TÜRKİYE BİLİMLER AKADEMİSİ
TURKISH ACADEMY OF SCIENCES

NEW ENERGY TECHNOLOGIES REPORT

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Türkiye Bilimler Akademisi
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NEW ENERGY TECHNOLOGIES REPORT

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New Energy Technologies Report

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TÜBA
TÜRKİYE BİLİMLER AKADEMİSİ
TURKISH ACADEMY OF SCIENCES

"This report is compiled from the presentations given at the New Energy Technologies Summer School, organized by the TÜBA Energy Working Group, held on August 18-23, 2024, at Ahmet Yesevi University in Turkistan, Kazakhstan."

CONTENTS

FOREWORD

The *New Energy Technologies Summer School* was held in Turkistan, Kazakhstan, in cooperation with TÜBA, Akhmet Yassawi International Kazakh-Turkish University and International Turkic Academy (Scientific and Educational Cooperation of the Turkic World) and with the contributions of the Turkish Cooperation and Coordination Agency (TIKA).

Organized by TÜBA 4 times until 2022 and organized in cooperation with stakeholders for the last 2 years, the summer schools aim to build bridges between scientists from sister, neighboring, and nearby countries where Turkish and related communities live, and to ensure diplomatic rapprochement and the development of their relations.

The *New Energy Technologies Summer School* lasted 5 days and was centered around teaching and discussing various energy technologies, focusing on both traditional and modern approaches. Students attended lectures on the latest developments, current problems, and opportunities in the field of energy technologies. The program also focused on the basic principles and established methods of energy production as well as innovative and sustainable solutions to meet future energy demands and discussed new approaches to energy production, management, and sustainability. In order to encourage participants to contribute to the development of future energy solutions, the program covered a wide range of topics such as Traditional Energy Sources in Thermodynamics, Nuclear Energy, Renewable Energy Sources, and Hydrogen Energy Technologies.

In recent years, the TÜBA Energy Working Group has been organizing thematic workshops on Wind, Solar, Nuclear, Geothermal, Energy Storage, Natural Gas, Biomass, and Alternative Energy Sources to support Türkiye's roadmaps and policies in the field of energy technologies. We believe that this report, which has been prepared within the framework of the issues evaluated within the scope of the workshop, will also contribute to the preparation of strategic plans and the consideration of various road maps. I would like to extend my thanks, best wishes, and respect to the members of the working group who contributed to the realization of the workshop and panel and the preparation and publication of the report, and to our scientists who contributed to the preparation of the report, to the members of the workshop and the Academy, to the managers and experts of relevant institutions, organizations, participants and all stakeholders who contributed, and I wish the report to be a useful resource for decision-makers and practitioners on the subject.

Prof. Dr. Muzaffer ŞEKER
President, TÜBA

PREFACE

TÜBA-Energy Working Group aims to generate information, develop strategies and policies, prepare strategic road maps, and contribute to the energy policies of our country by conducting studies on scientific and technological issues that our country needs in the field of energy. The Working Group brings together relevant stakeholders by organizing workshops and panels on energy issues of strategic importance for our country, evaluates scientific and technological dimensions in depth, and discusses and reports projections for the future.

During the five-day summer school, which included academicians from various universities, including TÜBA members, who are experts in their fields, participated in sessions titled "History of Energy", "Physics of Energy", "Fundamental Principles and Concepts in Thermodynamics", "Traditional Energy Sources", "Nuclear Energy", "Renewable Energy Sources", "District Energy Systems", "Environment and Sustainability Dimensions of Energy", "Hydrogen Energy and Related Technologies", "Fuel Cells", "Energy Storage Systems and Applications", "Energy Materials", "Smart Grid", "Energy Conservation and Efficiency Aspects", "Energy Policies and Strategies", "Waste to Energy Options", "Alternative Fuels", "Energy and Innovation", "Economic and Social Dimensions of Energy", "Energy and Agricultural Commodity Prices" sessions and panel discussions examined the past, present and future of energy systems on a global scale.

In the summer school, sharing information, exchanging ideas and training young researchers were really an essential goal, and fruitful discussions were held on numerous subjects, ranging from fundamental aspects of thermodynamics to social and economic dimensions of energy and energy utilization. There were also panel discussion sessions where various experts coming from various sectors discussed the local and global challenges, potential opportunities and future directions.

This report is based on the papers presented at the "TÜBA- New Energy Technologies Summer School" organized by the "Energy Working Group" of the Turkish Academy of Sciences (TÜBA) in cooperation with, Akhmet Yassawi International Kazakh-Turkish University and International Turkic Academy (Scientific and Educational Cooperation of the Turkic World) and with the contributions of the Turkish Cooperation and Coordination Agency (TIKA) and compiled from numerous leading studies available in the open literature to provide some eye-opening type perspectives.

Prof. Dr. İbrahim DİNÇER
Chair, TÜBA–Energy Working Group

ACKNOWLEDGMENTS

We would like to thank those who contributed to the organization of the New Energy Technologies Summer School event, held on August 18-23, 2024, at Ahmet Yesevi University in Turkistan, Kazakhstan, which is the source of this report. We would like to thank all the speakers for their presentations at the event: (*alphabetic order by surname*)

- Prof. Dr. M. Hakkı Alma
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- Prof. Dr. Can Özgür Çolpan
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- Prof. Dr. Naci Genç
- Prof. Dr. Arif Hepbaşlı
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- Prof. Dr. Şaban Nazlıoğlu

ABSTRACT

This report provides an overview of the main ideas and applications discussed during the New Energy Technologies Summer School, which took place at Ahmet Yesevi University in Turkistan, Kazakhstan, from August 18-23, 2024. It involves the basic physics of energy, its historical development, and the laws and practices influencing its use. In addition to reviewing conventional and renewable energy sources like solar, wind, hydro, geothermal, and nuclear power, the report addresses fundamental thermodynamic concepts. It investigates cutting-edge technologies like fuel cells, energy storage devices, and hydrogen energy. The report also covers alternative fuels, district energy systems, energy conservation, and smart grids. Finally, it examines how energy is used in different areas and its effects on the economy, environment, and society. A fundamental understanding of the energy business and its many potential and problems is given by this thorough study.

Keywords

Renewable Energy, Hydrogen, Energy, Exergy, Efficiency, Solar, Wind, Hydropower, Nuclear, Energy Storage

ÖZET

Bu rapor, 18-23 Ağustos 2024 tarihleri arasında Kazakistan'ın Türkistan şehrindeki Ahmet Yesevi Üniversitesi'nde düzenlenen Yeni Enerji Teknolojileri Yaz Okulu etkinliği sırasında vurgulanan temel kavramları ve uygulamaları özetlemektedir. Enerjinin tarihsel gelişimini, temel fiziğini ve kullanımını şekillendiren politika ve stratejileri içermektedir. Rapor, temel termodinamik ilkeleri kapsamakta ve güneş, rüzgâr, hidroelektrik, jeotermal ve nükleer enerji dahil olmak üzere geleneksel ve yenilenebilir enerji kaynaklarını incelemektedir. Hidrojen enerjisi, yakıt hücreleri ve enerji depolama sistemleri gibi gelişmekte olan teknolojileri öne çıkarmaktadır. Rapor ayrıca akıllı şebekeler, bölgesel enerji sistemleri, enerji tasarrufu ve alternatif yakıtların kullanımının kritik yönlerini tartışmaktadır. Son olarak, enerjinin farklı sektörlerde kullanımı da dahil olmak üzere enerjinin ekonomik, çevresel ve sosyal boyutlarını analiz etmektedir. Bu kapsamlı genel bakış, enerji sektörü ve onun çok yönlü zorlukları ve fırsatları hakkında temel bir anlayış sağlamaktadır.

Anahtar Kelimeler

Yenilenebilir Enerji, Hidrojen, Enerji, Ekserji, Verimlilik, Güneş, Rüzgâr, Hidroelektrik, Nükleer, Enerji Depolama

NEW ENERGY
TECHNOLOGIES REPORT

1. Introduction

Energy is a vital component of modern society that sustains our daily lives, promotes social advancement, and drives economic growth. Almost every aspect of human activity depends on energy, which also powers our homes and companies and makes communication and transportation easier. Access to affordable, reliable energy is essential for reducing poverty, improving living conditions, and preserving human well-being. The current global energy system faces numerous challenges, including resource depletion, geopolitical threats, and environmental issues. To overcome these obstacles and guarantee that everyone has fair access to energy, a comprehensive plan is required to make the shift to a sustainable energy future.

The main energy sources that have fueled industrialization and the world's economies are coal, oil, and natural gas. However, the extensive use of fossil fuels has had a negative impact on the environment, resulting in resource depletion, air pollution, and climate change. By releasing greenhouse gases into the atmosphere, the use of fossil fuels leads to global warming and its consequences, including rising sea levels, severe weather, and ecological harm. Furthermore, the transportation and exploitation of fossil fuels may negatively affect nearby communities and surroundings. A worldwide energy transition toward cleaner and more sustainable energy sources and systems is underway in order to address these issues. Coal, oil, and natural gas will gradually give way to solar, wind, nuclear, and hydropower during this transition.

Figure 1

Share of electricity generation by source in Türkiye [Data from (Ember, 2024a)]

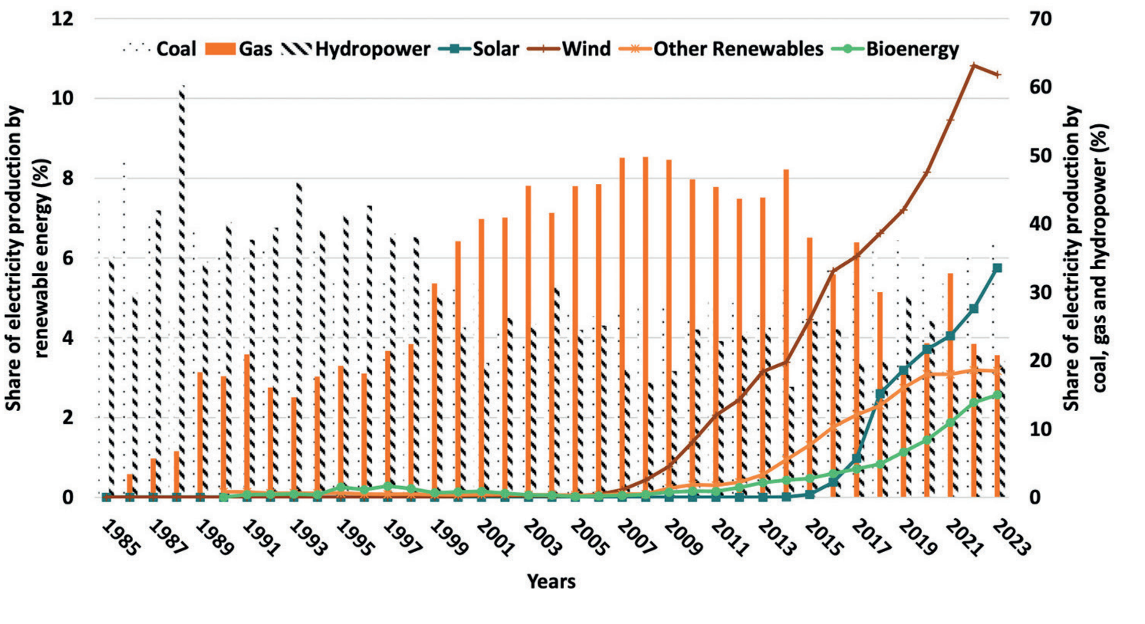
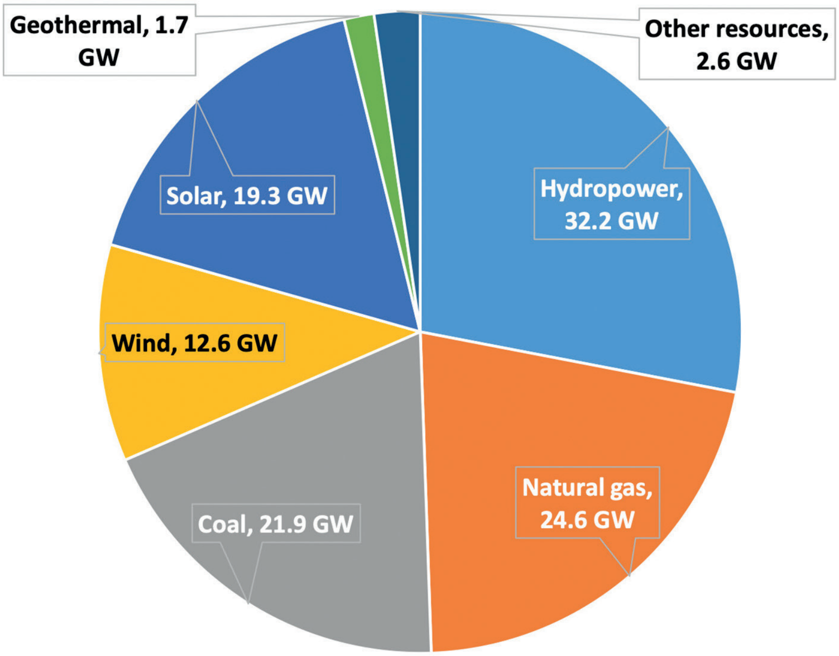


Figure 1 shows the changes in power generation share in Türkiye by source between 1985 and 2023. By emphasizing the rise in renewable energy sources and the decline in fossil fuel use, the graph depicts a shift in electricity generation of Türkiye. With a combined share of over 80%, coal and gas were the main sources of energy generation until the 2000s. The share of renewable energy is expected to rise significantly by the 2010s. Hydropower has consistently contributed a substantial portion, while solar and wind energies have seen rapid growth currently. The share of coal has been declining steadily, while gas has remained relatively stable. Hydropower has shown a gradual increase, and other renewables, particularly solar and wind, have a rapid growth.

The energy transition presents both opportunities and challenges. It requires significant investments in research of renewable energy systems, infrastructure upgrades, and policy changes to promote clean energy solutions. While the transition may pose economic and social challenges for certain sectors, it also offers numerous benefits, including job creation in the clean energy sector, improved air quality, and enhanced security in energy. A successful energy transition requires collaboration among governments, industries, and communities to ensure a just and equitable transition that leaves no one behind.

Figure 2

Installed electricity power of Türkiye [Data from (MENR, 2024)]



A promising pathway toward a sustainable energy future is provided by renewable energy sources, which are produced from naturally renewed resources including sunshine, wind, water, and geothermal heat. These sources could improve energy security, lower greenhouse gas emissions, and mitigate the negative environmental effects of fossil fuels. In recent years, technological developments have made renewable energy technologies much more efficient and cost-effective, increasing their competitiveness with traditional energy sources. Renewable energy is essential to supplying the expanding energy needs of the world while reducing environmental damage and guaranteeing a sustainable future for future generations as the world moves toward a low-carbon economy.

The installed electricity power capacity in Türkiye by source is given in Figure 2 (MENR, 2024). As of November 2024, the installed power of electricity consists of 40.4% of fossil fuels (natural gas and coal). Hydropower plays a significant role, contributing 32.2 GW of installed capacity, representing about 30% of the total. Geothermal, wind, biomass, and solar energies together account for about 29.8% of the total installed capacity.

2. Basics of Energy

This chapter explores the evolution of energy use, from pre-industrial sources to the current energy landscape, emphasizing key transitions and technological advancements. The history of energy, from pre-industrial to current, the physics of energy, energy policies and strategies, energy and innovation are discussed.

2.1. History of Energy

Energy is the capacity to produce change or perform work and has been integral to human civilization and life itself. It exists in various forms such as thermal, electrical, kinetic, nuclear, potential, chemical, and more. Throughout history, societies have harnessed various energy forms to support growth, reproduction, and daily activities. Energy is vital for all life forms and is integral to various processes, including growth, reproduction, and metabolism in living organisms. It powers human activities, from simple tasks to complex industrial operations, and is crucial for the functioning of modern civilization (Balikci, 2024a).

Pre-Industrial Energy Sources

In the pre-industrial era, solar energy is utilized in its simplest forms. Passive solar heating influenced the design of buildings to maximize sunlight for warmth and illumination. Agriculture depends heavily on sunlight for crop cultivation, while solar energy is also used for drying food and materials. Sundials, an early timekeeping method, exemplify the reliance of humanity on solar power.

Wind energy is a vital mechanical power source in pre-industrial societies. Sailing ships harness wind power for transportation and trade, while windmills perform tasks like grinding grain and pumping water for agriculture. Water and its power is another renewable energy source, employed through waterwheels to power mills, forges, and sawmills. Its applications ranged from grinding grain to supporting metalworking and textile production, playing a crucial role in early industries. Waterwheels were extensively used to grind grain into flour. In the textile industry, waterwheels powered machinery for fulling, which involved cleaning and thickening cloth. Waterwheels provided power for hammers and bellows in forges, facilitating metalworking processes such as smelting and shaping metal. Waterwheels powered sawmills, enabling the efficient cutting of timber into planks and boards, which is essential for construction and shipbuilding. In some cases, waterwheels were used to pump water for irrigation and drainage, supporting agricultural activities.

Before mechanization, human and animal labor were primary energy sources. Domesticated animals such as oxen and horses provided agricultural and transportation power. Tools and techniques gradually enhanced the efficiency of human and animal energy use. Before the widespread adoption of machinery, human and animal muscle power is a primary source of energy for various essential activities such as agriculture, transportation, and construction. Human muscle power is fundamental for tasks like farming, building, and crafting. Over time, humans developed tools and techniques to enhance their muscle power. Domesticated animals such as oxen, horses, and donkeys are used extensively in agriculture. Animals are crucial for transportation, pulling carts, carriages, and wagons over long distances.

Industrial Revolution and Fossil Fuels

The Industrial Revolution marked a significant turning point in history, particularly with fossil fuel usage. The shift to coal and oil as primary energy sources revolutionized production, urbanization, and society. During the Industrial Revolution, coal and oil usage as primary energy sources had a deep impact on production and urbanization, leading to significant economic and social changes.

The development of the steam engine, particularly improvements of James Watt in the late 18th century, enabled the mechanization of factories, leading to mass production (BBC, 2024). Steam engines, powered by coal, became the primary drivers of machinery in factories, revolutionizing industries such as textiles, iron, and transportation. Steam-powered railways and ships expanded trade and accelerated urbanization, making coal the backbone of industrial progress.

The efficiency and power provided by steam engines enabled factories to produce goods on a much larger scale than previously possible. This shift to mass production is a key driver of economic growth during the period. The ability to power machinery with coal-fueled steam engines led to the rise of factory-based manufacturing. The growth of factories created a high demand for labor in urban areas. The influx of workers into cities transformed them into bustling industrial centers. The rapid urbanization led to overcrowded cities with inadequate housing and infrastructure. To accommodate the growing urban populations, cities expanded their infrastructure, including transportation networks, sanitation systems, and public services.

The first oil well that initiated the petroleum industry was drilled in Pennsylvania in 1859 (ACS, 2024a). The significance of oil grew with the internal combustion engine, fueling automobiles and revolutionizing transportation. While oil spurred economic growth, it also introduced challenges such as pollution and resource dependency, shaping global geopolitics.

The invention of modern drilling techniques, such as the successful oil well of Edwin Drake in Pennsylvania in 1859, marked the start of large-scale oil extraction. This development was crucial for the growth of the oil industry. Founded by John D. Rockefeller in 1870, Standard Oil became a dominant force in the oil industry, illustrating the economic potential and influence of oil as a resource (ACS, 2024a).

Internal combustion engines significantly increased oil demand, as it became the primary fuel for automobiles and other machinery. Faster and more efficient transportation became easier by oil-powered vehicles and ships. It contributed to economic growth and global trade expansion. The extraction and use of oil contributed to environmental pollution, including oil spills and emissions, which had long-term impacts on ecosystems and public health.

The Industrial Revolution established a dependency on oil, a finite resource, which has had lasting implications for energy security and environmental policies. The availability of oil as an energy source supported further industrialization and urbanization, shaping modern economic and social structures. The oil industry became a significant economic force, influencing global politics and economies, particularly in oil-rich regions.

Electricity and the Second Industrial Revolution

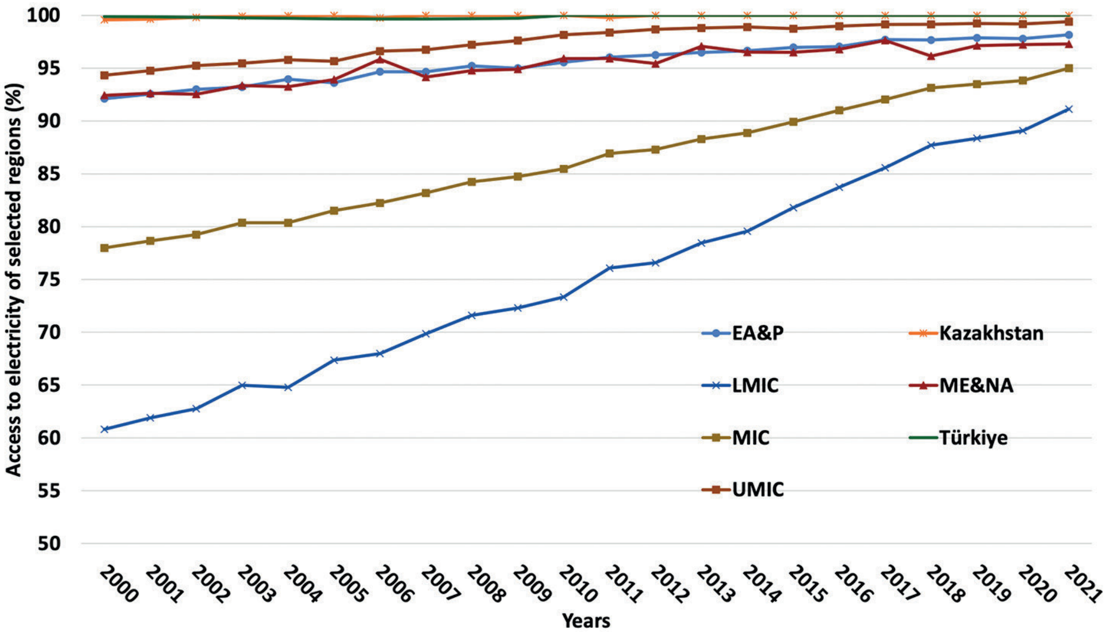
The Second Industrial Revolution (1870 to 1914) marked the rise of electricity as a transformative energy source. The first permanent central power station in the world was Thomas Edison's Pearl Street Station, which opened for business in New York City in 1882 (ETC, 2024). The Vulcan Street Plant is considered (more commercial than Svatá Kateřina Hydroelectric Power Plan, which was constructed the same year) the first commercial large-scale hydroelectric power station (ASCE, 2024).

The adoption of alternating current technology facilitated the expansion of electrical grids, revolutionizing industries and daily life. Innovations in electric power generation, transmission, and application enabled unprecedented technological and industrial growth. The Vulcan Street Plant began operation in 1882, in Wisconsin. Unlike Edison's steam-powered Pearl Street Station, the Vulcan Street Plant utilized the kinetic energy of the Fox River. It featured an Edison "K" type dynamo that produced approximately 12.5 kW of electricity (ASME, 2024). This energy was used to light three buildings: Appleton Paper, H.J. Rogers' home, the Pulp Company building, and the Vulcan Paper Mill.

The expansion of electrical grids during the Second Industrial Revolution played a critical role in transforming industrial and daily life. The development of alternating current technology was pivotal for the expansion of electrical grids. The first high-voltage (AC power) station was established in Deptford, London 1889 by Sebastian Ziani de Ferranti (Williams, 1992). The same year the first transmission line in North America was set between Willamette Falls, Oregon, and Portland, Oregon (National Grid, 2024).

Figure 3

Changes in the access to electricity [Data from (World Bank, 2024a)]



*UMIC: Upper-Middle-Income Countries
EA&P: East Asia and Pacific
LMIC: Lower-Middle-Income Countries
ME&NA: Middle East and North Africa
MIC: Middle-Income Countries

Figure 3 shows the share of the population with access to electricity in different regions from 1999 to 2021. Regions selected from different parts of the world have shown a significant increase in access to electricity over the period. Türkiye and the Upper-Middle-Income Countries (UMIC) have consistently had the highest levels of access, with rates exceeding 95% since the early 2000s. East Asia and Pacific (EA&P), Lower-Middle-Income Countries (LMIC), Middle East and North Africa (ME&NA), and Middle-Income Countries (MIC), have also made substantial progress, with access rates steadily increasing over time.

20th Century Developments

The 20th century witnessed a surge in energy diversity and innovation, including the advent of nuclear power and renewable energy sources. Nuclear power became a significant energy source in the 20th century. The period saw an intense focus on nuclear weapons development during World War II, leading to the creation of the atomic bomb. The discovery of nuclear fission in 1939 and the first nuclear chain reaction in 1942 by Enrico Fermi were pivotal moments (DOE OSTI, 2024). The Atomic Energy Act was signed in 1946, placing the nuclear energy industry under civilian control and marking the beginning of efforts to explore nuclear energy use (EPA, 2024). The first electricity from nuclear energy was generated in the Experimental Breeder Reactor I in 1951 in the United States (INL, 2024). While nuclear technology promised vast energy potential, challenges such as safety concerns, exemplified by the Chernobyl disaster, and high economic costs slowed its adoption. Despite these hurdles, advances in reactor design improved efficiency and safety.

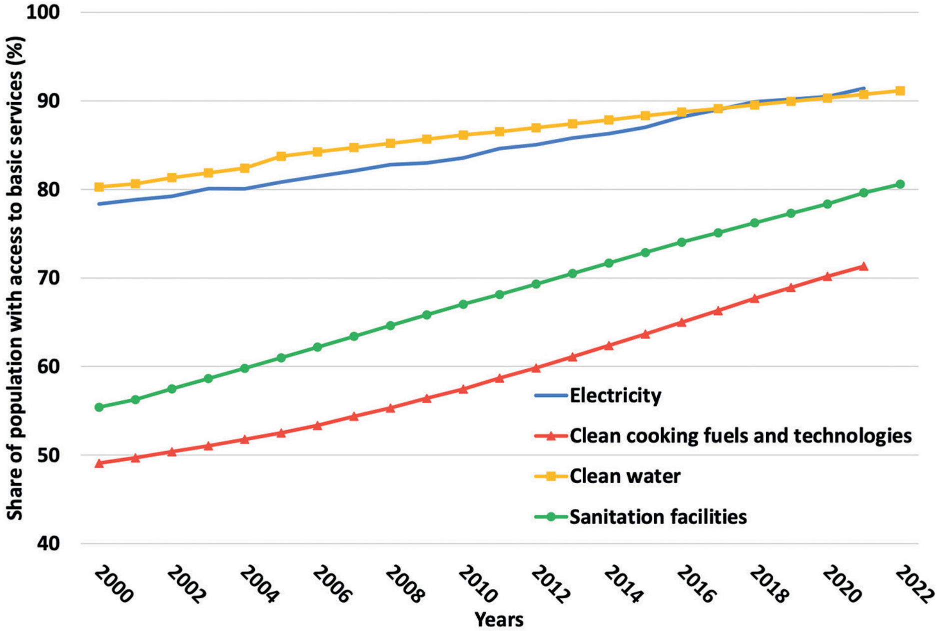
President Eisenhower's "Atoms for Peace" program aimed to promote peaceful nuclear Technologies in 1953. Between the 1950s-1960s focused on developing nuclear technologies for civilian electricity generation and naval propulsion (WNA, 2024). The USA, USSR, UK, and France are key players, each developing different reactor designs. The first electricity to a grid by nuclear power plant was supplied in Obninsk, USSR in 1954. The same year, the USS Nautilus, which is the first nuclear submarine, was launched. The first commercial power plant in the USA, Shipping port, began operation in 1957 (WNA, 2024).

The nuclear industry faced challenges such as safety concerns, economic costs, and environmental issues, leading to a slowdown in growth from the 1970s to the 1980s. The Chernobyl disaster in 1986 highlighted the risks of nuclear power. A revival in nuclear power interest was driven by the need for energy security and reducing carbon emissions until the 2000s. New reactor designs, such as Generation III reactors, focused on improved safety and efficiency. The Westinghouse AP1000 and the European Pressurized Water Reactor (EPR) reactors were developed as third-generation reactors and incorporated passive safety systems to enhance safety without human intervention in the late 20th century (Leverenz et al., 2004).

Figure 4 shows the share of the population with access to electricity, clean cooking fuels and technologies, clean water, and sanitation facilities from 2000 to 2022. All services have shown a steady increase in access over the period. Access to electricity and clean water has been consistently higher than the other two services throughout the period. While sanitation facilities have also shown improvement, the rate of increase has been slightly slower compared to the other services. The positive trend of increasing access to basic services, which is crucial for improving living standards and overall well-being, should be maintained all over the world.

