.³⁸ Coal, a fossil fuel, is a chemical rock that contains carbon, hydrogen, oxygen, sulfur, and nitrogen. Coal was the first fuel to be discovered.³⁹ Coal is a plant alteration process. It is formed by transforming peat, lignite, sub-bituminous coal, bituminous coal (hard coal), anthracite, and graphite.⁴⁰

Meeting the global demand for electricity was of great importance after the Industrial Revolution in the 18th century, driven by an increasing population and the development of steam-powered vehicles. After the 20th century, coal lost its importance as an energy source, supplanted by another fuel, namely oil.⁴¹

Since the 21st century, coal has become a less costly energy production source that can significantly eliminate countries' dependence on imported energy. To reduce the environmental damage caused by coal, factory filtration technologies should be improved, and environmentally friendly policies should be emphasised. Coal, an essential component of global fuel supplies, accounts for 27% of all energy used worldwide, and 38% of electricity production continues to be used in heating, iron and steel, cement, and other industries. When coal formation is examined, it can be said to occur because layers change over time due to the accumulation of plant residues in swamp areas. It remained under the depths due to sediment accumulation in these layers and land movements. These plants, buried deep, undergo physical and chemical changes due to heat and pressure and turn into coal.

The carbonisation process occurred between 500 million and 15 million years ago. Peat in the top layer of the formation of coal⁴² type soils. Coal according to their organic maturity Lignite⁴³, Sub-bituminous Coal⁴⁴,

38 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-tabii-kaynaklar-komur>

39 TKİ, (2003); The Place of Coal in Energy, ITU Faculty of Mining Policy Publications, Istanbul, PP.17-18

40 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-tabii-kaynaklar-komur>

41 TKİ (Turkish Coal Enterprises), (2009), Coal Sector Report, PDF , P.7

42 Peat is a type of organic soil formed over thousands of years through the cyclical accumulation of plant roots and stems as a result of the natural processes of decreasing water levels in lake beds, the prominence of plant activity, the death of plants due to rising water levels in winter, and the continuous repetition of this natural phenomenon.

43 Lignite is a type of coal that is also called brown coal and is at the bottom of the coal ranking, almost all of which is used as fuel in thermal power plants.

44 Sub-bituminous coal, also called semi-bituminous coal, bituminous shale, or bituminous schist, is a type of rock. According to the definition provided by the MTA (Mineral Research and Exploration Institute), it is a sedimentary rock with a fine-grained and generally laminated structure that contains an organic substance called kerogen and is insoluble in organic solvents.

Bituminous coal⁴⁵ and Anthracite⁴⁶ They are divided into types. Of the coal types, anthracite (90%) has the highest carbon composition, while lignite (50%) has the lowest carbon composition.

Thermal power plants produce electricity from coal. Boilers⁴⁷, steam turbines⁴⁸ and generators⁴⁹ are among the basic components of a thermal power plant. For the pure water in the pipes to be turned into pressurised hot water, coal must be burned in the boiler. Pure water is used to prevent pipes from being damaged when pressure and temperature occur owing to the presence of minerals. Steam turbines rotate by sending pressurised, hot water (approximately 550 °C) through pipes. Thus, heat energy becomes mechanical energy. Mechanical energy is converted into electrical energy by driving a generator via a shaft connected to the turbine. The steam produced as a result of pressure and heat turns into water upon cooling and is subjected to the same process again⁵⁰.

1.4.1.2 Oil Energy

The word petroleum is derived from the Latin words petro (stone) and oleum (oil). Petroleum can form when organic substances are subjected to pressure and heat. Oil contains hydrogen, carbon, and small amounts of nitrogen, oxygen, and sulfur. Crude oil is unrefined liquid oil. Asphalt is a semi-solid, solid oil composed of heavy hydrocarbons and tar. Pitch is the name given to tar and similar materials. Crude oil is also called a hydrocarbon because its main components are hydrogen and carbon.⁵¹

Petroleum is widely used in the textile, transportation, heating, and electricity sectors. The damage caused by oil, which is used across different sectors, was relatively high. When oil is burned, serious negative effects occur due to the gases released into the environment. Extracting oil resources from the surface is a very costly and difficult process. The extraction of these

45 Bituminous coal, or black coal, is a relatively soft type of coal that contains a tar-like substance called bitumen.

46 Anthracite. A type of high-calorie coal that is a natural solid fuel.

47 A boiler is a pressure vessel that converts the chemical energy of fuel into heat energy through combustion and transfers this heat energy to a carrier fluid.

48 Steam turbines are thermal turbomachines that convert the thermal energy of a fluid with high pressure and temperature into mechanical energy.

49 A generator, or simply a power source, is an electrical machine that converts mechanical energy into electrical energy.

50 Şahin H.E. (2012). Energy and Exergy Analysis of a Supercritical Type Steam Power Plant, Master's Thesis.

51 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-petrol>

resources is possible with significant technological developments. If these developments can be achieved, further reserve increases can also be achieved. If oil cannot be extracted in sufficient quantities, the market will be shown to be scarce, which will cause the general level of prices to increase. Oil is of great importance in the market for these reasons.⁵²

The birth of the oil industry began with kerosene production for lighting. The Canadian scientist Abraham Gesner met the need for continuous, affordable lighting and helped launch the oil industry. This contributed to the production of kerosene from oil that leaked to Earth in the second half of the 19th century.⁵³

The period 1860-1885 was known as the kerosene era for lighting. The replacement of vegetable oils with oils obtained from petroleum in industry and homes covers the period 1886-1900. The importance of gasoline increased with the mechanization and widespread use of automobiles from 1900-1914. Oil sharing among regions began in the 1900s.⁵⁴

Thus, the use of oil has become possible in these studies. After these developments, the conscious oil exploration and exploitation period replaced the process by which oil reached the people through leakage. The idea that oil can be extracted from the surface and used in new areas within people's knowledge has emerged. Thus, oil exploration and concession acquisition activities have intensified worldwide.⁵⁵

1.4.1.3. Natural Gas Energy

Natural gas is colorless, odorless, flammable, and lighter than air. The highest concentration of natural gas was methane (CH_4). It then consists of other light hydrocarbons⁵⁶, ethane (C_2H_6) and propane (C_3H_8). Natural gas

52 Bayraç, H. Naci, (2005)° 'Economic Analysis of the International Oil Market', *Journal of Finance-Politics and Economic Reviews* 499 (42), 6-20.P,7

53 P.İ.G.M., Oil in the World, "www.pigm.gov.tr", pdf, P. 1.

54 Kocaoğlu, Mehmet (Hzl.). *Petro-Strategy*. Istanbul: War Academies Printing House, 1996, P,6

55 Uluğbay, H. *Petropolitics from Empire to Republic*. Ankara: Ayraç Publishing House, 2003, PP. 31-33

56 Hydrocarbons are a general name for chemical compounds composed solely of carbon and hydrogen atoms (C_xH_y).

consists of light and small amounts of heavy hydrocarbons. Heavy hydrocarbons include carbon dioxide⁵⁷, nitrogen⁵⁸, helium⁵⁹, hydrogen⁶⁰ and sulfur.^{61,62}

When natural gas is first extracted underground, it has different compositions. It becomes usable after processing using certain methods. When natural gas can be liquefied at -1600°C , it can be transported over long distances and sold economically. Transportation of natural gas between countries is possible through pipelines. As a result of this process, transportation and distribution losses may occur. The main reasons for these losses were differences in the measurement methods for temperature and pressure.⁶³

Natural gas is divided into Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG). CNG (Compressed Natural Gas): First, high pressure such as 200-250 bars, is applied to the natural gas. It is then released via compression and storage. The CNG was stored in a tube at high pressure and in the gas phase. It is lighter than air, and is used under special conditions. Because this gas is contained in a cylinder, it can be used to its fullest extent. Liquefied Natural Gas (LNG) is formed by cooling natural gas to below 162°C with the effects of atmospheric conditions.⁶⁴

Natural gas is a fossil fuel with characteristics similar to those of oil. Natural gas is one of the healthiest energy sources for the environment because it does not produce ash or slag during combustion and does not release air-polluting sulfur dioxide or carbon dioxide into the atmosphere.⁶⁵ Natural gas is widely used for electricity generation, residential and industrial heating, and the service sector.⁶⁶

57 Carbon dioxide is the name of a compound that exists as a gas under normal conditions, having a molecule consisting of one carbon atom and two oxygen atoms covalently bonded.

58 Nitrogen is a colorless, odorless, tasteless, and inert gas.

59 Helium is a non-flammable, noble gas found in small amounts in the air.

60 Hydrogen is a diatomic gas that is colorless, odorless, non-metallic, tasteless, highly flammable, and exists as H_2 under standard temperature and pressure.

61 Sulfur is used in chemistry for several types of chemical compounds containing sulfur at an oxidation level of -2.

62 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-dogalgaz>

63 Özil, E. et al. (2013). Electricity Energy Technologies and Energy Efficiency Volume 1. Istanbul, Turkey: TESAB P,155

64 Avcı Ö (2009), Comparative Evaluation of Energy Production and Consumption in Turkey and the European Union, (Master's Thesis), Çukurova University, Adana.

65 Gültekin, A.H., Yüksel Örgün. "Natural Gas and Environment", Environment Journal, October-November-December 1993, Issue:9, 37-41.

66 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-dogalgaz>

1.4.1.4. Biomass Energy

Biomass is the total mass of living organisms within a given period.⁶⁷ In addition to carbon, the chemical content of biomass includes atoms containing hydrogen (H), oxygen (O), nitrogen (N), and small amounts of alkali, alkaline earth, and heavy metals.⁶⁸

Biomass energy comprises plant and animal remains. Biomass can be transformed into biogas, bioethanol, synthetic gas⁶⁹, and biodiesel via chemical processes⁷⁰. Bioethanol increases the fuel's oxygen content and eliminates the effects of gases that may harm the vehicle, ensuring more effective and efficient use of the fuel in cars. Because biomass is readily available in nature, it does not cause an increase in atmospheric carbon gas when burned.⁷² Biomass is also considered to be a form of organic carbon. The primary biomass resources are listed below;

1. Vegetable Biomass Resources

- Oilseed plant varieties (canola, sunflower, soybean, etc.)
- Plant varieties of sugar and starch (potato, wheat, corn, sugar beet, etc.)
- Fiber plant varieties (flax, kenaf, hemp, sorghum, miscanthus, etc.)
- Protein plant varieties (peas, beans, etc.)
- Vegetable and agricultural residues (branches, stalks, straw, roots, bark)

2. Biomass Resources Obtained from Forests and Forest Products

- Wood and forest waste (energy forests and energy plants, various trees)

3. Animal Biomass Resources

67 EUAS (2019). Electricity Generation and Trading Sector Report. http://www.euas.gov.tr/Documents/EUAS-Sektor_Raporu2019.pdf

68 Obernberger I, Thek G (2004). Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. *Biomass and Bioenergy*, 27(6), 653-669.

69 Biogas refers to the production of usable gas from organic waste.

70 Synthesis gas is a fuel gas mixture containing components such as hydrogen and carbon monoxide, carbon dioxide, and methane.

71 Biodiesel is a product obtained by converting organic oils into diesel fuel by mixing them with a base and alcohol.

72 EUAS (2019). Electricity Generation and Trading Sector Report. http://www.euas.gov.tr/Documents/EUAS-Sektor_Raporu2019.pdf

- Feces of animals such as cattle, horses, sheep, chickens, slaughterhouse wastes, and wastes generated during the processing of animal products.

4. Biomass Resources Obtained from Organic Garbage, City and Industrial Waste

- Sewage and bottom sludge, paper, industrial and food industry wastes, industrial and domestic wastewater, and municipal and large industrial facility wastes

Bioenergy production from biomass occurs from biosolids, liquids, and gases. The International Organization for Standardization/Technical Committee (ISO/TC) established this fuel classification.

Solid biofuels are defined in ISO/TC 238, whereas liquid biofuels are defined in ISO/TC 28/SC7⁷³.

Biomass energy can be expressed in two ways: classical and modern. Classic biomass energy consists of plant and animal waste and fuelwood. Modern biomass energy is generated from urban waste, agricultural industry waste processed using modern methods such as fermentation, forest-wood industry waste, and vegetable waste from the agricultural sector, and gasification. After processing, they emerge as electricity, heat, liquid, and gas fuel.⁷⁴

1.4.1.5. Nuclear Energy

Nuclear energy, another non-renewable energy source, results from splitting (fission) and combining (fusion) the nucleus of an atom. Nuclear energy is first converted into kinetic energy and then into electrical energy using reactors. Nuclear energy was initially used for military purposes and later for civilian purposes. It began to be used for commercial purposes after the second half of the 20th century.⁷⁵

Serious technological investments and financial resources are required to use nuclear energy. The damage caused by nuclear waste to nature can persist for several years.

The formation of matter is possible because of these atoms. The formation of atoms was possible because electrons covered the nucleus. Two separate

73 Ültanır M Ö (1996). What Should Turkey's Biomass Energy Strategy Be? Science and Technology. P, 342.

74 Turkish Environmental Foundation (2006), Turkey's Renewable Energy Resources, Ankara: Turkish Environmental Foundation Publications.P 131

75 TUBITAK (2003); Energy and Natural Resources Panel, http://vizyon2023.tubitak.gov.tr/teknolojiongorusu/paneller/enerjivedogalkaynaklar/raporlar/enerji_son_surum.pdf, PP. 4-6

particles exist in this nucleus: (+) charged protons and uncharged neutrons. Uranium is an element that forms the fuel for a nuclear reactor. There were 92 protons and 143 neutrons in the nuclei of the uranium atoms. Nuclear energy is generated due to the release of some of the energy produced by the 235 particles in the nucleus. A neutron with a reduced speed hitting the U-235 nucleus destroys the bond force balance of the nucleus and splits it (fission). Consequently, two or three neutrons are released. New neutrons that emerge break apart from the other nuclei. This process creates a chain-reaction mechanism. This energy is delivered to neutrons and fission fragments as kinetic energy. The particles that emerge from this energy collide with the coolant atoms in the reactor environment and transfer their kinetic energy to the coolant as heat. This fluid evaporates with heat energy. The resulting water vapor also produces electrical energy through turbine generators.⁷⁶

Nuclear reactors are classified in four ways: by fuel type, coolant, neutron moderator, and neutron energy. When classified according to fuels, reactors are divided into four categories: “enriched uranium fueled,” “natural uranium fueled,” “enriched uranium fueled,” “enriched uranium fueled,” “plutonium fueled,” and “enriched uranium fueled,” “thorium-fueled. Likewise, when classified by coolant, reactors are divided into four categories: “light water-cooled,” “heavy water-cooled,” “gas-cooled,” and “liquid metal-cooled” reactors. Classification of neutron moderators is divided into three: “light aqueous,” “heavy aqueous,” and “graphite” reactors. The classification by neutron energy is divided into two categories: “thermal” and “fast” reactors. Currently, the most commonly used commercial reactor types are light-water-cooled nuclear power reactors and heavy-water reactors.⁷⁷

1.4.2. Renewable Energy Sources

These are vital resources for countries with the least environmental impact. Renewable energy sources can be reused spontaneously. Therefore, it reduces factory and maintenance costs. These resources are examined under the following subheadings: hydroelectric energy, wind energy, solar energy, geothermal energy, hydrogen energy, and wave energy.

1.4.2.1. Hydroelectric Energy

Hydraulic energy is another type of renewable energy. It is a type of energy that can be obtained according to the flow intensity of water and the

76 Özemre, Ahmet Yüksel, Ahmet Bayülken, and Şarman Gencay. 50 Questions on Turkey's Nuclear Energy Problem. Second Edition. Istanbul: Kaknüs Publications., 2000, P,11

77 TMMOB Chamber of Physics Engineers, Nuclear Energy Report. Ankara: 2006, PDE, PP, 25-26

amount of increase or decrease. In other words, this is the conversion of the energy potential of water into electrical energy. Generally, this type of energy is generated by accumulating water behind dams in streams and rivers.⁷⁸ Hydroelectric power plants convert water power into electrical energy. Water in motion can affect the flow rate and the energy it contains. When water flows from an extremely high point, a large amount of energy is released. Water entering the channels or pipes flows towards the turbines, where the turbines with propeller-shaped arms rotate to produce electricity. Turbines are connected to generators to convert mechanical energy into electrical energy.⁷⁹

Water is the source of hydroelectric energy. Therefore, water is the least costly and most abundant resource in the universe, and the easiest to obtain. However, establishing dam power plants required for hydroelectric energy requires a long time and is very costly. Emerging businesses can cause serious damage to the environment and natural resources. Therefore, with the development of technology, policies to protect the environment and nature should be implemented.⁸⁰

In ancient times, before Christ, the use of water power began with water mills. They continue to be an indispensable source of energy.⁸¹

Small hydroelectric power plants (CHPP) are hydroelectric plants with an installed capacity of less than one megawatt. These turbine mechanisms can be installed on small streams and provide electrical energy for small settlements, unlike large-head dams (which generate electricity by sending water from a height).⁸²

1.4.2.2. *Wind Power*

Changes may occur as the sun, the source of heat and light of the universe, warms the earth. These changes affect the air's humidity, pressure, and temperature, which causes wind. As a result of universal heating in different ways, different pressures occur in the atmosphere. This causes seasonal differences in pressure. Thus, wind intensity may vary with season, pressure,

78 Güneş, A. M. (2014). Hydroelectric Power Plants from an Environmental and Legal Perspective, P.29

79 DSI General Directorate, "What is a Dam?", "<http://www.dsi.gov.tr/>"

80 Akpınar, A., Kömürçü, M.I., Kankal, M., "The Situation and Future of Hydraulic Energy in Turkey", 11th Turkish Energy Congress, October 21-23, 2009.

81 Ministry of Environment and Forestry, General Directorate of State Hydraulic Works, "Environment and Clean Energy: Hydroelectricity", Ed., Özcan DALKIR and Elif ŞEŞEN, Ankara, MRK Printing and Promotion Services Ltd. Şti., 2011.

82 Gürsoy U., Social Costs in Energy and Clean and Renewable Energy Sources, Turkish Medical Association Publications, Ankara, 2004, P. 135.

and temperature. Wind energy has been used both on land and at sea for centuries. It was widely used in maritime shipping operations in the 19th century. Subsequently, this method lost its importance with the application of steam power.⁸³

Mechanical and electrical energy can be obtained from the wind energy. Mechanical energy refers to the force provided by the wind in windmills and its use in agricultural and irrigation areas. While windmills generate mechanical energy, wind turbines convert wind energy into electricity.⁸⁴

Wind energy has important features, such as not requiring any fuel, being environmentally compatible, and self-renewing. With the development of technology in the 21st century, it has become one of the most widely used, developed, and ongoing resources. Regarding costs, production continues to increase as obstacles are removed through serious measures.⁸⁵

Wind energy systems are widely preferred for electricity generation applications. Although wind energy has disadvantages, such as high initial investment costs, lower capacity factors, and variability in energy production, its preferred features are as follows: it is an environmentally friendly and clean energy source, has no problems with depletion or price increases, has low maintenance costs, and is easy to operate with the help of technology. Wind turbines are the main structural elements in wind power plants. Wind turbines produce electrical energy by converting the kinetic energy of moving air into mechanical energy. They are produced with horizontal or vertical axes depending on their rotation axes. Most wind turbines must reach a certain wind speed. A wind turbine produces energy between the cut-in and cut-out wind speeds. The cut-in speeds of modern wind turbines are 2-4 m/s, the nominal speeds are 10-15 m/s, and the cut-out speeds are 25-35 m/s. Due to the determined wind speed, the power output from the system can reach its maximum. This greatest power is called the nominal power, and this wind speed is called the nominal speed. To prevent damage to the system, the wind turbines are automatically stopped once a certain wind speed is reached. The maximum speed is known as the system's cut-out speed. The body part is wrapped with a sound insulation system to prevent noise pollution in the wind turbine environment. Towers are constructed in the form of cages or

83 Haktanır, D. (2002). Could Wind Energy Be the Energy Source of the Future?. Nicosia. pp. 37-38

84 Hayli, S. "The Importance of Wind Energy, Its Situation in the World and in Turkey", *Firat University Journal of Social Sciences*, 11 (1), 1-26. 2001, pp. 3-12

85 Alemdaroğlu, N. (2007). *The Future of the Energy Sector: Alternative Energy Sources and Opportunities for Turkey*. Istanbul Chamber of Commerce Publications, Istanbul. P. 25

pipes. Because the tower heights can be high, the construction outside the lattice towers can be two or three pieces.⁸⁶

One advantage of wind turbines over other renewable energy sources is that they can produce electricity whenever wind occurs during the day or night.⁸⁷

Wind energy turbines comprise blades, shafts, and generators. Wind turbines have an energy production lifespan of 20-40 years. It has been stated that the most suitable turbines are those with a tubular tower, three blades, and a generator.⁸⁸

Wind turbine applications were examined for the three groups. The first is grid-related alternating current (AC) application. This is possible by transferring all the energy produced by wind turbines, or the remaining energy, to the national electricity grid. The second application is direct current (DC). This application is performed by providing the location's energy directly from the wind turbines. The third application is a remote DC system application. This application is used to meet the electrical energy needs of locations such as meteorological stations, railway signalling, lighthouses, and fire watchtowers.⁸⁹

1.4.2.3. Solar Energy

Solar energy is radiant energy released by the fusion process (transformation of hydrogen gas into helium) in the core of the sun. The intensity of solar energy outside the Earth's atmosphere is approximately 1370 W/m², but the amount reaching the Earth varies between 0 and 1100 W/m² due to the atmosphere. Even a small portion of this energy coming into the world is considerably higher than humanity's current energy consumption.⁹⁰

Solar energy is one of the oldest known renewable energy sources, used for centuries to generate energy from sunlight. Solar energy is a low-cost, clean energy source with no adverse environmental effects. The use of solar energy was direct and indirect. In the direct application method, a flat collector system collects solar radiation. The stored energy can be used for agriculture, housing, and heating. In addition, in the direct method, direct and indirect electrical

86 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>

87 Demirbaş Ayhan, "Global Renewable Energy Resources", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Sayı 28:8, 2006, PP.779-792.

88 Akova İ. (2008), Renewable Energy Resources, Ankara: Nobel Publishing Distribution, P, 94

89 Turkish Environmental Foundation (2006), Turkey's Renewable Energy Resources, Ankara: Turkish Environmental Foundation Publications, P, 68.

90 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-gunes>

energy is produced by storing the light from solar energy in a specific area using focused collectors, owing to reflection and refraction. This storage method can achieve temperatures that can reach and exceed 100 °C. When temperatures exceed 350 °C, they can be used in residences and kitchens. Solar energy can be converted into thermal energy using the direct electricity generation method; the resulting energy can be used in many applications. This system, which uses thermal application, is used in the agricultural sector and in daily life. This system is implemented because, despite technological advances, costs do not decrease to the desired levels, and efficiency cannot reach sufficient levels. In the indirect method of electrical energy production, batteries convert solar energy into electricity. Solar cells are commonly used in transportation and power plants. The indirect method occurs due to environmental events like heat evaporation and photosynthesis.⁹¹

Solar energy technologies are divided into photovoltaic and thermal solar technologies. Photovoltaic Solar Technology: Photovoltaic cells ⁹² convert sunlight directly into electricity. Thermal Solar Technologies: primarily Heat is primarily obtained from solar energy. This heat can also be used to generate electricity.⁹³

Electrical energy is produced from solar energy using solar cells or photovoltaic (PV) cells. This production was achieved by using two-layer semiconductor materials.⁹⁴ Photovoltaic cells are a type of device known as solar cells. By creating equal numbers of positive and negative charges from the photon energy incident on these devices, they converted solar energy into directly usable electrical energy.⁹⁵ The most commonly used semiconductor materials in solar cell production are crystalline ⁹⁶ silicon ⁹⁷, amorphous⁹⁸

91 Saygın, Hasan (2004); “Problems of Nuclear Energy in the Sustainable Development Agenda,” *Journal of Electrical Engineering*, 423, PP. 4-8.

92 Photovoltaic cells are the name given to semiconductor materials.

93 Mahmutoğlu M. (2013). *The Role of Renewable Energy in the Turkish Electricity Sector*, Master's Thesis, p. 22.

94 Dinçer, F., (2011). *Potential for Electricity Generation from Solar Energy in Turkey - Economic Analysis and Comparative Evaluation with EU Countries*, *KSU Engineering Journal*.

95 Altaş İ. H., *Photovoltaic Solar Cells: Structural Properties and Characteristics*, *Energy, Electricity, Electromechanics-3e*, April 1998, Issue 47, 66-71, Bileşim Publishing A.Ş., Istanbul.

96 Crystal, crystalline or cut glass, in chemistry, is the definite geometric structure of a solid element or compound, a collection of molecules, atoms or ions.

97 Silicon is one of the most abundant elements on Earth. Its semiconductor properties and abundance in nature, forests, and natural life, its practical and fast use in transistors, diodes and memories, have led to integrated circuits and computers being built on silicon technology.

98 Amorphous solid is a term used for solids in which the atoms do not have a stable crystalline structure.

silicon, gallium⁹⁹ arsenic¹⁰⁰, cadmium¹⁰¹ telluride¹⁰², and copper indium diselenide¹⁰³. Si is most commonly found in nature. It is the most widely used solar cell in the commercial environment.¹⁰⁴

1.4.2.4. Geothermal Energy

Geothermal energy is the temperature created by the heat and pressure accumulated at different depths in the Earth's crust. It is hot water that is above the regional atmospheric average temperature and may contain more dissolved minerals, various salts, and gases than the surrounding underground and surface waters. This is the heat energy resulting from water being transported to the surface via steam and gas.¹⁰⁵

Geothermal energy is a renewable energy source that was used to cook food and prevent health problems until the 20th century and today has great energy potential with technological developments. The heat accumulated deep within the earth can escape through cracks or emerge as hot water. This type of energy can be extracted underground with water-drilling machines and then converted into electrical energy at power plants, where it is stored. At the same time, it is a very low-cost, environmentally friendly energy source compared to other sources. The proximity and distance of the extracted hot water to the settlements where it is used are the most critical factors enabling its more effective use.¹⁰⁶

Usage areas of geothermal energy;

-
- 99 Gallium, with the chemical symbol Ga and atomic number 31, is a chemical element. It is solid at room temperature and melts upon contact with humans at room temperature. It is obtained along with aluminum during the purification of bauxite and zinc.
 - 100 Arsenic, with the symbol As and atomic number 33, is an element found in most minerals, usually in combination with sulfur and metals, or as a pure elemental crystal. Arsenic is a metalloid.
 - 101 Cadmium, with the chemical symbol Cd, is a silvery-white, soft, carcinogenic, toxic heavy metal element used in the electrical, ceramics, battery, and accumulator industries.
 - 102 Tellurium is an element whose use is becoming increasingly widespread in industry. Although it is a semi-metal, it has more metallic characteristics than some metals. It is generally obtained from compounds of gold ores.
 - 103 Copper indium diselenide solar cells are produced from a composite semiconductor material made of copper, indium, and selenium.
 - 104 Perdahçi C., The Use of Solar Cells in Roof Design, III. Renewable Energy Sources Symposium, 2005, Mersin.
 - 105 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-jeotermal>
 - 106 TÜGİAD (2003); Turkey's Energy Problems and Proposed Solutions, http://www.tugiad.org.tr/bultendosya/1_70.PDF, PP. 14-15

- Electricity production: After¹⁰⁷ steam and water are separated in fluid separators,¹⁰⁸ electrical energy is produced using turbines and generators in wells drilled in geothermal fields.
- Heat production: The aim is to utilize low temperature, pressure, and flow¹⁰⁹ geothermal resources for greenhouse, organic agriculture, product drying, and meeting regional heat requirements.
- Low-temperature geothermal water sources are used for thermal tourism and health purposes because they contain beneficial minerals.¹¹⁰

Geothermal resources can be classified in three different ways: water density, steam density, and the most commonly used temperature value. They were divided into three groups according to their temperature. These;

- Low Temperature Areas (20-70 °C)
- Medium Temperature Areas (70-150 °C)

Ansal, Hacer (1998). “Technology from Different Perspectives”, in Turkish Union of Engineers and Architects Chambers, Technology, Ankara: Kozan Ofset. pp. 43-45.

- High-temperature areas (higher than 150 °C)

Considering the low and medium temperature usage areas, under technological and economic conditions, it is used primarily in heating (greenhouse, building, agricultural uses), industry (food drying, lumbering, paper and textile industry, leather industry, cooling facilities), chemical substance production (boric acid), ammonium bicarbonate, and heavy water were used to obtain dry ice from the carbon dioxide in the fluid. For electricity generation, technologies using fluids have been developed and used in medium-temperature areas.¹¹¹

Hot water is close to the surface, it can also be pumped directly to locations where heating is required. This method uses geothermal energy to heat houses, greenhouses, and snowmelt. Heat pumps can pump heat into buildings, even in areas without geothermal reserves. This system allows buildings to

107 Separators are machines used in ships and industrial facilities to separate components in oil, fuel, and other liquids using physical methods.

108 A turbine is a device used to convert the energy of a fluid into work.

109 Flow rate is the volume of fluid passing through any cross-section of a path per unit time.

110 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-jeotermal>

111 Adıyaman Ç., Turkey’s Renewable Energy Policies, Master’s Thesis, Niğde, 2012, P, 66.

be heated in winter and cooled in summer, as the underground temperature remains constant throughout the year.¹¹²

1.4.2.5 Hydrogen Energy

Hydrogen, the simplest and most abundant element on Earth, consists of one proton and an electron. Hydrogen exhibits an unstable structure. Therefore, it is found in limited amounts on Earth and is present in various compounds. An example is a water molecule, which consists of two hydrogen atoms and one oxygen atom. Another example is oil, which contains a different number of hydrogen atoms.¹¹³

Hydrogen energy, which is the chemical energy released in its molecules, is generated due to the decomposition of pure hydrogen. This energy can be converted into heat and electrical energy using various methods. Research on environmentally friendly and highly efficient hydrogen energy sources increased in the 1970s. The concept of hydrogen energy was introduced worldwide at a conference held in 1974. Examples include hydrogen energy usage areas, transportation, industry, space rockets, and oil production. Hydrogen, which has a density of 1/14 of air, is a very light gas. It turned into a liquid at 253 °C under atmospheric pressure. Hydrogen has two different calorific values: gas and liquid. While the calorific value of gas is approximately 12 megajoules¹¹⁴ (MJ) per cubic meter, that of liquid hydrogen¹¹⁵ is 8,400 MJ per cubic meter. Combustion of hydrogen with oxygen was possible at approximately 2,600°C. The recombination of hydrogen atoms creates a temperature of 3,400 °C.¹¹⁶

Many research and development (R&D) activities for hydrogen have gained momentum since the 21st century. However, hydrogen is not a natural fuel source. Its production takes place using primary energy sources such as water, biomass, nuclear energy, and hydrocarbons. It stores and transports energy. Therefore, it is used to produce electricity and heat. Hydrogen and fuel cells can be used in various sectors and systems.¹¹⁷

112 Denizhan, Y. (2008). Choices That Will Affect Everyone's Lives Need to Be Made Today. *Industry and Automation*, 139, PP, 82-88.

113 Hydrogen Energy Information Note | May 2021 (TSKB), S, 3, <https://www.tskb.com.tr/uploads/file/hidrojen-enerjisi-bilgilendirme-notu-120721.pdf>

114 A megajoule (MJ) is equal to one million (10⁶) joules, or approximately the kinetic energy of a one-ton vehicle moving at 160 km/h (100 mph).