Figure 4

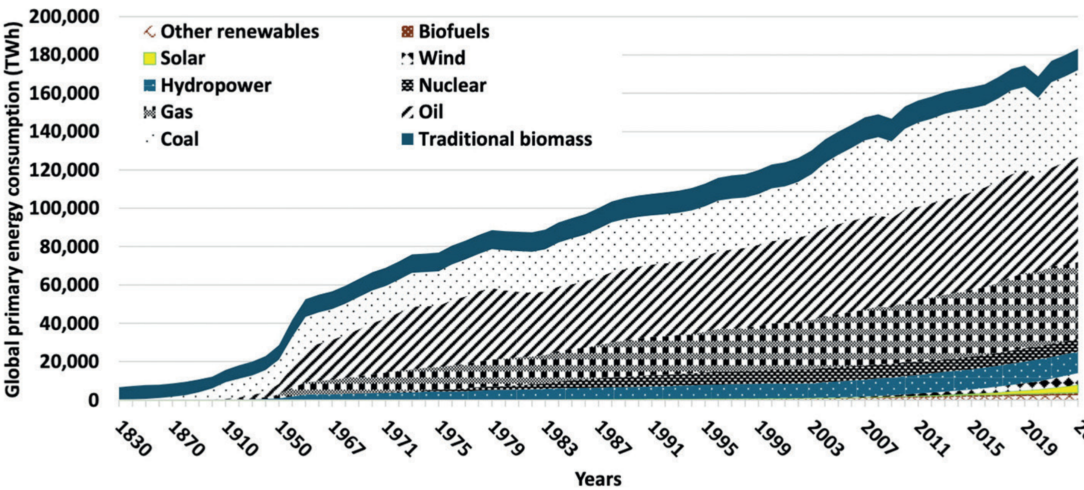
Changes in worldwide access to basic services [Data from (World Bank, 2024b)]



Renewables gained traction as environmental and geopolitical concerns grew. Breakthroughs like silicon solar cells and large-scale hydropower stations, such as the Three Gorges Dam in China, established the feasibility of clean energy solutions. Wind energy has also advanced, with utility-scale wind farms and more efficient turbines transforming electricity generation. The 20th century witnessed significant developments in renewable energy sources due to the increase in environmental concerns, technological advancements, and geopolitical factors. The first solar thermal power station in the world was built by Frank Shuman in Egypt in 1913. In 1905, Albert Einstein's work on the photoelectric effect provided a theoretical foundation for solar energy, explaining how light can be converted into electricity (Ground Report, 2024). This work later earned him a Nobel Prize. Bell Laboratories developed the first practical silicon solar cell, achieving a 6% efficiency rate in 1954. This marked the beginning of the modern era of solar energy, significantly improving the efficiency and viability of solar power.

Figure 5

Changes in primary energy consumption in the world by source [Data from (Ritchie et al., 2024)]



The modern application of wind turbines to generate electricity was established in the early 20th century. In the 1930s, the first electricity-generating wind turbines appeared (Gipe & Möllerström, 2022). Wind turbines are used to conserve fuel, such as charging batteries on German U-boats during World War II. In 1941, a megawatt-sized wind turbine was constructed at Grandpa's Knob in Vermont, although it only operated briefly due to material shortages (Gipe & Möllerström, 2022).

By the early 1900s, hydropower was already a popular energy source, with the U.S. leading the way. The U.S. had around 200 hydroelectric power plants by 1889, and Canada had installed 133,000 kW of hydroelectric capacity by 1900, mainly in Québec and Ontario (Humphrys, 2020). By the 1980s, Brazil and China emerged as leaders in hydropower. The Itaipu Dam, completed in 1984, became one of the largest in the world, and the Three Gorges Dam in China, completed later, further demonstrated the scale of hydropower projects (PPIAF, 2024).

Figure 5 illustrates the historical shifts in global energy consumption (in TWh from 1830 onwards), with a transition from coal to oil and gas, and a growing role for renewable energy sources. As of 2023, global consumption reached 180,000 TWh. 76.5% of this demand is supplied by oil, gas, and coal in 2023. While renewable energy supplied 2.7% of the demand in 2013, this share reached 7.7% in 2023. Renewable energy sources and hydropower have shown significant growth, particularly in recent decades.

Current Energy Landscape and Future Trends

The dynamic movement towards renewable energy sources characterizes both the current and future energy landscape. This movement is supported by global efforts to address climate change, policy reforms, and technical developments. Renewable energy and green hydrogen face challenges like intermittent and high infrastructure costs. However, innovations and incentives are mitigating these issues. The global energy landscape is undergoing significant transformation technological advancements and shifting geopolitical dynamics. This transition is driven by the urgent need to combat climate change.

Energy distribution and management are being optimized by advancements in big data, artificial intelligence (AI), and smart grids. New designs for wind turbines and photovoltaics are increasing efficiency and broadening the use of renewable energy. There are many opportunities as well as major problems associated with the transition to renewable energy. Since solar and wind energy are intermittent, it is impossible to generate electricity continuously. Energy storage technologies should be incorporated to guarantee a steady energy supply because this unpredictability has the potential to destabilize the system.

Infrastructure for renewable energy requires significant upfront investment. The adoption of renewable technologies may be slowed and investment discouraged by this cost barrier. The distribution of renewable energy is frequently not optimal by the energy infrastructure that is currently in place. Although it can be expensive and complicated, upgrading grid infrastructure to support increased renewable energy penetration is crucial. The expansion of renewable energy can be delayed by inconsistent policies, regulatory obstacles, and a lack of government backing. Promoting investment requires stable policy frameworks and the simplification of permitting procedures. The dominance of a few players in the energy market and volatility in energy prices can limit competition and innovation in the renewable sector. Innovations in energy storage, such as advanced battery technologies, are crucial for addressing the intermittent of renewables. These technologies are becoming cost-effective and more efficient, enhancing the viability of renewable energy.

With opportunities in production, installation, and research and development, the renewable energy industry contributes significantly to job creation. Energy security and economic resilience may benefit from this expansion. The switch to renewable energy reduces dependency on fossil fuels and emissions such as CO_2 and SO_2. This change helps create a more sustainable and cleaner environment. Emerging technologies that are accelerating the shift to renewable energy are changing the present energy landscape. These developments are essential for tackling the problems of climate change and energy sustainability. More adaptable and efficient solar panels are the result of advancements in solar technology. The goal of innovations in photovoltaics is to minimize land use and maximize energy capture. Emerging technologies like thin-film cells and perovskite-on-silicon tandem cells are enhancing the efficiency and flexibility of solar panels. Currently, solar PV panels are more cost-effective and environmentally friendly.

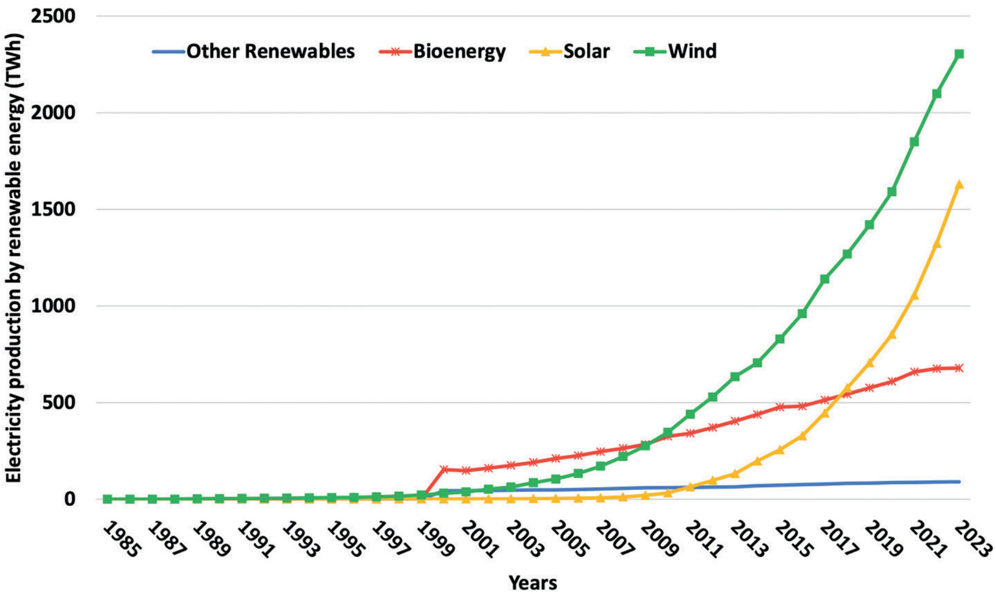
Big data and AI are transforming the energy sector by enabling real-time decision-making and predictive analytics. These technologies are crucial for optimizing energy production, grid management, and consumption. AI-driven solutions are also facilitating the development of the Internet of Energy (IoE), which enhances grid capacity prediction and autonomous energy trading. Energy storage systems are vital to address the intermittent of renewable energy sources. Innovations in flow batteries and solid-state batteries are improving energy density and storage capacity. These advancements are essential to ensure a reliable energy supply and to stabilize the grid. Smart grid technologies and the internet of things are enhancing the integration of renewable energy into existing energy systems. These technologies use sensors and analytics to optimize energy distribution, balance loads, and improve grid reliability.

Blockchain technology is also being explored for managing energy transactions and facilitating peer-to-peer energy trading. Wind energy is benefiting from taller turbines and floating wind farms, which expand the potential locations for wind power generation. In hydroelectric power, advanced turbine designs and kinetic hydro turbines are increasing efficiency and reducing environmental impact. Small modular reactors (SMRs) and next-generation nuclear designs promise enhanced safety and efficiency. These technologies offer a potential solution for providing reliable, sustainable, and clean energy without the long-lived radioactive waste associated with traditional nuclear power. Technologies for capturing and utilizing carbon dioxide (CO_2) are being developed to mitigate climate impacts. These technologies convert CO_2 into valuable materials, contribute to sustainability efforts, and reduce reliance on fossil fuels. The history of energy reflects the ingenuity and adaptability of humanity. From harnessing solar and biomass in ancient times to leveraging fossil fuels and embracing renewables, energy transitions have shaped economic, social, and technological progress. As the world confronts climate change, the continued evolution of energy systems offers opportunities for a resilient and sustainable future.

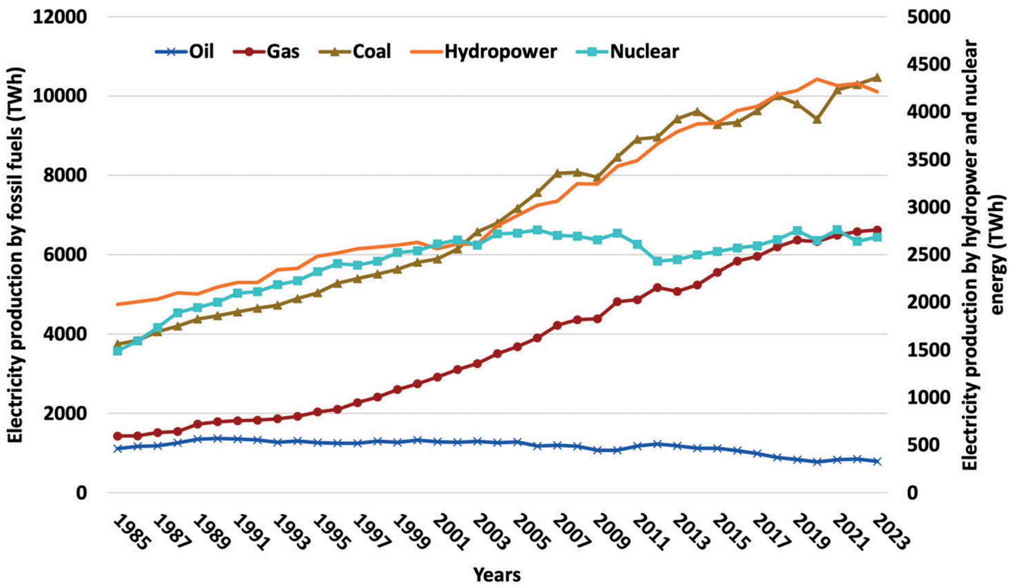
Figure 6

Global electricity production by (a) renewable energy (b) fossil fuels, hydropower, and nuclear energy [Data from (Energy Institute. 2024b)]

(a)



(b)



The global electricity production by various energy sources is given in Figure 6 (a) and (b). The significant growth of wind and solar power and a sharp increase in production since the early 2000s can be seen in Figure 6 (a). Geothermal and ocean energy (categorized as other renewable sources) have also shown a steady increase over the period. Bioenergy production has also been increasing, though at a slower rate than solar and wind. The overall electricity production has a significant increase across all sources from 1985 to 2023. Electricity production by natural gas has shown steady and continuous growth throughout the period, becoming a major source of electricity. Electricity production by nuclear energy has fluctuated with periods of growth and decline. It has remained a relatively stable source of electricity generation. Despite the integration and enhancement of renewable energy sources, natural gas and coal are still major electricity production sources.

2.2. Physics of Energy

The word "energy" is frequently used in daily speech. It does have a very particular physical definition, even though it is frequently used somewhat loosely. The ability to conduct work, or to provide a force that causes an item to move, is the definition of energy. Energy is just the force that moves objects. Potential energy and kinetic energy are the two categories of energy. Potential energy is stored energy such as chemical, elastic, nuclear, and gravitational energies and kinetic energy is the energy of movement such as thermal, mechanical, electrical, and magnetic (Cevik, 2024a). The best approach to conceptualize them is as follows: kinetic energy happens during an action, while potential energy occurs before an action. Basic SI units for length, time, and mass are the meter (m), second (s), and kilogram (kg), respectively. The SI unit of energy is the joule (J) and can be defined as follows:

$$1\,J = 1\,Nm = 1\,kg\frac{m^2}{s^2}$$

The energy required to deliver a force of one newton over a distance of one meter is measured in Joule, which is a derived unit. But energy is also measured in a variety of other units that are not included in the SI, like kWh and calories, which need to be converted before being stated in SI units. The commercial unit of energy is generally considered kWh. One kWh of energy refers to energy consumption by a device in one working hour at a constant power of one kW. The connection between energy units can be defined as follows:

$$1\,kWh = 1\,kW \times 1\,h = 1000\,W\ \times\ 1\,h = 1000\,\left(\frac{J}{s}\right)\ \times\ 3600\,s = 3{,}6 \times 10^6\,J$$

Some useful examples can be given to figure out the units. For example, 10 Megajoules (MJ) of food is 2390 kcal. The average energy use of humans is 200 MJ/day. The yearly global energy use is 500 Exajoules (EJ). One noted that 1 Megajoules is 10^6 J and 1 Exajoules is 10^{18} J.

Energy has many different forms. Thermal, chemical and potential energies are different from the kinetic energy of a falling tennis ball. Energy that moves in the form of waves or particles is known as radiant energy. Humans most frequently figure out this energy, which is produced by electromagnetic waves, as heat. A light bulb emits two types of energy when it is turned on: heat and visible light. Radiant energy is the source of both of these produced energies. Another type of radiant energy is sunlight. Sun emits radiant energy in the form of light, traveling at a speed of 3×10^8 m/s. This energy travels through space and reaches Earth.

Thermal energy is regarded as warmth or heat and is comparable to radiant energy. Thermal energy characterizes the degree of activity between atoms and molecules in an object, whereas radiant energy relates to waves or particles. A heat engine is used to convert heat into mechanical energy. For example, jet engines convert thermal energy (around 1700 °C) into mechanical energy, and work is produced. The hottest part of a jet engine is the turbine inlet.

The vibrations that reach the human ear are regarded by humans as sound. The ear drum is where sound waves are directed when they get to our ears. One component of the ear that transforms sound energy into mechanical motions is the eardrum. When arrives, the eardrum vibrates, and the vibrations are transmitted through three interconnected bones by a fluid. Several hair-like cells are bent by the flowing fluid, transforming the vibrations into nerve impulses. Auditory nerves transport these signals to the brain. They are regarded by the brain as sound.

Negatively charged electrons around a circuit flow and electricity (or electrical energy) is obtained. An electric generator converts mechanical energy into electrical energy. A typical generator has two parts: the armature and the field winding part. While the field winding part produces magnetic fields in the electric generator, the armature produces electric currents from magnetic fields. The alternating current (AC) generator and the direct current (DC) generator are commonly used. Unlike electric generators, an electric motor is used to convert electrical energy into mechanical energy. The stator holds the magnets (electromagnets or permanent magnets), and the rotor holds the electrical conductor in an electric motor. The magnetic field from the magnets applies force to the rotor as a result of the electric current flowing through the conductor. The motor rotates and produces a mechanical output as a result of this force.

Mechanical energy, which is the mechanical movement of objects, is the sum of the energy of motion, kinetic energy, and potential energy. Mechanical energy plays a critical role in everything from daily things to complex systems. Opening a door, mopping the floor, playing on a swing, using a can opener, flipping pancakes, and bouncing basketball are some of the mechanical energy examples in daily life. As an example for the calculation of kinetic energy, a Boeing 777-300 aircraft (with a max takeoff weight of 263080 kg) can be considered (Boeing, 2024). Take the cruising speed as 250 m/s (900 km/h). The kinetic energy of the plane can be calculated as: This represents the daily food energy intake of a thousand people or the full average daily energy consumption of over 40 people.

$$E_{kin} = \frac{1}{2}mv^2 = \frac{1}{2}(263080\ kg)\left(\frac{250\ m}{s}\right)^2 = 8.22\ GJ$$

Elastic potential energy (stored when an elastic object is deformed by applying a force) and gravitational potential energy (stored in an object by its height or vertical position, for example, water at the top of a waterfall) are two types of potential energy. Stretching, bending and compression require multiple forces to be acting on an object. A spring that is coiled has elastic potential energy. Spring stores elastic potential energy by compression or elongation. As the string of an archer's bow is pulled back, potential energy is stored. When the string is released, this potential energy is converted into kinetic energy, which is then transferred to the arrow, propelling it forward. When we pull to stretch a rubber band, energy is stored in it. The more you stretch the rubber band, the more energy it has.

Energy stored in the chemical bonds of the substance is called chemical energy. Types of chemical energy are petroleum, photosynthesis, wood/biomass, batteries, cellular respiration, natural gas, etc. Chemical energy is a form of energy stored within molecules and atoms. Chemical energy is realized as a result of a chemical reaction. Photosynthesis is a vital process and allows algae, plants, and some bacteria to convert light into chemical energy in glucose ($C_6H_{12}O_6$) form and can be defined as follows:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Chemical energy, such as gasoline or oil is burned to obtain kinetic energy and to run an engine. According to the conservation law of energy, the total energy of a completely isolated system is constant, can never be created or destroyed, and just can be converted from one form to another. In a closed system, various types of energy are converted into each other, but the total energy of the closed system doesn't change. Internal combustion engine converts chemical energy into kinetic energy by mixing gasoline with oxygen in a very fast combustion reaction and commonly used in vehicles. While heat is obtained as the useful output of the combustion reaction, waste products such as carbon dioxide and water vapor are released. Coal and natural gas are burned in the combustion chamber of a power plant. The heat obtained by the combustion reaction of coal or natural gas is utilized to produce water vapor at high temperatures. Eventually, vapor is utilized to turn a turbine to produce electrical energy. The amount of energy in any system consists of the initial energy of a system, the heat added or removed from the system, and the work done by or on the system.

2.3. Energy Policies and Strategies

Energy policy refers to the decisions made by lawmakers to manage energy production, consumption, storage, and distribution. These policies are critical for the functioning of modern economies, as they provide the necessary energy for industry, transportation, agriculture, and residential areas. Energy policies are crucial for ensuring sustainable energy use, economic growth, and environmental protection (Balikci, A., 2024b). They address the many aspects of energy management through a complex interaction of international cooperation, economic incentives, and regulations. In order to promote economic progress, safeguard the environment for coming generations, and match energy production and consumption with sustainable development goals, energy policies are essential. By addressing the issues brought on by climate change, they accomplish this by advancing renewable energy, improving energy efficiency, and guaranteeing energy security.

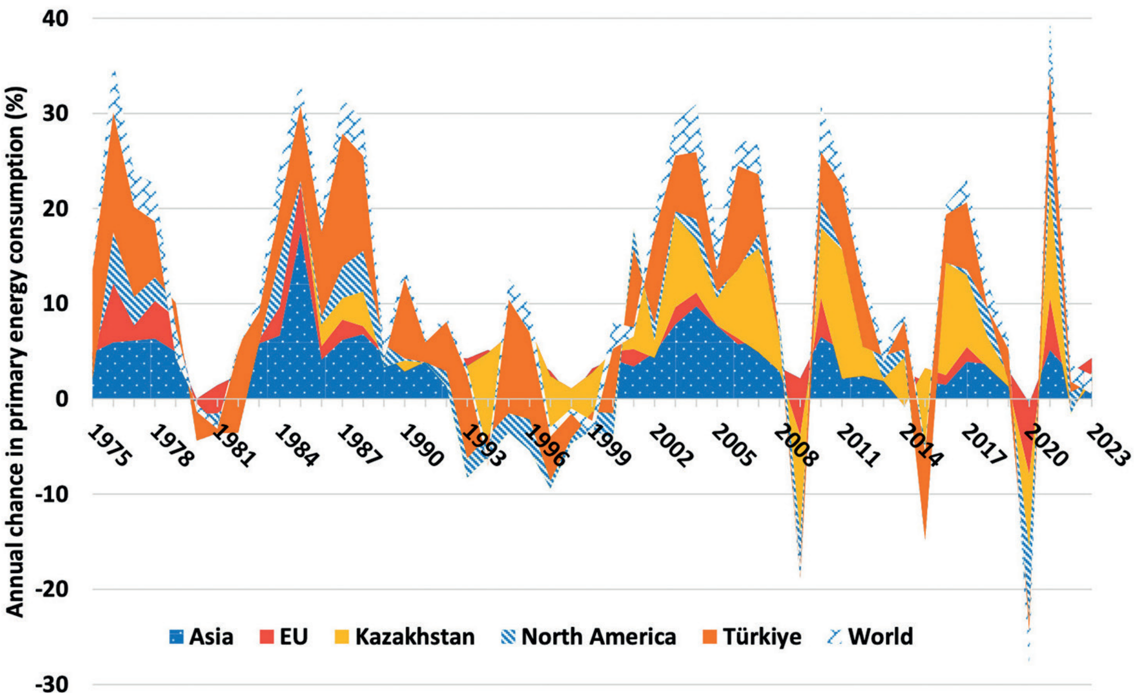
International energy policies and agreements play a significant role in shaping national energy policies. The Paris Agreement is one of the most influential agreements and aims to restrict global temperature to 1.5°C above pre-industrial levels (UNFCCC, 2018). The agreement places a strong emphasis on the adaptation of developing nations to climate change, financial assistance, and emission reductions. National policies are used to carry out the Paris Agreement, with nations establishing their goals and plans to fulfill their obligations. This adaptability enables nations to modify their strategies in accordance with their particular capabilities and situations. Countries are now developing and improving their national energy and climate policies as a result of the Paris Agreement. There are ambitious goals to reduce carbon emissions, increase energy efficiency, and adopt renewable energy. By encouraging nations to exchange innovations, best practices, and financial resources, the agreement promotes international cooperation. To address climate change and energy security, this collaboration is essential. Many countries have incorporated the goals of the Paris Agreement into their national energy strategies, focusing on transitioning to low-carbon energy systems. As a result, greater funding is being spent on novel technologies and renewable energy source-based systems.

By offering information, analysis, and suggestions to improve energy security, economic growth, and environmental preservation, the International Energy Agency (IEA) assists nations in their energy transitions (IEA, 2024a). Additionally, by establishing regional goals for carbon reductions, energy efficiency, and renewable energy, several regional accords, including the European Union's National Energy and Climate Plans (NECP, 2024), complement the goals of the Paris Agreement. National energy strategies are greatly influenced by international energy agreements and policies, such as the Paris Agreement, which encourages nations to cooperate on global climate goals and embrace sustainable energy methods. To execute energy policies that are suited to the needs and resources of the region, local governments are essential.

To determine whether solar, wind, or biomass resources are accessible for use in producing useful energy, local governments frequently carry out assessments. This enables them to create policies that reduce dependency on outside energy sources and optimize the use of regional resources. By interacting with local communities, energy policies can be customized to fit particular needs and preferences. Creating more efficient and well-liked policy measures may involve talking with businesses and households to learn about their preferences and usage patterns for energy. Many municipal governments undertake projects that focus on generating and using energy locally. This can include community-owned renewable energy projects, which not only offer electricity to local users but also give economic advantages to the community. Local governments often implement energy efficiency standards and building codes that exceed national requirements. These "reach codes" can drive significant improvements in energy efficiency in new and existing buildings. Local governments may invest in infrastructure improvements, such as smart grids or district heating systems, to enhance energy efficiency and reliability. These projects can be tailored to address specific local challenges, such as grid constraints or high energy costs. To support energy projects, local governments might develop innovative financing mechanisms, such as local energy funds or public-private partnerships, which can provide the capital required for energy efficiency and renewable energy-based projects.

Figure 7

Changes in primary energy consumption [Data from (US EIA, 2024a)]



The annual changes in primary energy consumption for Kazakhstan, Türkiye, countries in Asia, North America, the European Union, and the rest of the world from 1975 to 2023 are displayed in Figure 7. Over the years, energy consumption has fluctuated significantly, experiencing both periods of increase and fall. Energy consumption has continuously increased at the fastest rate in Asia, with certain years seeing extremely significant rises. Energy consumption in the EU fluctuates dramatically, experiencing both periods of rapid increase and reduction. Compared to other regions, North America has demonstrated a more gradual growth with less severe change. During this time, the energy consumption of Türkiye has been steadily raised.

Energy policies are often integrated with broader urban planning efforts, including transportation, land use, and housing policies. This comprehensive approach ensures that energy considerations are embedded in all aspects of local development. Local governments provide training and resources to ensure that municipal staff and local businesses have the skills and knowledge needed to implement energy policies effectively. This can include training on new technologies, energy management practices, and regulatory compliance. Energy policies often include laws and regulations that govern energy production and consumption. These can involve setting standards for energy efficiency, emissions, and the use of renewable energy sources. Many energy policies are influenced by international agreements aimed at addressing global issues like climate change.

Energy policies can also involve public policy measures such as economic modeling, energy planning, and the use of social sciences to understand consumer behavior and improve energy conservation. Clean energy transition (including renewable, hydropower, and nuclear) is a critical component of global efforts to address climate change, reduce greenhouse gas emissions, and transition to a sustainable energy future.

Figure 8

Bridges between industry, academia, and government for development [Modified from (Dincer & Aydin, 2023)]

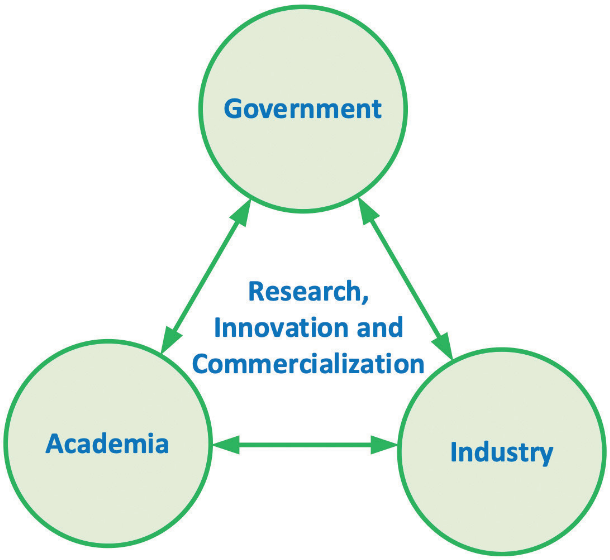


Figure 8 describes the bridges that must be established in order to establish an initiative. In this regard, establishing a link between business and academia is essential to the development of any area. Infrastructure development for this partnership is contingent upon government policy and assistance. As a result, industry and academia ought to collaborate to develop engineering studies by fusing industrial expertise with academic research infrastructure. This could involve creating new systems, improving current ones, integrating clean technology and renewable energy, standardizing procedures, and putting in place a framework for occupational health and safety.

The renewable energy sector has witnessed significant growth, driven by increased investments and supportive government policies. Policies and incentives to promote renewable energy adoption are implemented by many countries. This includes tax credits, subsidies, and mandates for renewable energy usage, which have spurred investment in clean technologies.

Solar energy has become increasingly competitive due to the falling costs of photovoltaic technology and advancements in energy storage systems. This has led to a significant increase in solar capacity and its share of global electricity generation. Both onshore and offshore wind energy have seen substantial growth. Offshore wind, in particular, is poised for major expansion due to technological advancements in turbine design and installation, making it a more viable option for clean energy generation. When electricity is generated by renewable energy sources air pollutants or greenhouse gases do not emit. In this way, it contributes to cleaner air and a reduction in the impacts of climate change. The development of green hydrogen and biofuels, along with advancements in energy storage, are emerging trends that complement traditional renewable energy sources and support the global energy transition. Improving energy efficiency and reducing consumption are vital strategies for achieving both economic and environmental benefits.

Energy-efficient appliances and devices are also promising ways to reduce energy consumption. Energy efficiency and saving are considered energy sources. This includes installing LED lighting or energy-efficient devices in buildings, energy-efficient HVAC systems, and high-efficiency engines in industry or vehicles. Energy efficiency and energy saving are possible with energy management. Implementing energy management systems allows businesses and households to control energy usage, determine inefficiencies, and optimize energy consumption. Encouraging simple behavioral changes, such as using programmable thermostats, turning off devices or lights when not in use, and reducing water heating temperatures, can contribute to energy savings. Energy efficiency leads to lower energy bills, providing immediate financial savings for households and businesses. This frees up resources for other investments or necessities. Properties with energy-efficient features often have higher market values, making them more attractive to buyers and investors. Energy-efficient systems and appliances tend to have longer lifespans and require less maintenance, leading to further cost savings over time. By reducing energy consumption, businesses and households can shield themselves from fluctuations in energy prices, ensuring more stable operational costs. Energy efficiency reduces the demand for energy production, which in turn lowers CO_2 and NOx emissions from power plants. When less energy is used, there is less demand for fossil fuels and other natural resources, leading to their conservation and reduced environmental impact. Reducing energy consumption decreases pollution and emissions, leading to cleaner air and water, and protecting ecosystems.

Innovative smart grids and energy storage systems play a critical role in advancing energy policies. These technologies are essential for enhancing the reliability, efficiency, and sustainability of modern systems. Smart grids are advanced electrical grids that incorporate digital communication technology to improve the monitoring, control, and efficiency of electricity distribution. Integration of renewable energy-based systems can be facilitated by smart grids by managing their intermittent nature. They allow for real-time adjustments to electricity supply and demand. By using communication technics and advanced sensors, smart grids can detect and respond to outages or faults, improving grid reliability and reducing downtime. Smart grids allow consumers to monitor their energy usage and participate in demand response programs. This can lead to more efficient energy consumption and cost savings.

Figure 9

Primary energy consumption in selected regions [Data from (US EIA, 2024b)]

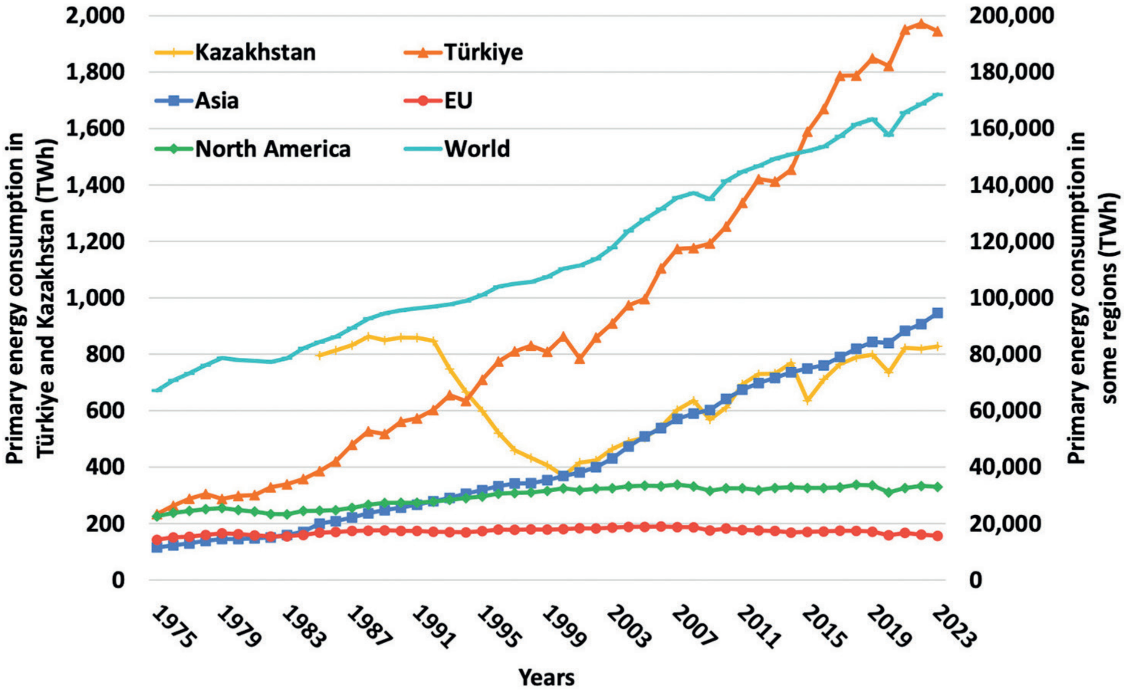


Figure 9 shows a growing global energy demand in the regions selected such as Kazakhstan, Türkiye, European Union countries, Asia, North America, and the World from 1976 to 2023. Türkiye has had a consistent and substantial rise in energy consumption throughout the period. European Union countries have a steady increase in energy consumption, with a noticeable uptick from 2000 onward. The average consumption of the world has a clear upward trend, mirroring the combined energy consumption of all regions.

Energy storage systems are vital to balance the electricity supply and demand, particularly when integrating renewable energy. Excess energy is stored by energy storage subsystems and the grid stabilizes the energy management. This reduces the additional power plant requirements and infrastructure upgrades. By storing energy generated from renewable sources, energy storage subsystems enable a more consistent and reliable power supply. Despite their benefits, research and development should be conducted to deal with challenges such as limited energy capacity, high initial costs, and environmental concerns related to the production and disposal of storage technologies.

Climate change caused significant challenges that require comprehensive and coordinated efforts to address. Energy policy has a crucial role in reducing the effects of climate change through various strategies. It is a global issue that affects regions differently, requiring international cooperation to address its impacts effectively. GHG emissions in one part of the world can have far-reaching consequences in others, making global coordination essential. The increasing frequency and intensity of storms, wildfires, and other climate-related disasters are direct consequences of climate change, leading to widespread environmental and economic damage.

Energy policies that promote energy efficiency and clean energy are critical for reducing emissions by decreasing fossil fuel reliance which is the major contributor to greenhouse gas emissions. Policies that set standards for appliances, buildings, and vehicles can reduce emissions by reducing energy consumption. Supporting the development of new technologies, such as smart grids and energy storage, can enhance the resilience and sustainability of energy systems. These technologies help integrate renewable energy sources and improve grid efficiency.

Investing in clean energy provides numerous economic opportunities, including new jobs and technological innovation. The clean energy sector is generating a wide range of jobs across various stages of the value chain. This includes roles for engineers, technicians, and construction workers involved in building and maintaining renewable energy infrastructure. The clean energy sector has shown significant potential for job creation. Renewable energy projects often stimulate local economies, particularly in rural areas, by creating jobs and increasing demand for local services and infrastructure. This can lead to economic revitalization in regions that might otherwise have limited economic activity. Investment in clean energy spurs innovation, leading to the development of new energy storage subsystems, electric vehicles, and smart grids. These technologies improve energy efficiency and reliability; and also create new business opportunities and industries. The push for cleaner energy solutions drives research and development in fields like energy storage and renewable energy technologies. The clean energy sector contributes to economic diversification by creating new industries and business opportunities. This can lead to increased entrepreneurial activity and investment, enhancing overall economic growth and stability.

Implementing energy policies has several challenges, such as political, social, and economic barriers. Inconsistent or frequently changing energy policies mean uncertainty for stakeholders and investors. In an inconsistent situation, making plans and securing financing are difficult for long-term projects. This instability can deter investment in renewable energy and energy efficiency initiatives. Different authorities may have varying policies and regulations, leading to a lack of harmonization and coordination. This fragmentation can complicate the development of energy projects and increase administrative burdens. Insufficient financial incentives, such as tax credits, subsidies, or feed-in tariffs, can hinder the competitiveness of renewable energy sources compared to fossil fuels. Without adequate incentives, the high upfront costs of renewable energy technologies can be prohibitive for many investors. Substantial investment requirements in infrastructure and technology can be a significant barrier, especially in regions with limited access to capital. Resistance from local communities or stakeholders can delay or block energy projects. Concerns may include environmental impacts, changes to local landscapes, or perceived health risks associated with new technologies. Insufficient public awareness of renewable energy and energy efficiency can impede policy implementation. Educating the public and stakeholders about the long-term benefits of sustainable energy practices is crucial for gaining support. Establishing clear, stable, and long-term energy policies can provide the certainty needed for investment and project development. This includes setting consistent targets and providing transparent regulatory frameworks. Simplifying and expediting permitting procedures can reduce delays and administrative burdens, making it easier to implement energy projects. Encouraging collaboration among governments, industry, and communities can help align interests and facilitate the deployment of energy projects. This includes harmonizing regulations across authorities and engaging stakeholders in decision-making processes.

There are many successful examples from all over the world. For example, Sweden reached its target of 50% renewable energy in 2012, eight years ahead of schedule (SI, 2024). The country utilizes a mix of wind, bioenergy, solar, and even innovative solutions like using body heat from commuters to heat buildings. Sweden aims for 100% fossil-free electricity production by 2040.

Costa Rica has consistently generated its electricity from renewable energy and hydropower for several years. Costa Rica holds the world record for the most consecutive days using solely renewable energy (TCS, 2024). The UK has installed power in offshore wind energy. The UK plans to increase its capacity fourfold by 2030 as part of its strategy to decarbonize its power system by 2035. Germany has set ambitious targets, aiming for 80% renewable power by 2030 and nearly 100% by 2035 (IEA, 2024a).

In 2022, renewables accounted for 46.9% of the power consumption of Germany, marking a significant increase from previous years. Uruguay has transformed its energy landscape, with more than 90% of its electricity generated from renewable sources in 2022 (IEA, 2024a). The country has rapidly increased its wind power capacity, achieving a significant shift in its energy mix within a few years. Lake Turkana Wind Power Project in Kenya is the largest wind farm in Africa, providing enough energy to supply one million homes. The biggest private investment in Kenyan history is attracted to this initiative, displaying the potential for developments in renewable energy (Cormack & Kurewa, 2018).

Figure 10

Global primary energy consumption [Data from (Energy Institute, 2024a)]

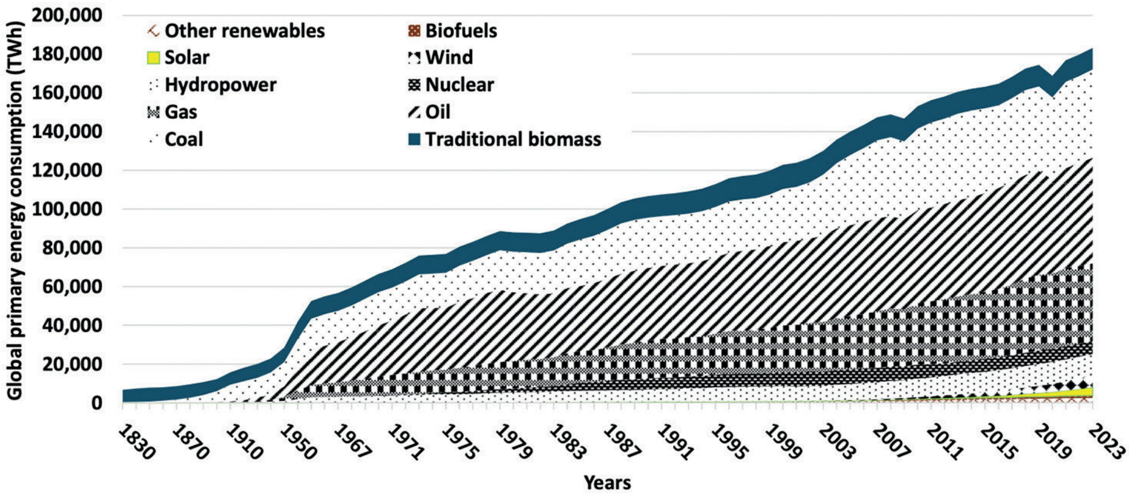


Figure 10 shows the global primary energy consumption in TWh starting in the 1800s. Global consumption was 180,000 TWh as of 2023 and fossil fuels (coal, gas, and oil) met 76.5% of this demand. In 2013, 2.7% of demand was met by renewable energy; by 2023, that percentage had risen to 7.7%. Global primary energy consumption has significantly increased over the period depicted.

The successful energy policies and strategies implemented by countries like Sweden, Costa Rica, the United Kingdom, Germany, Uruguay, and Kenya offer valuable lessons that can be applied elsewhere to promote renewable energy and enhance energy efficiency.

Oil, coal, and gas have been the dominant sources of primary energy consumption. While fossil fuels still dominate, there has been a noticeable increase in the consumption of hydropower, wind, solar, and biofuels in recent decades. Countries with successful energy transitions often set ambitious, long-term goals for the adoption of renewable energy and emissions reductions. Establishing clear and stable policy frameworks provides certainty for stakeholders and investors, encouraging investment in renewable energy infrastructure and technologies.

Support and stable policies, such as subsidies, tax incentives, and feed-in tariffs, are crucial for the development of clean energy sectors. These policies help reduce financial risks. Successful countries have effectively assessed and utilized their local wind, hydro, solar, and geothermal energy. Tailoring energy strategies to leverage these resources can maximize efficiency and cost-effectiveness. Smart grids and energy storage subsystems enhance the integration and reliability of clean energy-based systems.

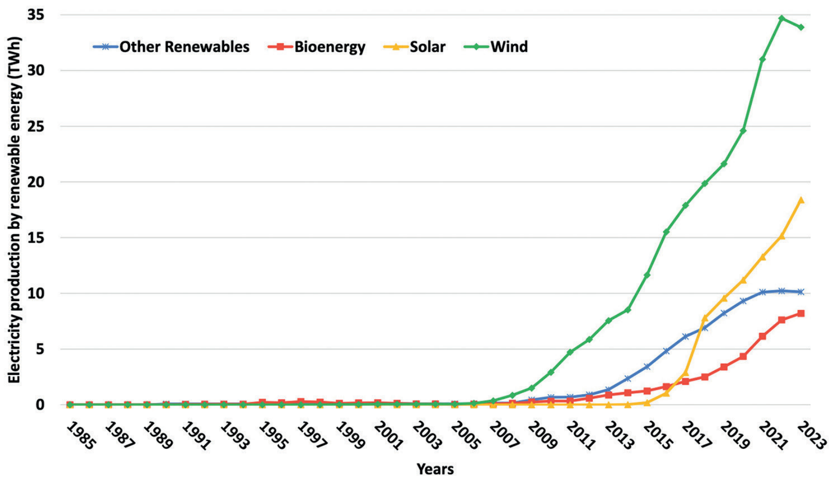
Investing in technology can drive development and improve energy systems. Public support and acceptability of renewable energy projects are increased when local communities are involved in their design and development. Transparent communication and involvement in decision-making processes can address concerns and build trust. Raising public awareness about clean energy and energy efficiency benefits is essential for gaining widespread support.

Educational campaigns and programs can encourage behavioral changes and increase acceptance of new technologies. International collaboration and knowledge sharing can accelerate the adoption of successful energy policies and strategies. Countries can learn from each other's experiences and adapt best practices to their specific contexts. Regional cooperation, such as shared energy markets and infrastructure, can enhance energy security and efficiency. Collaborative efforts can help optimize resource use and balance supply and demand across borders.

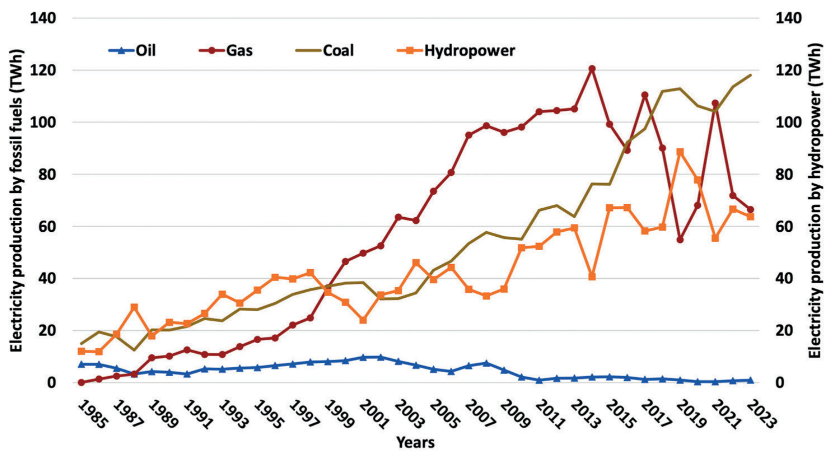
Figure 11

Electricity production in Türkiye by (a) renewable energy and (b) fossil fuels and hydropower [Data from (Energy Institute, 2024b)]

(a)



(b)



The annual electricity production of Türkiye by source is given in Figure 11 by focusing on the impressive growth of electricity production from renewable energy-based power plants in Türkiye from the 2010s onward. Notably, wind turbines have seen the most significant increase, reaching a production of approximately 35 TWh by 2023. Electricity generation by solar PV panels has also had substantial growth, increasing from around 18 TWh. Natural gas-based power systems have shown a consistent increase, reaching approximately 65 TWh by 2023, with a fluctuation. Hydropower plants and their electricity generation have also fluctuated, with a peak production of around 88.6 TWh in 2019. Future directions of the energy policies and strategies can be emphasized as follows:

- Achieving net-zero emissions is a complex challenge that requires a combination of policy measures and technological advancements.
- Establishing clear, science-based targets helps align national and corporate strategies with global climate goals. These targets should focus on deep emission cuts and include interim milestones to ensure progress is on track.
- Net-zero objectives should be embedded into the core strategies of businesses and governments. This includes incorporating climate considerations into financial planning, risk management, and operational decisions.
- Emission reductions can be encouraged by putting in place carbon pricing mechanisms like carbon taxes or cap-and-trade schemes by making fossil fuel use more expensive and clean energy more competitive.
- Governments can support the transition by setting regulations and standards that promote energy efficiency and renewable energy adoption. This includes building codes, vehicle emissions standards, and renewable energy mandates.
- Expanding the use of clean energy sources, such as solar and wind, and increasing electrification in various sectors are critical for reducing emissions. This transition requires critical investment in research and development.
- Carbon capture, utilization, and storage (CCUS) technologies are essential for mitigating emissions from hard-to-abate sectors like heavy industry and power generation. These technologies capture CO_2 emissions at the source and store or utilize them, reducing their impact on the atmosphere.
- Developing and deploying hydrogen as a clean energy carrier can help decarbonize sectors such as transportation and industry. Hydrogen production and use are expected to grow significantly, contributing to emissions reductions.
- Improving energy efficiency across all sectors can substantially reduce energy consumption and emissions. This includes adopting smart technologies, optimizing industrial processes, and enhancing building efficiency.
- Accelerating the development and scaling of climate technologies requires collaboration across industries, governments, and research institutions. This cooperation can facilitate the creation of new value chains and industrial ecosystems necessary for the net-zero transition.
- Cooperation between universities, government, and industry on a global scale is crucial in addressing global energy challenges, as it facilitates the sharing of resources, knowledge, and technology necessary for a sustainable energy transition.
- Energy security is a global concern that requires coordinated efforts to ensure stable and reliable energy supplies. International cooperation can help diversify energy sources and reduce dependency on a single supplier or region, thereby enhancing global energy security.

- Achieving the goals of the Paris Agreement and limiting global warming requires collective action. International cooperations develop joint strategies and mobilize resources to reduce emissions and promote clean energy systems.
- Collaboration across borders facilitates the development of clean energy technologies. Initiatives like Mission Innovation foster investment in research and innovation, making clean energy more affordable and accessible. This also includes technology transfer to developing countries, helping them leapfrog to sustainable energy systems.
- Strengthening regional collaborations can address specific energy challenges and leverage local resources. For instance, pan-African platforms focus on improving energy access and food security by uniting stakeholders across countries.
- Countries can enter into bilateral or multilateral agreements to pool resources, share risks, and set common standards for energy projects. Such agreements facilitate the development of clean technologies and support a diverse global portfolio of energy solutions.
- Organizations and initiatives play a critical role in coordinating international efforts, setting standards, and providing policy support.
- Providing training and resources to enhance the capabilities of energy planners and policymakers is essential. Programs that offer technical assistance and promote best practices can help assistance implement effective energy policies and technologies.

In conclusion, energy policies are essential tools for mitigating the effects of climate change. However, addressing climate change also requires overcoming political, economic, and social challenges, necessitating strong leadership and global cooperation. Addressing these challenges is vital for the successful application of energy policies. Investing in clean energy offers substantial economic benefits and helps mitigate climate change. Local governments are uniquely positioned to implement energy policies that reflect the specific needs and resources of their communities. The shift towards renewable energy is not only crucial for mitigating climate change but also offers economic and environmental benefits. Energy efficiency is a crucial component of sustainable development strategies. Smart grids and energy storage solutions are transformative technologies that support the transition to a more resilient and sustainable energy system.

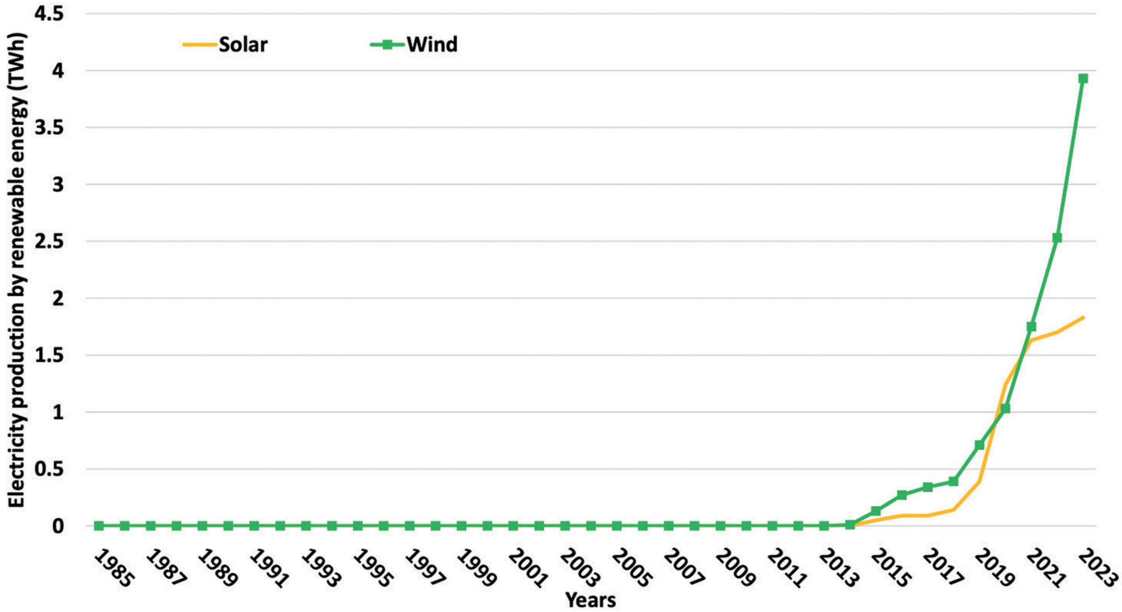
By overcoming political, economic, and social barriers, countries can advance their energy transitions and achieve their sustainability goals. The approach of each country reflects its unique resources and capabilities, demonstrating the diverse strategies that can be employed to achieve energy sustainability. By combining energy policy measures and technological advancements, countries and businesses can work towards achieving net-zero emissions. International cooperation is essential for overcoming the complex challenges of the global energy transition. By working together, countries can achieve more significant progress in energy security, climate change mitigation, and technological innovation, ultimately leading to a more sustainable and resilient global energy system.

Annually electricity production, and the significant growth, of Kazakhstan by source from 1985 onwards are given in Figure 12 (a) and (b). Wind and solar energy harvest have a gradual increase throughout the years, but still 5.06% of the total electricity generation. Coal has been the dominant source, with production reaching a peak of around 76.8 TWh in 2022. Hydropower has remained relatively stable, fluctuating between 5 and 12 TWh throughout the period.

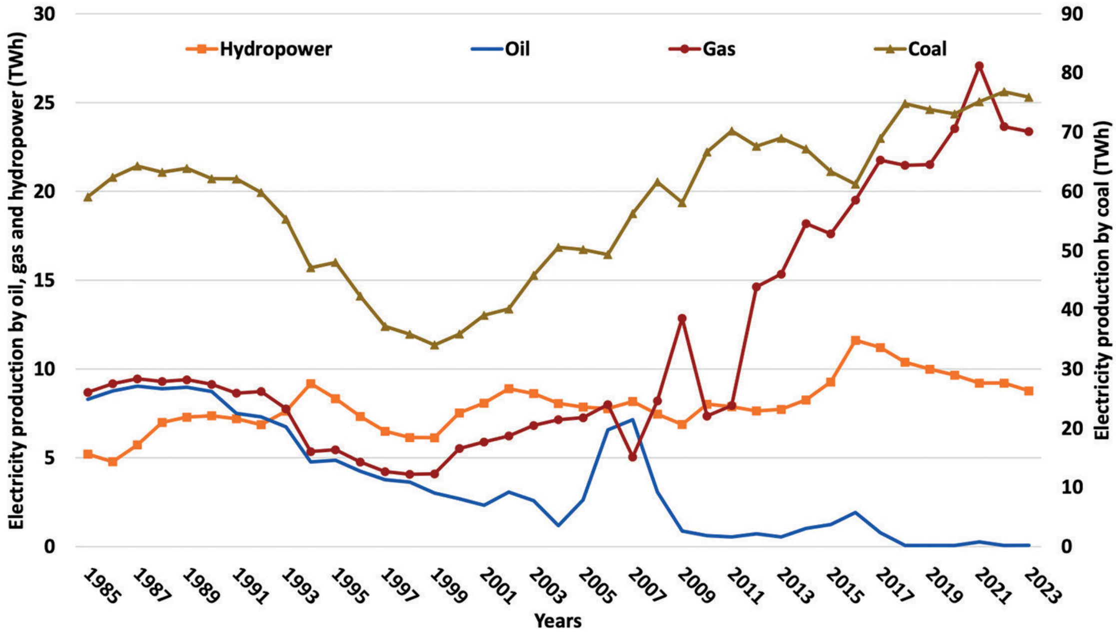
Figure 12

Electricity production in Kazakhstan by (a) renewable energy and (b) fossil fuels and hydropower [Data from (Energy Institute, 2024b)]

(a)



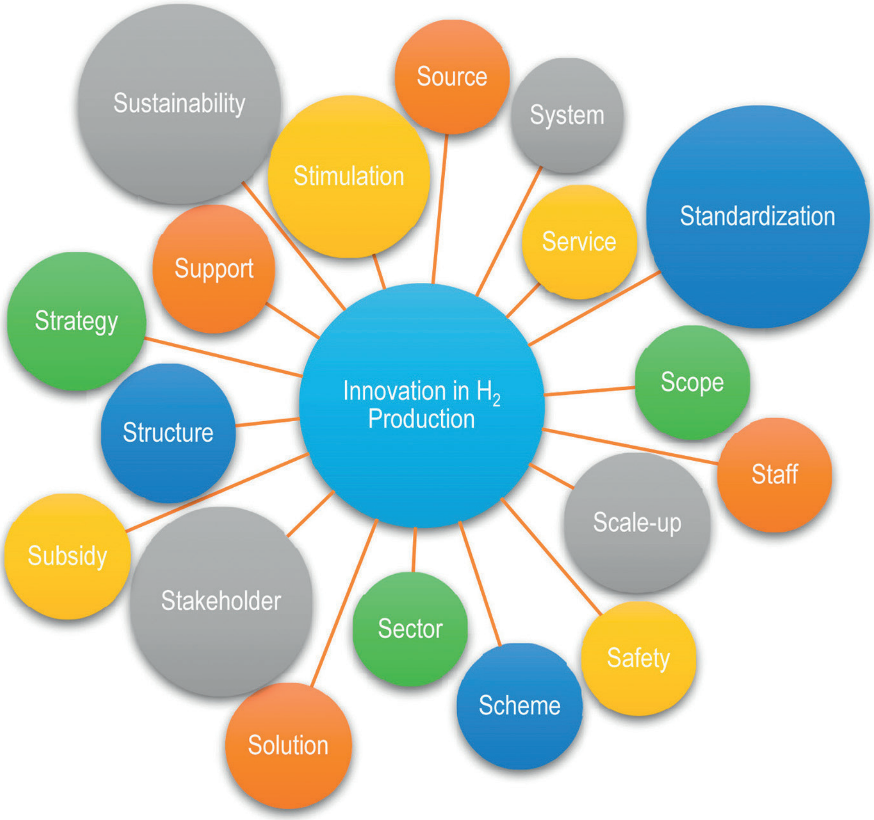
(b)



2.4. Energy and Innovation

Innovations in renewable energy projects have the power to solve the problems caused by climate change and modify the global energy landscape. Researchers and engineers are creating ground-breaking solutions that optimize energy generation, storage, and distribution efficiency while reducing environmental consequences as technology advances and investments in renewable energy rise (Baba, 2024a).

Figure 13
18S approach introduced to describe innovation in hydrogen production [Taken from (Dincer & Acar, 2017)].



The 18S idea, which is given in Figure 13, is a crucial method for identifying where we must work, comprehend, analyze, assess, and apply in order to accomplish a seamless transition to the hydrogen economy, introduces the components and dimensions of innovation in hydrogen production in this section (Dincer & Acar, 2017). This idea includes sustainability, source, solution, system, staff, service, scope, safety, scale-up, stakeholder, scheme, sector, standardization, subsidy, stimulation, structure, strategy, and support. The roles of these particular ideas are significant and should be considered for innovative solutions.

Innovation in Solar Energy

Solar energy production is becoming more economical and efficient thanks to next-generation photovoltaic technologies. Advancements such as multi-junction, tandem, and perovskite solar cells are increasing the efficiency of solar panels and broadening their range of applications. Monolithic perovskite/silicon solar cells offer up to 29% efficiency (Al-Ashouri et al., 2020). A 32.5% efficiency for perovskite/silicon tandem solar cells has been confirmed by the European Solar Test Installation (Ašmontas & Mujahid, 2023). However, stability and degradation in real-world conditions remain challenges.

Multi-junction cells layer multiple semiconductor materials to achieve efficiencies over 40% under concentrated sunlight (US DOE, 2024a). Advances in manufacturing processes, such as roll-to-roll printing for perovskite cells, aim to reduce costs. Improved encapsulation methods are being developed to protect perovskite cells from moisture and heat.

Bifacial solar cells use two sides to capture light, increasing efficiency but requiring robust materials to withstand environmental stress. Research on materials is focused on finding abundant and non-toxic materials to replace rare earth elements (i.e., indium and gallium). Integration with high-capacity batteries, H_2 production, and hybrid systems to store solar energy efficiently.

New modular design concentrated solar power (CSP) systems aim to reduce costs and improve scalability. Enhancements in molten salt storage systems to reduce costs and improve thermal efficiency. Research into using cheaper and more abundant materials for thermal storage. Creation of materials, such as sophisticated ceramics and alloys, which are resistant to high temperatures and corrosive conditions. Using superheated air at normal atmospheric pressure to improve efficiency and reduce complexity.

A potential invention that makes it possible to use solar energy on almost any surface is solar paints and coatings. Because of these photovoltaic qualities, materials, structures, automobiles, and even outdoor furniture can produce electricity when exposed to sunshine. By incorporating transparent solar cells into the glass, solar windows turn ordinary windows into resources that can produce electricity. Since this innovation effortlessly integrates energy generation with the current infrastructure, it has a great deal of potential for widespread implementation.

Innovation in Wind Energy

By allowing deployments in deep oceans where conventional permanent foundations are impractical, floating wind farms are transforming the production of offshore wind energy. These floating platforms make use of the steady and powerful winds found in offshore areas by utilizing sophisticated mooring systems. A strong substitute for conventional horizontal axis wind turbines is provided by vertical axis wind turbines (VAWTs). Because VAWTs can capture wind from any direction, they are appropriate for metropolitan settings and places with intricate wind patterns. Large kites attached to the ground are used in kite wind energy systems to harness high-altitude winds. Compared to traditional wind turbines, kites use fewer resources and provide a sizable amount of renewable energy.

Innovation in Hydropower Systems and Ocean Energy

Electricity is produced by utilizing the steady and predictable flow of ocean tides which is called tidal power. Innovations in tidal power systems include underwater turbines, which efficiently transform tidal energy into electrical power. Without the need for massive dams, run-of-river hydroelectric systems use the natural flow of rivers to produce electricity. These technologies enable more flexible installation and operation and have less of an impact on the environment. Utilizing the kinetic energy of ocean currents, underwater turbines produce renewable electricity. These innovative turbines offer a continuous and dependable source of clean electricity and may be placed in a variety of settings, including along coastlines and in the currents of the ocean.