115 A cubic meter is the volume of a cube with a side length of one meter.

116 Yumurtacı, Z., Bekiroğlu, K. N., Akaryıldız, E. (2002). "Basic Criteria in Hydrogen Energy Utilization." *TMMOB Chamber of Mechanical Engineers, Plumbing Engineering Journal*, Issue: 72, PP.38-50.

117 Hydrogen Energy Information Note | May 2021 (TSKB), S, 3, <https://www.tskb.com.tr/uploads/file/hidrojen-enerjisi-bilgilendirme-notu-120721.pdf>

Distributed or combined heat and power system;

- Standby power system.
- Renewable energy storage
- It can be used as auxiliary power for air, land, and sea transportation vehicles.

Hydrogen is produced by the reaction of hydrocarbon fuel with steam in a high-temperature process. Hydrogen production via biological reactions with microorganisms can be achieved through electrolysis. Microorganisms produce hydrogen gas via biological processes by consuming plant products. Another production method was performed using sunlight. This production can be carried out using photobiological¹¹⁸, photoelectrochemical¹¹⁹, photovoltaic¹²⁰ focused electrolysis, and thermochemical methods.¹²¹

There are various methods for storing and transporting hydrogen after it is produced. In the transportation process, hydrogen must first be compressed into a gas or converted to a liquid under pressure. After these operations are completed, the transportation process is performed by loading the tankers. However, owing to technological development and increasing demand, the aim is to transport hydrogen through existing natural gas pipelines. Storage is desired using methods that allow transportation. Methods that prioritise transportation for the storage of hydrogen (liquid and gaseous), metal hydrides, and chemicals. Hydrogen can be produced from nuclear sources, renewable sources such as biomass, and various fossil fuels, including hydrocarbons. Since the 21st century, most hydrogen production has been from fossil fuels, especially natural gas. Hydrogen production technologies from renewable sources continue to increase.¹²²

118 Photobiology is the branch of science that deals with the effects of light on living organisms. It studies the effects of light on living organisms. Photovoltaics is a method of generating electricity from the sun using solar cells or solar panels.

119 A photoelectrochemical cell (FEKH) is a solar cell that generates electrical energy from light.

120 Photovoltaics is a method of generating electricity from the sun using solar cells or solar panels.

121 Scita, R., Raimondi, P., Noussan, M. (2020). "Green Hydrogen: the Holy Grail of Decarbonisation? An analysis of the technical and geopolitical implications of the future hydrogen economy", Working Paper, 013.2020, FEEM, Italy.

122 Hydrogen Energy Information Note | May 2021 (TSKB), <https://www.tskb.com.tr/uploads/file/hidrojen-enerjisi-bilgilendirme-notu-120721.pdf>

Various technologies and methods are available for hydrogen production. Technologically, chemical¹²³, electrochemical¹²⁴, thermochemical¹²⁵, and photochemical methods have been used.¹²⁶ In addition to these production technologies, biological methods or various combinations of these methods¹²⁷ can be used.¹²⁸

1.4.2.6. *Wave, Tide, Ocean Energy*

Wind and solar energies have a significant impact on the generation of wave energy. In this context, the development of new technologies based on wind intensity and direction is essential.¹²⁹ Winds blowing on the surface of the seas or oceans create waves. The wave energy was obtained from the wave surface or subsurface wave pressure.¹³⁰ Thus, efficient energy use is possible. The emergence of tidal events driven by various currents has come to the fore as a means of generating wave energy in sea and ocean areas. At the same time, the salt content and water temperature in the seas can also contribute to energy production. The realization that waves produce electrical energy dates back to the 18th century. Wave energy was first used in the Rance River in France, and 240 MW of energy was generated from the installed turbines.¹³¹

Wave energy has many positive features such as self-renewal and environmental friendliness. However, its use is limited owing to its limited availability worldwide and high cost. It can convert approximately three-quarters of the water energy into electricity. In this respect, it is more efficient than solar and other renewable energy sources.¹³²

123 Chemistry is the branch of science that investigates and applies the structure, properties, compositions, interactions, and reactions of matter.

124 Electrochemistry is a sub-branch of chemistry that studies reactions occurring at the interface between an electronic conductor and an ionic conductor. The aim of electrochemistry is to study the exchange between chemical energy and electrical energy.

125 Thermochemistry is a sub-branch of chemistry whose area of interest is the relationship between heat and chemical reactions.

126 Photochemistry is a sub-branch of chemistry concerned with the chemical effects of light.

127 In a biological sense, hybrid represents the energy state in which an atom contains four valence electrons.

128 Hydrogen Energy Information Note | May 2021 (TSKB), <https://www.tskb.com.tr/uploads/file/hidrojen-enerjisi-bilgilendirme-notu-120721.pdf>

129 EMO (2003); Çeas, Kepez and the Failure of Energy Policies of the Last Twenty Years, Energy Engineers Chamber Publications, Istanbul.

130 http://www.eie.gov.tr/teknoloji/dalga_enerjisi.aspx,

131 Sümeyye AK (2019), An Econometric Analysis of the Sustainability of the Current Account Deficit in Turkey from an Energy Economics Perspective, Aydın Adnan Menderes University, Institute of Social Sciences, P, 8.

132 EMO (2003); Çeas, Kepez and the Failure of Energy Policies of the Last Twenty Years, Energy Engineers Chamber Publications, Istanbul.

Finishing machines generally installed on or near beaches extend vertically in the direction of wave movement. Thus, it generates power by capturing wave energy. Another form of finishing machine is the vibrating water column. In this machine, water enters an air-filled space trapped above and below the surface. Water is moved up and down by the wave action. Then, it sends air to the turbine to which it is connected.¹³³

Scientists have investigated the conversion of sea wave energy into electrical energy. Various wave energy converters were designed and tested at the model scale.¹³⁴ The trend towards wave energy began in Europe in 1973 when oil prices rose excessively. European countries have considered wave energy as a potential power source. They have continued their research in this direction.¹³⁵

In offshore and nearshore systems, air pressure is supplied to the turbine by the movement of a water column in a closed chamber, driven by the sudden descent of a volumetric mass floating on the water. The water accumulates in a tank and is fed directly to the turbines as the wave rises. In marine coastal systems, the operation of providing air pressure to the turbine by the movement of the water column in a closed place, collecting the water in a tank to be given directly to the turbines with the upward movement of the wave, and providing movement of the water with the power to lift or push a bulky mass.¹³⁶

1.5. Secondary Energy Sources

Secondary energy sources will be examined under the subheading of electrical energy.

1.5.1. Electrical Energy

Walking, running, moving the car, and going up or down the elevator require energy. Transforming one form of energy into another is necessary for life. For example, electrical energy is converted into light energy by a lamp, illuminating the room at night. Electrical energy is one of the most important sources of energy. Electrical energy can be obtained from all energy sources and converted into various types of energy. Electrical energy can be obtained from several sources. Power plants generate the electrical energy used in homes

133 http://www.eie.gov.tr/teknoloji/dalga_enerjisi.aspx,

134 McCormick, M., 1981. Ocean wave energy conversion, Wiley, Annapolis, Maryland.

135 Özger M.(2007), Wave Energy Estimation and Stochastic Modeling, PhD Thesis, Istanbul Technical University, Institute of Science, p. 8.

136 Sağlam M., Sulukan E. and Uyar T. S., Wave energy and technical potential of Turkey, Journal of Naval Science and Engineering, 6, 2 (2010), p.2.

and workplaces. When electrical energy is mentioned, the concepts of voltage and current are also considered. To eliminate energy losses, transformers first increase the electrical voltage produced in power plants and then reduced to the levels used in homes and workplaces at distribution centres. The electric current is passed through the rotor windings of the alternator, which consists of the stator and rotor parts, and a magnetic region is obtained. The rotor rotated by the turbine obtains electrical energy from the stator windings in a magnetic field. In small alternators, the stator acts as the electromagnet. The electric voltage is obtained from the rotor windings. Electrical energy is generated by the movement of a conductor under the influence of a magnetic field. The movement of the magnetic field obtained electrical energy (voltage).¹³⁷

1.6. Conceptual and Theoretical Framework of Technological Development

Technology concept: It is formed by the combination of the Greek words “technicos,” which means technique, systematic and performing operations within a certain program, and “logia,” which means words, addresses, and commands. In other words, it is the art of conducting business systematically and planning. In the world we live in, technology is identified by a specific tool. For example, new features of electronic devices are perceived as technological. Technology can also be defined as all the information that facilitates the creation of useful products and new product designs. Although technology can be a product of all information, it can also be classified as software, time, and service outputs that are not related to the product. Technology develops as knowledge increases.¹³⁸

The concept of technological innovation has four key features. First, the preferences of economic institutions seeking to gain profit from change are taken into account. Second, the timing of the emergence of new technologies remains uncertain. Third, development is the product of all the innovations. Fourth, the acquired secondary knowledge is limited by technological knowledge.¹³⁹

For any company, institution, or country, an expansion or rise in the technology unit can be defined as technological change. However, not all technological unit increases can be called technological development. The

137 Republic of Turkey Ministry of National Education, *Electrical-Electronics Technology, Fundamentals of Electricity*, Ankara, 2011, p. 4.

138 Istanbul Chamber of Industry. (2002). *International Direct Investments and Türkiye Situation Assessment and Strategic Plan*. 1st Edition. Istanbul: Boyut Matbaacılık. p. 6

139 Redding, Stephen J. (2002). “Path Dependence, Endogenous Innovation, and Growth”. *International Economic Review*, 43(4): 1215-1248. PP, 1215-1216

input and output techniques required for the technology should be carefully selected.¹⁴⁰

Technology development can be defined as obtaining more output from a predetermined structure or revealing different information that helps produce a higher-quality output.¹⁴¹

It is possible to talk about four factors that reveal technological development¹⁴²: R&D processes, written and visual dissemination of technological developments, skills gained by trying and using, and the emergence of innovations in capital or intermediate goods developed through other companies or countries.

Although many factors cause technological development, the most important are R&D processes and human resources. Innovation is a result of technological progress. Companies ensure that employees learn about R&D processes by gaining experience. Since countries with different development structures cannot allocate sufficient resources to R&D, they seek to advance technological development by acquiring technology from other countries. Technology transfer: This is carried out through trade, licensing, and information technologies. Efficiency increases cannot be experienced when technology is transferred from the outside. Other factors that enable technological development include new products, time, and quality standards. A new product is a further development of the existing product, whereas time innovation is the minimization of costs. An increase in quality standards means an increase in the quality of goods and services. Quality standards and new products are the main strengths of R&D.¹⁴³

1.6.1. The Place of Technology in Theory

Theoretically, technology will be examined under the subheadings: technology in classical economics; technology in Marxist economics; Schumpeter: creative destruction; technology in neoclassical economics; evolutionary technology theorem; and Endogenous Growth Theories and Technology.

140 Gomulka, Stanislaw (1990). *The Theory of Technological Change and Economic Growth*, London: Routledge. P,6

141 Rosenberg, Nathan (1982). *Inside The Black Box: Technology and Economics*, New York: Cambridge University Press. P, 3

142 Dosi, Giovanni (1988). "Sources, Procedures, and Microeconomic Effects of Innovation", *Journal of Economic Literature*, 26(3): 1120-1171, P.1125.

143 ZHU, Lei and JEON, Bang Nam; "International R&D Spillovers: Trade, FDI and Information Technology as Spillover Channels", *Review of International Economics*, 15(5), 2007, PP. 955-976. , P.955.

1.6.1.1. *Technology in Classical Economics*

According to classical economists, the most important progress required to increase labour and manage it from a certain place is made possible by the division of labour. Most of the qualified labour force is available because of the division of labour. The division of labor also increases labor productivity.¹⁴⁴ In addition to the labor that creates the items, the value of the items is also contributed by the tools that support the labor force.¹⁴⁵

Capital goods include labor and knowledge, that is, technology, which is the product of labor. They argue that technological innovations continue to increase in the industry field as they follow technological developments. While this situation may lead to an increase in industry income, Ricardo argued that the same increase cannot occur in the agricultural sector, and the law of diminishing returns will hold across all economic structures. Consequently, economic growth disappears as profits decrease.¹⁴⁶

1.6.1.2. *Technology in Marxist Economics*

In Marxist economics, technology and its effects on economic development are revealed through class relations. Technology is the most important part of the capitalist labor movement. Labor activities lie between humans and nature. Humans produce their own needs and manage all their relations with nature. Labour power creates use value by planning the production target for all the work it will do and then putting all its qualities into play. People makes themselves more qualified through their own activities.¹⁴⁷

Individuals use various tools and equipment during the production phase. It has become a situation determined by the development status of the forces that carry out labour production. Therefore, there are three important elements of the labor process. Human activities aimed at any goal consist of labor being the object of work, the materials to be produced, and the tools and equipment required for production.

In order for labour to produce a new product, the form of an organised structure, the use of knowledge, and the personal skills required for production have undergone historical differentiation. The three elements that occur in

144 Smith, Adam (2006). *Milletlerin Zenginliği* (Çev. Haldun Derin), İstanbul: Türkiye İş Bankası Kültür Yayınları. P, 5.

145 Ricardo, David (2007). *Ekonomi Politigin ve Vergilendirmenin İlkeleri* (Çev. Tayfun Ertan), İstanbul: Belge Yayınları. P, 115-132.

146 Gürak, Hasan (2010). *Creative Mental Labor and Technological Innovations*, p. 7.

147 Ansal, Hacer (1998). "Technology from Different Perspectives", in *Turkish Union of Engineers and Architects Chambers, Technology*, Ankara: Kozan Ofset. pp. 35-38.

the labour process—human activities aimed at a target, where labour is the object of work, the materials to be produced, and the tools and equipment required for production—have undergone different changes within the mode of production. In capitalism, personal creativity has a different form. The purpose of capitalist goods and services is not to create use value by labor but to create exchange value so that the capital owner can sell these goods and services in the market at a profit. In other words, production is performed for profit. The owner of capital purchases different structures of the labor process; by combining them, it employs the labor force with a certain managerial organization. In capitalism, the labor process has become an area of more profitable production competition. Therefore, the capital owner supplies the technological production systems that are necessary for production. In addition, it pursues technological developments to establish a control mechanism among workers who make up the labour force, aiming to keep the entire labour process under control. Capital aims to maximize profits. This profit is possible by increasing the workload and improving the efficient use of labour. Increasing productivity can be guaranteed by introducing more mandatory rules for how work is done. When the labour force decreases, capital seeks to eliminate its relationship with labour through various actions. In this context, it is no coincidence that machines replace labour power.¹⁴⁸

Throughout history, the emergence of capitalist labour stages, production knowledge, and experience in the form of capital-labour conflict resulted from the interaction between capitalist production and technological relations. In a capitalist understanding, every attempt to produce products at the production stage is possible by exploiting a labour force. Product production will completely change the economic structure through organised labour activity and various technological developments throughout the historical period.¹⁴⁹ The most important idea put forward by capitalism is the unification of capital accumulation with the help of technological development. The continued existence of capitalists is made possible by constantly technologically renewing the tools necessary for production. Since capitalists invest to earn profits, the tendency towards investment will raise workers' wages, and output will increase in the market. This increase will cause a crisis. The capitalists, whose earnings decreased due to the crises, developed regional markets for new goods and services and for labour-saving technological developments to restore their earnings. Labor savings created a reserve army for unemployed

148 Basalla, George (2000). *The Evolution of Technology* (Translated by Cem Soydemir), 9th Edition, Ankara: TÜBİTAK Publications, P,150.

149 Marx, Karl (2009). *Capital, Volume II* (Translated by Alaattin Bilgi), Ankara: Sol Publications, P, 43.

people in the market. Competition with labor force wages under pressure. Marx, who introduced the dictatorship of the proletariat due to crises and investments in production processes, argued that rising unemployment would deprive workers of the ability to share. Capitalists have been criticised for their mistaken expectations of increased production power driven by technological development and capital accumulation.¹⁵⁰

1.6.1.3. Schumpeter: Creative Destruction

Schumpeter defines innovation as the emergence of a different production function. Innovation can be expressed in five ways.¹⁵¹

Developing a new production method can introduce a new product to the market. Technological changes are likely in the form of waves. These changes are made possible through research, invention, and innovation. According to Schumpeter, each of these changes occurred over periods of approximately half a century. Each period has created different technological structures over a long period.¹⁵²

Orienting towards foreign markets or new national markets is one of the building blocks of capitalist thought. They understand that they constantly want to eliminate old factors and thoughts and create new ones instead. “Creative destruction” is the basis for further progress of the capitalist system. Over time, all capitalist entrepreneurs must adapt to technological development.¹⁵³

1.6.1.4. Technology in Neo-Classical Economics

According to neoclassical economics, technology, represented by a production function, is the conversion of inputs into outputs. Technological development also occurs as a result of the coefficients of the production and input-output relationships. For Solow, Q is the level of output, K is capital, and the production function is expressed as $Q=f(K,L,t)$, where L represents labor and t represents time. Changes in the skill level of the labour force. The shift that may occur in the production function owing to these effects indicates technological change. In the face of technological change, when production

150 Scherer, Frederic M. (1999). *New Perspectives on Economic Growth and Technological Innovation*, 2nd Ed., Washington, DC: Brookings Institution Press. P,25-26.

151 Schumpeter, Joseph (1934). *The Theory of Economic Development*, Cambridge: Harvard University Press. Schumpeter, Joseph (1939). *Business Cycles: A Theoretical, Historical and Statistical Analysis of The Capitalist Process*, New York: McGraw-Hill. P, 66

152 Freeman, Chris, and Luc Soete (2004). *The Economics of Innovation* (Translated by Ergun Türkan), Ankara: TÜBİTAK Publications. P,22.

153 Schumpeter, Joseph (2007). *Capitalism, Socialism and Democracy* (Translated by Hasan İlhan), Ankara: Alter Publishing. P, 103-104.

factors are neutral, the production function takes the form $Q = A(t) \cdot f(K,L)$. $A(t)$ shows the accumulated effects of the changes in the production function. Changes in the production function are caused by increases in the quantity of inputs, while technological advancements shift the production function. Technological knowledge accumulation occurs through external resources.¹⁵⁴

According to the neoclassical approach, companies use inputs and techniques most efficiently, given the prices of various factors. Companies do not agree to develop new techniques in a market where all other companies have the same production function under perfect competition. In this process, economic growth occurs through the supply of production factors and increased production. Not all techniques and technological developments have been examined from an economic-historical perspective. Since it is accepted that production consists only of capital and labour, the characteristics of the product, the workforce, etc., are not considered. It is accepted that technological development increases productivity.¹⁵⁵

1.6.1.5. Evolutionary Technology Theorem

After Nelson and Winter (1982) formulated the Evolutionary Technology Theorem, it was further developed through the contributions of Dosi, Freeman, Silverberg, and Soete on economic differentiation and the essence of technology. This approach examined the technology differences between companies that neo-classical economists avoided answering. Companies put decision-making mechanisms into practice by drawing on their past knowledge and experience.¹⁵⁶

Nelson and Winter's theory of evolution underpins companies' decision-making. However, in this theory, decisions are replaced by the term 'routine,' which refers to companies' regular, predictable behaviour. The area covered by the routine is wide. In other words, it routinely covers the broad technical structure for the production of goods and services, the hiring and firing of the labour force, the need to further increase the production of goods and services with high demand, and all kinds of R&D activities related to investments.

154 Soyak, Alkan (2002). "Globalization, Technology Policy, Turkey: An Evaluation from the Perspective of Industrial Property Rights and R&D Support", in Alkan Soyak (Ed.), *Globalization*, Istanbul: OM Publishing, pp. 93-107.

155 Ansal, Hacer (1998). "Technology from Different Perspectives", in Turkish Union of Engineers and Architects Chambers, *Technology*, Ankara: Kozan Ofset. pp. 38-40.

156 Gökten, Kerem (2006). "Evolutionary Thought in Economics and the Evolutionary Economics Approach to Technology", *Akdeniz University Journal of Faculty of Economics and Administrative Sciences*, (11): 24-44. p. 31.

Organisations with specialised routines can achieve greater success than others, thereby increasing their importance in the market.¹⁵⁷

Within certain companies, technological development and knowledge emerge from an evolutionary approach to technology. According to this theory, neoclassical economic development theory has some missing aspects. As a shortcoming, the unique aspects of technology have not been considered in previous processes. Technological innovations must be separated based on their importance in overcoming this deficiency.¹⁵⁸

- Increasing Innovations: These different innovations constantly emerge in any industry or service sector, depending on the intensity of demand increase, social factors, and technological opportunities. In addition to planned R&D activities, spontaneous innovations during the production phase increase productivity through the accumulation effect. Because each change's contribution is small, it is not added to the input-output tables.

- Radical Innovations: These innovations occur due to planned R&D activities. Institutional changes occur when time and product come together. This is important for particular companies or industries. Technological structures and innovations used for products and production are important. In general, its impact on the market is quite low.

Differences in Technology Structure: According to this idea, they are comprehensive innovations that can lead to the emergence of new sectors and have sudden effects on the entire economy. This idea, formed by the combination of radical and increasing innovations, affects many companies, potentially leading to changes in their management approach.

- Change in Techno-Economic Thought: The effects of some innovations that may occur in the technological structure are felt throughout the economy. This approach can directly and indirectly affect all areas of the economy, leading to the emergence of different products, services, systems, and industrial organizations.

The development of new techno-economic thought begins in economies where old ideas persist and dominate in a few sectors. A company committed

157 Nelson, Richard R., and Sidney G. Winter (1982). *An Evolutionary Theory of Economic Change*, USA: Harvard College Press. PP, 14-15.

158 Freeman, Christopher, and Carlota Perez (1988). "Structural Crises of Adjustment, Business Cycles and Investment Behaviour", in Dosi, Giovanni, Chris Freeman, Richard R. Nelson, Gerald Silverberg and Luc L. G. Soete (Eds.), *Technical Change and Economic Theory*, London: Frances Pinter Publisher. PP, 45-47.

to new thinking can play a key role by reducing production costs and achieving long-term product diversity.¹⁵⁹

1.6.1.6. Endogenous Growth Theories and Technology

The relationship between endogenous growth theories and technology, whose origins lie in Arrow's (1962b) research on "learning by doing" technological change, was treated as external in the economic literature until the mid-1980s. Arrow states that the main reason for changes in the production function is based on internal theories of technological changes. Learning and gaining knowledge are possible by gaining experience. Learning is assumed to be a product of the production process. Learning is achieved more quickly through various training programs and organisations. These views constitute the basic assumptions of endogenous growth theories.¹⁶⁰

Romer advocated for decreasing costs, that is, increasing returns to scale. Economic individuals who want to make profits and gain knowledge have long been among the explainers of economic growth. The new information obtained reveals a decrease in efficiency. This information cannot be completely stored. Information obtained by any Company has a positive external impact on the production conditions of other companies. This is a function of consumer goods, information storage, and other external factors. This increases the marginal product of information revelation.¹⁶¹

Romer demonstrated that technology is partially excludable and an external product not subject to competition. The most important factor in determining economic growth is investment in human capital. Insufficient R&D investment cannot increase economic growth. Technological development can be enhanced through various incentives that may occur under market conditions. Technological development is intertwined with growth. The technology ensures that the costs incurred for newly produced goods and services are one-off. Therefore, this technology is unsuitable for competitive market conditions. In this context, technology is considered to be in balance with external factors arising from information transfer under market conditions of monopolistic competition.¹⁶²

159 Taymaz, Erol (1993b). "Sanayi ve Teknoloji Politikaları: Amaçlar ve Araçlar", ODTÜ Gelişme Dergisi, 20(4): 549-580.

160 Arrow, Kenneth J. (1962b). "The Economic Implications of Learning by Doing", Review of Economic Studies, 29(3): 155-73. P. 155.

161 Romer, Paul M. (1986). "Increasing Returns and Long-Run Growth", The Journal of Political Economy, 94(5): 1002-1037. P. 1003.

162 Romer, Paul M. (1990). "Endogenous Technical Change", The Journal of Political Economy, 98(5): 71-102. P.71-73

Grossman and Helpman advocate industrial innovation as a driver of long-term economic growth. Technological development has occurred due to investments made by economists and individuals to gain profit. Companies transfer the necessary financing to R&D to provide new goods and services. As a result, companies can significantly increase their profits through monopolies. Thus, companies that produce new goods and services can gain an advantage over less-qualified goods and services. When economic growth is driven by companies that produce new goods and services in the long term, it further increases building and installation efficiency, thereby encouraging capital formation. When trade and technology policies are implemented in a market and reactions to innovation and economic growth are examined, it can be said that innovation has a comparative advantage in sectors producing goods and services with high technology. If technological developments are transferred to other regions, R&D activities and trade experience are considered. Government policies implemented by countries can affect trade partners and, subsequently, economic growth.¹⁶³

Aghion and Howitt accepted an economic growth model based on a creative combustion process. The source of economic growth stems from competition between companies that produce technological innovation. Each innovation involves producing goods and services that are superior to those of the previous ones. Another factor that motivates companies to continue R&D activities is the potential to patent a product with superior innovation and obtain monopolistic profits from it. However, these gains last until a new product is released into the market. The prediction that R&D activities will increase in the future will increase demand for a qualified labour force and wages in this market, reducing the potential for monopolistic gains. In this context, the expectation that R&D activities will increase in the future will significantly reduce R&D investment by reducing expected monopolistic gains.¹⁶⁴

1.7. Technology Indicators

There are various views on measuring technology worldwide. Research and development expenditures and patent numbers are the two main criteria used to measure technology. However, it is not possible for R&D expenditures to achieve definitive success. It is not possible to measure technology solely by patent numbers. Skates are a newly introduced product. There is no guarantee

163 Grossman, Gene M., and Elhanan Helpman (1991). *Innovation and Growth in the Global Economy*, Cambridge: MIT Press. P. 18-21

164 Aghion, Philippe, and Peter Howitt (1992). "A Model of Growth Through Creative Destruction", *Econometrica*, 60(2) P. 349

that every newly released product can be turned into commercial innovation. Although there are differences in measurement methods, the generally accepted indicators are R&D studies, the number of personnel working in R&D, the number of patents, technology transfer, and the number of scientific publications.¹⁶⁵

1.7.1. Research and Development (R&D)

The United Nations defines the concept of R&D as a creative, innovative, and systematic human activity that aims to develop stocks of knowledge and to add new ones to existing practices by ensuring their more effective use. Technology and scientific concepts are products that emerge from these activities.¹⁶⁶

Kumar examined technology activities using various indicators in his 1997 study of ten technology giants. The indicators examined were R&D expenditures, patent numbers, and technology payments. These indicators enabled us to obtain information on the technology. R&D expenditure is considered the most important input for technological activities. Patent numbers are another important indicator for explaining technological indicators. Patents have both strict- and long-lasting protective effects.¹⁶⁷

In models based on R&D, it is important to understand temporal economic growth. Schumpeter identified three sectors to better understand R&D studies. These include the output, intermediate products, and R&D sectors. The R&D sector has introduced new ideas and designs, leveraging human capital. After these new ideas emerge, they are sold to the intermediate-output sector. The intermediate output sector also becomes a monopoly producer of designed output by obtaining patents for new ideas. In the future, the intermediate output sector will continue to sell its products to the final output sector. The R&D sector is key to continued expansion.¹⁶⁸

165 Ülger, Ö. ve Durgun, Ö. (2017). The Effects of R&D Expenditures on Growth in Selected OECD Countries. Ömer Halis Demir University Faculty of Economics and Administrative Sciences Journal. Volume-Issue 10/4. PP, 105-130.

166 Sevgi, Levent, and Nejat İnce. (2004) "The Relationship Between Science and Technology Activities, Publication Number and Human Development Level in Türkiye." Cumhuriyet Science and Technology Magazine, CBT 879: 24

167 Kumar, Nagesh. (1997). Technology Generation and Technology Transfers in the World Economy: Recent Trends and Implications for Developing Countries. New Technologies Discussion Paper Series, P. 5.

168 Özer, Mustafa, and Necati Çiftçi. "The relationship between R&D expenditures and exports: Panel data analysis of OECD countries." *Dumlupınar University Journal of Social Sciences* 23.3 (2009): 39-50, pp. 39-40

Knowledge-oriented R&D that provides technological knowledge by hiring qualified scientists and engineers from overseas development, domestic sectors, and experts in their fields. Hymer proposed knowledge-oriented R&D in the 1960s. In the 21st century, the understanding of R&D activities has changed. Activities carried out in the past form the basis of today's human capital and contribute to productivity increase. Countries have included different innovations on their agendas, including the effects of new inventions, to increase understanding of research in the public sector. Financial support has changed in several countries. While there was a decrease in block grants between the state and universities, the aim was to provide more financial support for projects targeting specific targets.¹⁶⁹ The public and private sectors support R&D activities.¹⁷⁰

The public sector's goal in supporting R&D activities is to meet public needs, reveal basic information, and enable companies to benefit from it in their own research. Governments cover the financing of R&D activities carried out by the public and universities. The private sector can also support public-sector R&D. According to the OECD Frascati Guide, there are two possible explanations. According to the first view, public financial resources aim to support R&D activities directly. The results of R&D studies belong to those responsible for the outputs and products of the studies, not to those who provide financial resources. The other view is aimed at those who conduct R&D activities, supported by grants and other financial support. The results of R&D actions belong to those who conduct R&D. The aim of both views is for governments to fulfil their goals. Another purpose of public support for R&D is to provide monetary incentives. Therefore, companies receive government financial support. This support may include various tax deductions, machinery and equipment, and facilities to help companies obtain buildings.¹⁷¹

Government incentives for R&D activities are often criticized because they cause companies to reclassify their costs. Studies that drive technological change are not limited to a formal sense; their small differences should be taken into account at least as much as formal R&D. Because large companies

169 OECD; Science, Technology and Industry: Outlook 2004, Paris, Turkish Summary, 2004. p. 5. https://www.oecd.org/content/dam/oecd/en/publications/reports/2004/12/oecd-science-technology-and-industry-outlook-2004_g1gh459c/sti_outlook-2004-en.pdf

170 Guellec, Dominique, and Bruno van Pottelsberghe de la Potterie (2000). "The Impact of Public R&D Expenditure on Business R&D", OECD Directorate for Science, Technology and Industry (STI) Working Papers, 2000/04, Paris: OECD Publishing.

171 Yeldan, Erinc (2009). "Public R&D Support and Innovation Models: Which Innovation Model Should Be Chosen for the Legitimation of Public R&D Policies?", *Journal of Economic Sciences*, 1(2): 25-39. pp. 26-27.

mostly carry out formal R&D activities, these companies are given incentives to contribute more.¹⁷²

The factors that determine the incentives for R&D include the industrial situation and the technological levels of countries. Countries conducting R&D activities have a qualified workforce. Those who cannot sufficiently develop these activities continue their work in the manufacturing sector by imitating those who developed them. Encouraging imitative and implementative R&D in the early stages of technological capabilities is valid. In the context of innovative R&D activities, it would be appropriate to estimate the increase in the share of expenditures in national income and to design more effective technology planning.¹⁷³

1.7.2. Patent

Technological development and inventions are multipliers that contribute most to economic development. An effectively implemented patent system increases economic development within and outside the country. When the necessary protection measures do not protect an idea put forward, dangerous situations may arise, even if invention applications, a necessary condition for technological development, are filed. However, new practices cannot be implemented in the country's manufacturing sector. In the face of this dangerous situation, entrepreneurs abroad do not prefer to engage in invention activities in this country. On the contrary, if domestic and foreign entrepreneurs facilitate patenting, there will be an increase in technological development and innovation. Industrial Property Rights make it easier to identify the producer or seller of goods and services sold in markets where trade is conducted.¹⁷⁴

Intellectual and Industrial Property Rights are generally examined in 6 ways¹⁷⁵:

- (a) Patents related to new inventions.
- (b) Copyrights dealing with technical drawings of written and visual acts

172 Taymaz, Erol (1993b). "Industrial and Technological Policies: Aims and Tools", *METU Development Journal*, 20(4): 549-580. p, 561.