3. Fundamental Principles and Concepts in Thermodynamics

3.1. Thermodynamic Principles and Concepts

Thermodynamic analyses are performed through an exergy and energy approach. Balance equations including mass, energy, entropy, and exergy are written for each subsystem in an energy-related system (Dincer, 2024a).

Mass Balance Equation

The mass balance equation, which also describes the conservation of mass, (in a general form) for a subsystem can be expressed as follows:

$$\dot{m}_{in} = \dot{m}_{out}$$

Here, in and out refer inlet and outlet of a particular device.

Energy Balance Equation

The general energy balance equation by considering the first law of thermodynamics for a subsystem can be expressed as follows:

$$\dot{m}_{in}h_{in} + \dot{Q}_{in} + \dot{W}_{in} = \dot{m}_{out}h_{out} + \dot{Q}_{out} + \dot{W}_{\mathrm{out}}$$

where $\dot{Q}$ and $\dot{W}$ are heat and work rates for both input and output.

Entropy Balance Equation

According to the second law of thermodynamics, entropy is generated *($\dot{S}_{gen}$)* during an irreversible process. The entropy balance equation (in general form) for a subsystem can be expressed as follows:

$$\dot{m}_{in}s_{in} + \frac{\dot{Q}_{in}}{T_s} + \dot{S}_{gen} = \dot{m}_{out}s_{out} + \frac{\dot{Q}_{out}}{T_b}$$

$$\Delta S = \frac{Q}{T}$$

$$\Delta S_{total} = \Delta S_{system} + \Delta S_{surrounding}$$

Here s and b refer to source and boundary.

Exergy Balance Equation

Exergy is destroyed during entropy generation in a process or device. The exergy balance equation (in a general form) for a device can be expressed as follows:

$$\dot{m}_{in}ex_{in} + \dot{E}x^{Q_{in}} + \dot{W}_{in} = \dot{m}_{out}ex_{out} + \dot{E}x^{Q_{out}} + \dot{W}_{out} + \dot{E}x_d$$

$$\dot{E}x^{Q_{in}} = \left(1 - \frac{T_0}{T_s}\right)\dot{Q}_{in}$$

$$\dot{E}x^{Q_{out}} = \left(1 - \frac{T_0}{T_b}\right)\dot{Q}_{out}$$

$$\dot{E}x_d = T_0\dot{S}_{gen}$$

Specific exergy *(ex)* for open and closed systems can be defined as follows, respectively:

$$ex_i = (h_i - h_0) - T_0(s_i - s_0)$$

$$ex_i = (u_i - u_0) - T_0(s_i - s_0)$$

Thus, the relation between enthalpy and internal energy can be defined as follows:

$$h = u + Pv$$

Each balance equation should be written for the particular subsystems. As an example, the balance equations of a few subsystems, which are commonly utilized in integrated systems, are given below:

Compressor

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{W}_{comp} = \dot{m}_{out}h_{out}$$

$$\dot{m}_{in}s_{in} + \dot{S}_{gen;comp} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{in}ex_{in} + \dot{W}_{comp} = \dot{m}_{out}ex_{out} + \dot{E}x_{d;comp}$$

Pump

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{W}_{P} = \dot{m}_{out}h_{out}$$

$$\dot{m}_{in}s_{in} + \dot{S}_{gen;P} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{in}ex_{in} + \dot{W}_{P} = \dot{m}_{out}ex_{out} + \dot{E}x_{d;P}$$

Combustion Chamber

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{Q}_{fuel} = \dot{m}_{out}h_{out}$$

$$\dot{m}_{in}s_{in} + \frac{\dot{Q}_{fuel}}{T_{fuel}} + \dot{S}_{gen;CC} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{in}ex_{in} + \dot{E}x^{Q_{fuel}} = \dot{m}_{out}ex_{out} + \dot{E}x_{d;CC}$$

Turbine (both for gas and steam turbines, also, equations can be written separately for high-pressure, medium-pressure, and low-pressure turbines)

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} = \dot{m}_{out}h_{out} + \dot{W}_{\mathrm{T}}$$

$$\dot{m}_{in}s_{in} + \dot{S}_{gen;T} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{3}ex_{3} = \dot{m}_{4}ex_{4} + \dot{W}_{T} + \dot{E}x_{d;T}$$

Separator

$$\dot{m}_{in} = \dot{m}_{out-I} + \dot{m}_{out-II}$$

$$\dot{m}_{in}h_{in} = \dot{m}_{out-I}h_{out-I} + \dot{m}_{out-II}h_{out-II}$$

$$\dot{m}_{in}s_{in} + \dot{S}_{gen;sep} = \dot{m}_{out-I}s_{out-I} + \dot{m}_{out-II}s_{out-II}$$

$$\dot{m}_{in}ex_{in} = \dot{m}_{out-I}ex_{out-I} + \dot{m}_{out-II}ex_{out-II} + \dot{E}x_{d;sep}$$

Parabolic Solar Collector

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{Q}_{solar} = \dot{m}_{out}h_{out}$$

$$\dot{m}_{in}s_{in} + \frac{\dot{Q}_{solar}}{T_{sun}} + \dot{S}_{gen;solar} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{in}ex_{in} + \dot{E}x^{Q_{solar}} = \dot{m}_{out}ex_{out} + \dot{E}x_{d;solar}$$

Condenser

$$\dot{m}_{in}h_{in} = \dot{m}_{out}h_{out} + \dot{Q}_{cond}$$

$$\dot{m}_{in}s_{in} + \dot{S}_{gen;cond} = \dot{m}_{out}s_{out} + \frac{\dot{Q}_{cond}}{T_b}$$

$$\dot{m}_{in}ex_{in} = \dot{m}_{out}ex_{out} + \dot{E}x^{Q_{cond}} + \dot{E}x_{d;Cond}$$

Electrolyzer

$$\dot{m}_{in,water} = \dot{m}_{out,H_2} + \dot{m}_{out,O_2}$$

$$\dot{m}_{in,water}h_{in,water} + \dot{W}_{EL} = \dot{m}_{out,H_2}h_{out,H_2} + \dot{m}_{out,O_2}h_{out,O_2}$$

$$\dot{m}_{in,water}s_{in,water} + \dot{S}_{gen;EL} = \dot{m}_{out,H_2}s_{out,H_2} + \dot{m}_{out,O_2}s_{out,O_2}$$

$$\dot{m}_{in,water}ex_{in,water} + \dot{W}_{EL} = \dot{m}_{out,H_2}ex_{out,H_2} + \dot{m}_{out,O_2}ex_{out,O_2} + \dot{E}x_{d;EL}$$

Heat Exchanger (or HRSG)

The first fluid transfers its heat into another fluid (heat rejection process):

$$\dot{m}_{in-I} = \dot{m}_{out-I}$$

$$\dot{m}_{in-I}h_{in-I} = \dot{m}_{out-I}h_{out-I} + \dot{Q}_{HRSG}$$

$$\dot{m}_{in-I}s_{in-I} + \dot{S}_{gen;HRSG} = \dot{m}_{out-I}s_{out-I} + \frac{\dot{Q}_{HRSG}}{T_b}$$

$$\dot{m}_{in-I}ex_{in-I} = \dot{m}_{out-I}ex_{out-I} + \dot{E}x^{Q_{HRSG}} + \dot{E}x_{d;HRSG}$$

The second fluid which obtains heat from the other fluid (heat addition process):

$$\dot{m}_{in-II} = \dot{m}_{out-II}$$

$$\dot{m}_{in-II}h_{in-II} + \dot{Q}_{HRSG} = \dot{m}_{out-II}h_{out-II} \qquad \textit{(with a 100\% of heat transfer)}$$

$$\dot{m}_{in-II}s_{in-II} + \frac{\dot{Q}_{HRSG}}{T_s} + \dot{S}_{gen;HRSG} = \dot{m}_{out-II}s_{out-II}$$

$$\dot{m}_{in-II}ex_{in-II} + \dot{E}x^{Q_{HRSG}} = \dot{m}_{out-II}ex_{out-II} + \dot{E}x_{d;HRSG}$$

Expansion valve (where throttling occurs)

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} = \dot{m}_{out}h_{out} \ \textit{so;}\ h_3 = h_4$$

$$\dot{m}_r s_3 + \dot{S}_{gen;EV} = \dot{m}_r s_4$$

$$\dot{m}_{in}ex_{in} = \dot{m}_{out}ex_{out} + \dot{E}x_{D;EV}$$

in the evaporator; constant-pressure heat absorption ($\dot{Q}_{EVP}$ or $\dot{Q}_L$)

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{Q}_{EVP} = \dot{m}_{out}h_{out}$$

$$\dot{m}_{in}s_{in} + \frac{\dot{Q}_{EVP}}{T_{EVP}} + \dot{S}_{gen;EVP} = \dot{m}_{out}s_{out}$$

$$\dot{m}_{in}ex_{in} + \dot{E}x^{Q_{EVP}} = \dot{m}_{out}ex_{out} + \dot{E}x_{D;EVP}$$

The heating or cooling section of an air conditioning unit

$$\dot{m}_{in} = \dot{m}_{out}$$

$$\dot{m}_{in}h_{in} + \dot{Q}_{in;AC} = \dot{m}_{out}h_{out} + \dot{Q}_{out;AC}$$

$$\dot{m}_{in}s_{in} + \frac{\dot{Q}_{in;AC}}{T_s} + \dot{S}_{gen;AC} = \dot{m}_{out}s_{out} + \frac{\dot{Q}_{out;AC}}{T_b}$$

$$\dot{m}_{in}ex_{in} + \dot{Ex}^{Q_{in;AC}} = \dot{m}_{out}ex_{out} + \dot{Ex}^{Q_{out;AC}} + \dot{Ex}_D$$

Balance equations of the heating or cooling section of an air conditioning unit can be also written separately for air and water. Here, enthalpy, as a function of air and water vapor, can be written as follows:

$$h = h_a + \omega h_g$$

3.2. System Analysis and Efficiency Evaluation

The energy and exergy efficiencies of the overall system (such as an integrated system) can be expressed as follows:

$$\eta_{en} = \frac{\dot{W}_{net} + \dot{Q}_{useful}}{\dot{Q}_{in}}$$

$$\eta_{ex} = \frac{\dot{W}_{net} + \dot{Ex}^{Q_{useful}}}{\dot{Ex}^{Q_{in}}}$$

Here, work and useful heat such as electricity, power, residential heating, process cooling, and fuels produced within the system are considered output and written to the numerator. Heat inputs such as solar energy and fuel combusted with the system are written on the denominator. A typical combined system consists of turbines to generate power, and pump and compressor for water and air, and condensers (heat exchangers, combustion chambers, etc.). The net power output of a conventional combined cycle can be defined as follows:

$$\dot{W}_{net} = \dot{W}_{GT} - \dot{W}_{Comp} + \dot{W}_{ST} - \dot{W}_P$$

Energy and exergy efficiencies of a combined cycle

$$\eta_{en,CC} = \frac{\dot{W}_{GT} - \dot{W}_{Comp} + \dot{W}_{ST} - \dot{W}_P}{\dot{Q}_{in}}$$

$$\eta_{ex,CC} = \frac{\dot{W}_{GT} - \dot{W}_{Comp} + \dot{W}_{ST} - \dot{W}_P}{\dot{Ex}^{Q_{in}}}$$

where *GT, Comp, ST* and *P* refer to a gas turbine, compressor, steam turbine, and pump, respectively. Efficiencies (Energy and exergy) of an electrolyzer and fuel cell can be expressed as follows:

Electrolyzer:

$$\eta_{en,EL} = \frac{\dot{m}_{H_2} h_{H_2}}{\dot{W}_{EL}}$$

$$\eta_{ex,EL} = \frac{\dot{m}_{H_2} ex_{H_2}}{\dot{W}_{EL}}$$

Fuel cell:

$$\eta_{en,EL} = \frac{\dot{W}_{EL}}{\dot{m}_{H_2} h_{H_2}}$$

$$\eta_{ex,EL} = \frac{\dot{W}_{EL}}{\dot{m}_{H_2} ex_{H_2}}$$

Coefficient of performance (COP) is defined for refrigerators and heat pumps rather than efficiency as follows:

Refrigerator:

$$COP_{en;R} = \frac{q_E}{w_C} = \frac{\dot{Q}_E \ or \ \dot{Q}_L}{\dot{W}_C}$$

$$COP_{ex;R} = \frac{ex^{Q_E}}{w_C} = \frac{\dot{E}x^{Q_E}}{\dot{W}_C}$$

Heat pump:

$$COP_{en;HP} = \frac{q_{Co}}{w_C} = \frac{\dot{Q}_{Co} \ or \ \dot{Q}_H}{\dot{W}_C}$$

$$COP_{ex;HP} = \frac{ex^{Q_{Co}}}{w_C} = \frac{\dot{E}x^{Q_{Co}}}{\dot{W}_C}$$

A fundamental law of nature known as “conservation of energy” states that the total energy of the system never changes. This is not the same with “energy conservation,” which encompasses many actions meant to lower the demand for energy services from end users. Energy is the ability of the system to perform tasks. Change is made possible by energy. There is no creation or destruction of energy. Technical/technological (hardware) and managerial (software) abilities and expertise are combined in energy management. Although strictly wrong, the word “energy consumption” is frequently used because energy can only be transformed or converted, not consumed (Hepbasli, 2024).

Energy and exergy have many differences. Key differences such as energy being conserved in a quantity that cannot be created or destroyed, while exergy represents the quality of energy and its potential for useful work are highlighted. The importance of exergy analysis in evaluating the performance of systems, as it considers both energy and its quality, unlike traditional energetic analyses, is vital.

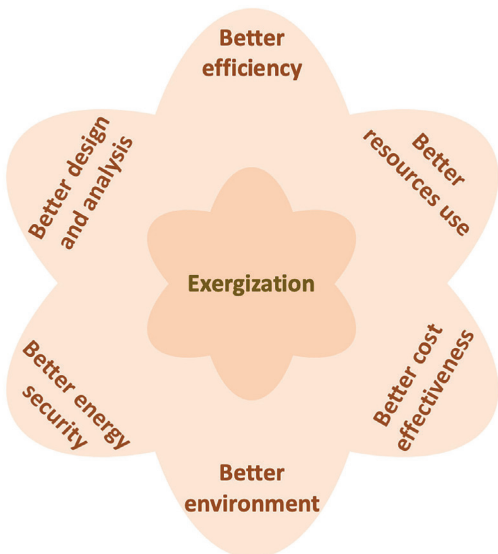
Energy consumption refers to the amount of energy used (in kJ, kWh, toe). Energy use refers to how energy is applied, such as in processes, production lines, heating, ventilation, etc. Energy consumption is a measure of the amount of energy used. The quantity of energy released by burning one ton of crude oil, or around 42 GJ, is known as the ton of oil equivalent (toe). The precise value of the toe is determined by convention because different crude oils have varying calorific values; sadly, there are a few somewhat differing definitions. Sometimes a lot of energy is expended with the toe. When converting electrical units, it is crucial to use the toe properly.

There are many ways to energy saving such as heat insulation, waste management and recovery technologies, heat management and transfer, and energy conservation technologies. While energy saving refers to less energy utilization by switching off devices, energy efficiency refers to less energy utilization for the same requirements (quality and service) (Hepbasli, 2010). Using less energy to do the same work is known as energy efficiency. In essence, to get rid of energy waste. Conserving energy does not entail consuming it. Changing to more energy-efficient lighting, such as LEDs, is an example of energy efficiency, whereas shutting off lights in unused spaces is an example of energy conservation.

Exergy is a measure of how far a system's state deviates from the state of the environment. It can be defined as the quality of energy, its ability to do work, its capacity to cause change, and the maximum amount of work that can be produced from a particular form of energy using the environmental parameters as the reference state. Exergization is the art of conceptually correctly using energy analysis and its methods to improve design and analysis, efficiency, cost-effectiveness, resource use, the environment, and energy security (Dincer, 2016).

Figure 14

Exergization [Modified from (Dincer, I., 2016)]



When studying exergy, reversible systems are considered in terms of how we can maximize our energy systems and make a comparison between actual and ideal systems. Comparing the reversible work for a procedure with its actual work is interesting. Two methods are used for this comparison: First, it is possible to define the second-law efficiency of a process or device. Second, irreversibility (exergy destruction) is defined as the difference between the reversible work and the actual work for a process. This is called exergy analysis which is a need for comprehensive thermodynamic analysis.

Figure 14 illustrates the benefits of exergy analysis, represented by the central term *exergization*. Exergy analysis provides a comprehensive evaluation of energy systems, going beyond traditional energy analysis by considering not only the quantity of energy but also its quality. By applying exergy analysis, we can achieve a multitude of benefits, depicted by the surrounding petals of the flower. These benefits include improved efficiency, better design and analysis, enhanced energy security, reduced environmental impact, better resource utilization, and increased cost-effectiveness. Exergy serves as a powerful tool for optimizing energy systems and promoting sustainability.

Greenization is the process of making systems more environmentally friendly through innovative system designs or configurations. The definition of the greenization factor (GF), which ranges from 0 to 1, is as follows (El-Emam et al., 2017):

$$GF = (EI_{ref} - EI) / EI_{ref}$$

Here, EI refers to the environmental impact factor for the greenized system. When $GF = 0$, it means that the system is not greenized. As it is closer to 1, the system is closer to being fully greenized (which means no or minimum negative environmental impact). The quantity of a resource that can be harvested or collected without depleting it is known as a sustainable yield. The most common applications of sustained yields are in fishing and forestry, which restrict short-term harvests to enable longer-term resource regeneration from the residual parent material. Specific yield (kWh/kWp) is one of the most commonly used performance metrics for solar systems. It is used to compare different locations and to analyze different engineering designs. The ratio of installed solar capacity to total annual energy production is known as the specific yield.

Energy management systems provide measurement and verification of the energy performance of organizations. They consist of general principles and guidance for different variables. Variables are a quantifiable factor that impacts energy performance and routine changes such as production parameters (production, volume, production rate), weather conditions (outdoor temperature, degree days), and operating parameters (operational temperature, operating hours, light level).

Enhancing resource usage can be achieved by producing several goods from a single energy source. The product of the efficiency of each device (sub-system) determines the overall efficiency of the system. For example, consider a system consisting of three sub-systems with efficiencies of 60%, 40%, and 40%, respectively. The overall efficiency of the system is calculated as $0.60 \times 0.40 \times 0.40 = 0.135$ (13.5%). Overall efficiency is lower than any subsystem, as expected.

The main drivers highlighted here should be considered as a whole. Energy efficiency considered to be a reliable source is a straight path towards energy sustainability. Policymakers, educators, investigators, stakeholders, and citizens are encouraged to consider energy and resources based on exergy. We need to adapt our path to new challenges so that we cannot be out of business. This means we need to change our minds by moving from energy to exergy. All roads lead to Rome, namely exergy when talking about sustainability. Promote the Energy to Exergy transition. In conducting any energy management program, measurement is essential.

4. Traditional Energy Sources

We are living in the coldest period on the crust of the earth in 65 million years. Energy is a property that enables something to do work. Energy is all around us, hearable as sound, visible as light, and feelable as solar and wind. Energy transfers from one form to the other when we hit a ball, lift our bag, or compress a spring. Energy has various forms kinetic, potential, and rest energy (Atakhanova, 2024a).

Many mechanical processes involve interchanges between kinetic energy, potential energy, and work. Energy exists in some other forms: chemical energy, heat energy, radiant energy, etc. There are various types of energy such as mechanical, electromagnetic, electrical, chemical, and thermal. An object has more kinetic energy the faster it moves. An object in motion has more kinetic energy the more mass it contains. Both velocity and mass affect kinetic energy.

Potential energy is the capacity to do some work. Potential energy is the energy of position. Stored chemically in fuel, the nucleus of an atom, and in foods. Gravitational potential energy is the type of potential energy that is influenced by height. There is gravitational potential energy in a falling snowflake, a suspension bridge, and a waterfall. Mass and energy are related to each other and can be converted into each other. The rest of the energy of a body is the energy equivalent of its mass. According to the first law of energy, energy is a source, and it is impossible to produce or destroy energy, which can be converted from one form to another. Energy sources typically exist in two forms non-renewable and renewable.

Figure 15 illustrates the shifting landscape of global electricity production from 1987 to last year. Coal, once the dominant source, has seen its share decline, from a peak of around 40.7% in 2013 to 35.5% in ten years. Conversely, solar energy-based systems and wind turbines have explosive growth, increasing from negligible shares to around 13.3% by 2023. Oil and gas have maintained relatively stable shares, while nuclear power has a slight decline. This trend reflects a global transition towards cleaner energy sources to address climate change concerns.

A schematic illustration of traditional energy sources is given in Figure 16. Traditional energy sources, primarily comprising fossil fuels such as coal, natural gas, and crude oil, have been the cornerstone of human energy use for centuries. These energy sources are derived from hydrocarbons, which originate from the decomposition of organic matter over millions of years. Despite growing awareness and utilization of renewable alternatives, fossil fuels continue to dominate global energy production due to their high energy density and established infrastructure.

Figure 15

Share of electricity production by source in the world [Data from (Energy Institute, 2024c)]

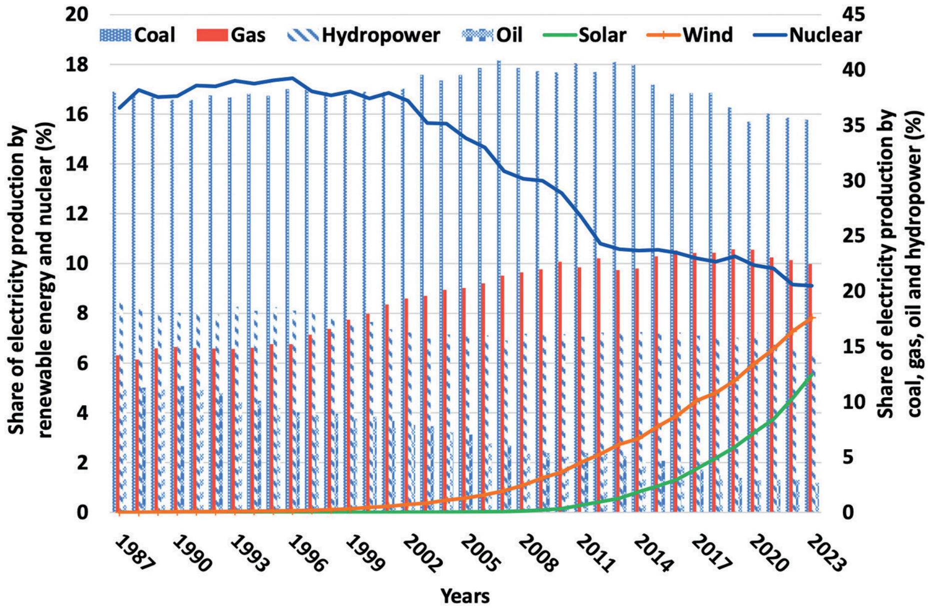
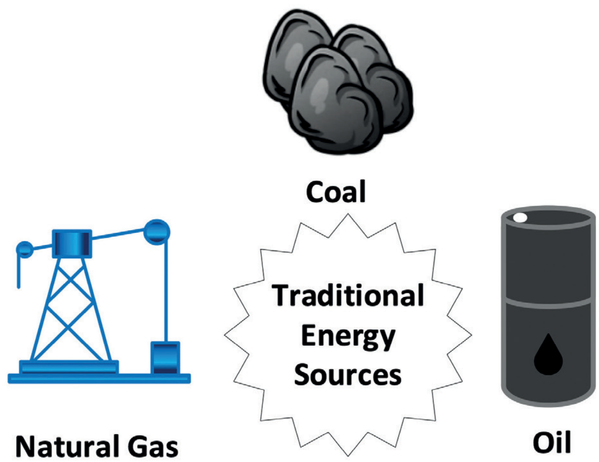


Figure 16

A schematic illustration of traditional energy sources



4.1. Coal

China, the United States, and India are the top three coal-consuming countries, together consuming over 70% of the global consumption (Energy Institute, 2024a). Although China alone consumes a significant amount of coal, coal use is expected to start to fall in the later years of the projection period due to a slowing economy and plans to implement laws to address air pollution and cut carbon dioxide emissions.

Commonly used types and properties of fossil fuels are oil, coal, natural gas, and refined products. Coal has historically been a key energy source for space heating, electricity generation, and district heating. The energy is released during combustion, making coal an integral component of thermal power plants. However, coal combustion significantly produces greenhouse gas emissions and pollutes the air.

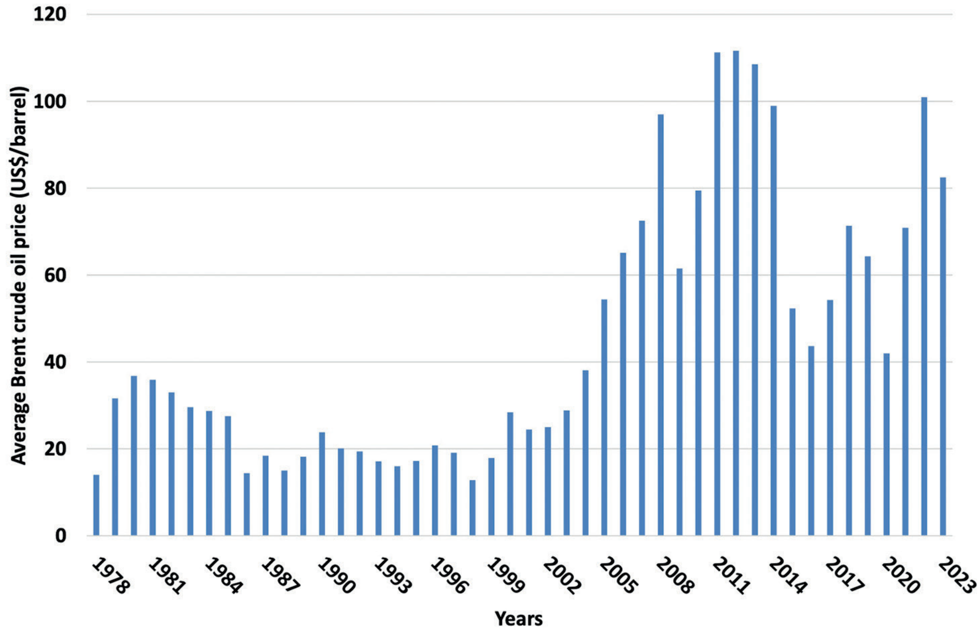
4.2. Oil

Crude oil undergoes refining processes to produce various refined products such as jet fuel, gasoline, and diesel. Oil remains essential for transportation and industrial activities. Refineries like those in Shymkent, Kazakhstan, and Izmit, Türkiye, exemplify the global reliance on crude oil processing. Izmit Refinery began production in 1961, and the processing capacity reached 11.3 million tons per year. The facility has a storage capacity of 3.0 million m³ (Tüpraş, 2024). Shymkent Refinery began production in 1986, and the capacity of the refinery was ramped up to 6 million tons a year within a Reconstruction Project in 2018 (Shymkent Oil, 2024).

Figure 17

Crude oil prices (a) Brent petrol and (b) first purchase in the US [Data from (EIA, 2024c) and (Statista, 2024)]

(a)



(b)

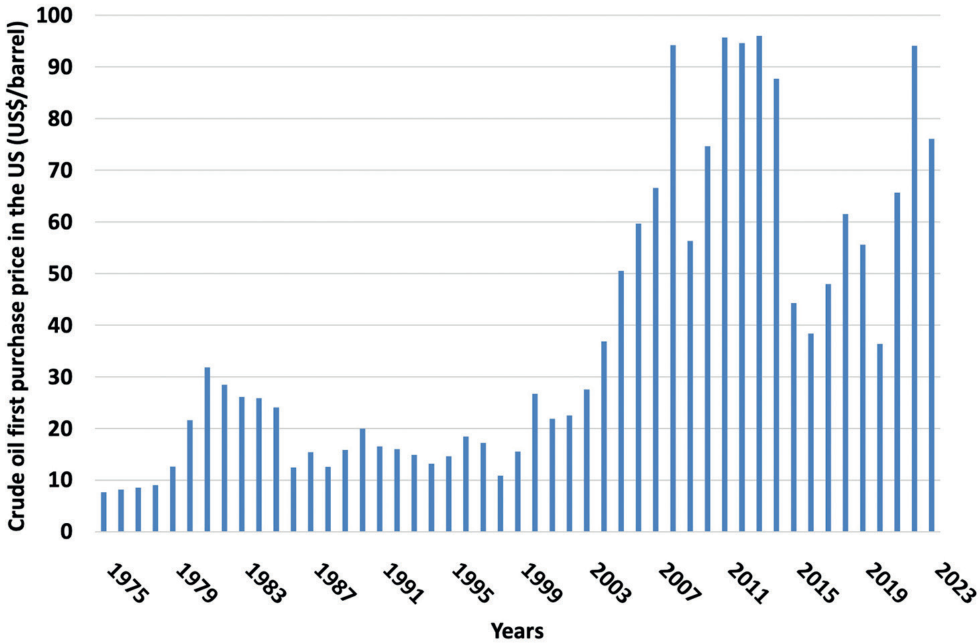


Figure 17 (a) and (b) illustrate the fluctuations and significant increase in crude oil prices from 1975 to 2023. Average Brent petrol prices reached a peak above $100 per barrel in the 2010s but then fell back to $50s. This situation highlights the dynamic and often unpredictable nature of the global oil market. Extractive industries, which involve the extraction of natural resources, are critical for the production of traditional energy sources. Countries rich in fossil fuel reserves, such as those leading in global energy production as of 2022, leverage these industries for energy security and economic growth. However, the environmental impacts of extraction activities, including land degradation and water contamination, pose challenges to sustainability.