173 Soyak, Alkan (2002). "Globalization, Technology Policy, Turkey: An Evaluation from the Perspective of Industrial Property Rights and R&D Support", in Alkan Soyak (Ed.), *Globalization*, Istanbul: OM Publishing House. pp. 113-114.

174 Kaya, İlker (2019). "The Effect Of Defense Expenditures On Technological Development: Panel Data Analysis For Selected Different Country Groups", Master's Thesis, Department Of Economics, Institute Of Social Sciences, Çanakkale Onsekiz Mart University, Republic Of Turkey, Pp. 30.

175 Soyak, A. (2005). *Legal Intellectual and Industrial Rights Journal*, pp. 11-30. <http://legaldergi.com.tr/urun/fikri-ve-sinai-haklar-dergisi-yil-2005-sayi-4/362137>

- (c) Drawings dealing with shaping and configuration
- (d) Trademarks to identify the originator or sponsor of the product.
- (e) Protection of Plant Species.
- (f) Secrecy protection that protects information

Patents give the right to own inventions.

According to the TRIPS Agreement, for an invention to be protected by a patent, it must be new, that is, not made before, address a different phase, or be applicable in the industrial sector. The protection period for the patent was 20 years from the date of registration.¹⁷⁶

The main goal of the patent system is for the entrepreneur to reveal an invention and gain a limited monopolistic power. Thus, technology emerges, and its spread expands. An effective patent system can support the different technological activities in these three areas. First, patents support entrepreneurs in covering initial R&D expenses. They also support innovation and R&D for a limited period. The period of personal use ensures that the entrepreneur creates a suitable economic environment for the development of the invention. Another purpose of the patent system is to facilitate further dissemination of technology. This situation explains why the patent period is limited and non-renewable and also explains the necessity for an invention and industrial application to emerge at the time of application. In other words, patents accelerate R&D and become sources of technological information.¹⁷⁷

Patents provide social benefits to inventors, as they require inventors to reveal their inventions and methods and to share ownership of their gains through patent law.¹⁷⁸

1.7.3. Number of R&D Personnel

R&D personnel are divided into three types: personnel involved in the research process, equivalent personnel responsible for technical work, and other support personnel.¹⁷⁹ Full-time equivalent (FTE) in the world: The

176 WTO (1994). "Trade-Related Aspects of Intellectual Property Rights", Annex 1C of Marrakesh Agreement Establishing the World Trade Organization, 15 April 1994. http://www.wto.org/english/docs_e/legal_e/27-trips.pdf, PP, 331-334.

177 OECD (1997a). Patents and Innovation in the International Context, OCDE/GD (97) 210. PP, 7-8. [https://one.oecd.org/document/DSTI/STP/TIP\(97\)14/FINAL/En/pdf](https://one.oecd.org/document/DSTI/STP/TIP(97)14/FINAL/En/pdf)

178 Goel, Kajeve K. (1999). Models of Technological Change, Theory and Application, USA: Greenwood Publishing Group. PP, 91-92.

179 OECD (1995). Measurement of Scientific and Technological Activities: A Guideline on Measuring Human Resources Dedicated to Science and Technology "Canberra Guideline", (Trans. TÜBİTAK), Paris: OECD. pp. 75-78. <https://www.oecd.org/content/dam/oecd/>

proportion of the workforce allocated to R&D varies depending on a country's development level. While the number of researchers is higher in countries with high economic growth, it is much lower in those with low economic growth.¹⁸⁰

1.7.4. Number of Scientific Publications

They are reports written and printed with their own comments and unique features, considering scientific writing rules. When comparing countries' scientific performance, studies published in scientific journals (indexed) and the number of citations to these studies are used.

1.7.5. Technology Transfer

It is the process of transferring technological developments that different countries, sectors, markets, or companies around the world use and benefit from. Thus, new technological applications are brought together, resulting in increased efficiency and economic benefits. Technology has an organized structure that enables exchange between supply and demand. Technology transfer involves the transfer of applications, collection, delivery, and communication of technologies. Technology diffusion refers to the movement from one place to another. While the economic contribution of new technological products is quite low in practice, an economic contribution emerges when new technology is added to production.¹⁸¹

Technology diffusion may occur through the sale of new technological goods and services in the market or involuntarily through the imitation of new equipment by other companies. Innovation that emerges spreads by being used in different forms and ways. While imitation refers to the use of information or practices that create innovation by others, it also maximizes competition.¹⁸²

Technological spillovers are failures of companies to be effectively protected within the rules.¹⁸³ The visible effects of technology spillovers have had very

en/publications/reports/1995/01/measurement-of-scientific-and-technological-activities_g1gh2403/9789264065581-en.pdf

180 Bidirdi Hanife (2015). "Technological Development Dynamics And The Quality Of Exports: Panel Data Analysis", Phd Thesis, Department Of Economics, Institute Of Social Sciences, Kocaeli University, Pp. 12-19.

181 Liu, Sifeng, Zhigeng Fang, Hongxing Shi, and Benhai Guo (2010). *Theory of Science and Technology Transfer and Applications*, New York: Taylor and Francis Group. Pp. 2-6.

182 Beije, Paul (1998). *Technological Change in the Modern Economy*, UK: Edward Elgar Publishing, Inc. P. 6.

183 Grossman, Gene M., and Elhanan Helpman (1991). *Innovation and Growth in the Global Economy*, Cambridge: MIT Press. P. 16.

little success in the market. In this case, it reduces companies' desire to introduce new products to the market during the production stage.¹⁸⁴

1.8. Diffusion Channels of Technological Development

The spread of technology, the advancement of production stages, and the adoption of different methods and tools are among the most important drivers of economic growth, as they are considered determinants of more efficient economic growth. Although R&D and innovation studies are seen as tasks in economies with high economic development, technology remains externally dependent in economies that have not yet completed their development. International dissemination of technology can be achieved more effectively through trade channels. Product trading is just one of these. Direct productivity gains can be achieved when information from outside the country contributes to equity and technological production processes. Companies can provide customers with information on the design and production stages of goods and services for export purposes. New emerging technologies can be sent to different countries using different methods. Technologies can be transferred through the import of new versions of various products. Trade in technology is possible through the collaboration of foreign sellers and buyers.¹⁸⁵

The transfer of technology can be affected by four different things;

- The techniques of the goods and services received are complex,
- The situation of countries exporting and importing technology,
- Earning methods of companies that obtain technology from outside,
- It is the ability of companies that outsource technology to understand this situation.¹⁸⁶

184 Liu, Sifeng, Zhigeng Fang, Hongxing Shi, and Benhai Guo (2010). *Theory of Science and Technology Transfer and Applications*, New York: Taylor and Francis Group. PP, 11-12.

185 Hoekman, Bernard; Javorcik, Beata Smarzynska. Lessons from empirical research on international technology diffusion through trade and foreign direct investment. *Global integration and technology transfer*, 2006, 1-28, PP,1-4.

186 Baranson, Jack, 1970. "Technology Transfer Through the International Firm," *American Economic Review*, American Economic Association, vol. 60(2), pages 435-440,P, 435.

An Overview of Energy and Technological Developments in the World and in Türkiye

This section will provide information on energy and technological developments worldwide and in Türkiye. It will first cover developments in primary and secondary energy sources World and in Türkiye, followed by information on technological advancements.

2.1. Primary Energy Resources in the World

According to the International Energy Agency (IEA) World Energy Outlook 2025 Report, the world's primary energy supply increased from 536 EJ in 2010 to 654 EJ in 2024. In the distribution of world primary energy supply by source in 2024 (Table 1), oil ranked first, accounting for 193 EJ (29.6%) of the total supply. Oil was followed by coal, with 178 EJ and a 27.3% share, and by natural gas, with 148 EJ and a 22.7% share. Next came bioenergy at 6.8%, nuclear energy at 4.8%, conventional biofuels at 3%, hydro at 2.5%, and solar and wind at 1.5%. Fossil fuels accounted for 82.4% of the primary energy supply in 2024, while renewable sources accounted for 12.7% with 83 EJ.¹⁸⁷

187 IEA (International Energy Agency). World Energy Outlook 2025, PDF, P.414
<https://www.iea.org/reports/world-energy-outlook-2025>

Table 1. World Energy Supply (EJ)

	2010	2023	2024	Current Policies 2035	Current Policies 2040	Current Policies 2050
Total energy supply	536	641	654	744	777	838
Renewables	43	78	83	142	169	217
Solar	1	8	9	35	47	66
Wind	1	8	9	23	28	35
Hydro	12	15	16	18	20	23
Modern solid bioenergy(solid, liquid, gas total)	26	42	44	57	63	76
Traditional use of biomass	21	19	19	17	16	14
Nuclear	30	30	31	42	49	57
Natural gas	115	144	148	175	182	194
Oil	174	192	193	201	204	215
Coal	153	176	178	165	155	138

Source: IEA (International Energy Agency). World Energy Outlook 2025¹⁸⁸ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035, 2040, and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

The share of fossil fuels, which was 83% in 2024, will remain significant if current policies are maintained. As shown in Table 1, the IEA estimates that, if current policies are maintained, the share of fossil fuels in the primary energy supply will decrease from 83% to 64.3% in 2050, but the amount consumed will not decrease in absolute terms and will increase by 3%. The share of renewable sources in the total energy supply is projected to be 26% in 2050, up 102% from 2024.

188 IEA (International Energy Agency). World Energy Outlook 2025, PDF, P.414
<https://www.iea.org/reports/world-energy-outlook-2025>

Table 2. Total Energy Supply (EJ) by World and Region

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	536.4	640.7	654.2	744.1	838.0
North America	112.7	112.4	113.2	118.6	128.8
United States	94.1	92.0	93.0	98.3	106.3
Central and South America	26.7	30.1	30.4	36.6	46.5
Brazil	12.2	14.6	15.0	18.1	22.9
Europe	89.1	74.2	74.9	73.3	71.0
European Union	64.5	53.2	53.5	50.7	46.6
Africa	25.6	34.2	34.5	43.2	58.7
Middle East	26.1	36.5	37.2	48.0	62.8
Eurasia	35.8	41.4	42.3	44.2	46.7
Russia	29.1	33.2	33.9	34.1	34.0
Asia Pacific	205.4	295.6	304.5	358.1	396.3
China	107.0	169.6	174.5	196.4	191.8
India	27.7	46.2	48.4	67.0	89.5
Japan	20.9	15.8	15.7	14.8	13.8
Southeast Asia	21.3	32.5	34.0	45.1	59.8

Source: IEA (International Energy Agency). World Energy Outlook 2025¹⁸⁹ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 2 shows that the total energy supply in the Asia Pacific region, which was 205.4 EJ in 2010, will be 304.5 EJ in 2024. This is due to China and India being the world's most populous countries and being included in this group. In terms of the geographical distribution of total energy supply worldwide in 2024, North America ranks second with 113.2 EJ. Europe 74.9 EJ, Eurasia 42.3 EJ, the Middle East 37.2 EJ, Africa 34.5 EJ, and Central and South America 30.4 EJ of energy supply. In 2050, the Asia Pacific region will have 396.3 EJ, and North America will have 128.8 EJ. Energy supply is projected to be 71 EJ for Europe, 62.8 EJ for the Middle East, 58.7 EJ for Africa, 46.7 EJ for Eurasia, and 46.5 EJ for Central and South America.

189 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 3. Total World Final Energy Consumption(EJ)

	2010	2023	2024	Current Policies 2035	Current Policies 2040	Current Policies 2050
Total final consumption	378	444	453	523	549	599
Electricity	64	91	95	131	145	172
Liquid fuels	154	178	180	195	200	216
Biofuels	2	5	5	7	8	11
Ammonia	-	-	-	0	0	0
Synthetic oil	-	-	-	0	0	1
Oil	152	173	175	187	192	204
Gaseous fuels	57	71	73	89	94	102
Biomethane	0	0	0	1	1	3
Hydrogen	-	0	0	0	0	1
Synthetic methane	-	-	-	-	-	-
Natural gas	57	70	72	87	91	97
Solid fuels	90	87	87	87	87	87
Solid bioenergy	33	35	35	36	37	38
Coal	56	51	51	50	50	48
Heat	12	16	16	19	19	19

Source: IEA (International Energy Agency). World Energy Outlook 2025¹⁹⁰. Note: The 2010, 2023, and 2024 values represent actual figures. The 2035, 2040, and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 3 shows that total energy consumption was 378 EJ in 2010 and 453 EJ in 2024. In 2024, the distribution of total World energy consumption is led by liquid fuels with 180 EJ, followed by oil with 175 EJ, electricity with 95 EJ, solid fuels with 87 EJ, gaseous fuels with 73 EJ, and heat with 16 EJ. It is projected that by 2050, total energy consumption will reach 599 EJ, with liquid fuels accounting for 216 EJ, oil for 204 EJ, electricity for 172 EJ, gaseous fuels for 102 EJ, solid fuels for 87 EJ, and heat for 19 EJ.

190 IEA (International Energy Agency). World Energy Outlook 2025, PDF, P.415
<https://www.iea.org/reports/world-energy-outlook-2025>

Table 4. Total Final Consumption (EJ) by World and Region

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	377.8	444.3	452.7	522.8	599.4
North America	76.7	78.4	78.7	82.8	87.4
United States	63.8	65.3	65.6	69.4	72.6
Central and South America	19.2	21.9	22.2	26.6	33.8
Brazil	9.1	10.7	11.0	12.9	16.2
Europe	63.1	55.3	55.8	54.8	52.1
European Union	46.0	39.9	40.2	38.0	33.8
Africa	17.8	23.8	24.0	30.5	41.8
Middle East	18.3	25.0	25.4	33.3	43.9
Eurasia	24.1	28.4	29.0	31.5	33.7
Russia	19.6	22.9	23.4	24.2	24.4
Asia Pacific	143.6	195.1	200.4	241.0	278.5
China	76.0	110.1	113.0	127.4	131.3
India	18.9	31.6	33.1	48.6	68.1
Japan	14.2	11.2	11.0	10.4	9.9
Southeast Asia	14.4	20.3	21.0	28.7	37.9

Source: The IEA (International Energy Agency) World Energy Outlook 2025¹⁹¹ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 4 shows that total World energy consumption was 377.8 EJ in 2010 and 452.7 EJ in 2024. Total energy consumption in the Asia Pacific region was 143.6 EJ in 2010 and 200.4 EJ in 2024. Geographically, North America ranked second World in total energy consumption in 2024, with 76.7 EJ. Europe follows with 63.1 EJ, Eurasia with 24.1 EJ, Central and South America with 19.2 EJ, the Middle East with 18.1 EJ, and Africa with 17.8 EJ. In 2050, the Asia Pacific region is projected to have 278.5 EJ of increased energy consumption, North America 87.4 EJ, Europe 52.1 EJ, the Middle East 43.9 EJ, Africa 41.8 EJ, Central and South America 33.8 EJ, and Eurasia 33.7 EJ.

191 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

2.1.1. Non-Renewable Energy Resources in the World

The primary non-renewable energy sources in the world are coal, oil, natural gas, biomass, and nuclear energy will be explained.

2.1.1.1. Coal Energy in the World

Coal has been used as an energy source for hundreds of years and is also known as a fossil fuel. The coal trade dates back to the Roman period. In addition to enabling the industrial revolution in the 19th century, coal also helped usher in the electric age in the 20th century. Coal remained important as a primary energy source until the second half of the 20th century. However, after this date, it was replaced by oil. As the value of coal in electricity generation became clear, it remained a key player on the global energy agenda. As the world population continues to grow and quality of life improves, demand for energy rises daily. The widespread availability of coal worldwide and its status as an economical fossil fuel that can meet increasing energy demand have always maintained its importance in the global market.¹⁹²

According to the BP 2021 World Energy Statistics Outlook report, as of the end of 2020, the world had a total of 1,074.108 billion tons of coal reserves, comprising 753.639 billion tons of hard coal and 320.469 billion tons of sub-bituminous coal and lignite reserves. Four countries account for 65.60% of the world's coal reserves. The United States ranks first at 23.2%, followed by Russia at 15.1%, Australia at 14%, and China at 13.3%. 42.8% of the world's coal reserves are located in Asia-Pacific, 23.9% in North America, 17.8% in the Commonwealth of Independent States, 12.8% in Europe, 1.5% in the Middle East and Africa, and 1.3% in Central and South America.¹⁹³

Global coal production decreased in 2014, after rising in the early 2000s. This decline continued until 2016. While total coal production worldwide was 7,075.02 in 2016, this figure increased to 7,339.54 in 2017. In 2019, the increase continued to reach 7,690.50. The main reason for this increase in 2017 was an increase in thermal coal and lignite production. In 2019, there was an increase in the total hard coal, such as thermal coal and coking coal, compared to 2018.¹⁹⁴

192 Turkish Coal Corporation Sector Report 2020, P.3, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

193 Turkish Coal Corporation Sector Report 2024, P.4, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

194 Turkish Coal Corporation Sector Report 2020, PP.5-6, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

Table 5. Changes in World Coal Production Over the Year (Million Tons)

Coal Type	2023	2024
Thermal Bituminous Coal And Lignite	7.886	7.960
Coking Coal	1.107	1.107
Total	8.993	9.068

Source: Türkiye Coal Corporation Sector Report 2024, P.7¹⁹⁵

Table 5 Worldwide coal production increased from 8.993 million tons in 2023 to 9.068 million tons in 2024. In 2024, thermal coal and lignite production increased by 74 million tons from 2023, while coking coal production remained unchanged. The United States produced 463 million tons of coal in 2024, a 11.7% decrease from 2023. The European Union produced 243 million tons in 2024, a 12.5% decrease from 2023. Thermal coal and lignite account for approximately 87.78% of World coal production, with the remainder being coking coal. China, the world's largest coal producer, produced 4.653 million tons of coal in 2024, accounting for approximately 51.31% of World coal production.

In 2018, global thermal hard coal consumption increased by 95.9 million tons compared to 2017, or 1.6%, to 5,935.6 million tons. OECD Thermal coal consumption decreased by 33.6 million tons, with a decrease of 5.4 million tons in Spain and 16.1 million tons in the United States, decreasing the total consumption to 1,112.0 million tons. Looking at the major coal-producing countries in the world and the total coal production of other countries, while 5,706.6 million tons of coal were produced in 2016, this figure increased to 5,935.6 million tons in 2019. In 2018, global coking coal consumption increased by 1.09% (10.7 Mt) compared to that in 2017, reaching 992.1 million tons. Coking coal consumption in the OECD decreased by 1.2% to 174.7 million tons. While global coking coal consumption totalled 996.3 million tons in 2016, it decreased by 4.3 million tons to 992 million tons in 2019.¹⁹⁶

195 Turkish Coal Corporation Sector Report 2024, P.7, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

196 Turkish Coal Corporation Sector Report 2020, P.8, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

Table 6. Major Countries and Consumption Amounts of Thermal Coal and Lignite 2023-2027 (Million Tons)

Region/Country	2023	2024	2025	2026	2027	2022-2023	2023-2024
Asia Pacific	6192	6353	6434	6531	6619	6.5%	2.6%
China	4146	4219	4244	4302	4348	6.3%	1.7%
India	1173	1241	1284	1308	1335	10.6%	5.7%
Japan	126	119	111	107	104	-11.5%	-5.9%
Southeast Asia	433	463	487	509	530	9.8%	6.9%
North America	396	378	357	348	336	-16.9%	-4.6%
USA	371	354	335	328	317	-17.8%	-4.7%
Central and South America	32	32	28	26	24	0.1%	0.1%
Europe	493	448	434	404	361	-17.4%	-9.1%
European Union	301	260	242	223	195	-25.2%	-13.5%
Eurasia	288	290	298	306	313	2.4%	0.6%
Africa	182	188	189	194	199	-3.9%	3.1%
Middle East	7	5	4	4	3	-16.9%	-23.5%
World	7590	7695	7745	7813	7853	2.6%	1.4%

Source: Türkiye Coal Corporation Sector Report 2024, P.11¹⁹⁷

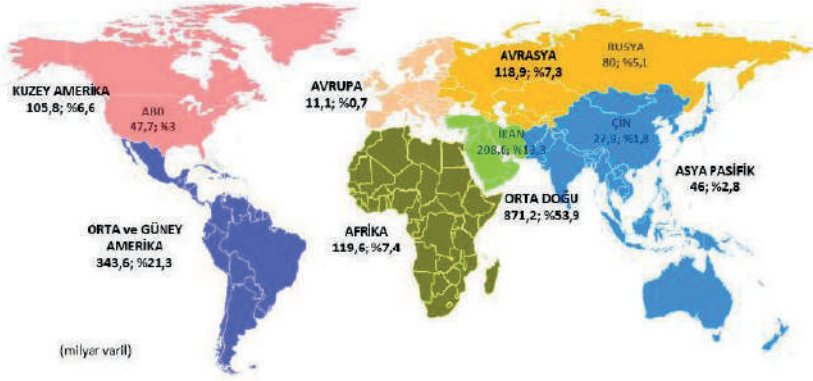
According to Table 6, total World consumption of thermal coal and lignite was 7.590 million tons in 2023, increasing by 1.4% to 7.695 million tons in 2024. China, which accounts for almost half of World coal and lignite consumption, increased its consumption by 1.7% from 4.146 million tons in 2023 to 4.219 million tons in 2024. In 2024, the US consumed 354 million tons, Europe 448 million tons, and North America 378 million tons. Southeast Asia saw the largest increase in consumption in 2024 compared to 2023, at 6.9%, while the Middle East experienced the largest decrease, at 23.5%. It is estimated that the Asia-Pacific region will be the largest consumer of coal in 2027. Southeast Asia, North America, Europe, and Eurasia will follow this.

2.1.1.2. Petroleum Energy in the World

According to the most recent OPEC reserve figures, global crude oil reserves for 2023 were announced at 1.57 trillion barrels. Global oil reserves

¹⁹⁷ Turkish Coal Corporation Sector Report 2024, P.11, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

decreased by 0.4% (6 billion barrels) compared to 2022 levels. In 2022, Venezuela remained the country with the largest oil reserves, with a 19.3% share, while the Middle East remained the region with the largest oil reserves, at 53.9%. The region that showed the largest increase in total oil reserves between 2022 and 2023 was North America. Looking at World oil reserves by region, the Middle East is followed by Central and South America with 21.3% and Africa with 7.4%. Eurasia has 7.3%, North America 6.6%, Asia Pacific 2.8%, and Europe 0.7% of reserves.¹⁹⁸



Shape 1. World Oil Reserves by Region in 2023¹⁹⁹

Table 7. World oil production, recorded at 83.2 mb/d in 2010, increased to 97.5 mb/d in 2024. This increase is projected to continue, reaching 109.4 mb/d by 2050. Even with a decrease in production in 2024 compared to the previous year, OPEC+ countries account for more than 60% of the overall production increase. In terms of regional production in 2024, following OPEC+ countries, the regions with the highest production volumes are Non-OPEC+, Middle East, North America, Eurasia, Asia Pacific, Central and South America, Africa, Europe, and the European Union.

198 Turkish Petroleum Corporation 2024 Oil and Natural Gas Sector Report, P, 10, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

199 Turkish Petroleum Corporation 2024 Oil and Natural Gas Sector Report, P, 10, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

Table 7. World Oil Production (mb/d)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World production	83.2	96.9	97.5	102.7	109.4
Non-OPEC+	33.2	46.2	47.6	51.7	47.4
OPEC+	50.0	50.7	49.9	51.0	62.0
North America	14.0	27.5	28.4	29.3	27.4
Central and South America	7.4	7.1	7.4	10.1	11.1
Europe	4.4	3.4	3.3	2.4	1.3
European Union	0.7	0.5	0.4	0.4	0.3
Africa	10.3	7.3	7.2	7.1	6.9
Middle East	25.4	30.4	30.2	33.6	43.9
Eurasia	13.4	13.8	13.5	13.8	13.9
Asia Pacific	8.4	7.5	7.5	6.5	4.9
Southeast Asia	2.6	1.8	1.7	1.7	1.6

Source: IEA (International Energy Agency). World Energy Outlook 2025²⁰⁰ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 7 It is projected that in 2050, OPEC+ countries will be the leading oil producers, followed by Non-OPEC+ countries with 47.4 mb/d, the Middle East with 43.9 mb/d, North America with 27.4 mb/d, Eurasia with 13.9 mb/d, Central and South America with 11.1 mb/d, Africa with 6.9 mb/d, Asia Pacific with 4.9 mb/d, Southeast Asia with 1.6 mb/d, and the European Union with 0.3 mb/d.

200 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 8. World Oil Demand (mb/d)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	87.6	99.2	100.0	105.3	112.8
North America	22.2	22.1	22.0	21.9	21.7
United States	17.8	18.1	18.1	18.3	17.9
Central and South America	5.5	5.7	5.7	6.4	7.8
Brazil	2.2	2.5	2.5	2.7	3.2
Europe	13.8	12.2	12.2	9.4	6.0
European Union	10.6	9.0	9.0	6.6	3.3
Africa	3.3	4.5	4.5	5.8	8.6
Middle East	7.0	8.3	8.4	9.2	11.6
Eurasia	3.5	4.2	4.2	4.9	5.6
Russia	3.0	3.4	3.3	3.7	3.9
Asia Pacific	25.1	34.5	34.9	38.3	41.2
China	8.8	16.1	16.2	15.8	13.7
India	3.3	5.2	5.4	7.8	10.5
Japan	4.2	3.0	2.9	2.4	2.1
Southeast Asia	4.0	5.0	5.1	6.5	8.0
International bunkers	7.1	7.7	8.1	9.3	10.5

Source: The IEA (International Energy Agency) World Energy Outlook 2025²⁰¹, Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

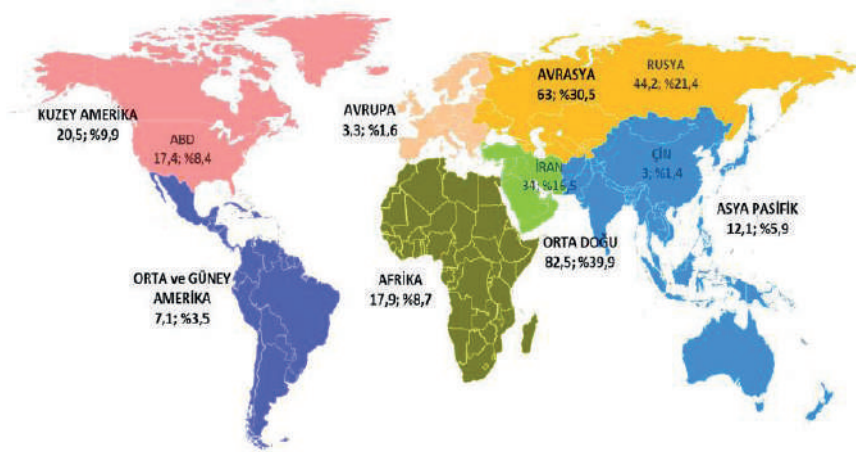
Table 8 shows that World oil demand, which was 87.6 mb/d in 2010, reached 100 mb/d in 2024. This demand is projected to reach 112.8 mb/d in 2050. Total oil demand in the Asia-Pacific region is shown as 34.9 mb/d in 2024. This is due to the inclusion of China and India, the world's most populous countries, in this group. Looking at the geographical distribution of World oil demand in 2024, North America ranks second with 21.9 mb/d. This is followed by Europe at 9.4 mb/d, the Middle East at 9.2 mb/d, Eurasia at 4.9 mb/d, and Central and South America at 6.4 mb/d. In 2050, the total

201 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

oil demand for the Asia Pacific region is projected to be 41.2 mb/d, followed by North America with 21.7 mb/d, the Middle East with 11.6 mb/d, Africa with 8.6 mb/d, Central and South America with 7.8 mb/d, Europe with 6 mb/d, and Eurasia with 5.6 mb/d.

2.1.1.3. Natural Gas Energy in the World

World natural gas reserves increased by 0.3% in 2023 compared to 2022, rising from 205.9 routine m³ to 206.4 product m³. The Middle East accounts for 39.9% of the world's natural gas reserves, Eurasia 30.5%, Asia Pacific 5.9%, Africa 8.7%, North America 9.9%, Central and South America 3.5%, and Europe 1.6% (shape 2). OECD countries hold 27.3 m³ of natural gas reserves, representing 13.2% of the total reserves.²⁰²



Shape 2. Distribution of World Natural Gas Reserves in 2023 (trillion m³)²⁰³

Table 9. World natural gas production, recorded at 4819 TWh in 2010, increased to 6785 TWh in 2024. This increase is projected to continue, reaching 9961 TWh by 2050. In 2024, North America ranked first in world natural gas production, accounting for more than 30% of the total production increase. In terms of regional production in 2024, following North America, the regions with the highest production volumes were, in order: Asia Pacific, the Middle East, Eurasia, Europe, Africa, Central and South America.

202 Turkish Petroleum Corporation 2024 Oil and Natural Gas Sector Report, P, 20, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

203 Turkish Petroleum Corporation 2024 Oil and Natural Gas Sector Report, P, 20, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

Table 9. World Natural Gas Production (TWh)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	4 819	6 630	6 785	8 519	9 961
North America	1 217	2 192	2 282	2 625	2 314
United States	1 018	1 864	1 929	2 268	1 875
Central and South America	170	202	211	292	353
Brazil	36	38	51	66	131
Europe	946	724	672	485	404
European Union	589	450	422	275	191
Africa	235	382	388	550	949
Middle East	524	972	995	1 613	2 354
Eurasia	603	667	684	814	967
Russia	521	511	525	597	639
Asia Pacific	1 125	1 491	1 552	2 141	2 621
China	92	306	329	571	696
India	107	59	62	76	153
Japan	332	331	332	383	374
Southeast Asia	335	361	379	607	828

Source: IEA (International Energy Agency). World Energy Outlook 2025²⁰⁴ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

According to Table 9, it is projected that in 2050, Asia Pacific countries will be the largest natural gas producers, followed by the Middle East with 2354 TWh, North America with 2314 TWh, Eurasia with 967 TWh, Africa with 949 TWh, Europe with 404 TWh, and Central and South America with 353 TWh.

204 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 10. World Natural Gas Demand (bcm)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	3 317	4 138	4 254	5 044	5 596
North America	838	1 158	1 179	1 253	1 192
United States	678	925	942	1 022	943
Central and South America	151	154	157	188	222
Brazil	29	30	32	38	51
Europe	697	504	507	477	426
European Union	446	328	329	296	244
Africa	107	174	172	214	323
Middle East	370	582	596	837	1 077
Eurasia	578	633	660	693	713
Russia	467	503	526	529	507
Asia Pacific	575	931	982	1 330	1 565
China	110	397	428	632	724
India	64	68	75	137	209
Japan	95	90	91	97	93
Southeast Asia	149	176	184	238	285
International bunkers	-	1	1	52	79

Source: IEA (International Energy Agency). World Energy Outlook 2025²⁰⁵ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 10. World natural gas demand, recorded at 3317 bcm in 2010, rose to 4254 bcm in 2024. This increase is expected to continue, reaching 5596 bcm by 2050. In 2024, North America ranked first in world natural gas demand, accounting for more than 25% of the total demand increase. In terms of regional demand in 2024, following North America, the regions with the highest demand volumes were Asia Pacific, Eurasia, the Middle East, Europe, Africa, and Central and South America, respectively. In 2050, Asia Pacific countries are projected to be the largest demanders of natural

205 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

gas, followed by North America with 1192 bcm, the Middle East with 1077 bcm, Eurasia with 713 bcm, Africa with 323 bcm, and Central and South America with 222 bcm.

2.1.1.4. Biomass Energy in the World

Biomass as a heat energy begins with the discovery of fire. Photosynthesis, carried out by plants and trees, produces organic matter and converts it into chemical energy. But when the plant dies, the decay process begins, releasing carbon back into the atmosphere. Biomass can be considered the first form of energy, as the energy found in dead plants has been used for millennia. While biomass met energy demands before the Industrial Revolution, the situation changed during it. Humanity has turned to alternative energy sources to produce energy. But abundant, non-renewable coal and oil are on the rise. Until the mid-1800s, biomass was the only source of energy. The United States used biomass, primarily wood, to provide approximately 91% of its energy until the 1860s. The world's energy needs are increasing as technology advances and the population grows. This situation has led human beings to seek new energy sources and to re-evaluate the usefulness of wood and biomass due to pollution caused by fossil fuels. As an alternative to fossil fuels such as gasoline, biomass and biofuels have emerged in recent years. Biofuels are produced from renewable biological raw materials. Biomass is generally less productive when used and is produced through basic conversion methods such as charcoal production, agricultural waste processing, and animal waste processing. It is used for heating and cooking purposes. In its modern use, plant cultivation comes to the fore. Electricity and heat production are achieved by directly burning the produced biomass.²⁰⁶

206 Biomass and Bioenergy Sectors Overview 2021, P, 44-45. <https://www.pwc.com.tr/tr/sectorler/enerji/biyokutle-ve-biyoenjeri-sektorlerine-genel-bakis-web.pdf>

Table 11. World Biofuels Production (PJ)

	2010	2023	2024
World	2543.2	4730	5128
North America	1 147.8	1847	1993
United States	1 114.2	1792	1917
Central and South America	782	1170	1277
Brazil	683.8	1057	1143
Europe	454.5	697	699
Africa	3	4	4
Middle East	0.5	3	4
Asia Pacific	154.1	1008	1150
China	64	182	237
India	7.6	124	156

Source: Energy Institute Statistical Review of World Energy 2025²⁰⁷

Table 11. World biofuel production, recorded at 2543.2 PJ in 2010, increased to 5128 PJ in 2024. In 2024, North America ranked first in world biofuel production, accounting for more than 40% of the total production increase. In terms of regional production in 2024, following North America, the regions with the highest production volumes were Central and South America, Asia Pacific, Europe, the Middle East, and Africa, respectively.

Table 12. World Biofuels Consumption(PJ)

	2010	2023	2024
World	2444	4749	4890
North America	1109.9	1914	2014
United States	1068.4	1782	1885
Central and South America	671.7	1075	1109
Brazil	607.8	947	972
Europe	505.2	876	800
Africa	0.7	4	4
Middle East	0.4	3	4
Asia Pacific	154.7	861	937
China	71.3	114	134
India	5.4	124	171

Source:Energy Institute Statistical Review of World Energy 2025²⁰⁸

207 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

208 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

Table 12. World biofuel consumption, recorded at 2444 PJ in 2010, increased to 4890 PJ in 2024. In 2024, North America ranked first in world biofuel consumption, accounting for more than 40% of the total consumption increase. In terms of regional production in 2024, following North America, the regions with the highest consumption volumes were Central and South America, Asia Pacific, Europe, the Middle East, and Africa, respectively.

2.1.1.5. Nuclear Energy in the World

The nuclear energy process, which began in 1789 with the discovery of uranium and continued in 1934 with the discovery of nuclear fission, has entered the agenda of industrialists, politicians, and scientists. At first, the works were carried out for defence and military purposes, but later they continued for commercial purposes. Many countries have used nuclear energy to convert the heat released by atomic splitting into electrical energy. With the oil crisis in the early 1970s, the installation of nuclear power plants began. To ensure energy security and reduce their dependence on oil and other hydrocarbon resources, countries without oil and other hydrocarbon resources have begun using nuclear power plants. Although the Three Mile Island (TMI) accidents in the USA in 1979 and the Chornobyl accidents in Soviet Russia (today within the borders of Ukraine) in 1986 caused a slowdown in nuclear power plants, they continued to gain momentum all over the world. Nuclear power plants stand out among alternative energy sources as preferred by countries due to their unique features. As of July 2020, 440 nuclear reactors in 31 countries and 54 in 19 countries are under construction. Nuclear power plants account for approximately 10% of the world's electricity supply. If analysed by country, France accounts for approximately 71% of electricity demand, Ukraine 54%, Sweden 34%, Belgium 48%, the European Union 28%, South Korea 26%, and the USA 20%. Is nuclear energy met by nuclear reactors? 11 of the world's nuclear reactors under construction are in China, 7 in India, and 4 in Russia. In addition, the construction of 4 nuclear reactors in the United Arab Emirates, 4 in South Korea, 2 in the USA and 1 in France continues. Although the majority of the people in Germany were against nuclear energy after the Fukushima nuclear accident, six nuclear reactors are currently in operation. The decommissioning process of 23 nuclear power reactors continues. Japan, where the Fukushima accident occurred, has stopped all its nuclear power plants due to safety standards. Continuing its efforts to bring other nuclear power plants back into operation, Japan aims to have

its nine nuclear reactors back online by 2020. In addition, the review of 18 more nuclear reactors continues.²⁰⁹

Table 13. World Nuclear Generation (TWh)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	2 756	2 740	2 835	3 856	5 192
North America	935	910	912	952	1 601
United States	839	808	815	834	1 450
Central and South America	22	24	26	49	65
Brazil	15	15	15	37	45
Europe	1 032	748	806	838	930
European Union	854	620	651	659	729
Africa	12	9	9	48	78
Middle East	0	39	40	70	94
Eurasia	173	220	217	261	333
Russia	170	217	215	256	327
Asia Pacific	582	791	825	1 637	2 090
China	74	435	451	937	1 257
India	26	48	54	184	276
Japan	288	84	91	212	210
Southeast Asia	0	0	0	0	12

Source: IEA (International Energy Agency). World Energy Outlook 2025²¹⁰ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 13. World nuclear energy generation, recorded at 2756 TWh in 2010, increased to 2835 TWh in 2024. This increase is expected to continue, reaching 5192 TWh by 2050. In 2024, North America ranked first in nuclear energy generation worldwide, accounting for more than 35% of the total increase. In terms of regional generation in 2024, following North America,

209 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-nuclear-energy>

210 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

the regions with the highest generation volumes were, in order: Asia Pacific, Europe, Eurasia, the Middle East, Central and South America, and Africa. In 2050, Asia Pacific countries are projected to be the largest nuclear energy producer, followed by North America with 1601 TWh, Europe with 930 TWh, Eurasia with 333 TWh, the Middle East with 94 TWh, Africa with 78 TWh, and Central and South America with 65 TWh.

Table 14. World Nuclear Consumption (EJ)

	2010	2023	2024
World	30.20	29.9	30.7
North America	10.31	10	10
United States	9.27	8.9	9
Central and South America	0.24	0.3	0.3
Brazil	0.16	0.2	0.2
Europe	11.26	8	8.4
Africa	0.15	0.1	0.1
Middle East	-	0.4	0.5
Asia Pacific	6.36	8.5	8.9
China	0.82	4.7	4.9
India	0.25	0.5	0.6

Source: Energy Institute Statistical Review of World Energy 2025²¹¹

Table 14. World nuclear consumption, recorded at 30.20 EJ in 2010, reached 30.7 EJ in 2024. In 2024, North America ranked first in nuclear consumption, accounting for more than 30% of the World increase. In terms of regional production in 2024, following North America, the regions with the highest consumption volumes were Asia Pacific, Europe, the Middle East, Central and South America, and Africa, respectively.

2.1.2. Renewable Energy Resources in the World

The renewable energy sector was affected by many negativities when the COVID-19 pandemic emerged. Supply chain disruptions, restrictions on the movement of labour and goods, postponed or cancelled tenders, and other factors have disrupted the renewable energy sector. However, the solar PV and wind energy sectors recovered in the second half of 2020. By the end of the year, each of these two technologies had achieved record new capacity. It

211 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

has added more than 256 GW of additional capacity, pushing the renewable energy sector to an all-time high. Total installed renewable energy capacity worldwide increased by 10%, reaching 2,839 GW. Most of the newly installed power capacity in 2020 came from the renewable energy sector rather than the fossil fuel and nuclear energy sectors. Net power capacity additions from renewable sources increased by 83% in 2020. Solar PV accounted for more than half of renewable resource additions, approximately 139 GW. Wind energy accounted for 36% of total additions, with an installed capacity of 93 GW. Hydropower accounted for 20 GW of additions. The remaining additions were made to biological resources, ocean, geothermal and concentrated solar power (CSP) systems. In the bioenergy, CSP, hydropower, solar PV, and wind energy sectors, China accounted for half of all global investment additions through new facility additions. In 2020, China approximately doubled its additions compared to the previous year.²¹²

Table 15. World Renewables Generation (TWh)

	2010	2023	2024
World	4 207	9 011	9 935
North America	857	1 453	1 535
United States	441	963	1 054
Central and South America	752	1 051	1 086
Brazil	437	630	655
Europe	954	1 784	1 925
European Union	653	1 228	1 338
Africa	116	221	234
Middle East	18	49	63
Eurasia	226	278	300
Russia	167	208	219
Asia Pacific	1 285	4 175	4 791
China	782	2 904	3 433
India	161	395	416
Japan	106	226	244
Southeast Asia	105	349	370

Source: IEA (International Energy Agency). World Energy Outlook 2025²¹³ Note: The 2010, 2023, and 2024 values represent actual figures.

212 Renewables 2021 Global Status Report, PDF, P, 51-52. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

213 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 15. World renewable energy generation, recorded at 4207 TWh in 2010, increased to 9935 TWh in 2024. In 2024, Asia Pacific ranked first in World renewable energy generation, accounting for more than 50% of the total increase in generation. In terms of regional generation in 2024, following Asia Pacific, the regions with the highest generation volumes were, in order: Europe, North America, Central and South America, Eurasia, Africa, and the Middle East.

Table 16. World Renewables Consumption (EJ)

	2010	2023	2024
World	21.98	45.31	48.77
North America	5.42	8.37	8.73
United States	3.58	6.24	6.65
Central and South America	3.77	5.63	5.77
Brazil	2.42	3.64	3.74
Europe	5.26	9.54	9.95
Africa	0.48	1.05	1.07
Middle East	0.06	0.27	0.29
Asia Pacific	6.19	19.43	21.86
China	3.09	11.99	13.90
India	0.61	1.63	1.77

Source: Energy Institute Statistical Review of World Energy 2025²¹⁴

Table 16. World renewable energy consumption, recorded at 21.98 EJ in 2010, reached 48.77 EJ in 2024. In 2024, the Asia Pacific region ranked first in world renewable energy consumption, accounting for more than 40% of the total consumption increase. In terms of regional production in 2024, following Asia Pacific, the regions with the highest consumption volumes were Europe, North America, Central and South America, Africa, and the Middle East, respectively.

2.1.2.1 Hydroelectric Energy in the World

Global hydroelectric energy could not increase sufficiently in 2020 despite 24% capacity additions led by China. There are reasons behind this slowdown, such as the effects of the COVID-19 pandemic and the market slowdown

²¹⁴ Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

caused by the temporary halt in construction. Energy demand has fallen as component supply chains have been disrupted. The ranking of the top 10 countries in global hydroelectric capacity did not change in 2019 and 2020. China, Brazil, Canada, the United States of America, the Russian Federation, India, Norway, Türkiye, Japan, and France made the top 10. The hydroelectric capacities of these countries represent more than two-thirds of the world's country production. China ranks first globally in hydropower production, increasing its output from 325 GW in 2019 to 12.6 GW in 2020 by developing the unused potential of marginal resources and pumped storage. China, Russia, India, Norway, Türkiye, Brazil, Canada, Indonesia, Angola and Guinea followed. Although some annual changes in global hydropower production are due to changes in installed capacity, it increased by 1.5% in 2020, reaching an estimated 4,370 TWh. This represents approximately 16.8% of the world's total electricity production. China added 12.6 GW of hydropower capacity in 2020. This is the highest amount in the previous five years. It reached 338.7 GW by the end of the year. These additions include the 1.6 GW Datengxia plant in the Guangxi Zhuang autonomous region, eight 200 MW turbines, and five 850 MW units commissioned at the Wudongde plant between Yunnan and Sichuan provinces. The biggest addition is the Wudongde facility, which ranks as the world's seventh-largest. It has a total installed capacity of 10.2 GW. The plans for 2021 include the reconstruction of the Fengman facility with a production capacity of 1.5 GW and the completion of the construction of the Baihetan mega project capable of producing 16 GW. China's total hydropower production increased by 4.1% from 2019 to 1,360 TWh. This production represents 18% of the country's electricity supply. In 2020, the Three Gorges Dam broke a world record for annual electricity production.²¹⁵

215 Renewables 2021 Global Status Report, PDF, P, 106-107. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

Table 17. World Hydroelectricity Generation (TWh)

	2010	2023	2024
World	3430.1	4260.8	4452.9
North America	645.9	622.8	605.5
United States	257.3	241.4	238.7
Central and South America	694	755.2	735.7
Brazil	403.3	426.0	413.2
Europe	650.8	642.6	698.0
Africa	107.7	167.1	170.1
Middle East	17.4	25.5	21.8
Asia Pacific	1097.6	1794.2	1952.6
China	711.4	1226.0	1354.3
India	108.7	149.4	156.5

Source: Energy Institute Statistical Review of World Energy 2025²¹⁶

Table 17. World hydroelectric power generation, recorded at 3430.1 TWh in 2010, increased to 4452.9 TWh in 2024. In 2024, Asia Pacific ranked first in World hydroelectric power generation, accounting for more than 40% of the total increase in production. Following Asia Pacific, the regions with the highest production volumes in 2024 were Central and South America, Europe, North America, Africa, and the Middle East, respectively.

Table 18. World Hydroelectricity Consumption (EJ)

	2010	2023	2024
World	12.35	15.3	16
North America	2.33	2.2	2.2
United States	0.93	0.9	0.9
Central and South America	2.50	2.7	2.6
Brazil	1.45	1.5	1.5
Europe	2.34	2.3	2.5
Africa	0.39	0.6	0.6
Middle East	0.06	0.1	0.1
Asia Pacific	3.95	6.5	7
China	2.56	4.4	4.9
India	0.39	0.5	0.6

Source: Energy Institute Statistical Review of World Energy 2025²¹⁷

216 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

217 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

Table 18. World hydroelectric consumption, recorded at 12.35 EJ in 2010, increased to 16 EJ in 2024. In 2024, Asia Pacific ranked first in world hydroelectric consumption, accounting for more than 40% of the total consumption increase. In terms of regional production in 2024, following Asia Pacific, the regions with the highest consumption volumes were Central and South America, Europe, North America, Africa, and the Middle East, respectively.

The devastating impact of the pandemic-induced recession has affected many of the world's leading hydropower technology providers. Voith Hydro has suffered from a slowing market. It reported a 46% decrease in orders and a 17% decrease in sales.²¹⁸ America represented the largest share of Voith's sales. Then comes Asia and Europe.²¹⁹ GE Hydro Solutions Andritz Hydro recorded a 12% decline in revenue, accounting for more than 25% of hydropower production. Although renewable energy was brought to the agenda in some plans, such as increasing economic growth, creating employment and reducing greenhouse gas emissions, it was not given enough importance by states in 2020. The International Energy Agency has included hydropower modernisation in its three-year recovery plan, calling for about \$20 billion in annual spending. This call aims to support production and accelerate the creation of skilled jobs.²²⁰

Likewise, the International Hydropower Association (IHA) and the International Renewable Energy Agency have joined forces to support the development of 850 GW of hydropower capacity by 2050 to achieve the climate targets of the Paris Agreement.²²¹

2.1.2.2. Wind Energy in the World

An estimated 93 GW of wind energy capacity was installed globally in 2020. This resulting energy capacity consists of 86.9 GW onshore, the highest

218 BloombergNEF, Energy Transition Investment Trends (London: 2021), slide 10, https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends_Free-Summary_Jan2021.pdf.)

219 Zhao, C. Chinese Heat Pump Association, personal communication with REN21, March 2021. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

220 Japan Refrigeration and Air Conditioning Industry Association (JRAIA), "Domestic shipment record of home air conditioners (room air conditioners)", <https://www.jraia.or.jp/statistic/detail.html?ca=0&ca2=0> (using Google Translate), viewed 20 March 2021; JRAIA, "Domestic shipment record of commercial air conditioners (package air conditioners)", <https://www.jraia.or.jp/statistic/detail.html?ca=1&ca2=3> (using Google Translate), viewed 20 March 2021.)

221 JRAIA, "Household heat pump water heater (Eco Cute) Domestic shipment record", <https://www.jraia.or.jp/statistic/detail.html?ca=0&ca2=1> (using Google Translate), viewed 20 March 2021.

ever, and approximately 6.1 GW offshore. 2020 installations have an increase of approximately 53% over 2019 installations. In many countries, particularly in the onshore sector, pandemic-related restrictions disrupted supply chains for several months in 2020. However, despite global health, economic, and political challenges, total global wind energy capacity increased by the end of the year compared to 2019. By the end of 2014, the capacity in operation worldwide had doubled by 2020.²²²

Table 19. World Wind Generation (TWh)

	2010	2023	2024	Current Policies 2035	Current Policies 2050
World	342	2 333	2 533	6 327	9 855
North America	105	487	526	809	1 108
United States	95	426	459	661	834
Central and South America	3	134	151	305	634
Brazil	2	96	108	198	383
Europe	154	614	630	1 562	2 398
European Union	140	479	489	1 234	1 894
Africa	2	29	30	112	284
Middle East	0	4	6	44	120
Eurasia	0	9	13	29	66
Russia	0	5	6	14	39
Asia Pacific	77	1 056	1 178	3 466	5 244
China	45	886	997	2 735	3 398
India	20	93	93	309	907
Japan	4	10	11	38	67
Southeast Asia	0	17	18	139	385

Source: IEA (International Energy Agency). World Energy Outlook 2025²²³ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

222 Renewables 2021 Global Status Report, PDF, P, 146-148. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

223 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 19. World wind energy generation, recorded at 342 TWh in 2010, rose to 2533 TWh in 2024. This increase is expected to continue, reaching 9855 TWh by 2050. In 2024, the Asia Pacific region ranked first World in wind energy generation, accounting for more than 40% of the total increase in production. Following Asia Pacific in terms of regional generation volume in 2024 were Europe, North America, Central and South America, Africa, Eurasia, and the Middle East. It is projected that by 2050, Asia Pacific countries will be the largest wind energy producers, followed by Europe, North America, Central and South America, Africa, Eurasia, and the Middle East.

Table 20. World Wind Consumption (EJ)

	2010	2023	2024
World	1.25	8.36	9.04
North America	0.38	1.80	1.75
United States	0.34	1.53	1.65
Central and South America	0.01	0.42	0.48
Brazil	0.01	0.34	0.39
Europe	0.55	2.21	2.26
Africa	0.01	0.10	0.10
Middle East	-	0.02	0.02
Asia Pacific	0.29	3.76	4.19
China	0.18	3.19	3.59
India	0.07	3.30	3.29

Source: Energy Institute Statistical Review of World Energy 2025²²⁴

Table 20. World wind energy consumption, recorded at 1.25 EJ in 2010, increased to 9.04 EJ in 2024. In 2024, the Asia Pacific ranked first in World wind energy consumption, accounting for more than 40% of the total increase. In terms of regional production in 2024, following Asia Pacific, the regions with the highest consumption volumes were Europe, North America, Central and South America, Africa, and the Middle East, respectively.

2.1.2.3. Solar Energy in the World

For solar energy to become a significant energy source worldwide, it must overcome many challenges, including policy and regulatory instability in many countries, unreliable or inadequate grid infrastructure, and financial and

224 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

banking difficulties. Overall, local residents' opposition to solar PV deployment is lower than a decade ago. Many utilities, including distributed generation, are involved in solar PV deployment and operations. Government policies evolved in 2020 to provide most of the global market with regulations on tariffs (FITs) and various incentives for key entities in the central market in tenders. Global solar energy supply capacity set a record in 2022, with new installations totalling 139 GWDC. It broke the record of the last 10 years by reaching an estimated 760 GWDC in 2020, including both on-grid and off-grid capacity. The COVID-19 pandemic has caused customer delays in the shipping and delivery of solar panels and related hardware. This has exacerbated existing procurement and project permitting difficulties in some markets, such as construction. Despite all these negativities, the solar energy production sector has achieved the largest capacity increase.²²⁵

Table 21. World Solar Generation (TWh)

	2010	2023	2024	Current Policies 2035
World	32	1 605	2 073	9 068
North America	3	245	311	856
United States	3	214	279	761
Central and South America	0	81	108	275
Brazil	0	51	74	168
Europe	23	302	360	1 106
European Union	22	247	297	926
Africa	0	17	24	205
Middle East	0	24	31	237
Eurasia	0	6	7	19
Russia	0	3	3	6
Asia Pacific	6	930	1 232	6 371
China	1	584	851	4 722
India	0	119	136	987
Japan	4	96	99	161
Southeast Asia	0	42	44	177

Source: IEA (International Energy Agency). World Energy Outlook 2025²²⁶ Note: The 2010, 2023, and 2024 values represent actual figures. The 2035 value are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

225 Renewables 2021 Global Status Report, PDF, P, 117-119. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

226 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

Table 21. World solar energy generation, recorded at 32 TWh in 2010, rose to 2073 TWh in 2024. This increase is expected to continue, reaching 9068 TWh by 2035. In 2024, the Asia Pacific region ranked first World in solar energy generation, accounting for more than 50% of the total increase. In terms of regional generation volume in 2024, Asia Pacific was followed by Europe, North America, Central and South America, the Middle East, Africa, and Eurasia. It is projected that by 2035, Asia-Pacific countries will be the largest producers of wind energy, followed by Europe, North America, Central and South America, the Middle East, Africa, and Eurasia.

Table 22. World Solar Consumption (EJ)

	2010	2023	2024
World	0.13	6.04	7.72
North America	0.02	1.01	1.26
United States	0.02	0.90	1.13
Central and South America	-	0.30	0.40
Brazil	-	0.18	0.26
Europe	0.09	1.11	1.36
Africa	-	0.09	0.09
Middle East	-	0.15	0.18
Asia Pacific	0.02	3.36	4.40

Source: Energy Institute Statistical Review of World Energy 2025²²⁷

Table 22. World solar energy consumption, recorded at 0.13 EJ in 2010, rose to 7.72 EJ in 2024. In 2024, the Asia Pacific region ranked first in World solar energy consumption, accounting for over 60% of the total consumption increase. Following Asia Pacific, the regions with the highest regional consumption volumes in 2024 were, in order: Europe, North America, Central and South America, the Middle East, and Africa.

2.1.2.4. World Geothermal Energy

Geothermal resources are used in various ways, including electricity generation and space heating and industrial heat. Direct use is used for energy applications in two ways (similar to solar energy and bioenergy): through thermal applications (without conversion to electricity). Geothermal electricity

227 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

production was approximately 97 TWh in 2020, while direct useful thermal output was approximately 128 TWh (462 PJ). The most distinctive feature of geothermal energy in 2020 is that it showed a disproportionately small growth in capacity compared to recent years. In 2020, Türkiye, the United States, and Japan were the countries that increased their geothermal energy capacity slightly with new facilities. In 2020, the 10 countries with the largest geothermal energy capacity stocks were the USA, Indonesia, the Philippines, Türkiye, New Zealand, Mexico, Kenya, Italy, Iceland, and Japan. In 2020, production capacity was lower than the specified values due to the gradual deterioration of geothermal field steam production capacity or to insufficient drilling and completion of wells to maintain steam flow over time. It has been reported that Türkiye's geothermal capacity increased by 99 MW in 2020 (excluding any value loss). This was the country's smallest annual increase since 2014 and less than half the average annual additions for the previous five years. The United States has a persistent global lead in installed geothermal power capacity, though the market has been relatively stagnant in recent years. Minor changes in 2020 increased the country's net geothermal capacity by approximately 32 MW, bringing the total net operating capacity to 2.6 GW. After over 30 years of renovation, including replacing all generating equipment and resource modifications, the Steamboat Hills power plant in Nevada has increased its capacity by approximately 19 MW. These increases are anticipated to increase plant productivity and efficiency while reducing maintenance costs per production unit. In November 2019, Hawaii, whose Puna geothermal power plant had been disabled by a volcanic eruption in 2018, resumed partial operations. Geothermal energy in the United States produced 16.9 TWh in 2020. This significant 9.4% increase from 2019 represents approximately 0.4% of U.S. net electricity.²²⁸ The top countries for direct geothermal energy use in 2020 include China, Türkiye, Iceland, and Japan, with global use accounting for around 75% of total. China is the largest user of geothermal energy (47% of total), with the geothermal energy sector growing at an average annual rate of more than 18% between 2015 and 2019 and consuming more than 21% annually. As of 2019, China has an estimated 14.2 TW of installed geothermal capacity, with 7 TWth for direct use (excluding heat pumps). Sectorally, 5.7 TW is allocated to district heating, serving bathing and swimming applications, and the remainder is used for food production and other industries. Most of China's hydrothermal resources have relatively low enthalpy; The wellhead temperature of 94% of the 546 production wells drilled in the 2015-2019 period is below 100°C.

228 Renewables 2021 Global Status Report, PDF, P, 100-101. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

Other leading countries (Türkiye, Iceland and Japan) experienced more modest capacity growth of around 3-4% annually. (consumption growth 3-5%). While geothermal development in Türkiye is mainly devoted to electricity production, investments in direct use have shrunk somewhat in the last decade. Iceland has significant thermal demand, served by district heating networks, and continues to have limited drilling. Although there are information gaps, it is estimated that in Japan, more than 80% of direct use is for hot spring facilities located near geothermal springs. Other countries that rely on geothermal heat include (in descending order) New Zealand, Hungary, the Russian Federation, Italy, the United States and Brazil, each representing less than 3% of direct use. There are several examples across Europe where low- to medium-enthalpy sources are mainly used for district heating and greenhouse cultivation. This market continues to evolve in 2020, with notable new developments in France, Germany and the Netherlands. In Germany, Munich completed drilling in 2020 for the country's largest geothermal facility, exceeding 50 megawatts thermal (MWth) and expected to provide heat for more than 80,000 city residents. France continues to see increasing use of localised geothermal energy. The sources continue to be used mostly for district heating. In the greater Paris area, several geothermal district heating systems have been developed in recent years, with new projects launched or announced in 2020. The local district heat network is estimated to cover 66% of energy demand.²²⁹

Table 23. World Geothermal Generation(Geothermal, Biomass and Other, TWh)

	2010	2023	2024
World	378.4	771.63	792.43
North America	93.4	83.35	81.52
United States	75.1	66.91	65.70
Central and South America	46.7	85.27	87.20
Brazil	31.9	57.76	58.24
Europe	137.1	224.62	223.49
Africa	3.9	9.73	10.79
Middle East	0.1	0.50	0.51
Asia Pacific	96.7	366.68	387.44

Source: Energy Institute Statistical Review of World Energy 2025²³⁰

229 Renewables 2021 Global Status Report, PDF, P, 102-103. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

230 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

Table 23. World geothermal, biomass, and other energy generation, recorded at 378.4 TWh in 2010, increased to 792.43 TWh in 2024. In 2024, the Asia Pacific region ranked first in World geothermal, biomass, and other energy generation, accounting for more than 50% of the total increase in generation. Following Asia Pacific, the regions with the highest regional generation volumes in 2024 were, in order: Europe, Central and South America, North America, Africa, and the Middle East.

Table 24. World Geothermal Consumption (Geothermal, Biomass and Other, EJ)

	2010	2023	2024
World	5.81	10.82	11.06
North America	1.59	1.45	1.40
United States	1.22	1.16	1.13
Central and South America	0.59	1.06	1.07
Brazil	0.35	0.63	0.64
Europe	1.76	3.03	3.02
Africa	0.08	0.26	0.26
Middle East	-	0.01	0.01
Asia Pacific	1.77	4.99	5.28

Source: Energy Institute Statistical Review of World Energy 2025²³¹

Table 24. World geothermal, biomass, and other energy consumption, recorded at 5.81 EJ in 2010, is projected to rise to 11.06 EJ in 2024. In 2024, the Asia Pacific region ranked first World in geothermal, biomass, and other energy consumption, accounting for over 40% of the total increase. Following Asia Pacific, the regions with the highest regional consumption volumes in 2024 were, in order: Europe, North America, Central and South America, Africa, and the Middle East.

2.1.2.5. Hydrogen Energy in the World

Hydrogen strategies have recently gained greater importance in achieving countries' goals of reducing greenhouse gas emissions, ensuring energy supply security, and promoting economic growth. Countries have begun creating their national hydrogen strategies and roadmaps. It is estimated that countries will only use green hydrogen produced from renewable energy. Countries aim

231 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

to achieve a largely decarbonised world by 2050. Countries have developed numerous national strategies and initiatives to advance hydrogen policies. The hydrogen initiatives announced by countries between June 2018 and November 2020 included both national initiatives and private-sector initiatives. Germany wants to become a leading country in Hydrogen production and applications by publishing the “National Hydrogen Strategy” plan in 2020.²³²

Germany, which sets the reduction of greenhouse gas emissions, the unification of various end-user sectors that are difficult to electrify, and the integration of renewable energy supply as its main goals, aims to invest 9 billion euros to realize hydrogen as the future’s sustainable energy. Within the framework of these strategies, it is stated that hydrogen imports will be necessary to meet long-term demand, given the limited number of renewable energy assets in Germany. Germany has a sizeable hydrogen market, with most of its production based on fossil fuels. However, supporting domestic hydrogen demand and production capabilities can be seen as an important step in developing the hydrogen economy. Japan is highlighting the transition to a hydrogen society. It has taken steps in this context with the “Strategic Road Map for Hydrogen and Fuel Cells” published in 2019.²³³

The “3E+S” energy policy, which increases “energy security”, “economic efficiency” and “environmental” suitability under the leadership of “safety”, is closely related to Japan’s interest in creating a hydrogen society. With this policy, Japan addressed its structural fragility arising from high energy import dependency, insufficient energy resource availability, and commitments to reduce greenhouse gas emissions.²³⁴

From 2030, Japan aims to increase international hydrogen supply chains and large-scale hydrogen energy production. It also plans to import 300,000 tons of hydrogen annually by 2030.²³⁵

In 2019, South Korea published the “Korea Hydrogen Economy Roadmap” and the “National Roadmap for Hydrogen Technology Development”. This plan has outlined its sector goals and key targets in hydrogen and fuel cell technology. South Korea’s hydrogen economy road map, which includes

232 https://www.bmbf.de/files/bmwi_Nationale%20Wasserstoffstrategie_Eng_s01.pdf

233 https://www.meti.go.jp/english/press/2019/pdf/0312_002b.pdf

234 https://www.weltenergieerat.de/wpcontent/uploads/2020/10/WEC_H2_Strategies_finalreport.pdf

235 <https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen>

2022 and 2040 targets, aims to switch all commercial vehicles to hydrogen by 2025.²³⁶

Today, China is the world's largest producer and user of hydrogen. It expanded the Energy Law to include "Hydrogen Energy" in April 2020. China has been developing fuel cells and hydrogen technologies for use in road vehicles for about 20 years. China has stated that it will reduce the use of fossil fuels such as coal, natural gas, and oil for hydrogen production and turn to renewable sources such as solar and wind.²³⁷

Approximately 100 businesses, various institutions and organisations, and 28 EU member countries established the "Hydrogen Energy Network" platform to discuss hydrogen, which held its first meeting in June 2019. As a result of this meeting, the Linz Declaration "Hydrogen Initiative" was signed. "Hydrogen Strategy for a Climate Neutral Europe" was published by the European Commission in July 2020. It is considered a relevant element of the energy system integration strategy. The European Hydrogen Strategy focuses on electrolysis-based hydrogen production, transport and the industrial sector. It is used in the industrial sector to replace carbon-intensive hydrogen, in the transportation sector, and in heavy-duty applications. In steel production, zero-carbon production is aimed for. The strategy also addresses the use of seasonal energy storage and hydrogen as backup energy sources for heating commercial buildings and residences.²³⁸

The Netherlands, which included a section on hydrogen in the Climate Agreement in 2020, published a hydrogen road map. It is planned to increase the installed power to approximately 500 MW by 2025 and to 3-4 gigawatts (GW) by 2030 through electrolyser-based green hydrogen production.²³⁹ France announced the 2023 and 2028 targets for low-carbon hydrogen in industry, transportation, and renewable energy storage, with financing of 100 million euros within the "Hydrogen Distribution Plan" framework published in 2018. France has set the main goal of the distribution plan to reduce greenhouse gas emissions and to realise a renewable electricity supply through hydrogen storage and "Power-to-Gas" technology. The concept of Power-to-Gas (P2G) refers to using electricity generated from renewable energy or

236 <https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen>

237 <https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen>

238 <https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen>

239 <https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen>

excess electricity to produce hydrogen via water electrolysis. Within the context of various policy initiatives and strategy documents, the role of hydrogen in the UK is discussed in relation to climate and industry. Therefore, there is no specific official hydrogen strategy. Achieving long-term decarbonization targets is possible by protecting the environment through reduced greenhouse gas emissions and by integrating renewable energy into the energy system. The UK plans to add up to 20% hydrogen in part of its natural gas network. It also aims to support the development of hydrogen technologies. The decision to allocate over 100 million Australian dollars to support hydrogen research and pilot projects in Australia was announced in the Australian National Hydrogen Strategy plan in November 2019.²⁴⁰ This plan stimulates domestic demand by creating a national production and supply chain.