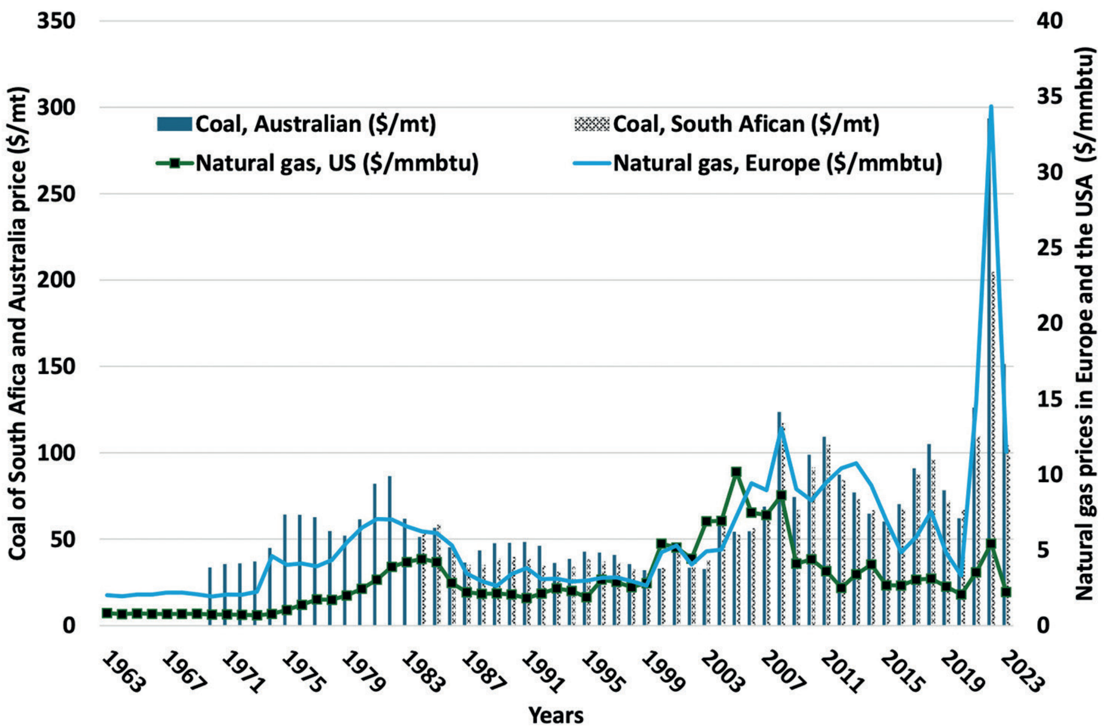
4.3. Natural gas

Natural gas, which is comprised of mainly methane (around 90%), is a cleaner fossil fuel relative to coal and oil due to the sulfur content of coal. Natural gas consists of methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}), hexane (C_6H_{14}), carbon dioxide (CO_2), and nitrogen (N_2) (Sorgulu et al., 2023). Thus, CO_2 is emitted due to natural gas combustion. It is widely used for space heating, cooking, electricity generation, and even as a fuel for transportation. Its versatility and lower carbon footprint compared to coal have made it an attractive option for many economies transitioning to cleaner energy solutions.

While fossil fuels remain dominant, there is a significant shift towards clean energy sources to address climate change and meet economic development needs. Understanding the properties and applications of traditional energy sources is essential for managing this transition effectively. For instance, Kazakhstan, a prominent energy producer, illustrates the balancing act between utilizing fossil fuels and exploring renewable alternatives.

Figure 18

Changes in coal and natural gas prices [Data from (World Bank, 2024c)]



Traditional energy sources have powered industrial and economic development for centuries. Coal, natural gas, and oil each play specific roles in meeting energy demands across various sectors. As the world transitions toward clean and sustainable energy systems, comprehending the dynamics of these conventional sources remains pivotal for addressing global energy and environmental challenges.

Non-renewable and conventional energy sources such as natural gas, oil, coal, petroleum, and nuclear are essentially finite in the crust of the earth. Natural gas hydrates in marine sediment and oil shale are unconventional sources. Due to their inability to be economically harvested and/or refined, unconventional resources are currently not utilized to a considerable extent. At ocean depths of roughly 500 meters, a mixture of methane and H_2O freezes into a solid, crystalline condition to form natural gas hydrates in marine sediment (Ruppel, 2011). It comes from organic stuff that has been trapped in the silt and decomposes. This resource is thought to be twice as huge as all known fossil fuels.

Changes in natural gas and coal (both South African and Australian) prices in the US and European Union countries from 1963 to 2023 are given in Figure 18. Both coal and natural gas prices increase with a significant fluctuation (mostly due to political reasons) during the period. Still, a significant amount of global energy is supplied from fossil fuels since fossil fuels are still convenient and relatively cheap.

5. Nuclear Energy

The energy found in the core of an atom is known as nuclear energy. The core of an atom contains the majority of its mass. The two subatomic particles that understand the nucleus are protons and neutrons. The atom is regarded as the fundamental unit of matter that governs the structure of the elements since it is the smallest component of a chemical element that still possesses its chemical characteristics. Atoms are bound together by bonds that contain an exact, enormous quantity of energy. The strength of a chemical connection is indicated by its bond energy. It is the amount of energy needed to break every bond of a certain kind in a single mole of a chemical molecule (Cevik, 2024b).

5.1. Nuclear Energy and Its Use

The energy released from the nucleus, which is composed of protons and neutrons and forms the center of atoms, is known as nuclear energy. There are two ways to create this energy source: fission, which occurs when nuclei divide atoms into several pieces, and fusion, which occurs when nuclei combine.

A nucleus splitting of an atom into two or more smaller nuclei while releasing energy is known as nuclear fission. Each uranium-235 (U-235) atom has a nucleus that contains 92 protons and 143 neutrons, for a total of 235. Because of the fairly unstable particle arrangement inside U-235, if the nucleus is energized by an external source, it may disintegrate. When a U-235 atom is struck by a neutron, the nucleus splits into two or three neutrons and two smaller nuclei, such as a krypton nucleus and a barium nucleus.

A chain reaction is created as more neutrons strike nearby U-235 atoms in a few seconds, which then splits and produces more neutrons in a multiplying effect. Energy is released as heat and radiation each time the fission reaction takes place. Similar to how electricity is produced from the heat of fossil fuels, the heat can be transformed into electricity in a nuclear power plant. Thermal generating is the process of burning material to produce electrical energy.

One uranium fuel pellet produces as much energy as one ton of coal, 149 gallons of oil, or 17,000 cubic feet of natural gas, demonstrating the abundance and energy-dense nature of uranium (NEI, 2024). However, it is not ready to enter a reactor when it emerges from the ground. Nuclear fuel is produced by mining and processing it. The front end and the back end are the two stages of the nuclear fuel cycle. Uranium is prepared for use in nuclear reactors by front-end processes. The back-end procedures guarantee the safe handling, preparation, and disposal of spent but still highly radioactive nuclear fuel.

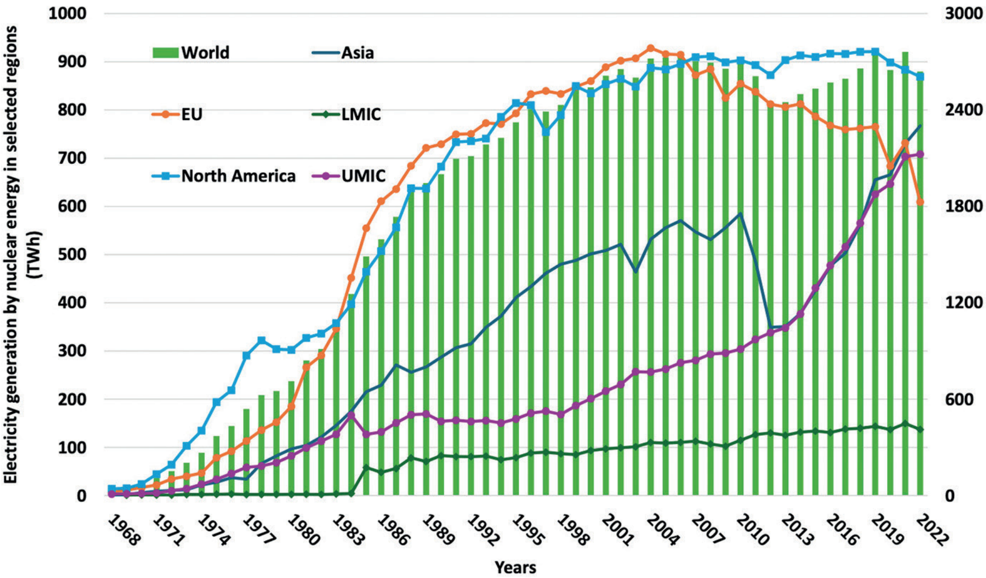
Because its atoms can readily split apart, a particular form of uranium (U-235) is used for nuclear fission in nuclear power reactors. U-235 is comparatively uncommon, accounting for just over 0.7% of natural uranium, despite uranium being over 100 times more frequent than silver (Long et al., 2012).

Near Arco, Idaho, is the first nuclear reactor to generate electricity. In 1951, the Experimental Breeder Reactor started to run on its own. In 1954, the first nuclear power facility built for community use was built in Obninsk, Russia. The Soviet Union put the Obninsk Nuclear Power Plant into service on June 27, 1954, and it ran effectively for nearly 50 years until closing on April 29, 2002 (INL, 2024).

Figure 19 shows the evolution of electricity generation using nuclear energy within different regions from 1965 to 2022. Globally, power generation by nuclear energy has had a significant surge from the mid-1970s, reaching a peak in the 2000s. Subsequently, there was a period of stagnation and even a slight decline in some regions in the 2010s. By 2020, global nuclear power generation had surpassed its previous peak, with a value of 2700 kWh.

Figure 19

Changes in electricity generation with nuclear power plants [Data from (Ember, 2024b)]



*LMIC: Lower-Middle-Income Countries UMIC: Upper-Middle-Income Countries EU: European Union Countries

5.2. Fission Reactors and Applications

Nuclear reactors and associated apparatus limit and regulate the chain reactions, most frequently powered by U-235, which generate heat through fission inside nuclear power plants. Large amounts of U-235 can be controlled by the creative design of a pressurized water reactor, which uses the heat generated in the fission reaction to create steam that may be used to generate electricity.

Steam is created when the heat warms the cooling agent in the reactor, which is usually water. After that, the steam is sent toward spinning turbines, which turn on an electric generator to produce low-carbon electricity. Similar to steam boilers, nuclear power plants generate steam using nuclear reactions as opposed to burning fuel. Nuclear reactor types can be listed as follows (IAEA, 2024):

- Pressurized water reactor (PWR)
- Pressurized heavy water reactor (PHWR)
- Boiling water reactor (BWR)
- Light water graphite reactor (LWGR)
- Fast neutron reactor (FNR)
- Advanced gas-cooled reactor (AGR)
- High-temperature gas-cooled reactor (HTGR)

PWR, with nearly 300 reactors, is the most common type. PWRs are utilized to produce electricity and use water as a coolant and working fluid. The design is unique in that it has a secondary circuit where steam is produced to power the turbine and a primary cooling circuit that passes through the core of the reactor at a very high pressure (15 MPa) (WNA, 2024). The pressure of the primary circuit is managed by the pressurizer. Steam is indirectly generated. Heat in the steam generator is transferred to the secondary circuit, which houses a turbine and a condenser, by water flowing through the core.

The temperature of the water in the reactor has reached around 325°C and is at suitable pressure to prevent boiling. Steam maintains the pressure in a pressurizer. Large reactors would have roughly 150-250 fuel assemblies with 80-100 tons of uranium, while PWRs have fuel assemblies with 200-300 rods apiece, placed vertically in the core (US NRC, 2024). With about 18% of the market, boiling water reactors (BWRs) are the second most popular technology. It employs light water as a coolant and moderator and the same kind of fuel as PWR. Except for a single circuit where the water is under reduced pressure and boils in the core at roughly 285°C, the BWR type of reactor is quite similar to the PWR. The design of the reactor calls for 12-15% of the water in the upper core to be steam, which reduces the moderating effect and, consequently, the efficiency of the reactor. Up to 750 assemblies, each containing 90-100 fuel rods, make up a BWR fuel assembly, which can hold up to 140 tons of uranium (WNA, 2024).

The process of nuclear fusion releases enormous quantities of energy as two light atomic nuclei unite to form a single, heavier one. Nuclei of two hydrogen isotopes, tritium ($^{3}_{1}H$) and deuterium ($^{2}_{1}H$), fuse to form a helium nucleus ($^{4}_{2}He$) in nuclear fusion. Additionally, a massive amount of energy and neutrons are emitted. Fusion reactions occur in plasma, a hot, charged gas composed of free-moving electrons and positive ions that have special characteristics not seen in solids, liquids, or gases. The fourth state of matter is plasma.

Ionized gases, such as plasma, are those in which enough energy is present to liberate electrons from atoms or molecules and permit the coexistence of ions and electrons. The most prevalent matter state in the cosmos is plasma.

5.3. Fusion Reactor and Potential Applications

The sun is powered by a fusion reaction. In our sun, nuclei must meet at incredibly high temperatures, roughly 10 million degrees Celsius, in order to fuse. They have enough energy from the high temperature to overcome their electrical repulsion with one another. The nuclear attraction between the nuclei overcomes the electrical repulsion and enables them to fuse once they are within exceptional proximity to one another. The attractive nuclear force outweighs the repulsive electrostatic force at distances measured in the nucleus radius. Thus, bringing the nuclei near enough to fuse is the primary technological challenge for fusion.

Fusion has the potential to produce almost four million times more energy than burning coal or oil, and four times more energy per kilogram of fuel than fission. Fusion radiation heats water and creates steam in the thermonuclear reactor. After that, a turbine can be turned by steam to produce energy.

An experimental device created to capture fusion energy is called a tokamak. The energy generated by the fusing of atoms inside a tokamak is absorbed as heat in the walls of the vessel. Similar to a traditional power plant, a fusion power plant uses this heat to create steam, which is subsequently converted into electricity using generators and turbines. A combination of deuterium and tritium-hydrogen atoms with additional neutrons is used in the majority of the fusion reactor ideas now in development. Fusion power plant schematics based on the tokamak idea.

Fusion is only possible under very specific operating conditions; otherwise, the plasma naturally stops, rapidly loses energy, and extinguishes before the reactor sustains any significant damage. The state known as ignition, in which a fusion reaction generates more energy than it is required to initiate, had been attained by the researchers. Scientists used the energy of 192 lasers to ignite a cylinder known as a hohlraum (WNA, 2024). The procedure caused a fusion reaction by imploding a small capsule containing deuterium and tritium inside the hohlraum.

The scope of accomplishment is far smaller than what would be needed to produce electricity for everyday use, let alone usher in a new era of renewable energy. Nuclear fusion may be a long-term source of low-carbon electricity since, like fission, it doesn't release carbon dioxide or other greenhouse gases into the environment. Greenhouse gas emissions from nuclear energy's life cycle are far lower than those from coal or natural gas-fueled power plants and are on par with renewable energy sources like wind and hydropower.

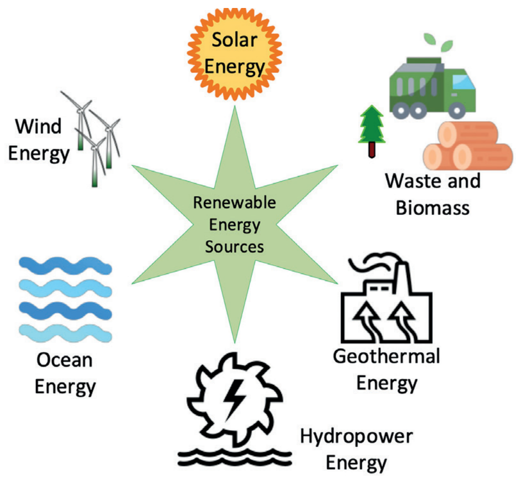
Deuterium and tritium must fuse at temperatures above 100 million degrees Celsius while simultaneously controlling magnetic and pressure forces to keep the plasma stable and sustain the fusion reaction long enough to generate more energy than was needed to initiate it. Even though tests currently frequently achieve conditions that are strikingly similar to those needed in a fusion reactor, enhanced confinement characteristics and plasma stability are still necessary to continue the reaction and generate energy.

6. Renewable Energy Sources and Hydropower

For many years, fossil fuels have been a major factor in the world economy. More significant than reserves of coal, natural gas, and crude oil is the lack of finance. Because of shale gas, fossil fuel reserves are significantly larger than previously thought (Baba, 2024b). More attention is being paid to inexpensive energy access and energy as a catalyst for economic expansion than to climate change. The use of natural, renewable energy sources has many benefits. They are limitless and never run out. They don't harm the environment and are clean and renewable. Since there are multiple varieties, each nation has at least one of them. The majority of natural resources can be used locally and on a small scale, which lowers energy transmission costs.

Figure 20

An illustration of renewable energy sources including hydropower



An illustration of renewable energy sources including hydropower is given in Figure 20. Solar sunshine, wind power, hydropower, biomass (including wastes), ocean currents, and geothermal sources are considered renewable energy sources. Solar energy is a clean energy, harnessing it does not pollute the environment or generate any adverse effects. Solar installed capacity has increased approximately 30 times over the last decade worldwide. Türkiye is 7th in Europe and 19th globally as of early 2024. In 2023, global investments in solar energy reached approximately $480 billion, up from $100 billion in 2013. The solar PV market is expected to grow 3 times by 2030 (IEA, 2024a).

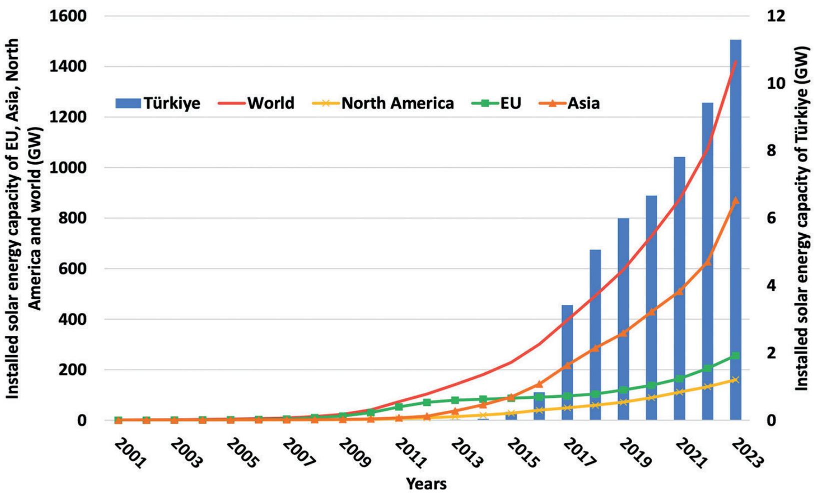
Solar energy usage does not emit any greenhouse gases. Avoid politics and price volatility. Solar energy is an inexhaustible source and often noise-free. However, solar radiation is not available at night, so it needs a storage system. Cloudy weather can make solar energy-based systems unreliable. Traditional solar PVs require a lot of land area.

6.1. Solar Energy Applications

While traditional solar PVs are set as on-grid and off-grid, novel PVs are integrated with buildings and called building-integrated photovoltaics (BIPV). Mirrors reflect and focus sunlight onto receivers that gather solar energy and transform it into heat in concentrating solar power (CSP) technology. A steam turbine or heat engine that powers a generator can then use this thermal energy to create electricity. Concentrated photovoltaic (CPV) technology generates electricity by using optics like lenses or curved mirrors. CPV systems necessitate additional funding for cooling systems, sun trackers, and concentrating optics. Compared to non-concentrated photovoltaics, CPV is far less widespread nowadays due to these additional expenses.

Figure 21

Changes in installed solar energy capacity [Data from (IRENA, 2024a)]



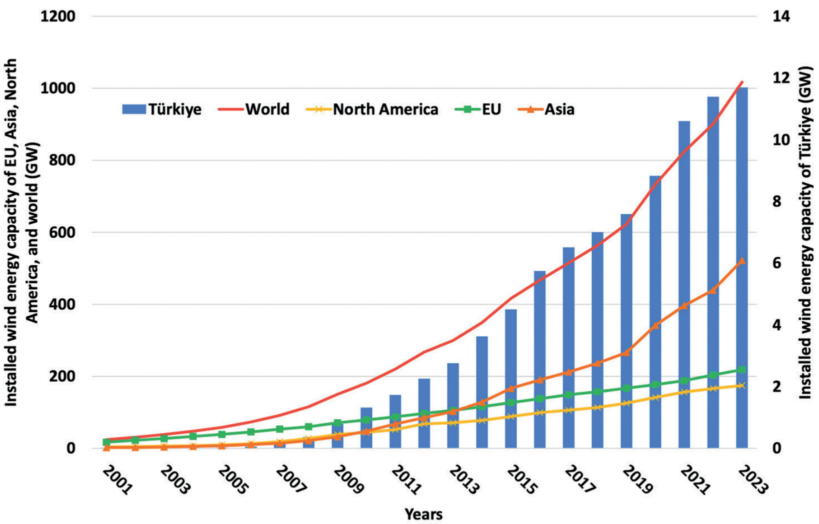
Changes in, the significant growth, installed solar energy capacity within the world and specific regions selected from all over the world for more than 20 years are given in Figure 21. According to the Republic of Türkiye, Ministry of Energy and Natural Resources, the solar PV panel capacity of Türkiye has reached 19.3 GW, which is 16.8% of the total capacity, by December 2024 (MENR, 2024).

6.2. Wind Energy Applications

Wind energy is converted into electricity using wind turbines, or mechanical power using windmills. Wind energy is a clean energy source. Wind turbines do not produce atmospheric emissions and can be built on ranches or farms. However, still higher initial investments are required. Transmission lines must be built. There is some concern over the noise.

Figure 22

Changes in installed wind turbine capacity [(Data from (IRENA, 2024b)]



Onshore and offshore wind capacities have increased approximately 10 times and 5 times over the last decade, respectively. In 2022, global investments in wind energy reached approximately $216.6 billion (REN21, 2024). The offshore market is expected to grow 5-6 times by 2030. The worldwide installed capacity of the wind turbine reached 1,021 GW as of 2024. Türkiye has the 6th biggest capacity in Europe and 13th globally (US NREL, 2024).

Figure 22 provides a visual representation of the growth in installed wind turbine capacity for specific regions from 2001 to 2023. Notably, the wind energy capacity of Türkiye has a significant increase during this period, mirroring the global trends. According to the Republic of Türkiye, Ministry of Energy and Natural Resources, the wind power capacity of Türkiye has reached 12.5 GW, which is 10.9% of the total capacity, by December 2024 (MENR, 2024).

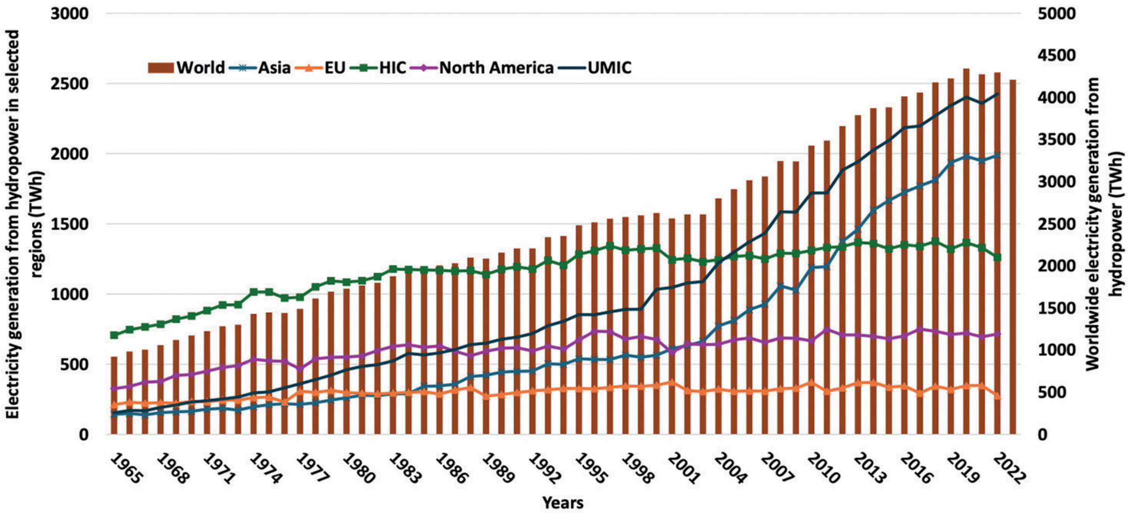
6.3. Hydroelectric Applications

The kinetic energy of flowing water is transformed into electric energy via hydroelectric power (or hydropower) systems. A turbine is a device that transforms a propeller when water falls or flows. The turbine generates electricity by converting a metal shaft into an electric generator. Global hydroelectric production increased by 2.9% in 2023, which is higher than the 10-year average (IEA, 2024b). With 24 GW installed in 2022, three-quarters of all worldwide growth, China remains the leader in capacity increases.

India is still working on several sizable hydropower projects, with a sizable amount of capacity anticipated to be operationalized in the upcoming years. One of the most important technologies for achieving the goal of 500 GW of non-fossil generating capacity by 2030 is hydropower. In 2022, Europe put nearly 2 GW of pumped storage hydroelectric capacity into service, the greatest since at least 1990. The goal of two projects in Portugal and Switzerland is to make it easier to integrate wind and solar PV (IEA, 2024b).

Figure 23

Changes in electricity generation from hydropower in selected regions [Data from (Ember, 2024c)]



* HIC: High-Income Countries EU: European Union Countries

Figure 23 illustrates the changes in worldwide electricity generation from hydropower from 1965 to 2022. Asia emerges as the dominant continent, with 46.3% of total worldwide hydropower electricity generation in 2022. The share of North American and European Union countries in total hydropower electricity generation is 16.6% and 6.4%, respectively. In Türkiye, 63.9 TWh of electricity, which is 19.3% of total electricity generation, is provided by hydropower.

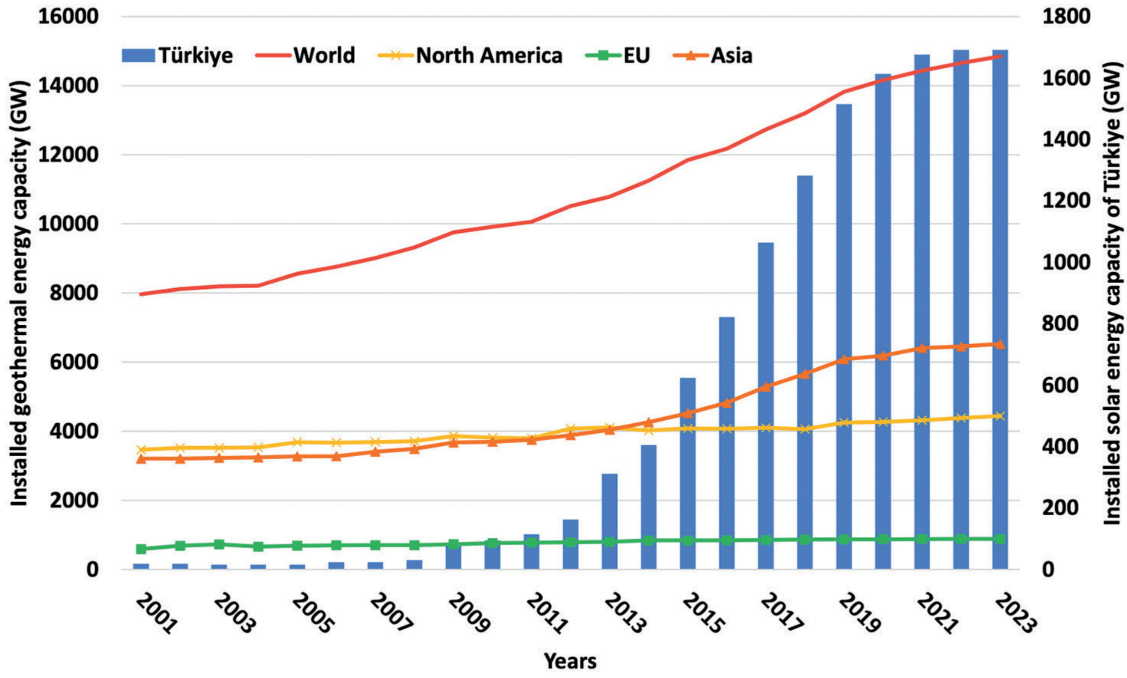
6.4. Geothermal Energy Applications

One of the first geothermal electricity generation was conducted in 1904 by Prince Piero Ginori Conti at Larderello, Italy (Lund, 2004). This experiment led to the construction of the first commercial geothermal power plant in the world in 1911, which initially produced 250 kW. In 1958, New Zealand became the second major producer of geothermal electricity with the commissioning of the Wairakei Power Station. Türkiye's total current installed direct-use applications have a thermal capacity of 5113 MWt. This is equal to 8.5% of the 60 GWt theoretical geothermal potential of Türkiye (MENR, 2024).

Figure 24 illustrates the growth of installed geothermal energy capacity worldwide and in specific regions from 2001 to 2023. It shows that both geothermal and solar energy have seen significant increases in capacity over this period. Asia has consistently led in geothermal energy capacity, while North America has been the dominant region for solar energy capacity. Interestingly, the solar energy capacity of Türkiye has grown rapidly in recent years, surpassing its geothermal energy capacity in 2019. This suggests a shift in the energy focus of Türkiye towards solar power.

Figure 24

Changes in total geothermal capacity [Data from (IRENA, 2024c)]



One type of thermal energy is geothermal energy, which is produced by the volcanic activity of the earth and the breakdown of natural minerals. Pumping hot water or water through heated rocks and back to the surface is how geothermal energy is produced. Thermal energy is exemplified by the warmth you get from the engine. Thermal energy is transformed into mechanical energy using a heat engine.

Geothermal energy is also harvested for electricity and heating. While steam from underground spins turbines for electricity, hot water is piped to residential and commercial areas for heating. However, some problems are faced such as depleted groundwater supplies and natural sulfur released into the air. Iceland has the most geothermal installed capacity in the world.