While it was announced that it aims to be the world leader in hydrogen production and export, Russia, whose export target was determined as 0.2 million tons in 2024 and 2 million tons in 2030, put the “Energy Strategy” plan on the agenda in June 2020. “Development of Hydrogen Energy in Russia” was approved in October 2020 for the 2020-2024 period. Hydrogen is widely used in the petrochemical and chemical industries. Incentives are also provided for the use of hydrogen resources. It can be seen that the support provided is mainly concentrated in the transportation sector.²⁴¹

Table 25. World Total Hydrogen Demand (PJ)

	2023	2024	Current Policies 2035	Current Policies 2050
World	11 708	11 965	14 760	18 240
North America	1 933	1 943	2 126	2 293
United States	1 608	1 611	1 707	1 815
Central and South America	372	369	550	850
Brazil	51	55	103	141
Europe	869	868	975	1 547
European Union	694	707	782	1 342
Africa	374	391	587	1 065
Middle East	1 625	1 719	2 439	3 139
Eurasia	803	794	844	851
Russia	721	715	745	732

240 http://www.energystrategy.ru/projects/docs/ES-2030_%28Eng%29.pdf

241 http://www.energystrategy.ru/projects/docs/ES-2030_%28Eng%29.pdf

Asia Pacific	5 734	5 881	7 424	8 705
China	3 438	3 512	3 915	4 079
India	1 123	1 173	1 777	2 289
Japan	227	219	217	216
Southeast Asia	441	451	624	745
International bunkers	-	-	13	61

Source: IEA (International Energy Agency). World Energy Outlook 2025²⁴² Note: 2023, and 2024 values represent actual figures. The 2035 and 2050 values are the IEA's estimates of the levels that will be reached in those years if current policies are maintained.

Table 25 shows that total hydrogen demand worldwide was 11,708 PJ in 2023 and 11,965 PJ in 2024. This demand is projected to reach 18,240 PJ in 2050. In terms of regional distribution of total World hydrogen demand in 2024, Asia Pacific ranked first, followed by North America, the Middle East, Europe, Eurasia, Central Africa, and South America. By 2050, the Asia Pacific region is projected to remain in first place, followed by the Middle East, North America, Europe, Africa, Eurasia, and Central and South America.

2.1.2.6. Wave, Tide, and Ocean Current Energy in the World

The difference between technologies reveals new theoretical potentials for electricity production. When the potential of all ocean energy technologies is combined, it is estimated that between 45,000 and 130,000 terawatt-hours (TWh) of energy will be generated. These figures mean that it can more than double global electricity demand. A significant increase in installed capacity is expected in the coming years. It is estimated by IRENA that ocean energy could reach 10 GW of installed capacity by 2030. The current cumulative global installed capacity for ocean energy technologies is dominated by tidal dam technology, a subcategory of tidal technologies. Tidal dam, which accounts for 98% of the global installed capacity, has reached this level thanks to two major installations: a 240 MW power plant in France in 1966 and a 254 MW plant in the Republic of Korea in 2011. Tidal turbines had a capacity of only 100 kilowatts (kW) a few years ago, but have now been successfully deployed, reaching 1.5 MW. This situation allows the development of many projects and further growth of capacity. The Meygen project in Scotland, which

242 IEA (International Energy Agency). World Energy Outlook 2025, Tables for Scenario Projections <https://www.iea.org/data-and-statistics/data-product/world-energy-outlook-2025-free-dataset>

targets a total production of 10 MW with several installations representing the first phase of larger tidal stream farm projects, is being successfully carried out. By 2022, approximately 20 MW of tidal current technology is planned. This number is expected to exceed 1 GW by 2025. With Wave Technology, which can be found between 30 degrees and 60 degrees latitude and in deep water (> 40 meters), 29,500 TWh of energy can be produced annually. Wave energy technologies do not evolve towards a single design type, as wind energy does. Wave energy technologies comprise a combination of technologies. The movement of a buoy is caused by waves coming from all directions, and energy is produced according to the primary connection. Ocean thermal energy conversion (OTEC) is determined by the temperature difference between its deeper layers and changes at the ocean's surface. If the temperature difference is around 20 degrees Celsius, energy can be produced using heat exchanger and turbine cycles. The Global Technical (OTEC) potential is the largest ocean energy resource, which can produce 44,000 TWh annually. Demonstration plants rated at 100 kW have been successful in Hawaii and Japan. Technology studies continue. Salinity Gradient energy can be produced from the difference in salt concentration between two liquids through reverse electrodialysis. This technology, which has the lowest potential among ocean energy technologies, produces only 1,650 TWh annually due to geographical constraints. Since the early 2000s, inventive activity in ocean energy technologies has reached more than 24,000 filed patents. The 15% compound annual growth rate between 2007 and 2017 has also driven breakthroughs in technology. While wave and tidal technologies have seen the most growth, other technologies, such as OTEC and salinity gradient, have also shown some improvement. Wave ranks first in patents registered in ocean energy technologies with 54.06%. Then come Tidal, Otec and Salinity.²⁴³

China ranks first when total registered ocean energy patents are examined annually (2000-2017) by country. The number of patents, which was almost nonexistent in 2000, reached approximately 800 in 2017. Then, in 2017, Korea and the USA came with 200 patents. Japan, the United Kingdom and Canada are coming.²⁴⁴

While ocean energy technologies account for the smallest share of the renewable energy market, their commercial use continues to grow. Its share

243 World Energy Council Türkiye Offshore Renewable Energy Report, December 2020, pp. 1-4. <https://www.dunyaenerji.org.tr/wp-content/uploads/2020/12/Acik-Deniz-Yenilenebilir-Enerji-Raporu.pdf>

244 World Energy Council Türkiye Offshore Renewable Energy Report, December 2020, p. 4. <https://www.dunyaenerji.org.tr/wp-content/uploads/2020/12/Acik-Deniz-Yenilenebilir-Enerji-Raporu.pdf>

in electricity production increased by approximately 2 MW in 2020. It will increase the total operating installed capacity to an estimated 527 MW by the end of the year. Ocean energy can be developed through tidal currents and wave power. In the UK, developments in these technologies are greatly concentrated. However, Canada, the United States, and China encourage research and development on this subject. The EU plans to achieve ocean power capacity targets of at least 40 GW by 2020 and 2050. Combining horizontal axis turbines, it designs devices for utility-scale production. Several other concepts are being developed to power remote communities or low-energy facilities. Wave power devices are still in the production phase. Therefore, there are no actions such as development in production yet. Devices consuming more than 100 kW of electricity are required to develop wave energy. For electricity market targets, smaller devices, typically below 50 kW, are used.²⁴⁵

2.2. Secondary Energy Source in the World

The title of secondary energy source in the world will be examined under the sub-heading of electrical energy source in the world.

2.2.1. Source of Electrical Energy in the World

Total global electricity generation in 2024 reached 31,255.9 TWh. Looking at electricity generation by fuel, coal ranks first. Electricity generation from coal was twice as much as electricity generation from renewable energy sources. Regarding the regional distribution of coal, Asia Pacific leads, followed by North America, Europe, Africa, Central and South America, and the Middle East. Natural gas follows coal. Regarding the regional distribution of natural gas, North America ranks first, followed by Asia Pacific, the Middle East, Europe, Africa, and Central and South America. After natural gas, electricity production from renewable energy sources ranks third. Looking at the regional distribution of renewable energy, the Asia Pacific leads, followed by Europe, North America, Central and South America, Africa, and the Middle East. Hydroelectricity ranks fourth. Regarding the regional distribution of renewable energy, the Asia Pacific leads, followed by Central and South America, Europe, North America, Africa, and the Middle East. Electricity generation from nuclear energy ranked fifth. Looking at the regional distribution, North America ranked first. North America was followed by Asia Pacific, Europe, the Middle East, Central and South America, and Africa, respectively. Electricity generation from petroleum ranked sixth. Looking at the regional distribution,

245 Renewables 2021 Global Status Report, PDF, P, 113. https://www.ren21.net/wp-content/uploads/2019/05/GSR2021_Full_Report.pdf

the Middle East ranked first. The Middle East was followed by Asia Pacific, Central and South America, Africa, North America, and Europe, respectively.

Table 26. 2024 World Total Electricity Generation by Fuel(TWh)

	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Other	Total
World	694.7	7001.2	10613.2	2817.5	4452.9	5415.2	261.2	31255.9
North America	57.5	2335.9	749.8	920.9	605.5	947.5	9.7	5626.8
Central and South America	90.6	248.8	54.6	26.2	735.7	346.7	3.6	1506.3
Europe	52.1	588.6	483.7	766.1	698.0	1213.7	85.5	3887.6
Africa	63.4	412.2	244.6	7.8	170.1	60.7	5.1	963.9
Middle East	324.4	1105.8	16.0	48.0	21.8	52.6	0.2	1568.7
Asia Pacific	91.6	1575.5	8776.0	814.2	1952.6	2771.1	151.3	16132.4

Source: Energy Institute Statistical Review of World Energy 2025²⁴⁶

2.3. Primary Energy Resources in Türkiye

Table 27 shows that Türkiye's installed power capacity based on primary energy sources was 69,519.8 MW in 2014, and this increased by more than 50% to 116,265.1 MW in 2024. In terms of energy sources, hydraulic power ranked first in 2024 with 32,203.0 MW. Following hydraulic power, the figures were: coal 21,221.3 MW, natural gas 20,577.8 MW, solar 20,232.1 MW, wind 12,870.8 MW, multi-fuel 4,874.3 MW, renewable 2,416.9 MW, geothermal 1,733.5 MW, and liquid fuels 135.4 MW. In 2014, hydraulic power also held the top position with 34.01% of the total. These were followed in order by natural gas, coal, multi-fuel, wind, liquid fuels, geothermal, renewable and solar energy sources.

Table 27. Türkiye's Installed Power (MW) by Primary Energy Sources for the Years 2014 and 2024

Energy Sources	2014	%	2024	%
Coal	14.813,9	21,31	21.221,3	18,25
Liquid Fuels	594,9	0,86	135,4	0,12
Natural Gas	18.724,4	26,93	20.577,8	17,70
Renewable +Waste+Waste Heat	299,1	0,43	2.416,9	2,08
Multi-Fuel	7.369,4	10,60	4.874,3	4,19
Hydraulic	23.643,2	34,01	32.203,0	27,70
Geothermal	404,9	0,58	1.733,5	1,49
Wind	3.629,7	5,2	12.870,8	11,1
Solar	40,2	0,1	20.232,1	17,4
Total	69.519,8	100,0	116.265,1	100,0

Source: TEİAŞ²⁴⁷

Table 28 shows that Türkiye's total energy supply by fuel type was 6.66 EJ in 2023, and this figure increased to 7.02 EJ in 2024. In terms of energy sources, oil ranked first in 2024 with 2.37 EJ. This was followed by natural gas (1.83 EJ), coal (1.80 EJ), renewable energy (0.75 EJ), and hydroelectricity (0.27 EJ). In 2023, oil sources also ranked first, accounting for 2.32 EJ of the total energy supply. This was followed by natural gas (1.73 EJ), coal (1.68 EJ), renewable energy (0.70 EJ), and hydroelectricity (0.23 EJ). There is no nuclear energy activity.

Table 28. Türkiye's Total Energy Supply: by Fuel (EJ)

Year	Fuel	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Total
2023	Oil	1.73	1.68	-	0.23	0.70	6.66
	Oil	1.73	1.68	-	0.23	0.70	6.66
2024	Oil	1.83	1.80	-	0.27	0.75	7.02
	Oil	1.83	1.80	-	0.27	0.75	7.02

Source: Energy Institute Statistical Review of World Energy 2025²⁴⁸

247 TEİAŞ, <https://www.teias.gov.tr/turkiye-elektrik-uretim-iletim-istatistikleri>

248 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

Table 29 Türkiye's total primary energy consumption by fuel type was 7.06 EJ in 2023, and this figure increased to 7.54 EJ in 2024. In terms of energy sources, oil ranked first in 2024 with 2.37 EJ. This was followed by natural gas (1.83 EJ), coal (1.80 EJ), renewable energy (0.84 EJ), and hydroelectricity (0.70 EJ). In 2023, oil resources also ranked first in total primary energy consumption with 2.32 EJ. This was followed by natural gas (1.73 EJ), coal (1.68 EJ), renewable energy (0.73 EJ), and hydroelectricity (0.60 EJ). There is no nuclear energy activity.

Table 29. Türkiye's Primary Energy Consumption: by Fuel (EJ)

	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Total
2023	2.32	1.73	1.68	-	0.60	0.73	7.06
2024	2.37	1.83	1.80	-	0.70	0.84	7.54

Source: Energy Institute Statistical Review of World Energy 2025²⁴⁹

2.3.1. Non-Renewable Energy Resources in Türkiye

This section will discuss the main non-renewable energy sources in Türkiye: coal, oil, natural gas, biomass, and nuclear energy.

2.3.1.1. Coal Energy Resources in Türkiye

Türkiye's most crucial hard coal reserves are located in the Zonguldak Basin. During reserve exploration studies, investigations were made down to -1200 m depth. As a result of the research, a total of 1.513 billion tons of geological reserves were reached. Approximately 48% of these reserves have been reached. While reserve definitions are made worldwide, economically exploitable reserves are used.²⁵⁰ In the basin, a total of 1,067,839 tons of coal was produced in 2023, with 285,504 tons by the private sector, and 1,004,000 tons in 2024, with 240,068 tons by the private sector.²⁵¹

²⁴⁹ Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

²⁵⁰ 2020 Coal Sector Report, P.24, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

²⁵¹ Coal and Energy Report 2025, P.25, <https://www.maden.org.tr/icerik/komur-ve-enerji-raporu-2025-yayimlandi-202603101123>

The coking feature of its coals is not found in the Amasra region. Coking reserves are located in the Kozlu, Üzülmöz and Karadon regions of the Basin. The proportion of coking coal reserves in total reserves is approximately 57%. With its semi-coking feature, high calorific value and low body ash content, the reserves in the Armutçuk region are suitable for use in iron and steel factories. Looking at the total reserves of 1.513 billion tons in 2021 by region, approximately 40% is located in Amasra, approximately 25% in Karadon, approximately 20% in Üzülmöz, approximately 10% in Kozlu, and approximately 2% in Armutçuk.²⁵²

The Türkiye Hard Coal Authority carries out hard coal mining in the concession area of the Zonguldak Hard Coal Basin, private sector companies through royalty, and companies that become operators after a license is transferred by TTK. With its complex geological structure, the Zonguldak hard coal basin makes it challenging to start production with fully mechanized systems. For this reason, labour-intensive, complex coal production is carried out by hand. Basin production conditions have begun to change as successful results have been achieved with semi-mechanised equipment (fortification). The basin plays an important role in the country's development through its hard coal production. Since 1942, approximately 392 coal reserves have been identified, and 236 million tons of coal have been sold. While 8.5 million tons of run-of-mine production was realized in the basin in 1974, salable production was 5 million tons in 1967 and 1974. The achieved production value in the basin could not be maintained, and after 1980, production dropped below 4 million tons. Royalty practice started in 1991. The reserves that TTK cannot operate have been implemented since 2004, provided they are subject to TTK. Thus, private companies operated in return for a royalty. When basin coal production is examined from 2010 to 2020, it is seen that TTK Salable Production, Royalty Production, and TTK Run-In Production have decreased. TTK Tüvenan Production had the largest production share in 2020. It has produced approximately 1,000,000 units. Then comes TTK Salable Production and Royalty Production.²⁵³

252 2020 Coal Sector Report, P.24, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

253 2020 Coal Sector Report, P.24, <https://www.taskomuru.gov.tr/ttk/sector-raporu/>

Table 30. Coal Production in Havza, Türkiye (Tons)

Years	Türkiye Coal Corporation Production	PrivateSector Production	Havza Total
2010	1.708.844	883.074	2.591.918
2023	782.335	285.504	1.067.839
2024	764.642	240.068	1.004.710

Source: 2024 Coal Sector Report²⁵⁴

Table 30 shows that coal production in Havza in 2024 was 1,004,710 tons. This figure represents a decrease of more than 50% compared to 2010. Compared to 2023, there has been a decrease of more than 60,000 tons. The Türkiye Coal Corporation produced 1,708,844 tons of coal in 2010, a decrease of more than 50% to 764,642 tons by 2024. Private sector production, on the other hand, decreased from 883,074 tons in 2010 to 240,068 tons in 2024.

Table 31. Türkiye's Coal Production, Consumption, and Import Balance (Thousand tons)

Years	Production	Imports Total	Consumption
2010	1.708.844	883.074	2.591.918
2023	782.335	285.504	1.067.839
2024	764.642	240.068	1.004.710

Source: 2024 Coal Sector Report²⁵⁵

Table 31 shows that coal production in Türkiye in 2024 was 764,642 tons. This figure represents a decrease of more than 50% compared to 2010. Compared to 2023, there was a decrease of 17,000 tons. Total coal imports decreased from 883,074 tons in 2010 to 240,068 tons in 2024, a decrease of more than 75%. On the other hand, coal consumption decreased from 2,591,918 tons in 2010 to 1,004,710 tons in 2024.

According to 2022 data, Türkiye's largest importer of coking coal is Australia, with 2,514,000 tons. The USA, Canada, Colombia, and Russia follow this. Among the countries from which Türkiye imported thermal coal

254 2024 Coal Sector Report, P. 32, <https://www.taskomuru.gov.tr/ttk/wp-content/uploads/2025/05/2024-Yili-Taskomuru-Sektor-Raporu-.pdf>

255 2024 Coal Sector Report, P. 32, <https://www.taskomuru.gov.tr/ttk/wp-content/uploads/2025/05/2024-Yili-Taskomuru-Sektor-Raporu-.pdf>

in 2022, Russia ranked first, followed by Colombia and Australia. In terms of sectors, in 2022, coal consumption in Türkiye was led by thermal power plants with 25,958,000 tons, representing 61.77% of total coal consumption. This was followed by coke plants with 5,934,000 tons and the iron and steel industry with 4,513,000 tons..²⁵⁶

2.3.1.2. Petroleum Energy Resources in Türkiye

Türkiye is strategically important due to its location among regions rich in proven oil and natural gas reserves, including the EU, the Caspian Region, the Middle East, Russia, and Central Asia. Türkiye is also of vital importance in transporting energy resources to countries with high oil and natural gas import dependency. Türkiye's strategic importance has been understood again with the implementation of the Türkiye Stream, which carries Russian gas to Europe through our country, and the TANAP project, which carries Azerbaijani gas to Europe through our country. The oil company TPAO and other energy companies continue to work to eliminate Türkiye's historical dependence on energy imports through different projects. Following the discovery of the Sakarya natural gas field by TPAO in the Black Sea in 2020, developments that could benefit the region's oil and natural gas sector have come to the fore.²⁵⁷

Producible oil reserves in Türkiye are approximately 360 million barrels as of 2019. Exploration well activities in Türkiye have gained momentum in recent years, as the remaining producible crude oil reserves have a lifespan of approximately 18 years. For this reason, a total of 153 drilling wells were opened in 2019, including 73 production wells and 80 exploration-detection wells. Companies that carry out production activities in Türkiye include Perenco, ARAR, TEMI Güney Yıldızı and TPAO. A total of 38 companies, 20 domestic and 18 foreign, carried out exploration and production activities in Türkiye as of the end of 2018. Crude oil is a product that cannot be used unless it is processed. Crude oil production, which was 2.9 million tons in 2019, was realized as 2.5 million tons on average between 2016 and 2019. Belonging to KOÇ Group, There are two refineries in Türkiye: TÜPRAŞ refineries located in Batman, İzmit, İzmir, and Kırıkkale, and the other is the STAR refinery in İzmir, an Azerbaijani investment. 27.2 million tons of crude oil was processed, and 28.1 million tons of production was carried out by TÜPRAŞ Refineries in 2019. Total refinery production in Türkiye

256 2024 Coal Sector Report, PP. 34-35, <https://www.taskomuru.gov.tr/ttk/wp-content/uploads/2025/05/2024-Yili-Taskomuru-Sektor-Raporu-.pdf>

257 Türkiye Petroleum Inc. 2020 Oil And Natural Gas Sector Report P, 34. <https://tpao.gov.tr/file/2109/2020-petrol-ve-dogal-gaz-sektor-raporu-55461375d26d2b70.pdf>

increased by 39% in 2019 compared to 2018, reaching 34.7 million tons. This increase is due to the Star Refinery coming into operation in October 2018. In 2019, total exports increased by 61% compared to 2018, reaching 14.3 million tons.²⁵⁸

Table 32. Türkiye's Oil Supply and Domestic Production (thousand barrels/day)

Years	Domestic Crude Oil Production	Crude Oil Imports	Other Product Imports
2015	51	503	242
2023	82	630	354
2024	107	603	376

*Source: Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report*²⁵⁹

Table 32 shows that domestic crude oil production in Türkiye in 2024 was 107,000 barrels/day. This figure represents an increase of more than 50% compared to 2015. A comparison with 2023 shows an increase of 25,000 barrels/day in 2024. Crude oil imports were managed at 603,000 barrels/day in 2024, up from 503,000 barrels/day in 2015. On the other hand, imports of other products increased from 242,000 barrels/day in 2015 to 376,000 barrels/day in 2024.

In 2024, Russia ranked first among our country's crude oil import sources, with 56.4%, followed by Iraq with 15.8% and Kazakhstan with 9.8%. While the top three countries remained the same as in 2023, it was observed that Russia's share increased significantly compared to the previous year, while the shares of Iraq and Kazakhstan in imports decreased. These three countries were followed by Saudi Arabia (5.3%), Nigeria (3.1%), and Norway (2.2%).²⁶⁰

2.3.1.3. Natural Gas Energy Resources in Türkiye

Natural gas consumption, one of the most important items in Türkiye's foreign trade deficit, has fluctuated over the years. Since Türkiye has limited fossil fuel reserves, it imports approximately 99% of its natural gas and oil. In this case, it increases foreign dependency. In Türkiye, 45.3 billion standard

258 KPMG 2021 Oil and Gas Sector Outlook: The New Reality, pp. 24-29. <https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2021/04/petrol-dogalgaz-sektorel-bakis-2021.pdf>

259 Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report, P. 38, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

260 Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report, P. 39, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

cubic meters (Sm³) of gas were consumed in 2019, and 41.9 billion Sm³ of gas was consumed as of November 2020. Over the last 10 years, an average of 46 billion standard cubic meters of natural gas has been used. The highest consumption in the last 10 years was made in 2017. That's why it is among the five largest natural gas markets in Europe.²⁶¹

Table 33. Türkiye's Türkiye's Natural Gas Imports and Domestic Production (billion m³/year)

Years	Domestic natural gas production	Net natural gas imports
2015	0.4	48.4
2023	0.9	50.5
2024	2.3	51.7

Source: Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report²⁶²

Tablo 33, Data shows that domestic natural gas production in Türkiye will reach 2.3 billion m³/year in 2024. This figure is 0.4 billion m³/year in 2015. Compared to 2023, there is an increase of 1.4 billion m³/year in 2024. Net natural gas imports increased from 48.4 billion m³/year in 2015 to 51.7 billion m³/year in 2024.

Looking at the distribution of Türkiye's natural gas imports by country, Russia's share decreased from 42.3% in 2023 to 41.7% in 2024. Azerbaijan ranked second with 22.2%, while Algeria ranked third with 10.3%. While the top three countries remained the same as in 2023, Russia's share decreased compared to the previous year, unlike its share in crude oil imports, while Azerbaijan's and Iran's shares in imports increased.²⁶³

Oil and natural gas exploration continues around the world to meet the ever-increasing demand for energy. Türkiye has taken an important step by purchasing drilling ships to conduct exploration activities in its region. Yavuz first explored in Kocaeli Dilovası in 2018 with Fatih, the first drilling ship in the Eastern Mediterranean region. Barbaros Hayrettin Pasha and Oruç Reis ships conduct seismic surveys, collect data and direct drilling activities, and

261 KPMG 2021 Oil and Gas Sector Outlook: The New Reality, pp. 19. <https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2021/04/petrol-dogalgaz-sektorel-bakis-2021.pdf>

262 Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report, P. 38, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

263 Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report, P. 39, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

continue their operations in the Eastern Mediterranean and the Black Sea. As a result of discoveries and data collected by the Ministry of Energy and Natural Resources through 2020, it was decided to carry out oil and natural gas exploration by drilling 5 wells in the Eastern Mediterranean, which was included in the 2020 budget. Conflicts of interest in the Eastern Mediterranean are effective because underground resources are energy-rich. Reconciliation problems continue among the 11 states bordering the Eastern Mediterranean (Italy, Tunisia, Greece, Türkiye, Egypt, Syria, Israel, Libya, Palestine, Lebanon and Cyprus). One of the most important factors strengthening Türkiye's position in the region is that the pipelines that will distribute the gas extracted in the region to Europe pass through Türkiye. The main political tensions in the Eastern Mediterranean are the Greek Cypriot Administration and Egypt's strategy to form an alliance and dominate the exploration activities in the region, Greece's refusal to recognize the exclusive economic zones of Türkiye and Libya, Israel's desire for the natural gas distribution line to pass through its borders, and It includes taking steps towards this. The Black Sea, on the other hand, has a peaceful environment, unlike the political tensions in the Eastern Mediterranean. The seismic research conducted in the region is the largest among the discoveries made so far by Türkiye. It is estimated that foreign dependency will decrease significantly as these reserves begin to be put into use.²⁶⁴

Türkiye Petroleum A.O, which further increased its momentum in 2021 and 2022, described as the post-pandemic recovery period, carried out drilling activities in a total of 168 wells in 2024; 9 deep-sea wells were drilled in the seas; and 50 exploration wells, 24 appraisal wells, and 85 production wells were drilled on land. In 2024, Türkiye Petroleum A.O reached its highest daily domestic oil and natural gas production level with 161,015 vpe/g, while average domestic hydrocarbon production increased by 67.6% compared to 2023, reaching 129,390 vpe/g. This figure marks the highest domestic production figure in TPAO's history.²⁶⁵

2.3.1.4. Biomass Energy Resources in Türkiye

The importance of biomass energy in Türkiye is increasing day by day due to factors such as widespread agricultural activities, the country's geographical structure, and soil suitability for biomass production. The demand for biomass is increasing, especially in rural areas. In addition to traditional biomass,

264 KPMG 2021 Oil and Gas Sector Outlook: The New Reality, p. 24. <https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2021/04/petrol-dogalgaz-sektorel-bakis-2021.pdf>

265 Türkiye Petroleum Inc.2024 Oil And Natural Gas Sector Report, PP. 44-45, <https://tpao.gov.tr/file/2505/2024-yili-sektor-raporu-3068683b014d15a6b.pdf>

modern biomass energy methods are also used in Türkiye. Among modern biomass methods, energy crop cultivation comes to the fore. Using different technological methods, biomass can be converted into solid, liquid, and gaseous fuels. In biomass production facilities in Türkiye, energy can be generated from animal, forest, urban, and industrial wastes. Forest waste and animal manure share significantly in heat production in Türkiye. On the other hand, fuel production can be achieved by processing agricultural waste. Studies continue in Türkiye to produce biofuel by fermenting corn, sugar beet, and molasses, and to produce biodiesel from algae. There are various problems in biodiesel production, such as limited access to raw materials or high production costs.²⁶⁶

When we look at the licensed biomass installed power (MW) situation in Türkiye, it was 345 MW in 2015, and by 2020, this increased to 1140 MW, providing a total of 1485 MW of energy. In 2020, the total number of biomass and waste heat production facilities in Türkiye reached 358. In 2020, a total of 49.6 GW of energy was obtained from renewable energy sources. Biomass accounted for 3% of the total energy generated from renewable sources. When examining the distribution of total installed biomass power capacity in 2019, biogas accounted for the largest share at 54%. Biogas is followed by solid biofuels, urban waste, and liquid biofuels, respectively. Biomass-related employment in Türkiye reached 3,400 in 2018. Looking at biomass-related employment, urban and industrial waste accounts for 65%, followed by biogas at 21% and liquid biofuels at 15%. Electricity generation from biomass increased by 783 GWh in 2020 compared to 2019, reaching 4,066 GWh. Biogas accounts for the largest share of biomass-based electricity generation. Production, which was 894 GWh in 2013, increased by 3,172 GWh in 2020, reaching 4,066 GWh. In Türkiye, heat production from biomass decreased by 153 TJ in 2019 compared to 2018, reaching 5,410 TJ. This decrease is due to the reduction in industrial waste production from 1,523 TJ in 2018 to 1,210 TJ in 2019. A total of 5,410 TJ of heat was produced in 2019. Biogas accounted for the largest share, at 3,700 TJ, followed by industrial waste and solid biofuels, each at 1,210 TJ.²⁶⁷

As of the end of May 2025, the installed capacity of biomass energy has increased to 2,435 MW.²⁶⁸ According to data from September 2025, biomass

266 Biomass and Bioenergy Sectors Overview 2021, pp. 59-61, <https://www.pwc.com.tr/tr/sectorler/enerji/biyokutle-ve-biyoenerji-sektorlerine-genel-bakis-web.pdf>

267 Biomass and Bioenergy Sectors Overview 2021, pp. 59-61, <https://www.pwc.com.tr/tr/sectorler/enerji/biyokutle-ve-biyoenerji-sektorlerine-genel-bakis-web.pdf>

268 Official Website of the Ministry of Energy and Natural Resources, <https://enerji.gov.tr/haber-detay?id=21520>

accounted for 2.27% of total electricity generation.²⁶⁹ It is estimated that Türkiye has an annual biomass potential of approximately 117 billion tons (approximately 32 Mtep), of which only a small portion is currently converted into electricity.²⁷⁰

2.3.1.5. Nuclear Energy Resources in Türkiye

There is an obligation to include nuclear energy alongside domestic and renewable energy sources to strengthen energy security. The operating life of new-generation nuclear power plants is 60 years. It continues its work regardless of climate and meteorological factors. Nuclear power plants require much smaller areas than other alternatives and do not emit greenhouse gases. Nuclear power plants can be considered among the most important alternative energy sources for protecting the natural environment and future generations.²⁷¹

In 1968, the first studies were initiated in Türkiye to determine the locations of nuclear power plant sites. Due to political and economic reasons in 1970-1971, the establishment of a 'heavy water' CANDU-type nuclear power plant, scheduled to be put into operation in 1977 with a power of 300-400 MWe and fueled by natural uranium, was cancelled. A license for ground reporting at the Akkuyu site was obtained in 1976. The construction of a 600 MWe nuclear power plant was unsuccessful in 1977 due to a loan guarantee. Sinop was another location where preliminary research was conducted, and its location was determined in 1980. But the studies were inconclusive. Other unsuccessful projects were in 1983: 665 MWe in Akkuyu to the Canadian company AECL (Atomic Energy of Canada Limited), 986 MWe in Akkuyu to the German company KWU (Kraftwerk Union), and Sinop to the US company GE (General Electric). They want to produce energy with a power of 1.085 MWe in . Work on establishing nuclear power plants continues today. Nuclear energy programs are among Türkiye's options for providing electrical energy for the near future.²⁷²

Work is continuing to commission the first reactor in the Akkuyu Nuclear Power Plant Project in 2023. The Akkuyu Nuclear Power Plant Project is our country's first nuclear power plant, providing electricity, employment, human resources, and technology. It is expected to make significant contributions

269 <https://gensed.org/turkiyenin-kurulu-gucu/>

270 https://yenader.org/tr_tr/biyokutle-enerjisi-nedir/

271 TR KPMG Sectoral Overview 2019, p. 25, <https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2019/07/sectorel-bakis-2019.pdf>

272 Tüba-Nuclear Energy Report 2019, p. 22. <https://www.tuba.gov.tr/files/yayinlar/raporlar/T%C3%9CBA%20N%C3%BCklear%20Enerji%20Raporu.pdf>

in many areas. It is estimated that 10,000 people who are citizens of the Republic of Türkiye will be employed. The Agreement on Cooperation on the Establishment and Operation of a Nuclear Power Plant in the Akkuyu Field was signed between the Government of the Republic of Türkiye and the Russian Federation on 12 May 2010. The Project Company was established following the signing of the agreement on 13 December 2010. A positive EIA decision was received from the Ministry of Environment and Urbanization on 1 December 2014, and an electricity generation license was obtained from EMRA on 15 June 2017. Construction activities of structures not related to nuclear security started on October 19, 2017, with a limited work permit. Construction of the first unit's reactor building began on April 2, 2018, upon issuance of the construction license. The core catcher was installed on October 26, 2019, and the second floor of the internal protection structure of the first unit reactor building was installed on June 26, 2020. The foundation of the second unit was laid on April 8, 2020. The Project Company applied for a construction license for the third unit on 28 March 2019 and for the fourth unit on 12 May 2020. Sinop Nuclear Power Plant was signed as the second nuclear power plant project between Türkiye and Japan on May 3, 2013. Studies are continuing on this subject. In addition, studies on human resource development are also ongoing. Among the students sent to nuclear energy engineering education, those who complete their education will be employed in various fields, from engineering to management, at the Akkuyu Nuclear Power Plant Project.²⁷³

The first reactor of the Akkuyu Nuclear Power Plant (NPP), Türkiye's first nuclear power plant, is planned to be commissioned in 2025, and the first nuclear energy will be supplied to Türkiye's electricity system. When fully operational, the 4,800 MW capacity plant will meet approximately 10% of Türkiye's electricity needs.²⁷⁴

2.3.2. Renewable Energy Resources in Türkiye

Over the years, the installed capacity of renewable energy in Türkiye has been increasing. While Türkiye's installed power based on renewable energy sources was 25.6 GW in 2013, it increased by approximately 10% annually and reached approximately 47 GW as of September 2020. While the share

273 TR KPMG Sectoral Overview 2019, p. 25-26, <https://assets.kpmg.com/content/dam/kpmg/tr/pdf/2019/07/sektorel-bakis-2019.pdf>

274 https://www.iletisim.gov.tr/turkce/dis_basinda_turkiye/detay/turkiyedeki-akkuyu-nukleer-santralinin-ilk-reaktoru-2025te-devreye-girecek#:~:text=%C4%B0leti%C5%9Fim%20Ba%C5%9Fkanl%C4%B1%C4%9F%C4%B1-,T%C3%BCrkiye'deki%20Akkuyu%20N%C3%BCkleer%20Santrali'nin%20ilk%20reakt%C3%B6r%C3%BC%202025',reakt%C3%B6r%C3%BC%20devreye%20alaca%C4%9F%C4%B1z.%22%20dedi

of renewable energy in total installed power was 40% in 2013, it was 50.4% as of September 2020. When we look at the increase in installed capacity from renewable energy sources between 2015 and 2020, the largest increase is in HEPPs. HEPPs are followed by SPPs, RESs, geothermal power plants (GPPs), and biomass power plants (BESs). HEPPs accounted for 82% of the installed capacity of renewable energy resources in 2015. There has been an increase in RES and SPPs over time. Due to these increases, the share of HEPPs in the installed capacity decreased to 63% as of September 2020. As of September 2020, the share of renewable energy sources in installed capacity was 17% for RES and 14% for SPPs. The share of GPPs and BESs was 3%.²⁷⁵

Table 34. Türkiye Renewable Energy: Generation by Source (TWh)

2023	Wind	Solar	Hydro	Other renewables	Total
	34.1	22.1	64.0	20.0	140.2
2024	Wind	Solar	Hydro	Other renewables	Total
	36.6	30.4	74.9	20.3	162.2

Source: Energy Institute Statistical Review of World Energy 2025²⁷⁶

Table 34 Türkiye's total renewable energy generation by fuel type increased from 140.2 TWh in 2023 to 162.2 TWh in 2024. In terms of energy sources, hydropower ranked first in 2024 with 74.9 TWh, followed by wind (36.6 TWh), solar (30.4 TWh), and other renewable energy (20.3 TWh). In 2023, hydropower also ranked first in total renewable energy generation by fuel type with 64 TWh, followed by wind (34.1 TWh), solar (22.1 TWh), and other renewable energy (20.0 TWh).

Türkiye's renewable energy consumption was 0.93 EJ in 2023 and 1.02 EJ in 2024.²⁷⁷

2.3.2.1. Hydroelectric Energy Source in Türkiye

In 1956, construction of the Seyhan I HEPP and DSI HEPP began. Alpaslan I, Akköprü, Kilavuzlu, and Ermenek HEPPs were put into operation

²⁷⁵ TSKB Energy Sector Outlook 2020, pp. 28-29. <https://www.tskb.com.tr/i/assets/document/pdf/enerji-sektor-gorunumu-2020.pdf>

²⁷⁶ Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

²⁷⁷ Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

in 2012; Deriner Dam and HEPP in 2013; Çine Dam and HEPP, and Manyas Dam and HEPP in 2014; Topçam Dam and HEPP in 2016; and Kiğı Dam and HEPP in 2017. DSI completed a total of 67 HEPPs with installed capacity less than 2 MW (Anamur, Erciş, Kernek, Silifke-I, Uludere, Durucasu). HES has been reached. The total installed power of HEPPs was 12,556 MW, and the average annual total energy production was 45.3 billion kWh. The construction of 2 hydroelectric power plants continues. Its total installed power is 1,758 MW, and its total annual average energy production is 6.0 billion kWh. When the HEPPs built and put into operation by DSI are completed, the hydroelectric potential will reach 14,314 MW, and these facilities will provide 51.2 billion kWh of energy annually.²⁷⁸

According to the legislation in force, the power plants installed by DSI are operated by EÜAŞ General Directorate. EÜAŞ operates 49 HEPPs with a total installed capacity of 12,832 MW as of the end of 2018. 37 of the HEPPs are reservoir type, 11 are canal type, and 1 is lake type. Tohma-Medik HEPP, with an installed capacity of 12.5 MW, was built under the Build-Operate-Transfer model. Gönen HEPP has an installed power of 10.6 MW, and Sütçüler HEPP has an installed power of 2.2 MW. It was taken over by EÜAŞ in 2018. In 2018, the privatisation processes for 10 HEPPs belonging to EÜAŞ were completed by signing operating rights transfer agreements, the tenders for which were held by the Privatisation Administration. HEPPs whose processes have been completed are Anamur, Mut-Derinceay, Bozyazı, Silifke, Zeyne, Menzelet, Kilavuzlu, Manyas, Gönen, Sütçü. HEPPs, established by the private sector under the production license issued by the Energy Market Regulatory Authority (EPDK) within the framework of the Electricity Market Law No. 6446, are operated by the private sector.²⁷⁹

According to the data in the 2019 Annual Report, the total installed capacity of 683 hydroelectric power plants in operation in Türkiye is 28,571 MW, and the average annual total production is 99.6 GWh. This value corresponds to approximately 62% of the total developed potential. 12,556 MW (44%) of the 28,571 MW installed capacity was developed and constructed by DSI. At the end of 2019, according to TEİAŞ data, hydroelectric installed power was 28,503 MW. Total electricity production was 88.89 billion kWh.²⁸⁰

278 Serpil Serdar, Türkiye Hydroelectric Potential And Development Status 2020, P.276, https://www.mmo.org.tr/sites/default/files/TEG-2020-10_Hidroelektrik_Serpil%20serdar.pdf

279 Serpil Serdar, Türkiye Hydroelectric Potential And Development Status 2020, P. 277. https://www.mmo.org.tr/sites/default/files/TEG-2020-10_Hidroelektrik_Serpil%20Serdar.pdf

280 Serpil Serdar, Türkiye Hydroelectric Potential And Development Status 2020, P. 276. https://www.mmo.org.tr/sites/default/files/TEG-2020-10_Hidroelektrik_Serpil%20Serdar.pdf

The use of renewable energy sources for electricity generation is regulated by Law No. 5346, and incentives for the diversity of renewable energy sources are regulated by Law No. 6094. Law No. 5346 remained in force from 8/05/2005 until 31/12/2020. A support of 7.3 US dollars-cents/kWh will be provided for the production of electrical energy in hydroelectric production facilities that have been or will be put into operation for a period of 10 years. The “Regulation on the Support of Domestic Components Used in Facilities Producing Electrical Energy from Renewable Energy Sources” will provide domestic production in the licensed production facility. If it is proven that parts are used, local incentive amounts are added for five years. The supports are listed in the table below.²⁸¹

The Regulation on Certification and Support of Renewable Energy Resources was prepared by Law No. 5346. It entered into force after being published in the Official Gazette No. 28782. The regulation dated 01/10/2013 was enacted to promote the production of electrical energy from renewable energy sources. Renewable energy resource certificates were issued to license holders to establish and operate the RES Support Mechanism (YEKDEM). A support of 1.3 USD-cents/kWh is provided for domestic turbine manufacturing, and 1.0 USD-cents/kWh support is provided for generator and power electronics manufacturing.²⁸²

Table 35. Hydroelectricity Generation and Consumption in Türkiye

Hydroelectricity: Generation(TWh)	2010	2023	2024
	51.8	64	74.9
Hydroelectricity: Consumption(EJ)	2010	2023	2024
	0.19	0.2	0.3

Source:Energy Institute Statistical Review of World Energy 2025²⁸³

In Table 35, while hydroelectricity generation in Türkiye was 51.8 TWh in 2010, it increased by more than 40% to 74.9 TWh in 2024. There was a 10 TWh increase in 2024 compared to 2023. In Table 35, while hydroelectric

281 Serpil Serdar, Türkiye Hydroelectric Potential And Development Status 2020, PP,279-280. https://www.mmo.org.tr/sites/default/files/TEG-2020-10_Hidroelektrik_Serpil%20Serdar.pdf

282 Serpil Serdar, Türkiye Hydroelectric Potential And Development Status 2020, PP, 279-280. https://www.mmo.org.tr/sites/default/files/TEG-2020-10_Hidroelektrik_Serpil%20Serdar.pdf

283 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

consumption in Türkiye was 0.19 EJ in 2010, it increased to 0.3 EJ in 2024. There was an increase in hydroelectricity consumption in 2024 compared to 2023.

2.3.2.2. *Wind Energy Source in Türkiye*

In Türkiye, it has been accepted that wind power plants with a capacity of 5 MW per square kilometre, located 50 meters above ground level, and with wind speeds above 7.5 m/s can be established in regions. A Wind Energy Potential Atlas (REPA) was prepared in light of these assumptions. REPA was created by providing wind resource information produced using a micro-scale wind flow model and medium-scale numerical weather forecast model. Türkiye's wind energy potential was determined as 48,000 MW. While the total terrestrial energy capacity was 37,836 MW, the total marine energy capacity was 10,013 MW. It is given in detail in the table below.²⁸⁴

This potential corresponds to 1.30% of Türkiye's surface area. Using the micro-scale wind flow model and the medium-scale numerical weather forecast model, REPA produced the following wind resource information with a resolution of 200 m x 200 m.

- Daily, monthly, seasonal and annual wind speed averages at 30, 50, 70 and 100 m altitudes,
- Monthly, seasonal and annual wind power densities at 50 and 100 m altitudes,
- Annual capacity factor at 50 m height,
- Annual wind types at an altitude of 50 m,
- Monthly temperature values at 2 and 50 m altitudes,
- Monthly pressure values at sea level and 50 m altitude are included.²⁸⁵

In May 2020, wind resource information was updated with support from the European Union, the European Bank for Reconstruction and Development, and the Türkiye Wind Energy Potential Atlas. The Türkiye Wind Energy Potential Atlas has been updated to a 100 m x 100 m resolution. Wind resource information for altitudes of 30, 60, 100, and 150 meters, and wind direction data for altitudes of 30 and 100 meters, were produced. Using these parameters, power density, wind class, and capacity factor for a

284 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>, <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>

285 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>, <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>

wind turbine with a power of 3 MW, and annual energy production values, were calculated. Efforts to revise the total capacity of wind power plants that can be established in Türkiye continue, thanks to the development of wind turbine technologies and updated wind resource information. As of the end of December 2020, the total installed power in Türkiye was 95 890.6 MW. The installed wind power capacity was 8,832 MW in 2020. Since 2004, the share of wind energy in total installed power has continued increasing.²⁸⁶

Table 36. Wind Generation and Consumption in Türkiye

Wind: Generation(TWh)	2010	2023	2024
	2.9	34.11	36.63
Wind: Consumption(EJ)	2010	2023	2024
	0.01	0.12	0.13

Source: Energy Institute Statistical Review of World Energy 2025²⁸⁷

In Table 36, while wind energy generation in Türkiye was 2.9 TWh in 2010, it increased significantly to 36.63 TWh in 2024. There was an increase in 2024 compared to 2023. In Table 36, while wind energy consumption in Türkiye was 0.01 EJ in 2010, it increased to 0.13 EJ in 2024. Energy consumption from wind increased in 2024 compared to 2023.

2.3.2.3. Solar Energy Source in Türkiye

Solar energy is the radiant energy released by the fusion process (transformation of hydrogen gas into helium) in the core of the sun. The sun is a clean, inexhaustible source of renewable energy, emitting approximately 3.9×10^{26} W of power. A very small amount of this energy emitted from the Sun reaches the Earth. An average of 1.367 W power falls on each square meter of the outer surface of the atmosphere. While it absorbs some of this radiation coming into the atmosphere, usually consisting of X-rays and ultraviolet rays, it reflects some of it. The work carried out by our Ministry to utilize this huge and renewable energy source has accelerated recently. Countries have accelerated the transition to renewable energy to avoid the environmental damage caused by fossil resources. In this way, a lot of research is being done on the production of heat and electricity from solar energy and its use is

286 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>, <https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar>

287 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

increasing over the years. Although there are multiple methods for generating electricity from solar energy, the general trend is toward photovoltaic systems, which directly convert sunlight into electricity. Studies on utilising solar energy have gained momentum, especially after the 1970s. Solar energy systems have advanced and become more cost-effective, establishing themselves as a clean, environmentally friendly energy source. The importance of solar energy is increasing, especially because it is a clean energy source and operates at low cost after installation.²⁸⁸

Türkiye is a country rich in solar energy due to its geographical location. According to Türkiye's Solar Energy Potential Atlas (GEPA), the annual average total sunshine duration is 2741.07 hours, and the annual average radiation value is 1527.46 kWh/m². In Türkiye, Southern regions have more sunshine hours than Northern regions. Since the Black Sea Region spends most of the year under rain, the number of sunny hours is relatively low. While the Marmara Regions and Aegean Regions have a moderate solar radiation potential of 1450-1550 kWh/m², Central Anatolia, Eastern Anatolia, Mediterranean and Southeastern Anatolia have a high solar radiation potential of 1600-2000 kWh/m². Investments in regions with high sunshine hours will be more cost-effective and efficient. When we look at Türkiye's monthly average radiation values in 2024, we see that the highest values are reached in summer. It is seen that the highest values are reached in June and July, in particular. It is observed that the lowest values occur in the winter months. When we look at December and January, we see that the lowest levels have been reached.²⁸⁹

Table 37. Solar Generation and Consumption in Türkiye

Solar: Generation(TWh)	2017	2023	2024
	2.9	22.9	30.37
Solar: Consumption(EJ)	2017	2023	2024
	0.01	0.08	0.11

Source:Energy Institute Statistical Review of World Energy 2025²⁹⁰

288 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-gunes>

289 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/bilgi-merkezi-enerji-gunes>

290 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

In Table 37, while solar energy generation in Türkiye was 2.9 TWh in 2017, there was a significant increase in 2024, with 30.37 TWh generated. There was an increase in 2024 compared to 2023. In Table 37, while solar energy consumption in Türkiye was 0.01 EJ in 2010, it increased to 0.11 EJ in 2024. Solar energy consumption increased in 2024 compared to 2023.

2.3.2.4. Geothermal Energy Source in Türkiye

Our country is located on an active tectonic belt due to its geological and geographical location and is rich in geothermal resources in the world. There are geothermal resources spread throughout our country and at different temperatures. Türkiye is the first country in Europe in terms of geothermal potential and the fourth in the world in terms of installed capacity. The top five countries in electricity production from geothermal energy are the USA, Indonesia, the Philippines, Türkiye, and New Zealand. The geothermal potential of our country is quite high and 78% of the potential areas are located in Western Anatolia, 9% in Central Anatolia, 7% in the Marmara Region, 5% in Eastern Anatolia and 1% in other regions. It is estimated that 90% of our geothermal resources are at low to medium temperatures and suitable for direct heat generation (heating, thermal tourism, industrial applications, etc.), while 10% are suitable for electrical energy production. Geothermal electricity production in our country began in 1975 with the Kızıldere Power Plant, with a capacity of 0.5 MWe. Since 2005, with the support of our Ministry, emphasis has been placed on developing existing resources and searching for new resource areas. After the Geothermal Resources and Natural Mineral Waters Law came into force in 2008, our visible geothermal potential increased rapidly with the private sector's participation in geothermal exploration, development, and investment activities. According to studies by the General Directorate of Mineral Research and Exploration, the total geothermal visible heat potential of our country has reached 40,000 MWt. Currently, approximately 15% of this power is used for heating and 4% for electricity generation, thereby contributing to our economy.²⁹¹

291 Official Website of the Ministry of Energy and Natural Resources, <https://enerji.gov.tr/bilgi-merkezi-enerji-jeotermal>

Table 38. Geothermal, Biomass and Other Generation and Consumption in Türkiye

Geothermal, Biomass and Other Generation(TWh)	2010	2023	2024
	1	19.96	20.33
Geothermal, Biomass and Other Consumption(EJ)	2010	2023	2024
	0.03	0.50	0.50

Source: Energy Institute Statistical Review of World Energy 2025²⁹²

In Table 38, while Geothermal, Biomass, and Other energy generation in Türkiye were 1 TWh in 2010, they increased 20-fold to 20.33 TWh in 2024. There was an increase in 2024 compared to 2023. In Table 38, while Geothermal, Biomass, and Other energy consumption in Türkiye was 0.03 EJ in 2010, it increased to 0.50 EJ in 2024. The values for 2024 and 2023 remained the same.

2.3.2.5. Hydrogen Energy Source in Türkiye

To contribute to ICHET's work, which was established under the leadership of UNIDO, Türkiye began activities to increase hydrogen research and development (R&D) in Istanbul in the early 2010s. Based on this, the "Bozcaada Hydrogen Island Project" was carried out in 2011 with the contributions of the Ministry of Energy and Natural Resources (ETKB). With this project, the electricity demand of the Bozcaada District Governorship building and health centre was met with hydrogen produced on October 7, 2011. However, stability in the project could not be achieved, and hydrogen production was abandoned.²⁹³

Hydrogen energy was first included in official documents on May 2, 2007, with the publication of the "Energy Efficiency Law" in the Official Gazette. On this date, the use of hydrogen and biofuel as alternative fuels was encouraged.²⁹⁴

A separate regulation for hydrogen fueled vehicles was issued in 2011. Under this regulation, revisions were made to the shape of vehicles powered by hydrogen fuel. Hydrogen energy sources were not of the necessary importance

292 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

293 UNIDO. (2011). <https://www.unido.org/news/first-hydrogen-energy-production-turkish-island-has-startedbozcaada>

294 Official Gazette, <https://www.resmigazete.gov.tr/eskiler/2007/05/20070502-2.htm>

until January 2020. Information about hydrogen was shared at the “Hydrogen Search Conference” organized by ETKB on January 15, 2020.²⁹⁵

At the conference, ETKB Minister Fatih Dönmez stated that they are considering obtaining hydrogen through 4 main benefits. These benefits include increasing the use of renewable energy sources, eliminating carbon emissions in the energy sector, producing hydrogen from domestic coal, and using hydrogen on board as a storage and holding medium. Storage technologies should be used more effectively to achieve a balance in electricity production from renewable energy sources. Minister Dönmez stated that adding 2-6% hydrogen to natural gas distribution lines is one of these methods. He said that hydrogen is intended to enter the distribution lines in Türkiye by the end of 2021, and that this will be possible by adding 1 to 3 billion cubic meters of hydrogen to the system.²⁹⁶

ETKB tasked the Türkiye Natural Gas Distributors Association (GAZBİR) with adding and integrating hydrogen into natural gas lines in 2018. GAZBİR's technical centre was opened in Konya on April 2, 2021, under the name GAZBİR-GAZMER. ETKB Minister Fatih Dönmez said that the domestic appliances powering project will be powered by natural gas and hydrogen for the first time. He stated that the project, which will be implemented through mixing, was completed at an investment cost of 6 million lira. According to laboratory results, it was burned by mixing 95-80% natural gas with 5-20% hydrogen. It has been concluded that mixing hydrogen with natural gas at a maximum rate of 20% in distribution networks is more efficient, without the need for significant revisions in consumer devices and natural gas internal installations.²⁹⁷

Türkiye is focused on green hydrogen production from renewable energy sources (solar and wind) in line with its 2053 net-zero emission targets. Pilot production has started with projects such as the South Marmara Hydrogen Coast, and a target of 2 GW by 2030 and 70 GW by 2053 is set.²⁹⁸ Türkiye

295 Official Website of the Ministry of Energy and Natural Resources, <https://enerji.gov.tr/bilgi-merkezi-enerjide-arama-etkinlikleri-ve-belgeler>

296 <http://icci.com.tr/enerji-bakanligi-hidrojen-stratejisini-ankaradaki-calistayda-acikladi>

297 GAZBİR, <https://www.gazbir.org.tr/uploads/page/Mart-Nisan-2021-Bulten.pdf>

298 <https://www.strategyand.pwc.com/tr/turkiyenin-yesil-hydrogen-yolculugu-gelecek-firsatlar-ve-zorluklar#:~:text=T%C3%BCrkiye's%20hydrogen%20C3%BCproduction%20capacity,hydrogen%20C3%BCproduction%20capacity%20staff%C4%B1%20targets.,https://tubitak.gov.tr/tr/haber/turkiyenin-ilk-hydrogen-vadisi-ve-turkiyenin-en-buyuk-kapasiteli-ilk-yerli-yesil-hydrogen-tesisi-establishing#:~:text=T%C3%BCrkiye's%20C4%B0lk%20Hydrogen%20Valley,Scientific%20and%20Technological%20Search%C5%9F%C4%B1rma%20Institution>

aims to increase green hydrogen production and reduce industry fossil fuel dependence within the scope of carbon regulations by 2026.²⁹⁹

2.3.2.6. *Wave, Tide, and Ocean Current Energy in the Türkiye*

Türkiye is a country bordered by the sea on three sides, with a coastline of 8210 km. However, not every coast has suitable conditions to obtain wave energy. 20% of all beaches in Türkiye have suitable conditions to obtain 18.5 TWh/year (approximately 2.11GW) of wave energy.³⁰⁰

The most suitable places in Türkiye to generate wave energy are the north of the Bosphorus, the Western Black Sea region, and the southwestern coasts of the Aegean Sea (between Marmaris and Finike). Türkiye's wave energy capacity is in the wave power range of 4-17 kW/m (m: wave crest length). The available resource is stated as approximately 10 TWh/year. It is 12.5% of Türkiye's hydroelectric energy potential.³⁰¹

Academic studies have been conducted on wave energy capacity. The investigations examined 15 years of numerical data of the Black Sea. The southwestern coasts of the Black Sea have been determined as the most suitable places to obtain wave energy. It has also been revealed that western regions have greater wave energy capacity than eastern regions.³⁰²

National Boron Research Institute (BOREN) and Türkiye Electromechanical Industry Inc. Wave energy applications have been carried out in our country in cooperation with (TEMSAN). Trials were conducted in the Karasu district of Sakarya on February 15, 2008, as part of the "Electricity Production from Wave Energy" project. The system, which has a power of 5 kW and is designed to be mobile, consists of 4 pontoons, buoys and a generator.³⁰³

In the announcement of the Western Black Sea Development Agency (BAKKA) dated 27.03.2017, positive developments regarding wave energy were reported following negotiations with the Australian company CSG

299 [https://www.aa.com.tr/tr/ekonomi/turkiyede-bircok-sirketin-2026ya-kadar-yesil-hydrogen-uretmesi-bekleyen/3290634#:~:text=Ye%C5%99Fil%20Hydrogen%20%C3%9Creditors%20Derne%C4%99Fi%20\(H2DER,%C5%9CCompany%20ye%C5%99Fil%20hydrogen%20%C3%BCretece%C4%99Fini%20reported.](https://www.aa.com.tr/tr/ekonomi/turkiyede-bircok-sirketin-2026ya-kadar-yesil-hydrogen-uretmesi-bekleyen/3290634#:~:text=Ye%C5%99Fil%20Hydrogen%20%C3%9Creditors%20Derne%C4%99Fi%20(H2DER,%C5%9CCompany%20ye%C5%99Fil%20hydrogen%20%C3%BCretece%C4%99Fini%20reported.)

300 Hepbasli A., Ozdamar A. and Ozalp N., Present Status and Potential of Renewable Energy Sources in Turkey, *Energy Sources*, 23, 7 (2001) PP. 631-648.

301 Sağlam M., Sulukan E. and Uyar T. S., Wave energy and technical potential of Turkey, *Journal of Naval Science and Engineering*, 6, 2 (2010) PP. 34-50

302 Akpınar A. and Kömürcü M. İ., Assessment of wave energy resource of the Black Sea based on 15-year numerical hindcast data, *Applied Energy*, 101, (2013) PP. 502-512

303 Kapluhan E., A Review in Terms of Energy Geography: Usage of Wave Energy in the World and in Turkey, *International Eurasia Journal of Social Sciences*, 5, 17 (2014) PP. 65-86

Exploration and Production Services. A pilot plant in Zonguldak has been requested. It was stated that the company agreed to install this 50 kW facility free of charge. Wave energy applications will start in the Black Sea.³⁰⁴ Zone Power; Black Sea 1.96-4.22 kWh/m, Marmara Sea 0.31-0.69 kWh/m, Aegean Sea 2.86-8.75 kWh/m, Mediterranean 2.59-8.26 kWh/m, Izmir-Antalya 3.91-12.05 kWh/m. When we look at wave power, the Black Sea region comes first, followed by the Marmara, Aegean, and Mediterranean regions.³⁰⁵

As of 2025, wave, tidal, and current energy resources in Türkiye are still in the R&D and potential assessment phase; electricity production from these sources on a commercial scale has not yet begun. Türkiye's 2025 renewable energy targets are mainly focused on increasing solar and wind capacity.³⁰⁶

2.4. Secondary Energy Source in Türkiye

The title of secondary energy source in Türkiye will be examined under the sub-heading of electrical energy source in the world.

2.4.1. Source of Electrical Energy in Türkiye

With the Electricity Market Law coming into force in 2001, the development and liberalization of the electricity market started in our country. Before 2001, market openness remained at a very limited level. Before 2001, a limited structure existed. Türkiye Electricity Authority (TEK) was established in 1970. TEK was established in 1994 as Türkiye Electricity Distribution Inc. (TEDAŞ) and Türkiye Electricity Production Transmission Inc. It is divided into two as (TEAŞ). Türkiye Electricity Production Transmission Inc. (TEAŞ) was established in 2001 as Türkiye Electricity Transmission Inc. (TEİAŞ), Electricity Production Inc. (EÜAŞ) and Türkiye Electricity Trade and Contracting Inc. (TETAŞ) was divided into three separate companies. TETAŞ was closed in 2018, with its powers and assets transferred to EÜAŞ. Publicly owned power plants are affiliated with EÜAŞ. Over the years, the public share in installed capacity has decreased from 80% to 20%. Within the scope of the Law on Privatisation Practices No. 4046, the privatisation

304 Ministry of industry and technology, <http://www.bakka.gov.tr/site/haber/951/>.

305 World Resources Institute, www.wri.org/climate

306 <https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik#:~:text=2026%20y%C4%B1l%C4%B1%20C5%9Eubat%20ay%C4%B1%20sonu%20itibar%C4%B1yla%20installed%20g%C3%BCc%C3%BCm%C3%BCz%C3%BCn%20sources%20g%C3%B6re,%20di%C4%9Fer%20sources%20C5%9,https://muhendis.web.tr/turkiyenin-dalga-enerjisi-potansiyeli-ve-kurulu-gucu/#:~:text=T%C3%BCrkiye%20k%C4%B1y%C4%B1lar%C4%B1n%C4%B1n%20be%C5%9Fte%20using%20one,%C3%A7e%C5%9Fitli%20k%C4%B1y%C4%B1s%20%C3%B6nc%C3%BC%20switchboards%20installed%C5%9F>

process for 20 distribution regions owned by TEDAŞ began with the transfer of Başkent Elektrik Dağıtım A.Ş. to Enerjisa Elektrik Dağıtım A.Ş. in 2009. The process was completed with the transfer of Toroslar Elektrik Dağıtım A.Ş. to Enerjisa Elektrik Dağıtım A.Ş. in 2013. When Türkiye's total electricity demand for the years 2000-2019 is examined, it can be said that it continued its decreasing trend in 2001, 2009 and 2019 and its increasing trend in the other years. This shows that electricity demand is directly linked to the country's gross domestic product (GDP) growth rate.³⁰⁷

Table 39. Electricity Generation in Türkiye

Electricity Generation(TWh)	2010	2023	2024
	211.2	331.1	352.9

Source:Energy Institute Statistical Review of World Energy 2025³⁰⁸

In Table 39, while electrical energy generation in Türkiye was 211.2 TWh in 2010, it increased and reached 352.9 TWh in 2024. There was a 21 TWh increase in 2024 compared to 2023.