District heating systems in Türkiye

The first geothermal space heating application in Türkiye was installed at the Park Hotel, Gonen/Balikesir in 1964 (Oktay & Dincer, 2009). The first geothermal district heating system of Türkiye was implemented in Balçova/İzmir in 1996 (Baba et al., 2022). Occupancy cooling is in high demand in Türkiye in hot and humid climatic regions. There, electricity consumption increases dramatically in summer. Geothermal cooling could create benefits for these regions. But so far, there is only one cooling example in Türkiye. A building in Balçova-İzmir has used an absorption cooling system since 2018.

Greenhouse applications in Türkiye

In terms of overall output, the Turkish greenhouse sector is the second largest in Europe. Because of the more hospitable climate in the southern provinces, it is concentrated there. The expense of traditional energy sources is the reason for the lack of development in colder climates. 79,000 hectares make up Türkiye's entire greenhouse area. Thirty percent of all heated greenhouse space is devoted to geothermally heated greenhouses. Given the low temperature needed for greenhouse heating, the trend for geothermal energy use is increasing. According to World Population Review, Türkiye is currently in 4th place in the World in vegetable production with an amount of 26.6 million tons (WPR, 2024).

6.5.Ocean Energy Applications

Utilizing the steady and predictable flow of ocean tides, tidal power generation produces electricity. Underwater turbines and dams are examples of innovations in tidal power systems that effectively transform tidal energy into electrical power. Utilizing the kinetic energy of ocean currents, underwater turbines produce renewable electricity. These cutting-edge turbines offer a continuous and dependable source of clean electricity and may be placed in a variety of settings, including along coastlines and in the currents of the ocean.

The depth of the ocean creates a temperature gradient that is just big enough over appropriate depths to harvest thermal energy with little efficiency. Ocean thermal energy conversion (OTEC) is the term for this process. OTEC may function between the surface water as a heat source and the atmospheric air as a heat sink in arctic climates where the temperature differential between the water and the atmospheric air can exceed 40°C.

Oceans are enormous reservoirs of mechanical energy in addition to being a vast thermal energy storage system, which is an indirect method of storing solar energy. Ocean waves, currents, and tides are all examples of this mechanical energy in action. A diurnal tidal effect is created by the kinetic energy of the moon's (together with the sun's lesser) gravitational pull on the waters beneath the rotation of the earth. Centrifugal and gravitational forces work together to create two water bulges at the equatorial belt. Tidal energy has a promising future in the production of electricity.

Ocean energy (same terminology both for sea and ocean) is utilized for electricity generation by turbines. Tidal turbines force spin turbines. However, some problems are faced such as possible disruption of marine life. The US and Japan lead the world in ocean energy.

6.6. Biomass and Waste to Energy Applications

Biomass, particularly wood, was a predominant energy source before the Industrial Revolution. It provided fuel for heating and cooking. It has a central role in daily life and early industrial activities. In rural areas, agricultural residues like straw and dried animal dung served as alternative fuels. In certain parts of Europe, particularly in Ireland and Scotland, peat was harvested from bogs and used as a fuel for heating and cooking (Midilli, 2024a).

Waste-to-energy conversion technologies reduce landfill waste and provide sustainable heat or power by turning organic waste materials into usable energy. Anaerobic digestion, pyrolysis, and gasification are examples of innovations in this field that successfully capture the energy potential of organic waste.

A new system called Bioenergy with Carbon Capture and Storage (BECCS) combines the production of bioenergy with the capture and storage of carbon dioxide emissions. This invention helps mitigate climate change by removing CO_2 from the environment in addition to producing renewable electricity from biomass. Using the high oil content and quick growth of some algae, algae biofuel production provides a viable substitute for fossil fuels. Algae are a flexible and carbon-neutral source of biofuel that may be grown in a variety of settings, such as coastal regions and wastewater treatment plants.

Since the term "biomass" is derived from the term "biological mass," "biomass energy" implies a type of energy that comes from living systems. Broadly speaking, biomass energy is the energy contained in materials that may be burned or transformed into synthetic fuels, such as wood and other crops. Biomass is any type of living life that has been fossilized. It is among the oldest sources of energy and has the potential to become one of the most important large-scale energy sources in the future.

The photosynthetic component of solar energy distribution is the source of biomass, which includes all terrestrial and marine plant life, all species that come after them in the food chain, and ultimately all organic waste. There are many different types of biomass resources, including garbage, crops, and timber. A fundamental feature of biomass is its chemical makeup, which includes lignin, sugar, starch, cellulose, hemicellulose, resins, and tannins.

Converting biomass or biorefinery leftovers into intermediates like syngas and bio-oil is the goal of the thermochemical platform. In the biorefinery idea, lignocellulosic biomass is often converted into liquid fuels in two phases. First, the solid lignocellulosic feedstock is converted, with some oxygen removed, into a gaseous or liquid phase chemical.

Utilizing regulated C-C coupling processes and elimination of the residual oxygen functionality, these compounds can be catalytically upgraded to the final hydrocarbons. Pyrolysis, for example, thermally degrades biomass into bio-oil components like furfural and levoglucosan, which can be upgraded to liquid hydrocarbons. Similarly, gasification produces syngas, which can undergo catalytic reactions to form ethanol and other fuels.

Biomass is a highly versatile and renewable energy source, offering significant potential for sustainable production of green chemicals, biofuels, and polymers. Compared to fossil fuels, biomass has minimal sulfur, nitrogen, and ash content, resulting in lower emissions of SO_2, NOx, and particulate matter. It is economically viable, abundant, sustainable, easily accessible, and capable of achieving a zero-carbon footprint. Lignocellulosic biomass, in particular, is abundant, cost-effective, and composed of non-food materials, making it an excellent candidate for biofuel production.

Biomass and waste are utilized for heating and electricity purposes. Ethanol produced from waste is utilized in cars. Heat obtained by burning them and useful gases such as syngas and biogas produced by using biomass are utilized in various energy systems. However, some problems are faced such as pesticides (fertilizers), deforestation, health problems, and CO_2 emissions. The US and Brazil have huge facilities to produce ethanol from corn and sugarcane.

7. Hydrogen Energy

Green hydrogen, produced using renewable energy, is emerging as a vital energy carrier. Advances in electrolyzer technology are reducing the cost and increasing the efficiency of green hydrogen production, expanding its applications across industrial processes and transportation (Dincer, 2024b).

7.1. Hydrogen Energy and Its Importance

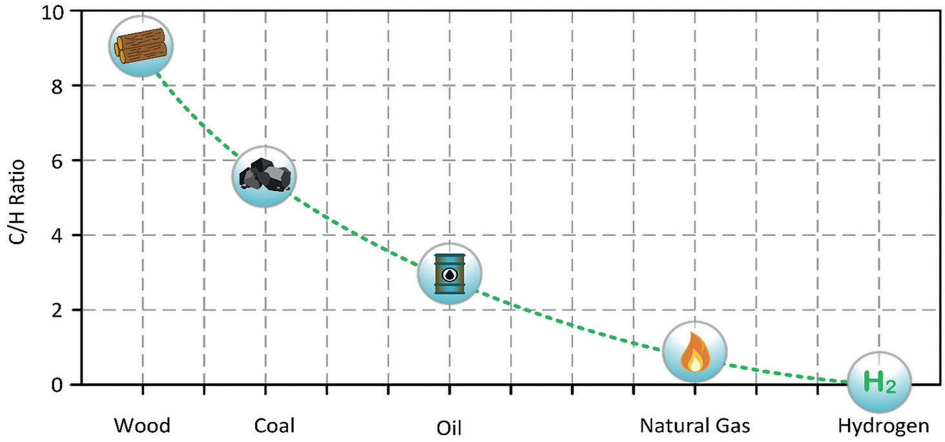
Economically viable, monetarily hopeful, socially beneficial, and energetically efficient solutions to problems associated with the growing energy consumption of the world, including global warming, may be offered by hydrogen. Furthermore, new research indicates that is necessary to start and quicken the energy transition from conventional energy systems to creative and sustainable substitutes.

Humanity began using wood as a source of energy for many everyday tasks and has continued to do so over the centuries through a variety of periods, including the coal era (especially during the Industrial Revolution), the oil era (mainly following World War I), and the natural gas era (increasingly after the 1980s). In the pursuit of hydrogen as a carbon-free fuel and energy carrier, there is a final endpoint. The carbon and hydrogen ratio (C/H ratio) of fuels over the centuries are given in Figure 25. Every neighborhood, city, nation, region, industry, economy, etc. has been directly impacted by the global coronavirus pandemic that we were experiencing.

The virus has affected everyone, either directly or indirectly. Health, the economy and finance, labor, education, the environment, energy, defense, food and agriculture, technology, sustainability, and many other aspects of the demands of society are all impacted. Task forces, expert groups, advisory committees, science boards, and other organizations have been established by numerous developing and/or developed nations to define policies, direct governments, and take action solely on health-related concerns and issues. I have noticed that while many people fiercely criticize organizations and governments, such health-related activities appear sufficient (Dincer, 2020).

Figure 25

Carbon and hydrogen ratio (C/H ratio) of fuels over the centuries [Taken from (Dincer, I., 2020)].



Thermo-catalysis is utilized to break down hydrogen sulfide (H_2S) that is taken from the ocean or obtained from other industrial operations. The general effect of chemical reactions, whether or not they are redox reactions, is the breaking of water molecules, so, hydrogen is generated via this reaction which is also called water splitting. Biomass is converted into syngas, which includes hydrogen, via a gasification process. Liquid biofuels are converted to hydrogen via reforming utilizing thermal energy. Cyclical reactions are used to split the hydrogen sulfide molecule to generate hydrogen by thermal energy.

7.2. Electrolyzers

PV panels are used to generate electricity by photonic energy to drive electrolyzer, so, the process called PV-electrolysis is used to generate hydrogen. Hydrogen is produced from water using sophisticated homogeneous catalysts or molecular devices that capture electrons through photo-initiation. The water electrolysis process in the photo-electro-chemical approach is powered by photovoltaic electricity produced by a hybrid cell. The bio-photolysis approach uses cyanobacteria-based biological systems to produce hydrogen under controlled conditions. Biomass is anaerobic fermented in the absence of light and hydrogen is generated. Utilizing a thermal source and electrical power to split water into solid oxide electrolyte cells, high-temperature electrolysis is another method for producing hydrogen. Water splitting is the result of hybrid thermochemical cycles, which use both electrical and thermal energy to drive chemical reactions cyclically.

The classification of clean hydrogen production methods is tabulated in Table 1. In the electrolysis method water and electrical energy are utilized. By using a direct current to induce electrochemical processes, water breaks down into O_2 and H_2. Natural gas and electrical energy are used in the plasma arc decomposition method to produce hydrogen and carbon soot. Methane, or natural gas, is run through a plasma arc that is created electrically. In the thermolysis method, steam is heated to temperatures above 2500 K, and water molecules undergo thermal breakdown.

Fossil hydrocarbons are broken down into H_2 and CO_2 using a thermo-catalytic method (also known as "thermo-catalytic fossil fuels cracking"), while CO_2 is sequestered or segregated to make the process environmentally friendly. After coal is turned into syngas, CO_2 is separated or sequestered (electric power used), and H_2 is obtained. With CO_2 capture and sequestration (electric power used), fossil hydrocarbons are transformed into H_2. Both photonic and biochemical energy are utilized in bio-photolysis, artificial photosynthesis, and photo-fermentation methods by employing bacteria and microbes to generate hydrogen.

Hydrogen has three essential roles; (i) energy carrier (steam methane reforming, utilizing in fuel cells, using excess electricity), (ii) fuel (cryogenic fuel in aerospace industry, utilized in combustion systems), (iii) feedstock (semiconductor production, ammonia production, and hydrogenation).

The six categories of "Hydrogen 1.0" concepts include better design, better resource use, better efficiency, better energy security, better environment, and better economy in Figure 26. It is important to remember that everything starts with a design that is anticipated to be superior to the standard methods for the hydrogen economy. This can literally be expanded to include the complete ecosystem design, which covers all aspects of the hydrogen economy, from the creation of hydrogen to its use, including distribution, storage, and transportation. The design element must be sufficiently inventive and integrated into each action, from the development of logistics and infrastructure to the design of a particular system.

Energy and exergy approaches, environmental impact assessments, sustainability, economic feasibility, and life cycle evaluations are all necessary for the design components in order to better design the systems. A better design of educational and training procedures to produce value-added jobs and goods and equip the workforce for the economic sectors of the hydrogen age can be covered by this type of analysis/assessment.

Better efficiency is the next domain in the graph, where system performance and by extension system efficiency are crucial for real-world operations. In order to increase the efficiency of the economic sectors (and consequently the hydrogen society) as a whole, as well as the hydrogen energy systems in particular, it is necessary to take into account both energy and exergy efficiencies for each one of these particular components and/or society-related systems and applications. Furthermore, these energy and energy efficiency factors should be taken into account for every stage of these systems and applications, either separately or in combination. The effectiveness with which beneficial outputs (like hydrogen) are created, stored, transported, disseminated, converted, and used is directly confirmed by such efficiencies.

Better utilization of resources is the next phase, which is another crucial action item. To better transition to and achieve the hydrogen economy, all types of resources, from natural resources to human resources, must be taken into consideration. As everyone may stress, in order to produce green hydrogen and, consequently, green hydrogen energy systems and applications, clean usage of natural and renewable resources is required. It is also crucial to train and educate human resources in order to generate the proper human capital for the hydrogen industries.

Furthermore, improving the environment becomes the next thing to think about. According to the 3S concept (source, system, and service), this is anything that needs the full spectrum of hydrogen energy, from source to system and from system to service, where the beneficial outputs are produced for use. Therefore, they must be accomplished in a way that is sufficiently synchronized for an environmentally friendly hydrogen ecosystem to arise.

Table 1
Classification of clean hydrogen production methods [Modified from (Dincer, I., 2012)]

Process Driving Energy	Hydrogen Production Method		Material Resources
Electrical Energy	Electrolysis		Water
	Plasma arc decomposition		Natural gas
Thermal Energy	Thermolysis		Water
	Thermocatalysis	H_2S cracking	Hydrogen sulfide
		Biomass conversion	Biomass
	Thermochemical processes	Water splitting	Water
		Gasification	Biomass
		Reforming	Biofuels
		H_2S splitting	Hydrogen sulfide
Photonic Energy	PV-electrolysis		Water
	Photo-catalysis		Water
	Photo-electro-chemical		Water
	Bio-photolysis		Water
Biochemical Energy	Dark fermentation		Biomass
	Enzymatic		Water
Electrical + Thermal	High temperature electrolysis		Water
	Hybrid thermochemical cycles		Water
	Thermo-catalytic fossil fuel cracking		Fossil fuels
	Coal gasification		Water
	Fossil fuels reforming		Fossil fuels
Electrical + Photonic	Photo-electrolysis		Water
Biochemical + Thermal	Thermophilic digestion		Biomass
Photonic + Biochemical	Bio-photolysis		Biomass, water
	Photo-fermentation		Biomass
	Artificial photosynthesis		Biomass, water

Figure 26
Hydrogen 1.0 era and its domains [Modified from (Dincer, I., 2023)]

Better energy security is the next stage, and for many nations worldwide, it is seen as one of the biggest concerns. Numerous nations endeavor to enhance their hydrogen environment and improve their energy security. This may potentially be expanded to include some additional nations, such as Türkiye, which is largely dependent on imported coal, oil, and natural gas. A better economy in the "Hydrogen 1.0" era is the final step. Everyone assumes that every decision must be more economically sound. It is considerably more crucial to take energy into account. A better economy is essentially the main worry when it comes to hydrogen energy, thus we need to provide more practical solutions.

European Hydrogen Observatory of Clean Hydrogen Partnership, which is an initiative by the Clean Hydrogen Joint, highlights key aspects of production, demand, distribution, and trade (EU EHO, 2024). Hydrogen production capacity of Europe stood at 11.23 Mt in 2023, with 7.94 Mt produced in total. This production relied primarily on water electrolysis (31.41 kt) and reforming with carbon capture (42.53 kt). The cost of production varied depending on the method, with grid-connected electrolysis averaging 7.94 EUR/kg, SMR at 3.76 EUR/kg, and SMR with CC at 4.41 EUR/kg. On the demand side, Europe consumed 7.93 Mt of hydrogen in 2023, with 26.86 kt provided by clean hydrogen sources. Distribution infrastructure included 187 hydrogen refueling stations (HRS) and 1581 km of operational hydrogen pipelines. Finally, 29.77 kt of hydrogen was traded between European countries in 2023. Europe had 5.40 GW of electrolyzer manufacturing capacity by May 2024, suggesting a growing domestic capability for hydrogen production technology (EU EHO, 2024).

7.3. Fuel Cells

An electrochemical device called a fuel cell directly transforms the chemical energy of fuel into electrical power. A fuel cell is comparable to a battery in the most straightforward analogy imaginable, except for the fuel and oxidizer flow. The earliest fuel cell demonstration is credited to Sir William Grove in 1839. In essence, it reversed a water electrolysis reaction by using distinct platinum electrodes in hydrogen and oxygen gas while immersed in a diluted sulfuric acid electrolyte solution (Colpan, 2024a).

Fuel cells offer several significant advantages, including high conversion efficiency, scalability, low environmental impact, and silent operation. However, challenges remain in their widespread adoption. These challenges include high costs associated with fuel cells themselves and the production of hydrogen fuel. Additionally, there are ongoing issues related to the storage and delivery of hydrogen, as well as concerns about the long-term durability of fuel cell systems.

Materials and operating conditions of fuel cell types are tabulated in Table 2. Fuel Cells consist of some components such as membrane, catalyst later, platinum, carbon, Ionomer, gas diffusion layer, gasket, flow field plate, and end plate. Generally, the membrane for PEMFC produces a perfluorosulfonic acid type membrane (e.g., Nafion™ (Nafion, 2024)). It has high proton conductivity (when fully hydrated) and is electrically insulated. Membranes eliminate crossover of chemical species (e.g., H_2 ve O_2) and are chemically, thermally, and mechanically durable under operating conditions. Catalyst Layers interface with reactant, catalyst, and ion and electron conductors that enable a reaction. It has high electrical and ionic conductivity and high porosity (40-70%). Mostly produced from expensive metal catalysts (e.g., Pt). Pt-based alloys achieve high reaction rates with low amounts of Pt (e.g., Pt-Co alloy). The gas Diffusion Layer is utilized between the catalyst layer and the flow field plate. These layers have a porous structure with high electrical conductivity and high mechanical strength. It optimizes gas and liquid transport. Typically, carbon cloth or paper (hydrophobic or hydrophilic micro-porous layer could be added) (around 100-300 µm). Flow Field Plates distribute reactant gases homogeneously. It expels excess water rapidly. Flow field plates have high electrical conductivity (e.g., graphite, stainless steel) and different designs. Gaskets are used to establish a seal and prevent fuel leaks, which helps to maximize efficiency. The membrane is generally cut larger than the electrodes and placed around each electrode.

The membrane electrode assembly is the heart of a fuel cell, where electrochemical reactions occur to generate electricity. Its manufacturing involves several critical steps. First, the necessary components, catalyst (typically platinum-based), polymer electrolyte membrane (often Nafion), and gas diffusion layers are either purchased or synthesized. Next, the catalyst is dispersed into a suitable solvent to form catalyst ink. This ink is then carefully applied to either the membrane or the gas diffusion layer, depending on the chosen coating method. Finally, the MEA is assembled using a hot press. The hot press conditions (temperature, pressure, and time) are crucial for achieving a strong bond between the components while minimizing degradation of the membrane and delamination of the catalyst layers. Parameters such as the temperature and pressure of the hot plate should be carefully chosen to ensure adequate bonding of the ionomer in the membrane while avoiding excessive heat-induced damage.

Table 2

Materials and operating conditions of fuel cells [Modified from (Colpan et al., 2018) and (O'hayre et al. 2016)]

	PEMFC	DMFC	AFC	MCFC	SOFC
Operating Temperature	60-200°C	60-80°C	60-220°C	~650°C	600-1000°C
Electrolyte Material	Polymer membrane	Polymer membrane	Liquid KOH	Molten carbonate	Ceramic
Charge Carrier	H^+	H^+	OH^-	CO_3^{2-}	O^{2-}
Catalyst Material	Platinum	Platinum, Platinum-ruthenium	Platinum	Nickel	Nickel/yttria stabilized zirconia
Interconnect Material	Carbon-based	Carbon-based	Carbon-based	Stainless steel based	Ceramic based
Fuel	H_2	CH_3OH	H_2	H_2, CH_4	H_2, CH_4, CO

*AFC: Alkaline fuel cell
*DMFC: Direct methanol fuel cell
*MCFC: Molten carbonate fuel cell
*PEMFC: Proton exchange membrane fuel cell
*SOFC: Solid oxide fuel cell.

Proton exchange membrane and solid oxide fuel cells (PEMFCs and SOFCs) represent distinct approaches to fuel cell technology, each with its own set of advantages and drawbacks. PEMFCs excel in immediate cold starts and offer high flexibility in load amplitude, making them suitable for applications requiring rapid response. However, they rely on costly platinum catalysts and are sensitive to impurities in the fuel stream, particularly carbon monoxide (CO) (Okonkwo et al., 2021). In contrast, SOFCs utilize less expensive non-noble metal catalysts and demonstrate greater fuel flexibility (Othman et al., 2012).

Their simple system with only two phases (gas and solid) simplifies operation. However, SOFCs suffer from long cold start times, limiting their use in applications demanding rapid startup. Additionally, their load flexibility while operating can be insufficient for scenarios with highly variable energy production needs. While SOFCs show promise for stationary power generation and industrial applications, PEMFCs currently hold an edge in applications requiring rapid response and high load variability.

Fuel cell characterization and performance testing are crucial steps in evaluating their performance and reliability. The process typically begins with a start-up and conditioning procedure, followed by a leakage test to ensure proper assembly. Humidification of the MEA is essential to achieve maximum water uptake, while gas crossover checks assess membrane integrity. A break-in procedure helps stabilize performance. Fuel cell testing involves varying current density or cell voltage at specific intervals, such as measuring current density from open circuit voltage to 0.4 V with 0.05 V increments. Repeating tests and averaging results improve data accuracy. Polarization curves, which depict the change in cell voltage with current density, are generated under different operating conditions. These curves are influenced by MEA structure, flow field design, and operating parameters. Polarization curves serve as valuable tools for fuel cell stack sizing and design, providing insights into performance limitations and guiding optimization efforts (Colpan et al., 2011). The molar flow rate of the reactant entering the fuel cell can be calculated as follows:

$$\dot{n}_x = \lambda \frac{iA}{nF} = \lambda \frac{I}{nF}$$

where λ is the stoichiometric ratio, F is the Faraday constant ($C/mol_{eq.electron}$) and n is the moles of equivalent electrons per moles of x reactant ($mol_{eq.electron}/mol_x$). I, A and i are Current (A), Active area (cm^2), and Current density (A/cm^2), respectively.

The molar flow rate (mol/s) of hydrogen can be defined as follows:

$$\dot{n}_{H_2} = \lambda_a \frac{iA}{nF}$$

The amount of hydrogen (mol) consumed can be defined as follows:

$$n_{H_2} = \dot{n}_{H_2} \times t$$

The volume of hydrogen (m^3) can be defined by considering the ideal gas law as follows:

$$V = \frac{n_{H_2} \times \bar{R} \times T}{P}$$

The electrical efficiency of the fuel cell can be defined by considering Gibbs free energy change of reaction. Maximum achievable thermodynamic efficiency can be calculated as follows:

$$\eta_{fc}^{max} = \frac{-\Delta G}{-\Delta H} = \frac{\Delta H - T\Delta S}{\Delta H} = 1 - \frac{T\Delta S}{\Delta H}$$

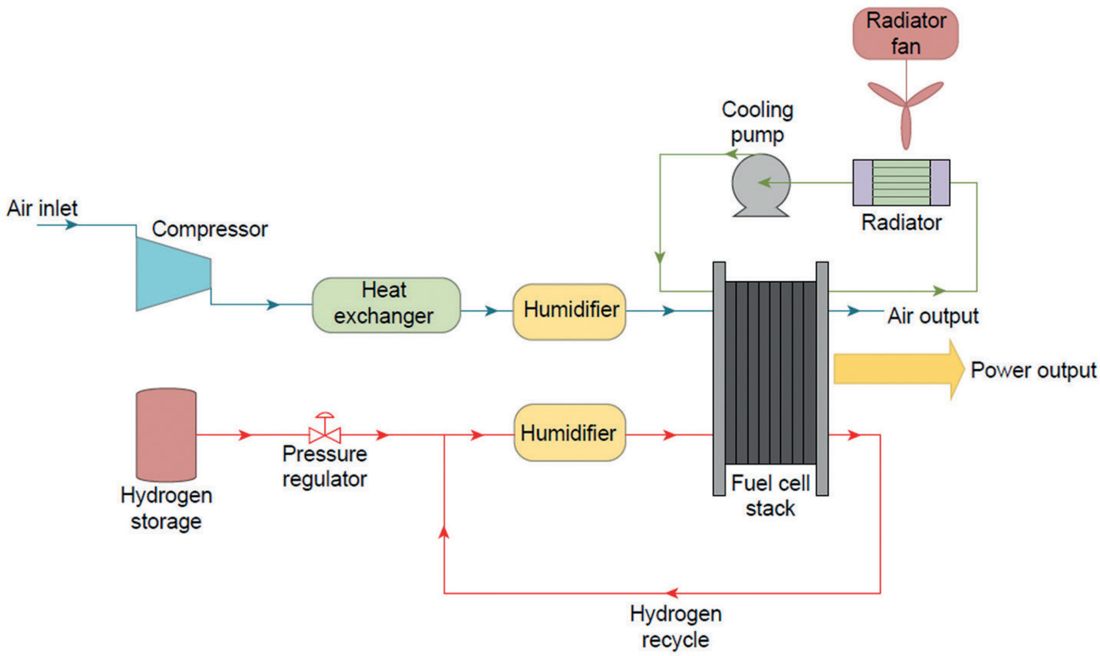
Here, ΔG and ΔH refer to Gibbs free energy change and enthalpy change of a reaction, respectively. ΔS is the entropy change of the reaction. Fuel cell efficiency can be defined as follows:

$$\eta_{fc} = \frac{\dot{W}_{fc}}{\dot{n}_{H_2} \cdot HV_{H_2}} = \frac{i_{cell} \cdot A_{cell} \cdot \Sigma V_{cell}}{\dot{n}_{H_2} \cdot HV_{H_2}}$$

where $\dot{W}_{fc}$ is the electrical power produced by a fuel cell and $\dot{n}_{h2}$. Is the molar flow rate of hydrogen. *HV* is the heating value and the lower heating value of hydrogen can be considered 241,830 kJ/kmol.

Fuel cell system components are given in Figure 27. Fuel cell stacks are constructed by connecting multiple single cells in series. Bipolar plates are used to connect. These plates serve a dual purpose: forming channels for air and fuel flow while simultaneously conducting electrons. The active area of each cell and the total number of cells significantly influence stack performance. While numerous small cells simplify alignment and connection, a smaller number of cells with larger active areas can lead to high current/low voltage combinations and substantial resistance losses. Other crucial design considerations include compression force, structural integrity, and pressure drop across long manifolds. Typical active areas range from 50 to 300 cm². The stack design is tailored to specific application requirements, such as power output, voltage, efficiency, and volume/weight constraints. Selecting the nominal operating point involves balancing power output with efficiency, with typical operating cell voltages ranging from 0.6 V to 0.7 V (Colpan et al., 2018).

Figure 27
Fuel cell system components [Taken from (Colpan et al., 2018)]



Ensuring uniform reactant distribution to each cell is vital for consistent performance. Uneven flow distribution can result in variations in cell performance, necessitating careful manifold sizing to control flow velocity and minimize pressure drop. Pressure drop can be calculated using analytical or numerical solution methods. Other system components are the pump, compressor, fan, heat exchanger, humidifier, voltage regulator, fuel tank, battery, and electronic control unit.

7.4. Hydrogen Storage and Utilization

Hydrogen can be stored as gas and liquid (cryogenic temperatures) in high-pressure tanks, liquid tanks, metal hydrides, and other chemical compounds. Also, as a promising way for hydrogen storage, natural gas pipelines can be utilized as storage media. Hydrogen can be injected into natural gas for cost-effective storage and transportation. As an energy carrier, green hydrogen has the potential to reduce environmental effects. Blends of green hydrogen and natural gas have gained popularity recently, particularly in combustion systems. Blending natural gas and hydrogen can significantly reduce the storage problem (Sorgulu et al., 2023).

7.5. Materials for Hydrogen Energy Applications

Substances utilized in energy generation, conversion, storage, and transmission are referred to as energy materials. Conductive and redox-active polymers, carbon-based materials, transition metal oxides (chalcogenides, nitride, phosphide), mxenes, MOFs, and perovskites are utilized in energy systems (Koca, 2024).

Modification of atomic arrangement, molecule structure, and electron transfer qualities in a limited area can improve the electrocatalytic efficiency of the material. It controls the physicochemical characteristics of electrocatalysts in addition to changing the active center generation mechanism. As a result, intermediate species nucleation of the electrocatalysis, transport, and stabilization are optimized, which enhances the activity of the process, stability, and selectivity.

Hydrogen Evolution Reaction (HER) and Oxygen Evolution Reaction (OER) have captured a great deal of attention. HER at the cathode and OER at the anode of the electrolyzers for the water splitting involves a multi-step electron transport path, (2 for HER and 4 electron-proton coupled reactions for OER). The HER and OER mechanisms are complex processes, and the velocity of reactions is slow, leading to excessive overpotential. Thus, the usage of electrocatalysts is important to perform water electrolyzes at low overpotentials. A potential of 1.23 V (thermodynamic and under standard conditions) is required to drive electrochemical water splitting. It corresponds to an energy input of $\Delta G = 237.1\ kJ/mol$.