Table 40. Türkiye Electricity: Generation by Source (TWh)

2023	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Other	Total
	0.5	69.5	119.8	-	64.0	76.2	1.3	331.1
2024	Oil	Natural Gas	Coal	Nuclear energy	Hydro electric	Renewables	Other	Total
	0.7	65.9	122.7	-	74.9	87.3	1.3	352.9

Source:Energy Institute Statistical Review of World Energy 2025³⁰⁹

Table 40 Türkiye's total electrical energy generation by fuel types increased from 331.1 TWh in 2023 to 352.9 TWh in 2024. In terms of energy sources, coal ranked first with 119.8 TWh in 2023, followed by renewable energy sources (76.2 TWh), natural gas (69.5 TWh), hydroelectricity (64 TWh),

307 TSKB Energy Sector Outlook 2020, PP.10-11<https://www.tskb.com.tr/i/assets/document/pdf/enerji-sektor-gorunumu-2020.pdf>

308 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

309 Energy Institute Statistical Review of World Energy 2025, <https://www.energyinst.org/statistical-review>

other energies (1.3 TWh), and oil (0.5 TWh). In 2024, by fuel type, coal ranked first with 122.7 TWh, followed by renewable energy sources (87.3 TWh), hydroelectricity (74.9 TWh), natural gas (65.9 TWh), other energies (1.3 TWh), and oil (0.7 TWh). Electricity production from nuclear energy has not been realized.

2.5. Status of Technological Development in the World

This section will provide information on research and development activities, patents, and scientific publications, which are considered key indicators of technological advancement worldwide.

2.5.1. R&D Activities

The Global Innovation Index, published in 2025, evaluates 139 countries based on seven main components (institutions, human resources, infrastructure, market depth, business environment depth, know-how and technological outputs, creative outputs). Each country is analyzed based on geographic region and income group. The Global Innovation Index includes seven separate geographic regions. The top three countries in each geographic region are shown in Table 41.³¹⁰

Table 41. The Top Three Most Innovative Countries in the World, by Region

Region	1st country	2nd country	3rd country
Europe	Switzerland	Sweden	United Kingdom
Southeast Asia, East Asia and Oceania	South Korea	Singapore	China
North Africa and West Asia	Israel	UAE	Türkiye
North America	USA,	Canada	-
Latin America and the Caribbean	Chile	Brazil	Mexico
Central and South Asia	India	Iran	Uzbekistan
Sub-Saharan Africa	South Africa	Botswana	Senegal

Source: Global Innovation Index 2025³¹¹. Note: Island economies are excluded.

310 Export and Innovation Report 2025, P.18, PDE:https://tim.org.tr/files/downloads/Raporlar/Inovasyon_ve_Ihracat_Raporu_2025.pdf

311 <https://www.wipo.int/web-publications/global-innovation-index-2025/assets/89507/global-innovation-index-2025-en.pdf>, Export and Innovation Report 2025, P.18, PDE:https://tim.org.tr/files/downloads/Raporlar/Inovasyon_ve_Ihracat_Raporu_2025.pdf

Table 41 lists the top three most innovative countries by region. In Europe, Switzerland ranks first, Sweden second, and the United Kingdom third. In Southeast Asia, East Asia, and Oceania, South Korea ranks first, Singapore second, and China third. In North Africa and West Asia, Israel ranks first, the UAE second, and Türkiye third. In North America, the USA ranks first and Canada second. In Latin America and the Caribbean, Chile ranks first, Brazil second, and Mexico third. In Central and South Asia, India ranks first, Iran second, and Uzbekistan third. In Sub-Saharan Africa, South Africa ranks first, Botswana second, and Senegal third.

Table 42. The Three Most Innovative Countries in the World by Income Level

Income Level	1st country	2nd country	3rd country
High	Switzerland	Sweden	USA
Medium-High	China	Malaysia	Türkiye
Medium-Low	India	Vietnam	Philippines
Low	Rwanda	Togo	Uganda

Source: Global Innovation Index 2025³¹².

Table 42 lists the three most innovative countries by income level. At the high level, Switzerland ranks first, Sweden second, and the USA third. At the medium-high level, China ranks first, Malaysia second, and Türkiye third. At the medium-low level, India ranks first, Vietnam second, and the Philippines third. At the low level, Rwanda ranks first, Togo second, and Uganda third.

Table 43. World R&D Expenditure and High-Technology Product Outlook (%)

	2010	2021	2022
Share of R&D Expenditures in World GDP (%)	2	2.6	2.7
	2010	2023	2024
Share of High-Technology Products in World Exports (%)	20.5	23	24.7

Source: World Bank³¹³

312 <https://www.wipo.int/web-publications/global-innovation-index-2025/assets/89507/global-innovation-index-2025-en.pdf>,
Export and Innovation Report 2025, P.19, PDE.https://tim.org.tr/files/downloads/Raporlar/Inovasyon_ve_Ihracat_Raporu_2025.pdf

313 World Bank, <https://databank.worldbank.org/source/world-development-indicators>

Table 43 shows that the share of World research and development expenditures in GDP increased from 2% in 2010 to 2.7% in 2022. There was also an increase in 2023. Furthermore, the share of high-technology products in World exports increased from 20.5% in 2010 to 24.7% in 2024. There was a 1.7% increase between 2023 and 2024.

2.5.2. Patent

Worldwide, patent applications increased from 1,998,300 in 2010 to 3,725,000 in 2024. This represents an increase of 150,000 applications in 2024 compared to 2023 (Table 44). Regarding patent grants, the number rose from 915,000 in 2010 to 2,111,400 in 2024. This represents an increase of over 100,000 patent grants in 2024 compared to 2023.

Table 44. Patent Applications and Patent Grants Worldwide

	2010	2023	2024
Patent Applications	1,998,300	3,552,300	3,725,000
Patent Grants Worldwide	915,000	2,006,900	2,111,400

Source: WIPO IP Facts and Figures 2025³¹⁴

Table 45 shows patent applications by region. While there were 2,680,400 applications worldwide in 2014, this number is projected to reach 3,725,000 in 2024. In terms of resident share, Asia ranked first in 2014, followed by Europe, North America, Africa, Latin America, and Oceania. In terms of share of world total, Asia ranked first in 2014, followed by North America, Europe, Latin America, Oceania, and Africa. In terms of share of world total, Asia ranked first in 2024, followed by North America, Europe, Latin America, Oceania, and Africa.

314 WIPO IP Facts and Figures 2025, <https://www.wipo.int/publications/en/details.jsp?id=4825>

Table 45. Patent Applications by Region, 2014 and 2024

Region	Number of applications		Resident share (%)		Share of world total (%)	
	2014	2024	2014	2024	2014	2024
Africa	15,000	19,100	19.3	20.4	0.6	0.5
Asia	1,607,300	2,612,500	79.7	84.6	60.0	70.1
Europe	345,900	362,700	62.1	55.8	12.9	9.7
Latin America and the Caribbean	63,500	55,600	11.8	15.3	2.4	1.5
North America	614,900	638,600	48.1	43.0	22.9	17.1
Oceania	33,800	36,500	10.7	7.7	1.3	1.0
World	2,680,400	3,725,000	67.3	72.6	100.0	100.0

Source: WIPO IP Facts and Figures 2025³¹⁵

Table 46 shows the information on patent applications at the top 20 offices worldwide in 2024. In 2024, China submitted the highest total number of patent applications. The we, Japan, Republic of Korea, EPO, India, Germany, Canada, Australia, Russian Federation, Brazil, UK, Mexico, China, Hong Kong SAR, France, Singapore, Indonesia, Türkiye, Italy, and Vietnam, followed by China. Looking at resident applications, China ranks first. The we, Japan, Republic of Korea, EPO, India, Germany, Russian Federation, France, UK, Türkiye, Italy, Brazil, Canada, Australia, Indonesia, Singapore, Vietnam, Mexico, China, and Hong Kong SAR follow China. Looking at non-resident applications, the US ranks first. China, EPO, Japan, Republic of Korea, India, Canada, Australia, Brazil, Germany, China, Hong Kong SAR, Mexico, Singapore, Vietnam, Indonesia, UK, Russian Federation, France, Italy, and Türkiye follow the US.

Table 46. Patent Applications at the Top 20 Offices, 2024

Office	Resident	Non_ Resident	Total	Non_ Resident(%)
China	1,672,001	156,053	1,828,054	8.5
US	270,069	333,125	603,194	55.2
Japan	237,169	69,686	306,855	22.7
Republic of Korea	195,786	50,459	246,245	20.5
EPO	86,395	113,007	199,402	56.7
India	63,217	41,940	105,157	39.9
Germany	40,085	19,177	59,262	32.4
Canada	4,304	31,070	35,374	87.8
Australia	2,542	27,945	30,487	91.7
Russian Federation	21,502	5,196	26,698	19.5
Brazil	5,752	19,845	25,597	77.5
UK	11,105	7,847	18,952	41.4
Mexico	1,172	15,017	16,189	92.8
China,Hong Kong SAR	495	15,445	15,940	96.9
France	12,751	1,378	14,129	9.8
Singapore	1,898	11,523	13,421	85.9
Indonesia	2,285	8,617	10,902	79
Türkiye	10,004	347	10,351	3.4
Italy	9,120	1,188	10,308	11.5
Viet Nam	1,226	8,678	9,904	87.6

Source: WIPO IP Facts and Figures 2025³¹⁶

2.5.3. Number of Scientific Publications

The EU, China, the US, India, Japan, and South Korea together produce more than 70% of the world's peer-reviewed S&E publications. As with global trends in degrees awarded and R&D spending, the output of peer-reviewed S&E publications has increased rapidly in middle-income countries, particularly China, in recent years. The rate of growth in China has been faster than in high-income countries, including EU countries and the United States. China's S&E publication output increased almost tenfold from 2000 to 2018. China's S&E publication output exceeded that of the US. In 2018, the US and the

316 WIPO IP Facts and Figures 2025, <https://www.wipo.int/publications/en/details.jsp?id=4825>

EU, among the largest producers, generated more biomedical and health sciences articles than China. However, China produced more publications in engineering product manufacturing than the United States and the EU.³¹⁷

More cited publications generally have a more significant impact on a particular scientific discipline. The relative impact of an economy's S&E research can be compared with the representation of its papers among papers around the world. The top 1% of cited articles is created by accounting for the size of each country's S&E publication pool. The US index was 1.9 in 2016. The top 1% share of cited articles is approximately twice the size of its share of total S&E articles. Between 2000 and 2016, the EU's index of highly cited articles increased from 1.0 to 1.3, while China's index more than doubled from 0.4 to 1.1, demonstrating increasing influence from both fields.³¹⁸

The United States maintains its position as the leading global producer of high-quality scientific research, demonstrating a strong research influence with highly cited publications, primarily in science and engineering. However, China's total publication output and growth have surpassed that of the United States. In 2023, four countries each produced more than 100,000 peer-reviewed articles; together, they accounted for more than 50% of the world's article output: China was the largest producer, followed by the United States, India, and Germany. China's publication output has increased rapidly since 2003 and is now more than double that of the United States. The most productive field of study for authors in China was engineering (26%); in the United States, health sciences (36%); in India, computer and information sciences (28%); and in Germany, health sciences (24%). Since 2006, authors in the United States and the EU-27 countries have continued to publish a large proportion of highly cited science and engineering articles relative to their total publication volume. During this period, the relative share of highly cited science and engineering articles published by Chinese authors has steadily increased but has remained lower than that of authors from the United States and the EU-27. The number and share of science and engineering publications co-authored by US researchers with international collaborators have increased over the past 15 years; the most frequent collaborators are Chinese researchers, but collaborations with authors located in China have decreased since 2019.³¹⁹

317 2020 National Science Board Science & Engineering Indicators, P.12, <https://nces.nsf.gov/indicators>

318 2020 National Science Board Science & Engineering Indicators, P.12, <https://nces.nsf.gov/indicators>

319 Discovery: R&D Activity and Research Publications, 2025, PDEP.6, <https://nces.nsf.gov/indicators>

In 2023, researchers in the United States contributed the highest number of articles with international co-authorship (225,565, representing 32% of all such articles). The most frequent partners for the United States were China, the United Kingdom, Canada, and Germany. Elsewhere, the percentage of worldwide science and engineering articles produced through international collaboration increased over time, rising from 19% in 2012 to 22% in 2023. Each region, country, or economy that led in publications showed an increase in its rate of international collaboration. 32% of articles by UK researchers had international co-authors in 2002 and 68% in 2023. Similarly, Germany's rate of international collaboration increased from 35% to 56% during the same period. The United States and Japan recorded significant increases in international cooperation between 2003 and 2022 (from 20% to 40% and 16% to 32% respectively), while India (from 16% to 23%) and China (from 13% to 17%) showed smaller increases. China was the only country to experience a decline in international cooperation since its peak in 2018 (22%).³²⁰

2.6. Status of Technological Development in Türkiye

Under this heading, information will be provided on research and development activities, patents, and scientific publications, which are considered fundamental technological development indicators.

2.6.1. R&D Activities

The ratio of gross domestic R&D expenditure to GDP increased from 1.39% in 2023 to 1.46% in 2024, representing an increase of 274 billion 279 million TL. This ratio rose from 0.80% in 2009 to 1.46% in 2024, a 0.7% increase compared to 2023. Financial and non-financial companies accounted for the largest share of R&D expenditures at 64.8%, followed by higher education institutions at 30.9%. General government R&D expenditures, including those by non-profit organizations, accounted for 4.3% of total R&D expenditures. Personnel expenses constituted the largest component of R&D expenditures at 59.5%. In 2024, 53.8% of R&D expenditures were financed by financial and non-financial companies, while the general government accounted for 30.4%, higher education for 12.9%, foreign sources for 2.9%, and other domestic sources for approximately 0.01%.³²¹

320 Discovery: R&D Activity and Research Publications, 2025, PDF, P.63, <https://nces.nsf.gov/indicators>

321 TURKSTAT, News Bulletin, Research and Development Activities Survey, 2024, <https://veriportali.tuik.gov.tr/press/53932>

In Türkiye, R&D activities are primarily carried out through R&D and Design centers. As of 2025, there are a total of 1,361 R&D and 343 Design Centres in Türkiye. 91,968 personnel are employed in R&D Centres, and 8,540 in Design Centres. 74,684 projects have been completed, and 16,056 are ongoing in R&D centres in Türkiye. A total of 44,893 patents have been obtained through the activities of R&D centres. On the other hand, 15,327 projects have been completed, and 2,534 are ongoing in design centres. As a result of activities carried out in design centres, 944 patents have been granted. The number of R&D centers in Türkiye increased rapidly from 15 in 2008 to 2013, peaking at 324 in 2017. However, it fell to 230 in 2018 and 154 in 2019, marking a rapid decline. From 2020 onwards, the number of newly opened R&D centers has followed a more stable trend, reaching 56 in 2021, 73 in 2023, and 75 in 2025. Looking at the distribution of R&D centers across Türkiye by province, Istanbul ranks first with 32%. Ankara follows with 12%, and Kocaeli and Bursa each with 10%. This distribution shows that R&D centers are largely concentrated in cities with high industrial and technological density. In 2024, the percentage of enterprises engaged in innovation activities reached 39.6%, indicating widespread adoption of innovation. The percentage of enterprises innovating in business processes was 36.1%, while the percentage of enterprises innovating in products was more limited at 23.6%. The percentage of enterprises engaged in ongoing innovation activities was 21.6%, while the percentage of enterprises that had abandoned innovation activities remained low at 9.3%. It is estimated that 7.8% of R&D activities are carried out within the enterprise, while 7.4% are outsourced to other enterprises or organisations; therefore, in 2024, innovation activities are predominantly shaped by non-R&D innovations and process improvements.³²²

2.6.2. Patent

The Türkiye patent institution prepared ten international research and preliminary examination reports in 2017 113. 1,710 international research and preliminary examination reports were prepared in 2020, an increase of 82% compared to the previous year. As of January 1, 2019, the Türkiye Patent Institution and TÜBİTAK conducted a study. Within the scope of the PCT, support is provided for international patent applications filed with WIPO. For this support, a preliminary examination is first made by TURKPATENT, EPO, JPO, SIPO, KIPO, and USPTO. Fee support is provided to projects deemed appropriate. In 2020, TÜBİTAK supported 1,385 international

322 Export and Innovation Report 2025, P25-28, PDFhttps://tim.org.tr/files/downloads/Raporlar/Inovasyon_ve_Ihracat_Raporu_2025.pdf

research and examination requests within the scope of the 1602 Patent Support Program. Research and examination reports have continued to be prepared since 2005. Until 2016, within the scope of protocols with the Industrial Property Offices of Austria, Russia, Denmark, and Sweden, most research/examination reports were conducted in these countries due to insufficient capacity. These agreements were terminated after 2016. 13,415 research/review reports were examined, an increase of 8,059 in 2019 and 66.5% in 2020.³²³

Table 47. Türkiye Patent Application Statistics

		2022	2023	2024
Local	Türkiye Patent	8.697	8.274	9.866
	Pct	140	155	138
	Epc	172	234	182
	Total	9.009	8.663	10.186
Foreign	Türkiye Patent	88	96	107
	Pct	194	216	240
	Epc	6.565	7.458	8.106
	Total	6.847	7.770	8.453
Grand Total		15.856	16.433	18.639

Source: Türkiye Patent 2024 Activity Report³²⁴

Table 47 shows that in 2022, a total of 15,856 patents were registered, including 9,009 domestic and 6,847 foreign patents. In 2023, domestic patent registrations decreased by 346 from the previous year, to 8,663. Foreign patent registrations increased by 923 in 2023, bringing the total to 7,770. In 2024, a total of 18,639 patent applications were filed, including 10,186 domestic and 8,453 foreign patents. The number of domestic patent applications increased by 17% compared to 2023, rising from 8,663 to 10,186. The number of foreign patent applications also increased from 16,433 to 18,639.

323 Turkish Patent 2020 Activity Report, PDF, PP. 23-24. <https://www.turkpatent.gov.tr/faaliyet-raporlari-yillik>

324 Turkish Patent 2024 Activity Report, PDF, PP. 25, <https://www.turkpatent.gov.tr/faaliyet-raporlari-yillik>

Table 48. Türkiye Patent Registration Statistics

		2022	2023	2024
Local	Türkiye Patent	3.165	2.229	3.120
	Pct	66	70	96
	Epc	176	237	114
	Total	3.407	2.536	3.390
Foreign	Türkiye Patent	60	55	59
	Pct	158	92	122
	Epc	6.710	7.251	7.941
	Total	6.928	7.398	8.122
Grand Total		10.335	9.934	11.512

*Source: Türkiye Patent 2024 Activity Report*³²⁵

Table 48 shows that in 2022, a total of 10,335 patents were registered, including 3,407 domestic and 6,928 foreign patents. In 2023, domestic patent registrations decreased to 2,536. Foreign patent registrations increased to 7,398 in 2023. In 2024, a total of 11,512 patents were registered, including 3,390 domestic and 8,122 foreign patents.

Table 49. Türkiye Research and Review Performance

	2022	2023	2024
Number of Applications (TURKPATENT+PCT)	14.667	12.141	13.469
Number of Requests Received for the Preparation of a National Research and Investigation Report	16.276	13.146	16.010
Number of National Research and Review Reports Compiled	19.496	19.379	20.330
Number of International Research Reports Conducted within the Scope of PCT	1.464	1.826	1.843
Number of International Research Reports Conducted within the Scope of PCT	55	34	33

*Source: Türkiye Patent 2024 Activity Report*³²⁶

325 Turkish Patent 2024 Activity Report, PDF, PP. 25, <https://www.turkpatent.gov.tr/faaliyet-raporlari-yillik>

326 Turkish Patent 2024 Activity Report, PDF, PP. 25, <https://www.turkpatent.gov.tr/faaliyet-raporlari-yillik>

Table 49 shows that the Number of Applications (TURKPATENT+PCT) decreased from 14,667 in 2022 to 13,469 in 2024. The Number of Requests Received for the Preparation of a National Research and Investigation Report increased in 2024 compared to 2023. The Number of National Research and Review Reports compiled increased from 19,496 in 2022 to 20,330 in 2024. The Number of International Research Reports Conducted within the Scope of PCT continued to increase from 2022 to 2024. The Number of International Research Reports Conducted within the Scope of PCT decreased during the 2022-2024 period.

2.6.3. Number of Scientific Publications

The number of articles published by academics in Türkiye in SCI/SSCI/AHCI journals was discussed in the topic of scientific publications. Following an upward trend from 1996 to 2004, the increase in the number of articles published in SCI/SSCI/AHCI journals accelerated from 2000 onwards, and the proportion of indexed publications increased from 65% to 75%. After 2005, it decreased following a fluctuating trend. This situation is also seen in publications that have been corrected for quality. The share of SCI/SSCI/AHCI publications declined sharply in 2010. However, it caught the increasing trend in 2012. It reached the same level as in 2005. With the increase in the number of universities and researchers in higher education in Türkiye after 2000, scientific publications also increased. When looking at the scientific publication situation, it would be more appropriate to examine the growth in publications per researcher. This indicator was significantly increased after 2000. The number of publications per capita in SCI/SSCI/AHCI journals reached its highest level in 2007. The decrease in 2010 started to increase again in 2013. Other journal publications have decreased in 2012 and increased since 2015. The number of publications per capita shows that productivity gains have been achieved. In line with the regulations on associate professorship criteria, the number of SCI/SSCI/AHCI-indexed publications per person among new researchers has increased since 2001. It decreased in 2010 and expanded in 2013. While these indices showed an increase, other publications reported a decrease until 2010. Other publications began trending upward after 2015.³²⁷

According to 2024 data, each of Türkiye's 201 universities has at least one TR Index publication per faculty member. The average number of publications per faculty member at these universities is 0.35. This ratio reflects the national

327 Türkiye Science Report ,2020 ,PDE PP, 67-68. <https://www.tuba.gov.tr/files/yayinlar/raporlar/Tu%CC%88rkiye%20Bilim%20Raporu.pdf>

academic production capacity of higher education institutions and serves as an important indicator of the level of development of the research culture. Looking at the total number of publications, it is seen that state universities produced 33,417 TR Index publications, while foundation universities produced 4,115. In 2024, 200 universities had journal and book publications indexed in the Web of Science database. The average number of publications per faculty member at these universities was 0.85. 43 universities produced more than one publication per faculty member. Examining the distribution of Web of Science-indexed publications between public and private universities, it is evident that public universities produced 79,956 publications, while private universities produced 16,196. In 2024, 176 universities had at least one publication in journals and books indexed in the Web of Science database, with their institutional addresses listed, through national and international collaborations. The average national collaboration rate at these universities was calculated as 50.66%; the average international collaboration rate was 29.64%.³²⁸

328 University Monitoring And Evaluation General Report – 2025, PDF, PP. 85-91, <https://veriyonetim.yok.gov.tr/documentFiles/1768898650895.2025-universite-izleme-ve-degerlendirme-genel-raporu.pdf>

Econometric Analysis of the Relationship Between Energy and Technological Development

This section presents an empirical analysis of the study, using econometrics to examine the relationship between energy and technological development in Türkiye. Annual data from the period [1996-2022] were used for the analysis. The Granger (1969) causality analysis method was employed. First, previous studies in the literature will be discussed, followed by a mention of the data set and method used in the econometric analysis. The methodology and findings will then be presented. Finally, the study will conclude with conclusions and recommendations. The aim of this study is to investigate the relationship between technological development and energy. For this purpose, the study examines the relationship between technological development and energy in Türkiye over the period 1996-2022. First, the stationarity of the series was investigated using the ADF and PP unit root tests. Dickey-Fuller (1979) and Phillips-Perron (1998) tests were used for this examination. Then, the lag length was determined. Finally, the Granger (1969) causality analysis method was used.

A review of the literature reveals that there are very few studies examining the relationship between technological development and energy in Türkiye. This situation constituted the main motivation for the study. Furthermore, the study aimed to contribute to the literature due to the analytical techniques used, the current data, and the topicality of the subject. In this respect, it differs from other studies in the literature. The goal is to present policy recommendations based on the results.

3.1. Literature Review

Energy, being a variable in the production function, is closely related to growth. Therefore, when an energy policy is implemented, its effects on economic growth are examined. The link between energy consumption and economic growth is of great importance for development and progress. Therefore, a literature review reveals numerous studies on the relationship between energy consumption and economic growth. These studies have found positive relationships between energy consumption and economic growth. Generally, variables such as energy consumption, production, renewable energy consumption and production, real gross domestic product or real gross domestic product per capita, energy dependence, capital, labour, and carbon dioxide emissions are used. This study examines the relationship between energy and technological development. Technological development is defined as R&D expenditures and patent applications. For energy, renewable energy production is used. In studies on renewable energy production, variables such as CO₂ emissions, per capita income, foreign trade, prices of substitute products such as natural gas and oil, and regulatory and institutional factors are used as determinants.

Due to the depletion of non-renewable energy sources and increasing environmental awareness, renewable energy sources have become the subject of numerous studies. The impact of technological advancements on the development of renewable energy sources has attracted the attention of researchers. Therefore, studies in this field have shown an increasing trend recently. This section summarises studies and their results that analyse the relationships between these two variables and other variables using econometric methods.

Johnstone et al. (2010), in a study of 25 selected OECD countries, investigated the impact of renewable energy policies on innovation during 1979-2003 using panel data analysis. A positive contribution of public policies to patent applications used in renewable energy production was identified. Furthermore, it was concluded that different policy tools are needed for different renewable energy sources.

Gan and Smith (2011) conducted a Panel LCM analysis across 26 OECD countries for the 1994-2003 period. He examined the effects of bioenergy market deployment policies and renewable energy on economic growth in his analysis. Economic growth has been found to affect per capita renewable energy and bioenergy supply positively.

Popp et al. (2011) used Panel Data Analysis to analyze 26 OECD member countries from 1991-2004. They concluded that technological progress led to increased investment, but its impact was small.

Marques and Fuinhas (2012) conducted Panel Fixed Effects (FE), Panel Random Effects (RE), and Panel Corrected Standard Errors (PCSE) analyses across 23 European Union countries for the 1990-2007 period. In his study, he found that per capita CO₂ emissions, import dependency in energy, the share of coal in electricity production, the share of oil in electricity production, the share of natural gas in electricity production, the share of nuclear energy in electricity production are the factors that reduce the total energy supply. It has been concluded that energy per capita, policy processes and R&D expenditures are the factors that increase energy supply.

According to Erdal (2012), renewable energy and energy efficiency technologies have positive effects on employment. Activities to reduce carbon emissions in Türkiye will increase investments in the renewable energy sector and boost employment in sectors such as construction, energy, and agriculture.

Teke (2013) examined renewable energy and R&D investments worldwide, compared Türkiye's current situation with other countries, and proposed solutions.

Aguirre and Ibikunle (2014) conducted a Panel Fixed Effects (FE) Panel Adjusted Standard Errors (PCSE) analysis across 38 countries (OECD, European Union, and BRICS member countries) for the period 1990-2010. In his study, CO₂ emissions, the Kyoto Protocol, continuous commitment to renewable energy, estimated biomass amounts, and solar potential positively contributed to the energy supply. Energy use, including electricity production from coal, oil, natural gas, and nuclear energy, has negative effects.

Aflaki et al. (2014) used Panel Data Analysis to analyze 15 European Union countries from 1990-2012. They found that public R&D investments, policies supporting renewable energy, and per capita income positively affected renewable energy deployment, whereas policy support variability negatively affected it.

In their theoretical study, Benson and Magee (2014) explain that, while this study on inventions does not establish a causal relationship for the different rates, it provides a broader theoretical basis for why these rates show such large differences and why they may remain stable over time.

Kim and Kim (2015) focused on the importance of R&D activities in renewable energy policies and international trade. An unbalanced panel analysis was conducted using data from 16 solar energy producing countries and 14

wind energy producing countries from 1991-2008. In addition to the positive contribution of concentrated R&D activities to foreign trade, the result that export rates increase with R&D activities, especially in wind energy, has come to the fore.

Irandoost (2016) examined Norway, Sweden, Finland, and Denmark from 1975 to 2012. They used a Vector Autoregression (VAR) model and the Toda and Yamamoto Causality Tests. The results also show that, across the four Scandinavian countries, the causal relationships from growth to renewable energy and from technological innovation to renewable energy are unidirectional. However, no evidence was found to confirm a causal relationship between renewable energy and growth.

Geng and Ji (2016) conducted panel cointegration and panel causality analyses within the scope of 6 developed countries (USA, France, Germany, Italy, Canada, Japan) from 1980-2010. In his analysis, he revealed the long-term positive effects of technological innovation on renewable energy development. In the short term, no effect was found.

Mert and Çağlar (2016) analyzed the impact of financial development on renewable energy production in Türkiye during the period 1970-2011. The Hatemi-J method was used in the analysis. In the study, no causal relationship was found between financial development and renewable energy sources. However, a causality was found from negative shocks in financial development to negative shocks in renewable energy sources.

Jin et al. (2018) examined the relationship between technological innovation and energy consumption in China for the period 1995-2012. In the study, which was estimated using a dynamic panel data model, it was found that technological innovation leads to an increase in energy consumption in the short term, and that energy consumption does not have a significant effect on technological innovation.

Przychodzen and Przychodzen (2020) applied Panel Least Squares (EKM) analysis on 27 Post-Socialist transitions from 1990 to 2014. In his study, he stated that economic growth rate, unemployment, government debt, total CO₂ emissions and the Kyoto Protocol are the factors that increase the share of renewable energy sources in electricity production. The competition policy score stated that total natural resource rents, coal rents and CO₂ emissions per capita were the reducing factors.

Bamati and Raoofi (2020) used Panel Generalised Least Squares (GEKK) analysis, considering 25 developed and developing countries over the period 1990-2015. In his study, he concluded that per capita income and oil prices are

factors that increase renewable energy production in developed and developing countries.

Hille et al. (2020) analysed the impact of various support policies implemented across 194 countries on renewable energy technologies, specifically solar and wind. Using data from 1990-2016, the study concluded that support policies and public R&D programs in the renewable energy field increased patent activity and, consequently, the patent acquisition rate.

Li et al. (2020) investigated the determinants of renewable energy consumption in OECD countries between 1990 and 2017. In the study, which used panel cointegration analysis to identify the determinants of renewable energy consumption, it was found that income, human capital, energy efficiency, energy prices, and eco-innovation are important factors in explaining renewable energy consumption.

Alam and Murad (2020) used Autoregressive Distributed Lag Model (ARDL), Pooled Mean Group (PMG), Dynamic Fixed Effects (DFE) and Mean Group (MG), Dynamic Ordinary Least Squares (DOLS), and Fully Modified Ordinary Least Squares (FMOLS) techniques for panel data analysis of 25 OECD countries from 1970-2012. The results show that technological progress, trade openness, and economic growth significantly influence the long-term use of renewable energy in OECD countries.

Yılmaz (2021) tested the asymmetric interaction between financial development, economic growth, and energy consumption in G7 countries during the period 1980-2018 using the Hatemi-J test. A causal relationship was found between financial development and renewable energy consumption, and between renewable energy consumption and financial development. A causal relationship from renewable energy consumption to growth was found, and growth was determined to be a Granger cause of renewable energy consumption.

Kılınç and Kılınç (2021) conducted an analysis using the Panel ARDL and the Emirmahmutoğlu and Köse (2011) causality test method in selected countries within the 2003-2019 period. In his study, he concluded that R&D and demonstration expenditures, as well as increases in the number of patent applications, will increase renewable energy production. He found a causal relationship between R&D expenditures and patent applications to renewable energy production.

Zheng et al. (2021) analysed the impact of technological innovation on renewable energy production in a study covering 30 provinces in China between 2005-2017. In the study, in which spatial and non-spatial econometric

models were preferred, it was concluded that increases in renewable energy technological innovation lead to higher renewable energy production.

Dinh et al. (2021) used the Driscoll–Kraay Nonparametric Covariance Matrix Estimator and the Fixed Effects Regression Model for 9 Southeast Asian countries from 1994–2015. They concluded that there is a U-shaped relationship between medium and high-technology exports and renewable energy consumption, meaning a pattern that initially decreases and then increases.

Khezri et al. (2021) used the Spatial Durbin Model for the period 2000–2018 across 31 Asia-Pacific Countries. The development of R&D reduces the effects of market expansion on hydroelectric energy production; however, these effects are increasingly driving momentum toward bioenergy, geothermal, solar, and wind energy sources.

Khan et al. (2022) used the Granger Causality Test and VAR Model for the period 2000–2021, focusing on Germany. The analysis's findings imply that progress in renewable energy is associated with increased spending on technological innovation.

Avşar (2023) used the Vector Error Correction Model for the period 1980–2022, focusing on Türkiye. The results of their research showed a significant positive relationship between technological development and renewable energy in the long term, and a bidirectional causal relationship between renewable energy production and economic growth in the short term.

Ülger et al. (2024) investigate causal relationships across 15 countries from 1990 to 2019, primarily in two groups. The Dumitrescu and Hurlin panel causality test was used as the method. According to the findings of the analysis, a bidirectional causal relationship exists between urbanization and economic growth, technological innovation and economic growth, urbanization and ecological footprint, and technological innovation and ecological footprint; while a unidirectional causal relationship exists from renewable energy consumption to economic growth, from economic growth to ecological footprint, and from ecological footprint to renewable energy consumption. Based on these results, policy recommendations are presented for policymakers.

Güven et al. (2025) examined the effects of technological advancements, renewable energy consumption, and economic growth on ecological footprint in E7 countries using panel data analysis, providing policymakers with evidence-based conclusions on environmental sustainability. The analysis used a panel dataset covering the period 1990–2024, comprising data from E7 countries.

The findings suggest that balancing economic growth with environmental sustainability is possible through strategies based on technological innovation and renewable energy transition.

Bekereci et al. (2026) analyse the relationships between natural resource use, renewable energy consumption, financial development, information and communication technologies, foreign direct investment, and GDP per capita for G7 countries during the period 1981–2022, evaluating the ecological footprint as a sustainable environmental performance indicator. In this study, the long-term equilibrium relationship was confirmed using panel cointegration tests, and then long-term effects were examined using the CCE-MG estimator. The empirical findings support the Environmental Kuznets Curve (EKC) hypothesis, showing that economic growth initially increases environmental degradation, but the environment improves as income levels rise. Renewable energy and information and communication technologies (ICT) mitigate environmental impacts; natural resource use and financial development increase environmental pressure, while foreign direct investment has no significant effect.

Aflaki et al. (2014), Bamati and Raoofi (2020) focusing on developed countries, as well as studies by Alam and Murad (2020), Doğan and Özarslan Doğan (2021), Kılınç and Kılınç (2021), and Aşar (2023) found a significant positive relationship between renewable energy production and technological development. However, studies by Gan and Smith (2011) and Bamati and Raoofi (2020) focusing on developing countries did not find a significant relationship between technological development and renewable energy production. Geng and Ji (2016) found a bidirectional causal relationship between renewable energy consumption and technological development. Irandoust (2016) and Kılınç and Kılınç (2021) identified a unidirectional causal relationship from technological development to renewable energy production.

This study differs from others in that it examines the most recent time period related to the group of countries under consideration. In this respect, the policy implications are made using current data. Furthermore, the limited number of studies on this topic specifically in Türkiye is another feature that distinguishes it from other research in the literature. With these features, it aims to contribute to the literature. This study aims to contribute to the literature by demonstrating how R&D expenditures and patent applications in Türkiye reduce costs in renewable energy production and positively impact energy efficiency through technological advancements.

3.2. Data Set and Model

This study examines the relationship between technological development and energy in Türkiye during the period 1996-2022 using Granger Causality Test methods developed by Granger (1969). The selection of this time period was influenced by the scarcity of data. Therefore, the most up-to-date dataset available was used. Research and development expenditures (%GDP) and patent applications are used as variables for technological development. Renewable energy production (TWh) is used as the energy variable in the model. Furthermore, the model's variables were developed by reviewing the literature. Accordingly, the dependent variable is renewable energy production (LNYN, TWh), and the explanatory variables are R&D expenditures (LNAG, %GDP), patent applications (LNPT, resident), economic growth (LNGDP, constant 2015 USD), trade openness (LNTR, %GDP), and medium and high technology exports (LNTC, % manufacturing exports), with ε_t representing the error term. The renewable energy production variable is taken from the Institute of Energy's 2025 World Energy Statistics Review. R&D expenditures, economic growth, trade openness, and medium- and high-technology exports were obtained from the World Bank Development Indicators database. Patent applications were obtained from the World Bank Development Indicators database and the Türkiye Patent 2024 Activity Report. The logarithms of all variables used in the model were calculated and included in the model. The model created for this study is shown below.

$$LNYN_t = \beta_0 + \beta_1 LNPT_t + \beta_2 LNAG_t + \beta_3 LNGDP_t + \beta_4 LNTR_t + \beta_5 LNTC_t + \varepsilon_t \quad (1)$$

This model was established by examining the works of Alıcı and Işık (2024), Avşar (2023), Zheng et al. (2021), Kılınç and Kılınç (2021), Khezri et al. (2021), Dinh et al. (2021) in the literature.

According to the descriptive statistics in Table 50, the low standard deviations of the variables LNYN, LNPT, LNAG, LNGDP, LNTR, and LNTC indicate that the data are clustered in a narrow range around their means. LNGDP has the highest maximum value, while LNAG has the lowest maximum value. LNGDP attains the lowest minimum value, while LNAG attains the highest minimum value. Furthermore, according to the Jarque-Bera test, the series are found to have a normal distribution.

Table 50: Descriptive Statistics

	LNYN	LNPT	LNAG	LNGDP	LNTR	LNTC
Mean	4.015	7.459	-0.358	9.070	3.927	3.393
Median	3.835	7.845	-0.231	9.044	3.891	3.397
Maximum	4.926	9.105	0.337	9.566	4.380	3.603
Minimum	3.192	5.241	-1.016	8.680	3.628	3.220
Jarque-Bera	2.097	2.863	1.861	2.039	2.282	0.165
Probability	0.350	0.238	0.394	0.360	0.319	0.920
Std. Dev.	0.501	1.382	0.413	0.287	0.169	0.099
Observation	27	27	27	27	27	27

3.3. Econometric Method

First, this section provides methodological information regarding the econometric method used. In the later stages of the study, the stationarity of the series was determined using ADF and PP unit root tests. Following the unit root tests, the lag length was determined. Then, as a second step, since the series were stationary in their first differences, Granger (1969) causality test was used.

In 1981, Augmented Dickey-Fuller (ADF) added the lagged values in the dependent variable in the unit root test to the model as independent variables in order to eliminate the autocorrelation problem in the error term.³²⁹

As the first step of the Extended Dickey-Fuller method in the unit root test investigation for stationarity, a generalisation is made, as shown in equation (2), for a p-th order autoregressive process.

$$Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \Phi_3 Y_{t-3} + \dots + \Phi_p Y_{t-p} + \varepsilon_t \quad (2)$$

Since the error term will be serially correlated for a first-order autoregressive process model shown in equation (2), to eliminate this problem, lagged values of the variable are added to the model, or the values taken by the error term are added to reach equation (3). As seen here, the difference operation has been applied. Δ This expression represents the difference operator. δ_i the term also in difference operation Φ' It provides the general functions of these.

$$\Delta Y_t = \delta Y_{t-1} + \delta_1 \Delta Y_{t-1} + \delta_2 \Delta Y_{t-2} + \dots + \delta_p \Delta Y_{t-p} + \varepsilon_t \quad (3)$$

329 Küçükaksoy, İ., Çiftçi, İ. And Özbek, R.İ. (2015). Export-Oriented Growth Hypothesis: Application İn Turkey. Çankırı Karatekin University Journal Of Faculty Of Economics And Administrative Sciences, 5(2), 691-720.P, 701.

After the difference operation, the Augmented Dickey-Fuller (ADF) equations for stationarity are obtained. The resulting equations (4), (5) and (6) are shown below,³³⁰

$$\Delta Y_t = \delta Y_{t-1} + \sum_{j=1}^P \delta_j \Delta Y_{t-j} + \varepsilon_t \quad (4)$$

$$\Delta Y_t = \mu + \delta Y_{t-1} + \sum_{j=1}^P \delta_j \Delta Y_{t-j} + \varepsilon_t \quad (5)$$

$$\Delta Y_t = \mu + \beta t + \delta Y_{t-1} + \sum_{j=1}^P \delta_j \Delta Y_{t-j} + \varepsilon_t \quad (6)$$

Included in the equations ΔY The term stationarity of the variable being investigated provides the difference of that variable. Furthermore, μ constant term, βt shows the trend. P gives the delay length. ε_t This represents the error term. According to the hypotheses shown below, if H_0 is rejected, the alternative hypothesis will be accepted, and the series will be found to be stationary by the stationarity test. The Augmented Dickey-Fuller test is used for δ -estimation of the parameter δ and ε_t . It is based on statistics.

The hypotheses used for the equations are given below.

H_0 : $\delta = 0$ (Time series are not stationary.)

H_1 : $\delta < 0$ (The time series is stationary.)

In the hypotheses, the null hypothesis H_0 states that the time series is not stationary, while the alternative hypothesis H_1 states that it is stationary.³³¹

The unit root test developed for the Phillips-Perron test is nonparametric. In this test, modifications have been made to the ADF test regarding the distributions of random shocks, and a correction factor has been added. First, the variance of the error term is calculated. Then, a consistent estimator of the long-term variance factor is calculated. Furthermore, the t-statistic in

330 Sevüktekin, Mustafa; Narlangoçler, Mehmet (2010). *Econometric Time Series Analysis with Views Applications*. Ankara: Nobel Publishing and Distribution.P.323

331 Ekinci Aykut (2011). *The Impact of Foreign Direct Investments on Economic Growth and Employment: The Case of Türkiye (1980-2010)*. Eskişehir Osmangazi University Journal of Faculty of Economics and Administrative Sciences, 6(2), 71-96. P.79, Güvenek, Burcu; Alptekin, Volkan; Çetinkaya, Murat (2010). *Analysis of the Relationship Between Inflation and Income from Indirect Taxes Using the VAR Method*. Kamu-İş, 11(3), 1-28.P.7, Özsoy, Ceyda (2007). *The Place and Importance of Vocational and Technical Education in Economic Development in Turkey*, Unpublished Doctoral Thesis, Anadolu University, Institute of Social Sciences, 2007, Eskişehir.PP.158-159

the Phillips-Perron test has been transformed to ensure that the asymptotic distribution of the test statistic is not affected by the serial correlation coefficients. The extended ADF models used in the Phillips-Perron test are listed below:

$$\Delta Y_t = \alpha + \beta_1 + \theta D(T_B)_t + \delta DU_t + (\rho - 1)Y_{t-1} + \sum_{i=1}^k \rho_i \Delta Y_{t-i} + \varepsilon_t \quad (7)$$

$$\Delta Y_t = \alpha + \beta_1 + \delta DU_t + \gamma DT_t + (\rho - 1)Y_{t-1} + \sum_{i=1}^k \rho_i \Delta Y_{t-i} + \varepsilon_t \quad (8)$$

$$\Delta Y_t = \alpha + \beta_1 + \theta D(T_B)_t + \delta DU_t + \gamma DT_t + (\rho - 1)Y_{t-1} + \sum_{i=1}^k \rho_i \Delta Y_{t-i} + \varepsilon_t \quad (9)$$

In the Phillips-Perron stationarity test, the $\alpha I = 1$ statistic for the presence of a unit root is compared with Peron's critical value t . Here $\text{tai}(\gamma) < \text{Ka}(\gamma)$ When this occurs, the null hypothesis is rejected and the alternative hypothesis is accepted. Accepting the alternative hypothesis implies that the time series used does not contain a unit root, or in other words, it is assumed to be stationary. The null hypothesis is that a unit root exists. The alternative hypothesis is that a unit root does not exist.³³²

The Granger Causality Test, developed by Granger (1969), is one of the most widely used methods for analyzing causal relationships between two or more variables. According to this approach, if the predictive error of variable Y decreases not only with its lagged values but also with the past values of variable X , then X is considered a Granger cause of Y . However, for the test to yield reliable results, the series used must be stationary. Analyses with non-stationary series can lead to spurious causal relationships that do not actually exist. Taking the first or second differences to make the series stationary often results in a partial loss of information in the series³³³.

The Granger causality test is one of the most frequently used methods in the literature due to its relatively simple applicability.³³⁴ The test model is as follows:

332 Ümit, A. Öznur, (2007). Time Series Analysis of the Relationship Between Budget Deficit and Current Account in Turkey. PhD Thesis, Anadolu University Institute of Social Sciences, Eskişehir.P.166, Sevıtktekin, Mustafa; Çınar, Mehmet (2014). Econometric Time Series Analysis with Eviews Applications. Bursa: Dora Publishing House.PP. 378-380

333 Takım, A. (2010). The relationship between GDP and exports in Turkey: Granger causality test. Atatürk University Journal of Social Sciences Institute, 14(2), 315-330. P6

334 Öner, H. (2018). Examining the Relationship Between Consumer and Producer Price Indices Through Granger Causality Test. Journal of Finance, Economics and Social Research, 3(1), 318-327.P.322

$$y_{1t} = \alpha_{10} + \beta_{11}y_{1t-1} + \beta_{12}y_{2t-1} + y_{11}y_{1t-2} + y_{12}y_{2t-2} + \delta_{11}y_{1t-3} + \delta_{12}y_{2t-3} + u_{1t} \quad (10)$$

$$y_{2t} = \alpha_{20} + \beta_{21}y_{1t-1} + \beta_{22}y_{2t-1} + y_{21}y_{1t-2} + y_{22}y_{2t-2} + \delta_{21}y_{1t-3} + \delta_{22}y_{2t-3} + u_{2t} \quad (11)$$

The Granger causality test is performed by examining whether the coefficients of the lagged values of the independent variables in the model are collectively equal to zero. If the coefficients in the first equation are different from zero at a certain significance level, it is concluded that variable X is a Granger cause of variable Y. Similarly, if the coefficients in the second equation are significantly different from zero, it is accepted that Y is a Granger cause of X. In this study, instead of variables X and Y, the variables under study were used, and the possible Granger causality relationship between them was analysed.³³⁵

3.4. Econometric Application Results

In subsequent stages of presenting the econometric methodology of the study, the stationarity of the series was determined using ADF and PP unit root tests. Following the unit root tests, the lag length was determined. Then, as a second step, since the series were stationary in their first differences, Granger (1969) causality test was used.

Table 51: Unit Root Test Results

Variables		ADF	PP
		Constant	Constant
LNYN	I(0)	-0.172 (0.930)	0.009 (0.951)
	I(1)	-5.804 (0.000)***	-5.806 (0.000)***
LNPT	I(0)	-1.543 (0.496)	-1.464 (0.535)
	I(1)	-4.319 (0.002)***	-4.356 (0.002)***
LNAG	I(0)	-0.149 (0.931)	-0.382 (0.898)
	I(1)	-5.523 (0.000)***	-7.036 (0.0000)***

335 Öner, H. (2018). Examining the Relationship Between Consumer and Producer Price Indices Through Granger Causality Test. *Journal of Finance, Economics and Social Research*, 3(1), 318-327.P.322

LNGDP	I(0)	0.404 (0.979)	0.400 (0.979)
	I(1)	-4.685 (0.001)***	-4.510 (0.001)***
LNTR	I(0)	0.621 (0.987)	1.774 (0.999)
	I(1)	-4.589 (0.000)***	-4.834 (0.000)***
LNTC	I(0)	-1.245 (0.638)	-0.935 (0.760)
	I(1)	-4.755 (0.000)***	-7.833 (0.0000)***

***: 0.01%.Indicates that the null hypothesis is rejected at a significance level of. Note: critical values ;1% level: -3.711, 5% level: -2.981, 10% level: -2.629

According to the ADF unit root test results in Table 51, in the constant model, LNYN, LNPT, LNAG, LNGDP, LNTR, and LNTC have unit roots in I(0) and become stationary in I (1) at the 1% significance level after taking their first differences. Looking at the Phillips and Perron test results, the same results as the Enhanced Dickey-Fuller test results were obtained. Accordingly, in the constant model, LNYN, LNPT, LNAG, LNGDP, LNTR, and LNTC have unit roots in I(0) and become stationary in I (1) at the 1% significance level after taking their first differences. Following the unit root tests, the lag length was determined.

Table 52. Appropriate Delay Length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	89.006	NA	6.80e-11	-6.385130	-6.094800	-6.301526
1	204.653	169.0218*	1.61513*	-12.51179*	-10.47948*	-11.92655*

According to Table 52, the model's lag count is 1 according to the AIC (Akaike Information Criterion), FPE (Final Prediction Error), LR (Sequential Modified LR Test Statistic), SC (Schwarz Information Criterion), and HQ (Hannan-Quinn Information Criterion) criteria.

After determining the appropriate lag length and performing unit root tests, the econometric analysis was completed with Granger (1969) causality test. Since stationarity is required for this test, first-differences were used.

Table 53. Causality Test Result

Null Hypothesis:	F-Statistic	Prob.
Δ LNPT- Δ LNYN	6.177	0.000***
Δ LNYN - Δ LNPT	1.733	0.200
Δ LNAG - Δ LNYN	13.833	0.001***
Δ LNYN - Δ LNAG	0.883	0.357
Δ LNAGDP - Δ LNYN	5.554	0.007***
Δ LNYN - Δ LNAGDP	1.371	0.253
Δ LNTR - Δ LNYN	8.270	0.008***
Δ LNYN - Δ LNTR	3.533	0.002***
Δ LNTRC - Δ LNYN	0.998	0.008***
Δ LNYN - Δ LNTRC	2.444	0.131

*Not: “-” does not Granger Cause represents. “ Δ ” the data is represented as difference series. The lag length is chosen as 1. ***: 0.01%. Indicates that the null hypothesis is rejected at a significance level of*

According to the results in Table 53, the null hypothesis that there is no Granger causality from patent applications to renewable energy production is rejected at the 1% significance level, thus accepting the existence of causality. Similarly, the null hypothesis that there is no Granger causality from research and development expenditures to renewable energy production is rejected at the 1% significance level, thus accepting the existence of causality. The null hypothesis that there is no Granger causality from economic growth to renewable energy production is rejected at the 1% significance level, thus accepting the existence of causality. The null hypothesis that there is no Granger causality from trade openness to renewable energy production is rejected at the 1% significance level, thus accepting the existence of causality. The null hypothesis that there is no Granger causality from renewable energy production to trade openness is rejected at the 1% significance level, thus accepting the existence of causality. It is concluded that there is a bidirectional causal relationship between the two variables. The null hypothesis that there is no Granger causality from medium and high-technology exports to renewable energy production is rejected at the 1% significance level, thus accepting the existence of causality. These results are seen to support the studies conducted in the literature by Irandoust (2016), Kılınç and Kılınç (2021), Aflaki et al. (2014), Bamati and Raoofi (2020) on the basis of developed countries, as well as the results of Alam and Murad (2020), Doğan and Özarslan Doğan (2021), Kılınç and Kılınç (2021), and Avşar (2023). These results also differ from those found by Gan and Smith (2011) and Bamati and Raoofi (2020).

Conclusion

Humanity's destruction of the environment has continued to increase since the Industrial Revolution. One of the most important elements of this destruction is greenhouse gas emissions. When greenhouse gases increase, it causes air pollution and depletion of the ozone layer. Thus, threats such as global warming arise. Fuels such as oil and coal, which are among the fossil fuels, are the most important factor in greenhouse gas emissions. Turning to renewable energy sources is among the most important policies that can reduce greenhouse gas emissions. Renewable energy sources such as wind and solar have become the focus of countries because they do not run out and do not emit greenhouse gases into nature. Renewable energy production is rapidly expanding, particularly as global environmental awareness grows. Generating energy while reducing carbon dioxide emissions plays an effective role in combating climate change by decreasing greenhouse gas emissions. The use of these resources is also rapidly increasing, driven by countries' desire to reduce their dependence on external sources for energy and thus ensure energy security. It plays a key role in meeting energy needs, especially for countries that lack fossil fuel resources. Technological advancements are driving increased use of these resources, lower installation costs, and improved energy production efficiency. This relationship is also significant from an economic perspective, as energy is one of the driving factors of economic development.

This book interprets and evaluates the theoretical and conceptual framework on the subject with the support of current literature. This book consists of three parts. In the first chapter, the conceptual and theoretical framework of energy and technology is explained. The second section provides an overview of energy and technological development worldwide and in Türkiye. In the third section, econometric analysis of the relationship between energy and technological development was made. In the third chapter, previous studies in the literature were first reviewed, and then information was given about the data set and method used in econometric analysis. The methodology

and findings are then presented. Finally, the study ends with conclusions and recommendations. The econometric application in the third chapter examines the relationship between technological development and energy in Türkiye, taking into account the period 1996-2022. First of all, Dickey-Fuller (1979) and Phillips-Perron (1998) unit root tests were used to examine the stationarity of the series. The delay length was then determined. Finally, Granger (1969) causality analysis method was used. When the literature is examined, it is seen that there are very few studies examining the relationship between technological development and energy in Türkiye. This situation formed the main motivation of this study. In addition, it is aimed to contribute to the literature due to the analytical techniques used, the use of current data and the topicality of the subject. In this respect, it differs from other studies in the literature. The aim is to provide policy recommendations based on the results.

When the literature is examined, in addition to the studies focusing on developed countries by Aflaki et al. (2014), Bamati and Raofi (2020), it is revealed that there is a significant positive relationship between renewable energy production and technological development in the studies conducted by Alam and Murad (2020), Doğan and Özarlan Doğan (2021), Kılınç and Kılınç (2021) and Aşar (2023). However, studies focusing on developing countries by Gan and Smith (2011) and Bamati and Raofi (2020) did not find a significant relationship between technological development and renewable energy production. Geng and Ji (2016) found a bidirectional causal relationship between renewable energy consumption and technological development. Irandoust (2016) and Kılınç and Kılınç (2021) identified a one-way causality relationship from technological development to renewable energy production.

This study differs from others in that it examines the most current time period for the country group considered. In this regard, policy inferences are made using current data. In addition, the limited number of studies on this subject in Türkiye is another feature that distinguishes it from other studies in the literature. It aims to contribute to the literature with these features. This study aims to contribute to the literature by revealing how R&D expenditures and patent applications in Türkiye reduce costs in renewable energy production and have a positive impact on energy efficiency thanks to technological developments.

The variables used in the model established in the study are research and development expenditures (% of GDP) and patent applications, which are indicators of technological development. Renewable energy production (TWh) was used as the energy variable in the model. Additionally, the variables of

the model were developed by examining the literature. Accordingly, the dependent variable is renewable energy production (LNYN, TWh), and the independent variables are R&D expenditures (LNAG, % GDP), patent applications (LNPT, resident), economic growth (LNGDP, constant 2015 USD), trade openness (LNTR, % GDP) and medium and high technology exports (LNTC, % manufacturing exports).

According to the given descriptive statistics data, the low standard deviations of the LNYN, LNPT, LNAG, LNGDP, LNTR and LNTC variables indicate that the data are clustered in a narrow range around the mean. LNGDP has the highest maximum value, while LNAG has the lowest maximum value. LNGDP reaches the lowest minimum value, while LNAG reaches the highest minimum value. Additionally, according to the Jarque-Bera test, it is seen that the series have a normal distribution. After unit root tests, the lag length was determined. Then, as the second step, Granger (1969) causality test was applied since the first differences of the series were stationary.

ADF unit root test results: in the stationary model, LNYN, LNPT, LNAG, LNGDP, LNTR and LNTC have unit roots in $I(0)$ and after taking their first differences, they become stationary in $I(1)$ at the 1% significance level. Looking at the Phillips and Perron test results, the same results were obtained as the Improved Dickey-Fuller test results. Accordingly, in the fixed model, LNYN, LNPT, LNAG, LNGDP, LNTR and LNTC have unit roots in $I(0)$ and become stationary at the 1% significance level in $I(1)$ after their first differences are taken. After unit root tests, the lag length was determined.

The number of delays of the model is 1 according to AIC (Akaike Information Criterion), FPE (Final Prediction Error), LR (Sequential Modified LR Test Statistics), SC (Schwarz Information Criterion) and HQ (Hannan-Quinn Information Criterion) criteria.

After determining the appropriate lag length and performing unit root tests, the econometric analysis was completed with the Granger (1969) causality test. Since stationarity was required for this test, first differences were used.

Granger (1969). According to the results, the null hypothesis that there is no Granger causality from patent applications to renewable energy production is rejected at the 1% significance level and the existence of causality is accepted. Similarly, the null hypothesis that there is no Granger causality from research and development expenditures to renewable energy production is rejected at the 1% significance level and the existence of causality is accepted. The null hypothesis, which states that there is no Granger causality from economic growth to renewable energy production, is rejected at the 1% significance

level and the existence of causality is accepted. The null hypothesis, which states that there is no Granger causality from trade openness to renewable energy production, is rejected at the 1% significance level and the existence of causality is accepted. The null hypothesis that there is no Granger causality relationship from renewable energy production to trade openness is rejected at the 1% significance level and the existence of causality is accepted. It was concluded that there is a bidirectional causal relationship between the two variables. The null hypothesis, which states that there is no Granger causality from medium and high technology exports to renewable energy production, is rejected at the 1% significance level and the existence of causality is accepted. These results appear to support the results of Alam and Murad (2020), Doğan and Özarslan Doğan (2021), Kılınç and Kılınç in the literature, as well as the studies conducted on developed countries by Irandoust (2016), Kılınç and Kılınç (2021), Aflaki et al. (2014), Bamati and Raoofi (2020). (2021) and Aşar (2023). These results also differ from the results found by Gan and Smith (2011) and Bamati and Raoofi (2020).

Econometric analysis of Türkiye over a period of time revealed a causal relationship between R&D expenditures, patent applications, economic growth and medium and high-tech exports and renewable energy production. Additionally, bidirectional causality was found between trade openness and renewable energy production. These results show that energy needs and demands are increasing due to population growth in Türkiye, and investments in renewable energy production are also increasing. The importance of R&D expenditures in the use of technology in renewable energy production in Türkiye and the contribution of patent applications in this field are extremely important. Therefore, it is obvious that renewable energy production will continue to increase with technological support. Technology investments are of great importance for the sustainability of economic activities and the ability of countries to achieve their economic goals. Since economic growth and trade development contribute positively to the country's economy, more resources are allocated from the budget to ensure renewable energy production. It shows that technology is one of the most important factors in renewable energy production in Türkiye. Renewable energy technologies contribute to economic growth by both creating a suitable environment for low-cost energy production and reducing price volatility. Technological developments, in addition to government incentives and subsidies, also reduce the costs of renewable energy projects and facilitate their dissemination.

It is a very important factor that closely concerns areas such as energy, economy and politics. Renewable energy production is rapidly increasing due to factors such as increasing energy demand due to global population

growth, the gradual depletion of fossil fuel resources and the need to combat climate change. Technological developments have a significant impact on this increase in production. Developments in renewable energy technologies increase efficiency, develop new production methods, reduce installation costs and therefore facilitate the rapid spread of these resources around the world. Renewable resources require high installation costs. Investments in these resources, especially in developing countries, should be increased through measures such as subsidies, public investments, and facilitating the private sector's access to credit. According to the findings of the study, increases in patent applications will accelerate the commercialization and dissemination of innovations in the field of renewable energy. To accelerate this dissemination, bureaucratic processes need to be simplified and costs reduced. According to the analysis, increases in medium and high technology exports also increase renewable energy production. In this context, the export of renewable energy technologies should be supported by mechanisms such as international trade agreements or export credits, thus increasing the international competitiveness of local companies and disseminating these technologies worldwide. Export of these technologies will also contribute to economic growth. The study emphasizes the necessity of allocating resources to R&D expenditures, which is the technology variable that has the greatest impact on renewable energy production; Supporting these efforts at both national and international levels is of great importance in terms of supporting collaborations, developing renewable energy technologies and therefore increasing energy production.

Increasing renewable energy production is possible with technological development. In this study, this situation has been examined and proven econometrically. For this reason, concrete steps should be taken in technology development activities to ensure renewable energy production. Global R&D activities should be supported in this context, and university-industry collaborations should be encouraged to promote energy-related innovation strategies. Financial incentives should be provided for the use of energy technologies, and renewable energy supply and demand should be more closely monitored.

Türkiye aims to increase its installed solar and wind power capacity approximately fourfold from 30 GW to 120 GW by 2035, as part of its "2035 Roadmap for Renewable Energy". Within this framework, it is planned to commission at least 7,500-8,000 MW of new capacity annually, increasing the share of domestic and renewable energy in line with the 2053 carbon neutrality target. They also plan to switch to a competitive bidding model

for Renewable Energy Resource Area (YEKA) tenders, aiming to hold 2,000 megawatts of solar and wind power tenders annually.³³⁶

The limitation of this research is that the relationship between energy and technological development is investigated using Granger's (1969) causality method. Future research could examine the relationships among energy, technological development, and other factors. Another limitation of the research is that it only examines Türkiye. Therefore, it is recommended that future studies include various countries or country groups, different analytical techniques, and various factors. Furthermore, it may be worthwhile to examine direct and indirect factors in future studies investigating the relationship between energy and technological development.

336 Official Website of the Ministry of Energy and Natural Resources: <https://enerji.gov.tr/haber-detay?id=21380#:~:text=Bayraktar%2C%202005%20y%C4%B1%C4%B1nda%2012%20bin,y%C3%BCzde%2059'a%20ula%C5%9Ft%C4%B1%C4%9F-C4%B1n%C4%B1%20a%C3%A7%C4%B1klad%C4%B1.&text=T%C3%BCrkiye'nin%202035%20y%C4%B1%C4%B1nda%20120,devreye%20almas%C4%B1%20gerekliyor.%E2%80%9D%20dedi.&text=Bayraktar%2C%20YEKA%20ihalelerinde%20y%C4%B1%C5%9Fma%20modeline,%20y%C4%B1%C4%B1n%20alt%C4%B1na%20indireceklerini%20anlatt%C4%B1.&text=Bayraktar%2C%20t%C3%BCm%20bunlar%C4%B1%20yapabilmek%20i%C3%A7in,ne%20%C3%A7%C4%B1karmay%C4%B1%20hedefliyoruz.%E2%80%9D%20dedi>

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