The electrochemical HER process, which reduces protons in acidic media or water molecules in an alkaline medium to hydrogen molecules (H_2) on the surface of an electrode with a minimum external voltage applied, can be broken down into three main phases. The first stage is the Volmer reaction, in which an electron and a proton combine to form an adsorbed hydrogen atom (H*) on the surface of the electrode material (M). In acidic and alkaline electrolytes, the proton sources are the water molecule and the hydronium cation (H_3O+), respectively. Then, either the Tafel reaction or the Heyrovsky reaction may produce the H_2. Another proton diffuses to the H* in the Heyrovsky step, where it combines with a second electron to form H_2. Two nearby H* combine on the surface of the electrode to evolve H_2 in the Tafel step.

The catalyst-reactive intermediate interaction should be suitable for the active electrocatalyst. If the contact is too strong, the reaction products fail to dissociate and stop the reaction by blocking the active sites, whereas if it is too weak, too few intermediates attach to the catalyst surface, slowing down the reaction. It has been discovered that transition metal sulfides, phosphides, oxides, carbides, and nitrides exhibit the highest catalytic activity towards HER among the electrocatalysts.

One of the most promising approaches to solving the problems of energy supply and environmental degradation is photocatalysis, which may directly transform solar energy into chemical energy while also achieving solar energy conversion and storage goals. Among the many ways to use solar energy, photocatalysis can start or speed up chemical reactions through light-matter interaction, which can address the issues of solar energy conversion and storage at the same time. According to semiconductor photochemistry, the function of photocatalysis is to start or speed up particular redox (reduction and oxidation) reactions when exposed to radiation.

Electrons in the valence band are stimulated into the conduction band, leaving holes in the valence band, when exposed to radiation with an energy equal to or higher than the semiconductor photocatalyst's band gap. Reduction and oxidation reactions are brought on by these photogenerated electrons and holes, respectively. Due to additional factors that affect the photocatalytic mechanism, only a small number of materials with appropriate band-gap potentials can work as a photocatalyst for overall water splitting. Three steps are involved in the overall water-splitting process on a semiconductor photocatalyst:

- The photocatalyst creates photoexcited electron-hole pairs in the bulk by absorbing photon energy above the band-gap energy of the material,
- Without recombining, the photoexcited carriers split apart and move to the surface,
- The photogenerated electrons and holes reduce and oxidize the adsorbed species to yield H_2 and O_2, respectively.

8. Energy Storage Systems and Applications

8.1. Energy Storage and Its Importance

Energy storage systems are vital to balance the electricity supply and demand, particularly when integrating renewable energy. Excess energy is stored by energy storage subsystems and the grid stabilizes energy management. This reduces the additional power plant requirements and infrastructure upgrades. By storing energy generated from renewable sources, energy storage subsystems enable a more consistent and reliable power supply. Despite their benefits, research and development should be conducted to deal with challenges such as limited energy capacity, high initial costs, and environmental concerns related to the production and disposal of storage technologies.

Energy storage systems are pivotal in modern energy grids, addressing challenges posed by renewable energy integration and variable energy demands. Excess energy is stored in these systems during low-demand periods to improve energy security, efficiency, and sustainability. A classic example of the importance of energy storage is seen in the "duck curve," which highlights grid stress caused by solar energy generation peaking at midday while demand rises in the evening. Energy storage flattens this curve by redistributing energy supply (Colpan, 2024b).

8.2. Energy Storage Methods

Energy storage technologies are categorized into mechanical, thermal, thermochemical, electrochemical, electrical, and biological systems. Each category has unique characteristics tailored to specific applications.

8.3. Mechanical Energy Storage Systems

Pumped hydro storage (PHS), flywheels, and compressed air energy storage (CAES) are types of mechanical energy storage. PHS is the most mature storage technology. Water is pumped to an elevated reservoir and released during peak electricity demand. Advantages include a long lifespan, large capacities, and quick response times. However, geographic constraints and high capital costs are significant challenges.

In a compressed air energy storage system, energy is stored as compressed air in reservoirs such as salt caverns. Efficiency ranges from 40% to 60%, with adiabatic systems improving performance by storing heat generated during compression. Air is compressed and chilled in stages until it liquefies in a liquid air energy storage (LAES) device. For discharge, liquid air is returned to gas through evaporation (by heat from surrounding or waste heat). Stored heat further warms the air, which can then power a turbine to produce electricity. Rotational kinetic energy is stored in a spinning mass in a flywheel with high efficiency. Flywheels have rapid response times and long lifespans but are limited by low energy density compared to batteries and high self-discharge rates. Depending on the materials of the flywheel, a rotational speed of up to 100,000 rpm can be applied (Dincer & Rosen, 2021).

The largest pumped hydro storage facility in the world (Bath County Pumped Storage Station in the USA) was commissioned in 1985 to provide 30.9 GWh of energy with a round-trip efficiency of 78%. The Gorona del Viento project was demonstrated in the Canary Islands, Spain (An island with 100% renewable energy). Wind turbines with a capacity of 11.3 MW are connected to the PHS station. PHS unit is used to store excess energy and produce electricity when required. Within the project wind turbines and pumped hydro are integrated to achieve 100% renewable energy generation on the island. Highview Power's liquid air energy storage (in Manchester, UK) plant stabilizes a capacity of 50 MW (300 MWh) to provide essential grid stabilization services while serving 480,000 homes (Highview Power, 2024). Alqueva Floating Solar Farm is integrated with the Alqueva pumped storage project in Portugal with a capacity of 5 MW. 12,000 solar panels float over a 4-hectare area (Unex, 2024). Floating panels are more effective for land and water usage, reduce evaporation losses by shading the water, increase solar cell efficiency through water cooling, and take advantage of existing infrastructure.

8.4. Thermal Energy Storage Systems

Thermal Energy Storage (TES) occurs in three ways, thermochemical storage, sensible heat storage, and latent heat storage. Materials like water or molten salts are employed to store energy via temperature changes in a sensible heat storage system. For example, molten salts are widely used in concentrated solar power (CSP) plants. 340,000 tons of molten salt is utilized for thermal energy storage in the Noor Energy 1 project in Dubai. Sunshine is reflected by using 70000 heliostat to a tower with a height of 260 m (Solarpaces, 2023). In an underground TES (UTES) unit, geological strata made up of sand, soil, and solid bedrock can be utilized as the storage medium. Thermal energy, with desired capacities, can be stored across seasons. UTES is mostly used for district heating applications and can be used to store the heat from solar energy by collectors or industrial processes, or the cold from the winter air. In a latent heat storage system, phase change materials (PCMs) are utilized to store energy during phase transitions, offering higher energy density and constant-temperature discharge, critical for applications like cold storage. PCMs can be classified as sub-zero PCMs, ice, low-temperature PCMs, and high-temperature PCMs.

Recent trends in the PCMs are to develop nano-enhanced PCMs such as metals, metal oxides, carbon nanotubes, graphene, and graphite to improve thermal conductivity and reduce sub-cooling and micro and nano-encapsulated PCMs to enhance heat transfer, thermal conductivity, and leakage issues.

8.5. Thermochemical Energy Storage Systems

Reversible chemical reactions are necessary for high-density energy storage in thermochemical storage. By reducing the chemical potential binding force between the sorbent and the sorbate, heat is stored. Calcium looping is a notable example, suitable for seasonal energy storage and integration with CSP systems. A reversible reaction occurs between CaO and CO_2 to form calcium carbonate ($CaCO_3$). Heat is released during the process of recombining CaO and CO_2 to create $CaCO_3$ when energy is needed. Salt hydration is the process of hydrating and then dehydrating a solid salt to absorb and release energy. Water molecules are released when heat is applied, allowing the salt to dehydrate and be stored apart from it (US DOE, 2024b). When heat is needed, salt is mixed with water, which absorbs the heat and releases it.

Chemicals or fuels such as hydrogen, ammonia, and metal hydrides are produced to store energy. The versatility of hydrogen as a fuel and storage medium positions it as a key player in the transition to a hydrogen economy. Besides, excess electricity is converted into synthetic fuels, which is called "Power to X" like e-methanol or ammonia, enabling long-term storage and utilization. In a compressed hydrogen storage unit, storage tanks can be maintained at room temperature without establishing thermal management. However, power input is required to compress hydrogen. Besides, pressurized tanks should be manufactured from durable materials (e.g., steel composite) to prevent accidents. Liquid hydrogen has a higher energy density than gaseous hydrogen. However, additional costs are required for liquefying at -253°C. If the thermal insulation is not perfect, storing hydrogen for a long time would not be appropriate. Metal hydride storage depends on chemical adsorption. It has high volumetric energy density and gives hydrogen with high purity. The operating pressure is low. However, the charge and discharge of hydrogen are slow. Cooling is needed to be cooled during charging and heated during discharging. 220 MW of renewable energy is converted to 100 metric tons per day of green hydrogen in the Advanced Clean Energy Storage Hub project, in Delta, Utah (ACES Delta, 2024). Besides, green hydrogen is stored in two massive salt caverns.

8.6. Electrochemical Energy Storage Systems

Batteries are one of the most used electrochemical energy storage. Lithium-ion batteries are widely used for mobile and grid-scale applications due to their high energy density and efficiency. Variations include nickel-manganese-cobalt, lithium-iron-phosphate, and nickel, cobalt, and aluminum chemistries, each suited to specific use cases. Cobalt has a stabilizing effect that prevents cathode corrosion. Besides, cobalt and nickel allow for higher energy densities per unit mass. Flow batteries are considered power and energy capacity, making them ideal for utility-scale applications. Vanadium redox flow batteries, for instance, boast long lifespans and high reliability. Li-Ion Batteries consist of three parts: (i) anode (carbon-based particles, silicon-based, or titania-based materials), (ii) separator (porous material, either organic, polymeric, or like fiberglass materials), and (iii) cathode. Components of a complete battery storage system are a battery cell, battery module, battery racks, HVAC, inverter and power controls, and step-up transformer.

Flow batteries have many advantages over conventional batteries, such as:

- Energy storage capacity and power rating are decoupled
  - Cell and stack properties and geometry determine power
  - The volume of electrolytes in external tanks determines the energy storage capacity
  - Flow batteries can be tailored for a particular application
- Long lifetime
  - Electrolytes do not degrade
  - Electrodes are unaltered during charge/discharge
- Potentially very long discharge times
  - 4-10 hours is common
- Self-cooling
  - Inherently liquid-cooled
- Relatively high conversion efficiency is achieved
- All cells in a stack supplied with the same electrolyte
  - All cell voltages are equal
  - Individual cells are not susceptible to overcharge/undercharge
  - No need for cell balancing

Despite advantages, flow batteries have disadvantages, which need to be researched, over conventional batteries, such as:

- Higher costs of some elements or active materials, such as vessels or membrane
- Increased complexity and cost associated with pumps, sensors, and plumbing
- Lower specific energy and specific power
  - Best suited for fixed (non-mobile) utility-scale applications
- Potential leakage of acidic solutions and chemical requirements

One of the largest flow batteries in the world is connected to the grid in China. Within the Dalian Flow Battery Energy Storage Peak-Shaving Power Station, the first Phase with a capacity of 100 MW/400 MWh vanadium redox flow battery is completed. The project target is to reach a 200 MW/800 MWh flow battery (Bestmag, 2022).

8.7. Electrical Energy Storage Options

Supercapacitors and superconducting magnetic energy storage (SMES) systems are different types of electrical energy storage options. Supercapacitors bridge the gap between conventional capacitors and batteries, offering fast charge/discharge rates and long cycle lives. SMES utilize superconducting magnets to store energy. Despite high efficiency, its cost and cryogenic cooling requirements limit widespread adoption.

A comparison of electrical energy storage types including conventional capacitors, supercapacitors, and superconducting magnetic energy storage (SMES) is tabulated in Table 3.

Table 3

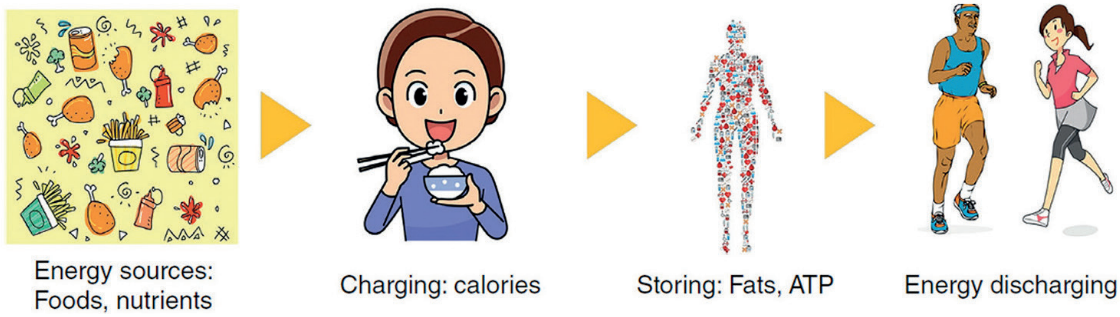
A comparison of electrical energy storage types

	Energy Density	Efficiency	Self-Discharge Rate
Conventional Capacitors	Low (2-10 kWh/M^3)	Moderate (60-85%)	High (40%/Day)
Supercapacitors	High (10-30 kW/M^3)	Enhanced (85-95%)	Low (20-40%/Day)
Superconducting Magnetic Energy Storage (Smes)	Very High (1-4 MW/M^3)	High (80-90%)	High

8.8. Biological Energy Storage Systems

Biological systems, such as those based on chemiosmosis (ATP), and biofuels like biodiesel, present promising applications in biological energy storage systems. Energy storage technologies enable diverse applications, including load balancing, grid stabilization, and integration of renewable energy sources like wind and solar.

Figure 28
Energy storage in the human body [Taken from (Dincer & Rosen, 2021)]



Energy storage in the human body is illustrated in Figure 28. Future advancements aim to enhance energy density, efficiency, and scalability while addressing cost and environmental concerns. Emerging trends include nano-enhanced phase change materials, solid-state batteries, and hydrogen storage innovations. The overarching goal is to support the transition to a sustainable energy future, ensuring reliability and affordability across energy systems.

9. Smart Grid and District Energy Systems

Smart grid and district energy systems are interconnected technologies that play a crucial role in modernizing our energy infrastructure. Smart grids utilize advanced technologies like sensors, automation, and two-way communication to optimize electricity generation, transmission, and distribution. This allows for greater integration of renewable energy sources, improved grid reliability, and more efficient energy consumption. District energy systems provide centralized heating and cooling to multiple buildings through a network of pipes. These systems often leverage waste heat from industrial processes or utilize renewable sources like geothermal energy, significantly reducing environmental impact and improving energy efficiency. The synergy between these two technologies lies in their ability to work together. Smart grids can optimize the operation of district energy systems by monitoring energy demand and supply in real-time, adjusting operations to maximize efficiency and minimize costs. This integrated approach can lead to more sustainable, reliable, and affordable energy solutions for communities.

9.1. Smart Grid

The four functions of an electrical grid are power generation, transmission, distribution, and control. It may facilitate all or some of these functions. To improve efficiency, dependability, asset utilization, and customer experience, information and communication technologies are integrated with electricity infrastructure to create a smart grid. A smart grid is a vast network of systems with three layers for each functional domain (Genc, 2024):

- the power and energy layer
- the IT/computer layer
- the communication layer

The energy sector is undergoing a transformative shift driven by the integration of digital technologies with traditional power systems. The emergence of the smart grid epitomizes this evolution, enabling bi-directional energy flows and seamless communication across the grid. Coupled with district energy systems, these advancements promise a future of enhanced efficiency, reliability, and sustainability in energy management.

The smart grid is a modernized electrical system that incorporates information and communication technologies (ICT) into power infrastructure. This integration enables enhanced efficiency through optimal resource utilization, improved fault detection and system resilience for reliability, and an improved consumer experience with active participation and tailored energy solutions. Smart grids offer significant features and benefits. They enable decentralized generation by integrating distributed energy resources, including renewable sources like solar and wind. They improve power quality by ensuring stable voltage and frequency and include a self-healing capability with automatic fault detection and resolution. Additionally, they support active consumer participation through tools like smart meters and demand-side management, enabling informed energy use.

9.2. District Energy Systems

District energy systems represent localized energy production and distribution networks, delivering heating, cooling, and electricity to specific districts or communities (Midilli, 2024b). They offer advantages such as increased energy efficiency through centralized generation that minimizes losses, flexibility to integrate renewable energy and storage systems, and a reduced carbon footprint through the potential use of low-carbon technologies like geothermal or waste heat recovery. Integration with smart grids further enhances their functionality, enabling real-time monitoring for efficient load balancing, supporting variable renewable energy generation through advanced controls, and aligning energy storage systems with distributed generation to address intermittency.

Table 4

Key differences between traditional and smart grids

Aspect	Traditional Grid	Smart Grid
Data Integration	Limited	Comprehensive and predictive
Customer Focus	Minimal	Proactive and engaging
Energy Flow	One-way	Bi-directional
Fault Detection	Reactive	Predictive and automated
Cybersecurity	Vulnerable	Resilient

The differences between traditional grids and smart grids are striking. Traditional grids are characterized by limited data integration, minimal customer focus, one-way energy flows, reactive fault detection, and vulnerability to cyberattacks. In contrast, smart grids offer comprehensive and predictive data integration, proactive customer engagement, bi-directional energy flows, predictive and automated fault detection, and resilience against cyberattacks.

Table 4 highlights the key differences between traditional and smart grids. Traditional grids have limited data integration, minimal customer focus, and rely on one-way energy flow. Fault detection is reactive, and cybersecurity vulnerabilities are significant. In contrast, smart grids boast comprehensive and predictive data integration, proactive customer engagement, and bi-directional energy flow. They enable predictive and automated fault detection and are designed to be more resilient against cyber threats. These advancements in smart grids offer improved efficiency, reliability, and sustainability in energy distribution.

Deploying smart grids and district energy systems comes with several challenges. Technological hurdles include the integration of renewable sources, voltage stabilization, and maintaining system inertia. Infrastructure challenges involve retrofitting legacy systems with modern ICT. Cybersecurity remains a critical concern to protect against potential threats. Regulatory challenges require the establishment of supportive policies and frameworks, while social acceptance necessitates consumer participation in demand-side management.

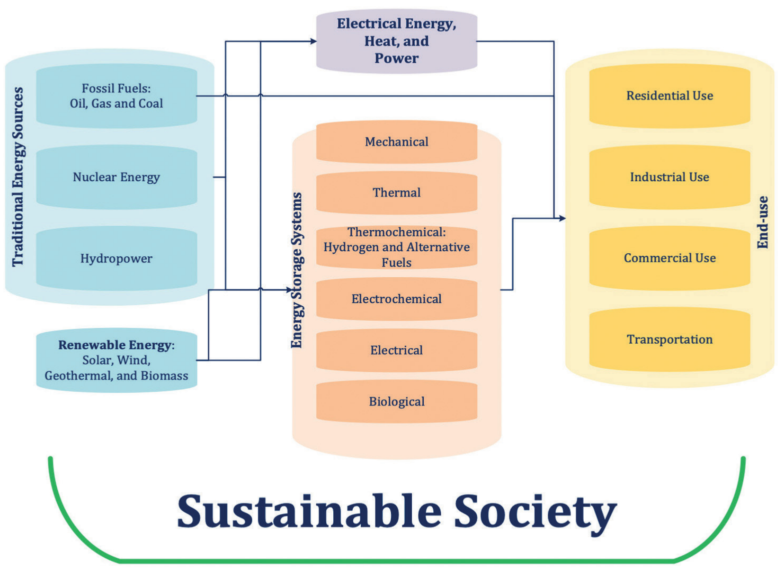
Smart grids and district energy systems collectively represent the cornerstone of a sustainable energy future. By leveraging ICT, automation, and advanced analytics, they enhance system reliability, integrate renewable energy sources, and empower consumers. However, realizing their full potential requires overcoming technical, regulatory, and societal challenges through innovative solutions and stakeholder collaboration.

10. Alternative Fuels

The relentless rise in the global population, coupled with rapid technological advancements and industrialization, has led to an unprecedented increase in energy demand. Traditional fossil fuels, including oil, coal, and natural gas, currently supply a significant portion of the primary energy needs of the world. However, their use has resulted in severe environmental challenges, such as greenhouse gas emissions, global warming, acid rain, and the accumulation of petroleum-derived plastics, contributing to ecological degradation. Moreover, the finite nature of these resources and their concentration within a few geopolitical regions exacerbate energy insecurity. In light of these issues, the adoption of alternative and renewable energy sources has become imperative for a sustainable future. Countries have to determine a rational policy that requires the use of new and renewable energy sources and eco-friendly fuel and material technologies (Alma, 2024).

Figure 29

Energy landscape by source, system, storage, and service



A schematic illustration of the energy landscape by source, system, storage, and service is given in Figure 29. Clean energy sources such as solar, biomass, wind, geothermal, hydropower, and nuclear are promising alternatives to fossil fuels. Hydrogen and alternative fuels, as chemical energy storage options, are critical for sustainable systems. These sources are not only abundant but also environmentally friendly.

10.1. Biofuels

Bioenergy is particularly significant as it can provide up to 27% of global transportation fuel by 2050 (IEA, 2024a). Bioenergy generation has seen rapid growth. This expansion is driven by renewable energy targets and the increasing energy demands of emerging economies with substantial biomass and renewable waste resources.

Biofuels, derived through contemporary biological or thermochemical processes, are categorized into four generations: (i) first-generation biofuels (these include biodiesel and bioethanol, which are widely used in transportation) (ii) second-generation biofuels (these are produced from lignocellulosic biomass wastes, offering a more sustainable alternative without competing with the food supply) (iii) third-generation biofuels (algae-based biofuels involve processes like transesterification to produce biodiesel and gasification followed by fermentation to produce ethanol) and (iv) fourth-generation biofuels (these involve genetically modified organisms such as cyanobacteria to enhance fuel production efficiency).

Biomass conversion techniques are combined in a biorefinery to create materials, chemicals, and fuels in an environmentally friendly manner. It employs physical, chemical, biochemical, and thermochemical methods for conversion, ensuring minimal waste and maximum value addition. For instance, physical upgrading methods such as drying, pulverization, and pelletizing; chemical and biochemical methods, such as hydrolysis followed by fermentation or chemical conversion; thermochemical methods such as processes like pyrolysis, gasification, and liquefaction to produce bio-oil and syngas. Biorefineries are instrumental in converting lignocellulosic biomass into fine chemicals, biofuels, and green polymeric materials, thus contributing significantly to the circular economy.

Pretreatment and hydrolysis of lignocellulosic biomass are critical for biochemical methods, particularly bioethanol production. Methods such as acid hydrolysis, enzymatic hydrolysis, and consolidated bioprocessing enable efficient conversion of cellulose into fermentable sugars. Innovations like ultrasonic-assisted pretreatment and ionic liquid pretreatment have further enhanced process efficiency.

Liquefaction processes, including hydrothermal liquefaction, transform biomass into bio-crude under high pressure and moderate temperature. This bio-crude can be upgraded to fuels comparable to conventional diesel and gasoline. Biomass is gasified to syngas at a high temperature. Direct liquefaction or hydrothermal liquefaction are terms used to describe the high-pressure liquefaction of biomass. In this process, biomass is thermochemically converted to liquid (bio-crude) at low temperatures and high pressures with or without reducing gas and a catalyst. On the other hand, potassium and sodium carbonates act as catalysts.

The combustion properties of bio-oil have been investigated for heat and power generation in engines, turbines, furnaces, and boilers despite their low heating value and extreme water content. Because bio-oil is difficult to ignite, the engine should be driven on conventional fuels before converting to bio-oil. Liquification first thermochemically transforms biomass into bio-polyols, which are subsequently utilized to create beneficial green products. Polymers with a large number of hydroxyl groups, such as cellulose, hemicellulose, and lignin, are found naturally in biomass feedstocks. The conversion of liquid biomass into biopolymers is made feasible by hydroxyl groups. While alternative fuels offer numerous benefits, challenges remain. The economic viability of advanced biofuel technologies often depends on supportive policies and market incentives. Despite these challenges, the potential of alternative fuels to mitigate climate change, enhance energy security, and promote economic growth is undeniable. Continued innovation and investment in renewable energy technologies are essential to realizing a sustainable energy future.

10.2. Sustainable Aviation Fuels

Sustainable Aviation Fuels (SAFs) have the potential to completely transform air travel with the potential to drastically lessen the environmental impact of the aviation industry. Finding an alternative to traditional aviation fuels made from fossil fuels is essential to reducing climate change and creating a more sustainable future as the demand for air travel keeps rising. SAFs cover a wide variety of fuel sources and production processes, each with unique environmental effects and energy balances. Traditional aviation fuels are a significant contributor to greenhouse gas emissions, primarily CO_2, which drives global warming. Additionally, the combustion of fossil fuels releases other pollutants such as nitrogen oxides (NOx), particulate matter, and sulfur oxides (SO_2), which can negatively impact air quality and human health. The aviation sector is forced to decarbonize and reduce its overall environmental impact.

SAFs are derived from renewable and sustainable sources, offering the potential for substantial reductions in lifecycle greenhouse gas emissions compared to conventional jet fuel. Biomass-based fuels, waste-derived fuels, hydrogen, synthetic liquids, and advanced biofuels are promising alternative fuels for the aviation sector.

Biomass-based fuels are produced from agricultural residues (such as corn, sugarcane), forestry waste, dedicated energy crops (such as camelina, switchgrass), and algae. Different conversion techniques and technologies, including hydroprocessing, gasification followed by Fischer-Tropsch synthesis, and alcohol-to-jet processes, can convert biomass into aviation fuel. Novel methods are required for the sustainability of biomass-based SAFs in order to prevent deforestation, changes in land usage, and competition with food production. Utilizing wastes such as municipal solid waste, cooking oil waste, and industrial off-gases offers a circular economy approach to SAF production. Converting these wastes into fuels reduces landfill area requirements, waste disposal issues, and provides a lower-carbon alternative to fossil fuels. Technologies like gasification and pyrolysis are employed in these processes.

Renewable electricity is utilized to produce hydrogen as an alternative and sustainable aviation fuel. Hydrogen is used both as fuel and reacted with captured carbon dioxide to synthesize liquid hydrocarbons, including jet fuel. Both renewable energy and carbon capture and utilization technologies are crucial to obtaining sustainable liquid hydrocarbons. Advanced biofuels produced from non-food feedstocks or through novel conversion technologies offer significant improvements in sustainability and efficiency compared to first-generation biofuels. These SAFs are derived from algae, microbial fermentation, and genetically engineered crops optimized for biofuel production.

A life cycle assessment that considers every step of fuel production, from feedstock procurement or agriculture to fuel burning in aircraft engines, is necessary to evaluate the overall sustainability of SAFs. The main objective of sustainable aviation fuel usage is to lower greenhouse gas emissions in comparison to traditional jet fuel. This covers emissions from combustion, conversion, transportation, and feedstock generation. To prevent indirect land-use change, which can result in deforestation and higher emissions, sustainable feedstock sourcing is essential. It is recommended that energy crops be cultivated on marginal land or sustainably incorporated into current agricultural systems. Certain processes for producing biofuel may require a lot of water. SAF production needs to minimize water consumption and avoid impacting water-stressed regions. Both production and combustion of SAFs should minimize the release of pollutants that can harm air and water quality. The energy required to produce SAFs should be significantly less than the energy contained in the final fuel product to ensure a net energy gain and overall sustainability.

The development of SAFs is essential for the transition of the aviation industry towards sustainable and environmentally benign ways. Research and development are needed to optimize SAF production technologies, reduce costs, and ensure the environmental integrity of various SAF pathways. Supportive policies, investments in infrastructure, collaborations between research centers, industry, and governments are essential to scale up SAF production and make it commercially available. While challenges remain, the potential of SAFs to significantly reduce the environmental impact of aviation makes them a vital component of a sustainable future for air travel.

11. Economic, Environmental, and Social Dimensions of Energy

This chapter explores the impact of energy systems and sources on the environment and human life. Economic and social dimensions of energy, environmental effects of energy systems, sustainability dimensions of energy, and the impact of energy on agriculture are discussed.

Figure 30

Energy use per person in some regions (kWh per capita per year) [Data from (Energy Institute, 2024a)]

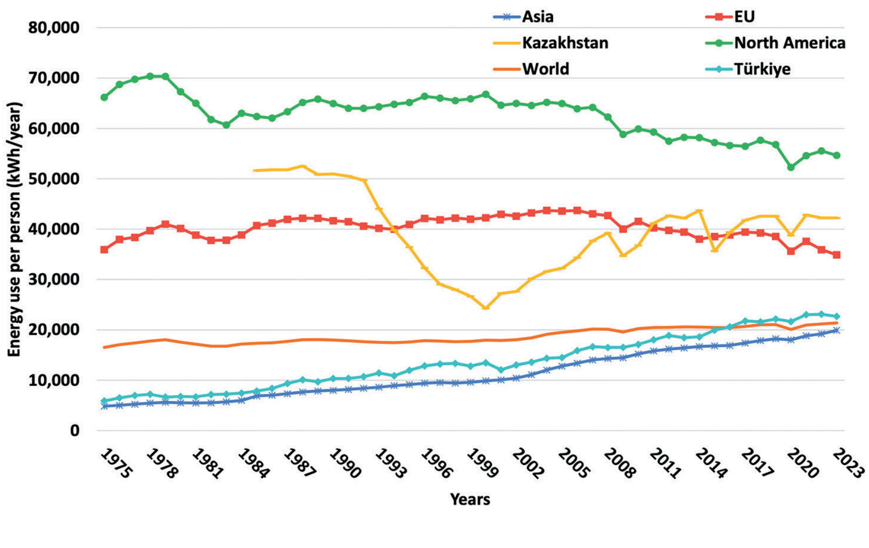


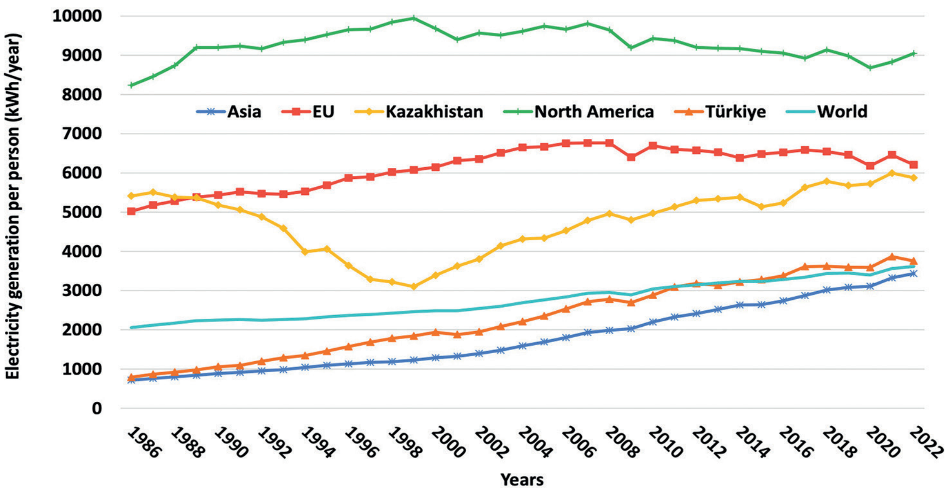
Figure 30 illustrates the total energy consumption (including electricity, heating, transportation, etc.) per capita in various regions selected from all over the world from 1975 to 2023. Notably, as expected, North American countries mainly the USA and Canada have consistently maintained the highest energy use per person throughout the period. The EU has shown a similar trend over the years. Türkiye have a significant increase in energy use per capita from 2900 to 23000 kWh in 50 years. Energy use in Kazakhstan has fluctuated, showing a notable decline from the late 1980s to the early 2000s, followed by a period of stability.

11.1. Economic and Social Dimensions of Energy

Energy plays a pivotal role in shaping both the economic and social fabric of societies. It drives economic growth, enhances living standards, and influences global and local environmental outcomes. However, energy production and consumption also bring challenges, including pollution, climate change, and socio-economic inequalities (Atakhanova, 2024b). Access to reliable and affordable energy directly improves living standards. It powers homes, schools, and hospitals, enabling essential services and fostering economic development. However, disparities in energy access lead to social inequality, limiting opportunities for education and health in underserved regions.

Figure 31

Changes in electricity generation per capita [Data from (Ember, 2024d)]



While Figure 30 shows changes in energy use (including electricity, heating, and transportation) per capita, Figure 31 illustrates changes in electricity generation per capita. North America has historically been the leader in electricity generation. Electricity generation in Türkiye has a significant growth, increasing five times more and reaching 3800 kWh per capita during the period.

Energy production significantly impacts the local environment. In extractive industries, activities such as mining and drilling degrade land, affect water quality, and reduce biodiversity. Coal-based electricity generation further exacerbates these issues, producing air pollution and hazardous waste. Thermal power plants, in particular, contribute to poor air quality, impacting community health and productivity. Socio-environmental consequences include (i) increased health risks, (ii) reduced productivity and income levels, and (iii) widening social inequality.

Figure 32

Changes in electricity generation for various regions [Data from (Ember, 2024a)]

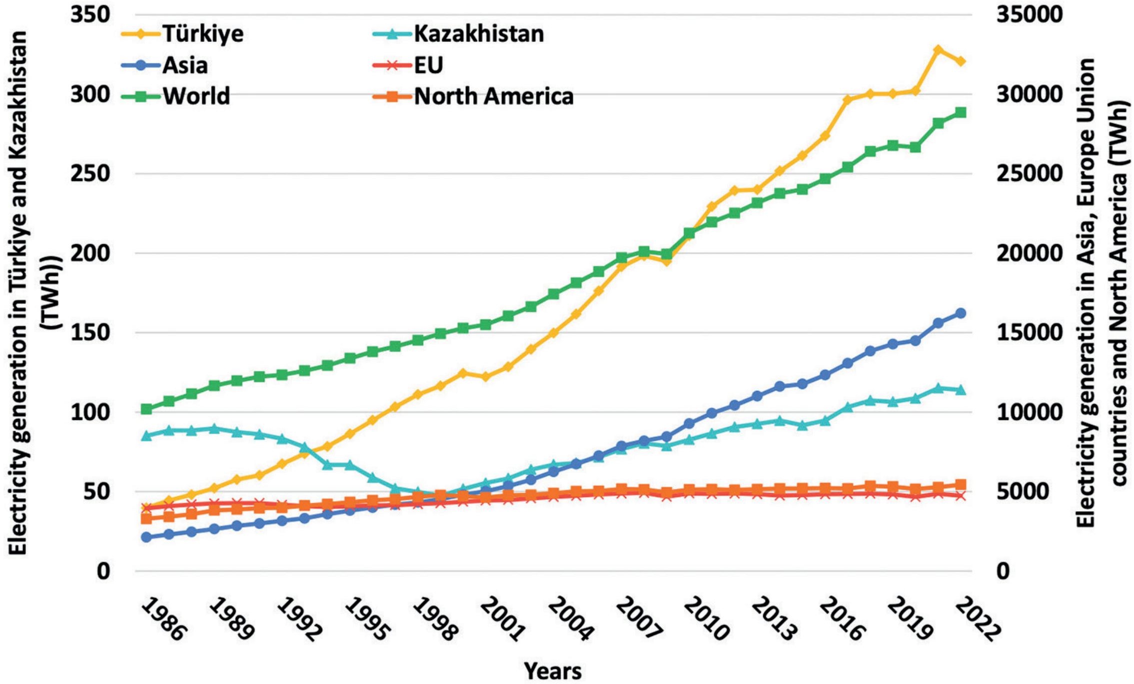


Figure 32 shows the yearly changes in electricity generation from 1986 to 2022 for specific regions, including Türkiye, Kazakhstan, and countries in Asia, the European Union, and North America. The continent of Asia, where 60% of the total population lives, has consistently been the leading region in electricity generation. The electricity generation in Türkiye has reached 335 TWh in 2023. In 2022, overall global electricity consumption has reached 28,843 TWh with a notable increase in recent years.

The combustion of fossil fuels generates significant quantities of greenhouse gases (GHGs), including CO_2, driving global warming. Addressing these challenges requires reducing fossil fuel consumption, transitioning to renewable energy sources, and expanding carbon sinks through reforestation and sustainable land management. Future generations face the dual responsibility of mitigating climate change and transitioning to sustainable energy practices. This includes improving energy efficiency, conserving resources, and fostering education on sustainable practices. Individual actions, such as reducing energy waste, contribute to larger systemic change.

Despite these economic benefits, the environmental costs due to land degradation and biodiversity loss, localized air and water pollution, and health and social challenges stemming from industrial activities are significant. Local air pollution from energy production adversely affects public health, increasing respiratory illnesses and reducing overall quality of life. This, in turn, lowers economic productivity and exacerbates income inequality.

Access to energy plays a pivotal role in improving education. Electrified schools enable better learning environments, supporting the development of human capital essential for sustainable growth. Effective climate action hinges on integrating renewable energy sources, enhancing energy efficiency, and reducing GHG emissions. Key strategies including expanding renewable energy production, promoting energy conservation across sectors, and encouraging education and awareness of sustainable energy use are essential. Individuals can contribute by adopting daily practices that minimize energy waste and support clean energy transitions.

Energy is both a driver of economic development and a source of environmental and social challenges. The associated costs from local pollution to global climate change must be addressed. There is a complexity of balancing economic benefits from energy industries with the imperative for sustainability in many countries. A comprehensive approach involving renewable energy, efficiency measures, and informed societal participation is essential for fostering a sustainable energy future.

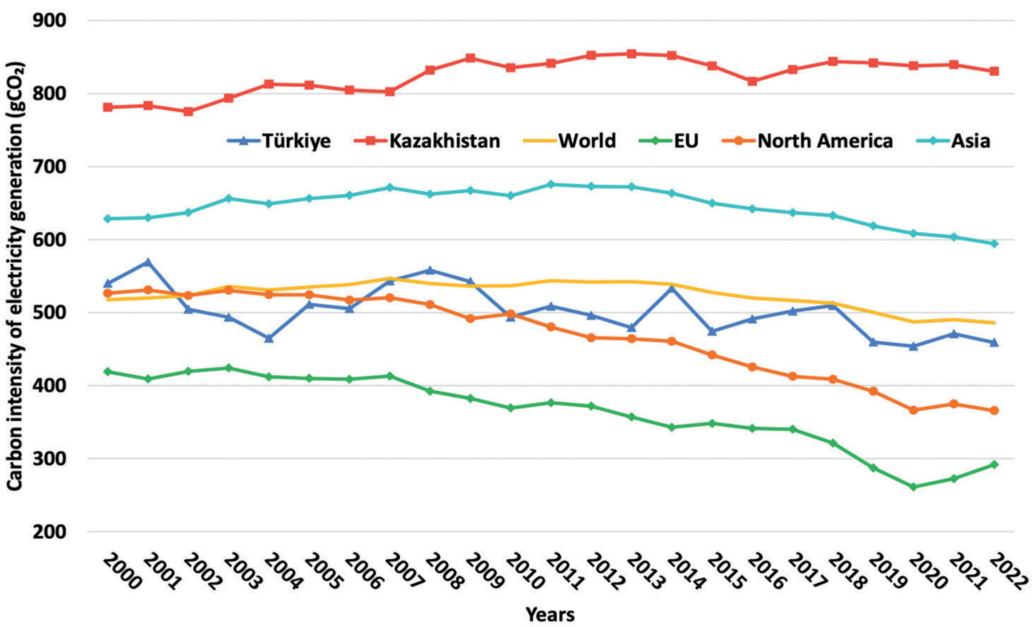
11.2. Environment and Sustainability Dimensions of Energy

Energy is the capacity to do work, essential for powering industries, homes, and transportation. Energy sources are divided into clean (e.g., solar, wind, hydro, nuclear) and non-clean (e.g., coal, oil, natural gas). Sustainability aims to meet present needs without compromising the ability of future generations to meet their own. It ensures long-term ecological balance by addressing environmental, social, and economic factors. Energy production and consumption are at the heart of sustainable development. Sustainable energy practices are crucial to reducing environmental impacts and ensuring resource availability for the future (Aydin, 2024).

The environmental dimension consists of (i) greenhouse gas emissions which is the impact of energy sources on climate change, (ii) biodiversity and ecosystems (energy production affects natural habitats), (iii) hazardous waste and toxic emissions (the environmental consequences of energy generation, (iv) water consumption (the water resources used in energy processes), and (v) depletion of non-renewable resources (the finite nature of fossil fuels and other non-renewable energy sources). Green or clean energy sources and systems are energy sources and systems with low environmental impact.

Figure 33

Carbon intensity (in grams of CO_{2eq} emitted per kWh) of electricity generation [Data from (Ember, 2023)]



The carbon intensity, measured in grams of CO_2 per kilowatt-hour (gCO_2/kWh), of electricity generation in various regions is given in Figure 33 for 20 years. The overall carbon intensity has trended downwards for most regions due to the usage of clean sources and more efficient technologies such as renewable energy sources, hydropower, and nuclear energy. The European Union and North American countries have significant reductions in carbon intensity, driven by environmentally friendly policies.

Throughout history, energy sources have evolved from wood to renewable energy. Early humans-controlled fire and used wood as their primary energy source. Industrialization led to coal dominating the energy market. After World War I, oil became the global energy leader. Especially after the 1973 oil crisis, natural gas gained prominence for electricity generation and heating. However, sustainability aims to achieve a better future by balancing social, economic, and environmental aspects. One of the most significant challenges is climate change. It refers to changes in temperature, wind, precipitation, and other aspects of the climate system of the Earth. The primary driver of recent climate change is the increase in GHG emissions due to deforestation, burning fossil fuels, and industrial processes.

Climate change has widespread and profound impacts on natural and human systems such as ecological disruption, agricultural productivity, human health, economic costs, and social and political stability. Altered habitats, shifts in species distributions, and increased extinction risks. Changes in crop yields, increased pests and diseases, and water scarcity. Increased heat-related illnesses, respiratory issues, and spread of vector-borne diseases. Damage to infrastructure, increased disaster costs, and loss of livelihoods. Climate-induced migration, resource conflicts, and social unrest.

Table 5

Key indicators of climate change

Indicator	Trend	Source
Global Temperature	+1.2°C since pre-industrial era	NASA (NASA, 2024)
Sea Level Rise	+3.3 mm/year	NOAA (NOAA, 2024)
Arctic Ice Extent	-13% per decade (since 1979)	NSIDC (NSIDC, 2024)
Ocean Acidification	+30% since pre-industrial era	NOAA (OAA, 2024)
Frequency of Extreme Events	Increasing	IPCC (IPCC, 2024)

Table 5 provides a summary of key indicators of climate change, highlighting the observed trends and their sources. According to data from NASA, the global average temperature has risen by 1.2°C since the pre-industrial era (NASA, 2024). Sea levels are also rising at a rate of 3.3 millimeters per year, as reported by NOAA (NOAA, 2024). The Arctic ice extent has been decreasing at a rate of 13% per decade since 1979, based on data from NSIDC (NSIDC, 2024). Ocean acidification has increased by 30% since the pre-industrial era, as measured by NOAA (NOAA, 2024). The IPCC reports an increasing trend in the frequency of extreme weather events, such as heatwaves, f droughts, and floods (IPCC, 2024). These indicators collectively demonstrate the significant and ongoing impacts of climate change on the planet.

There is a correlation between estimated global average temperature and atmospheric CO_2 levels over the past 800,000 years. The temperature data is derived from ice core records, providing insights into past climate conditions. During warmer periods like the Eemian, CO_2

levels were higher, while colder periods like the last ice age saw lower CO_2 levels. Notably, the current level of atmospheric CO_2 is significantly higher than at any point in the past 800,000 years. This rapid increase in CO_2 is attributed to human activities, primarily the burning of fossil fuels, and is a major driver of climate change (EPA, 2024).

Orbital changes trigger climate change over timescales of thousands of years. The image illustrates the three Milankovitch cycles, which are astronomical variations in the orbit of the earth and tilt that influence long-term climate patterns over tens to hundreds of thousands of years. A more elliptical orbit leads to greater variations in solar radiation received by Earth throughout the year. Obliquity (tilt) describes the angle of an axis of the earth of rotation relative to its orbital plane. This tilt changes over time, affecting the intensity of seasons in different hemispheres. Precession is the slow, circular motion of the axis of the earth as it spins. This causes the direction of the tilt of the earth to change over thousands of years, influencing the timing and intensity of seasons concerning the position of the earth in its orbit. These cyclical changes in orbital parameters of the earth can significantly impact the distribution of solar radiation on the surface of the earth, driving variations in temperature and precipitation patterns over long timescales.

There is a relationship between atmospheric carbon dioxide (CO_2) concentration and global temperature. When CO_2 concentration is doubled (from 280 ppm to 560 ppm), the increase in global temperature approximately occurs at 3°C. Increasing atmospheric CO_2 levels are a significant driver of global warming.

The Keeling Curve, a graph depicting monthly average CO_2 values at the Mauna Loa Observatory, provides a visual representation of the steady increase in atmospheric carbon dioxide concentration since measurements began in 1958 (ACS, 2024b). The curve highlights a clear upward trend, with CO_2 levels rising from around 315 parts per million (ppm) in the late 1950s to over 426 ppm in April 2024. The Keeling Curve serves as a powerful indicator of the ongoing impact of human activities on the climate system of the earth and highlights the urgent need for global efforts to mitigate greenhouse gas emissions.

The various anthropogenic forcings that have influenced the climate of the earth are investigated for particular periods. Radiative forcing, generally measured in W/m^2, represents the change in the energy balance of the earth caused by these factors. Carbon dioxide (CO_2) and methane (CH_4), as greenhouse gases, have a dominant warming effect, while aerosols, such as sulfate aerosols from fossil fuel combustion, exert a cooling effect. Other factors, like land use changes and stratospheric ozone depletion, also contribute to radiation forcing. The net anthropogenic component, shown as the tallest bar, represents the combined effect of all these factors.

Representative Concentration Pathways (RCP) scenarios represent a scenario where radiative forcing reaches (W/m^2) by the year 2100. Scenarios vary between 8.5 W/m^2 radiative forcing to 3 W/m^2 radiative forcing (RCP3-PD). RCPs show emissions reductions peaking before 2100 and falling thereafter (Meinshausen et al., 2011). RCP 8.5, emissions increase continue at 30 Gton C after 2100 (No emission reductions). RCP 6, emissions start to fall to 15 Gton C after 2100. RCP 4.5, 5 Gton of C would stabilize at around 540 ppm after 2100. RCP 3-PD CO_2 is expected to start decreasing soon. CO_2 levels after 2100 according to RCPs are 950 ppm for RCP 8.5 and 700 ppm for RCP 6. For RCP 4.5, it stabilizes at 540 ppm. This is about twice the CO_2 level of pre-industrial levels. RCP 3-PD CO_2 is expected to start falling soon. For RCP 8.5, the global temperature would rise 4-6°C. It is accepted that dangerous levels of climate change are reached if temperatures rise more than 2°C. Considering the annual emission curves for 4 RCPs. If the RCP 3-PD route is followed, the 460 Gton C quota won't be exceeded. RCP 3-PD is the only scenario that keeps global temperature below 2°C increase compared to pre-industrial levels. 460 Gton C quota runs out by 2064 for RCP 4.5, by 2062 for RCP 6, and by 2048 for RCP 8.5. Certainly, the target of staying below the 2°C average temperature increase is exceeded with RCP 8.5, RCP 6, and even RCP 4.5 (Meinshausen et al., 2011). It is reported that there is a temperature increase of between 0.8 and 2.5°C for every 1000 Gton C given to the atmosphere. Approximately 640 Gton C have been released into the atmosphere since 1750 (Stocker et al., 2013). Remaining emission quota to stay below 2°C average temperature increase: ***1100-640=460*** emission quota of approximately 460 Gton C remaining (CDIAC, 2024).

The changes and trends in CO_2 emissions per capita for various regions selected from all over the world for 50 years are given in Figure 34. While the global average has been steadily increasing, there are significant variations across regions. North America has consistently emitted the highest amounts of CO_2 per person, with little fluctuations over the years. Figure 35 shows the changes in emissions in the transportation sector over the years. Global emissions in aviation and shipping sectors are provided. Emissions in Türkiye increased significantly, especially from 2010 to 2020.

Figure 34

Carbon dioxide emissions per capita in selected regions [Data from (IEA, 2024c)]

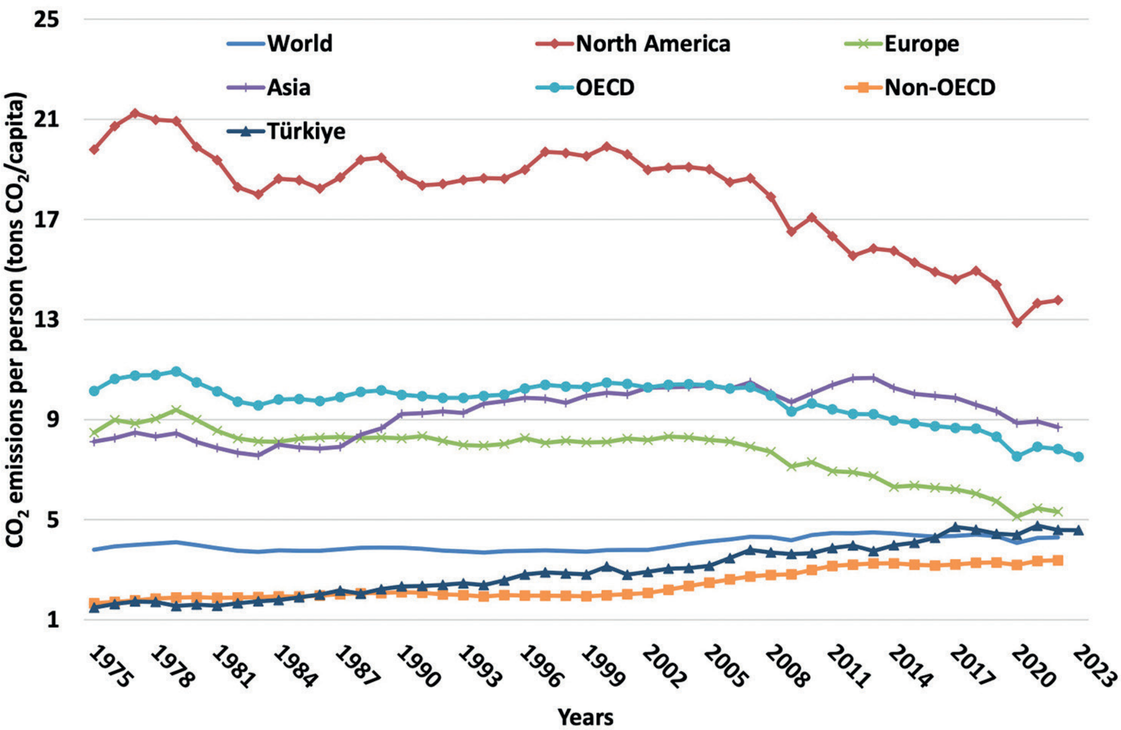
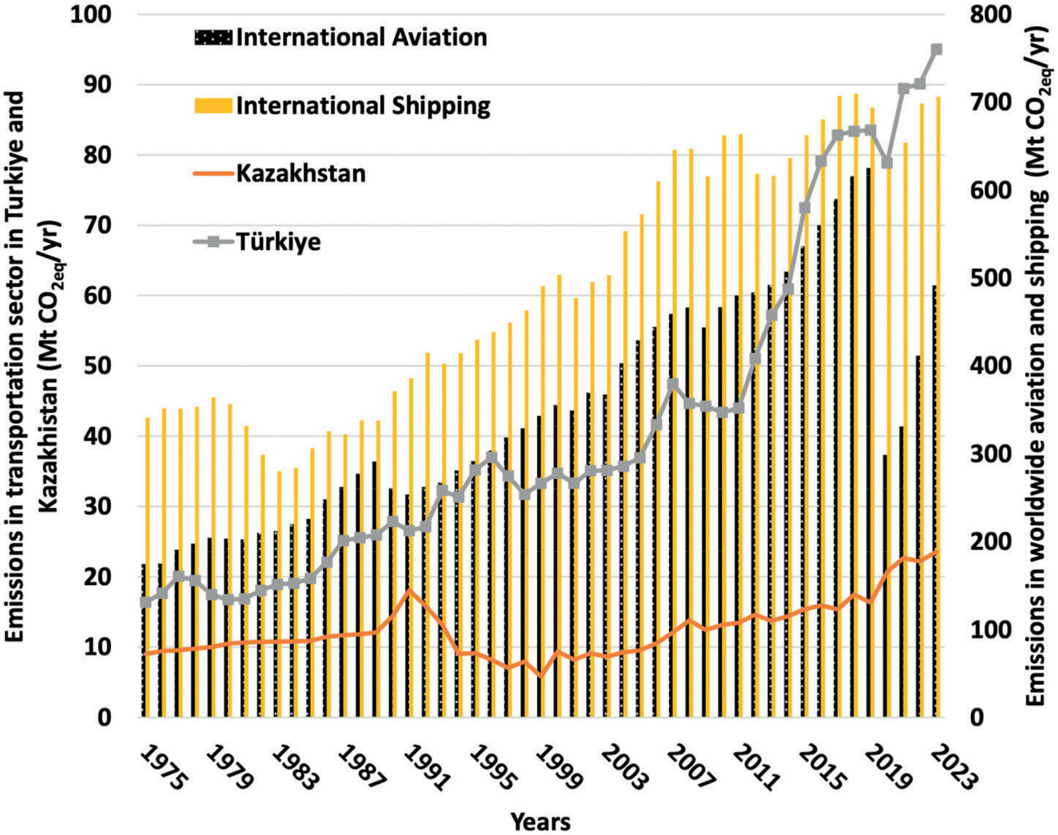


Figure 35

Changes in emissions in the transportation sector in Mt CO_{2eq} per year [Data from (IEA, 2024c)]



CO_2 Emissions (gCO_2/kWh), land uses (m^2/GWh), and water uses (L/kWh) of various energy sources are tabulated in Table 6 to provide a comparison of the environmental impact of the energy sources based on data from the International Energy Agency (IEA, 2024c). Coal seems to be the most impactful, with the highest CO_2 emission and land use. Wind turbines have the lowest emissions and land use with 16 gCO_2/kWh and 15 m^2/GWh, respectively (IEA, 2024c). Regarding water use, nuclear power, renewable sources, and hydropower have exceptionally low water consumption as to fossil fuels. Climate change, air, water, and soil contamination, habitat destruction, and loss of biodiversity are the main effects on the environment.

Table 6

Environmental impact of various energy sources [Data from (IEA, 2024c)]

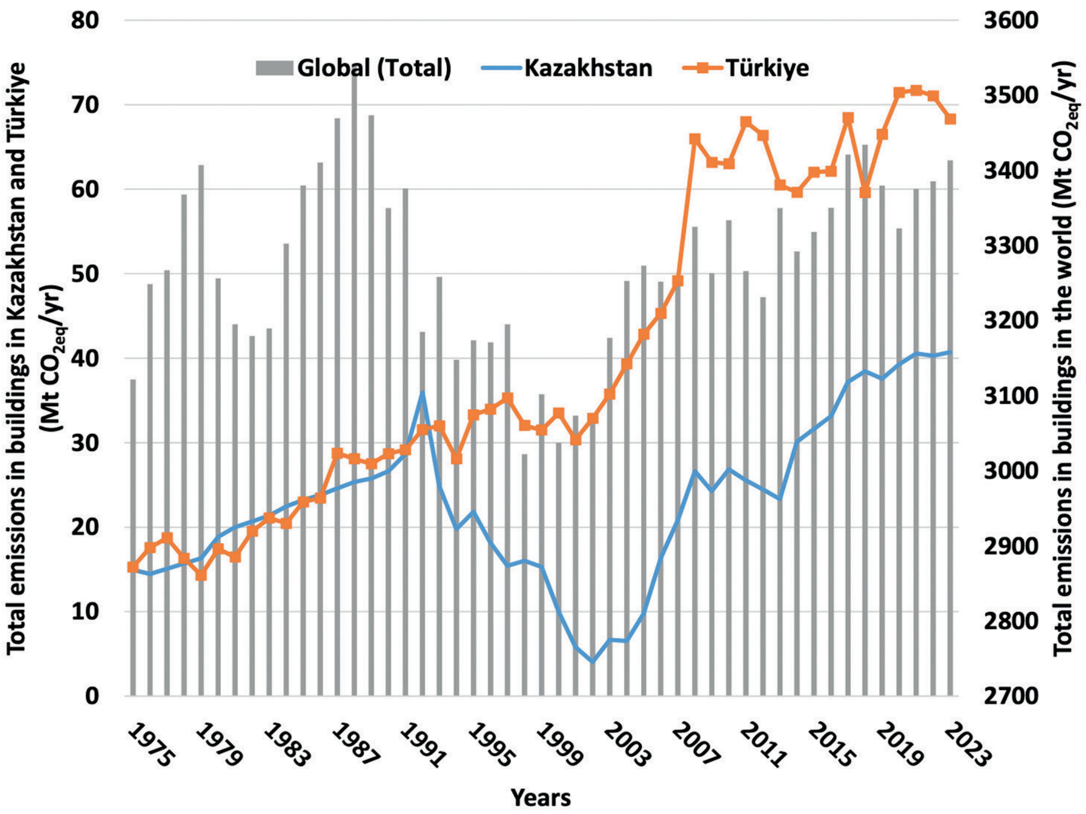
Energy Source	CO_2 Emissions (gCO_2/kWh)	Land Use (m^2/GWh)	Water Use (L/kWh)
Coal	820	400	2
Natural gas	490	200	1.2
Nuclear	16	50	0.1
Solar PV	41	55	0.1
Wind	11	15	0.05
Hydro	24	20	0.1
Biomass	18	30	0.3
Geothermal	38	15	0.2

Figure 36 shows the changes in total emissions in buildings for Kazakhstan, Türkiye, and globally from 1975 onwards. Total emissions show a steady increase throughout the period, with some fluctuation. Energy systems whether nuclear, fossil fuel, or renewable, play a critical role in modern society. Ensuring the security of these facilities is vital. Security breaches can have destructive consequences, including power outages, environmental damage, and even loss of life. Robust security measures, including physical barriers, surveillance systems, cyber defenses, and trained personnel, are essential to protect these vital assets and maintain a reliable and safe energy supply. Despite these security measures, still accidents occur:

- An oil spill have occurred in Exxon Valdez in Prince William Sound in 1989. 260,000 barrels of oil spilled. Massive marine life death, and long-term ecosystem damage (Britannica, 2024).
- Another accident happened in the BP Deepwater Horizon in the Gulf of Mexico in 2010. 4.9 million barrels of oil spilled and extensive marine and coastal damage occurred with economic losses.
- One of the newest oil spills was on the coast of Newport Beach, California in 2021. Marine and coastal ecosystem impact (Carlowicz, 2021)
- In 2013, a significant railway accident occurred in Lac-Mégantic, Quebec, involving a train carrying 72 tankers of crude oil. The derailment resulted in a catastrophic explosion and fire, tragically claiming 47 lives and causing widespread destruction to the town center, including numerous buildings and essential infrastructure (Valiante, 2019).
- In 2008, a major environmental disaster occurred at the TVA Kingston Fossil Plant in Tennessee. A catastrophic breach of a coal ash containment pond released a massive volume of toxic sludge, inundating 300 acres of land, destroying homes, and causing significant environmental damage (EPA, 2024).

Figure 36

Changes in total emissions in buildings (Data from [IEA, 2024c])



Innovative and efficient technologies are required for clean energy systems. The decline in emission per kWh of electricity or kW of power is achieved with an improvement in energy systems. Not only CO_2 emissions, but also SO_2 emissions, NO_x emissions, and mercury emissions decrease with energy-efficient systems. Stricter regulations and improved technologies are required for a trend toward cleaner systems, mainly combustion units. Strategies to reduce emissions can be listed as follows:

- Energy efficiency in buildings, transportation, industry
- Energy source change (replacing fossil fuels with renewable energy sources)
- Utilizing more nuclear energy
- Carbon Pricing (Implementing mechanisms like carbon taxes or cap-and-trade systems to reduce emissions)
- Reforestation and afforestation (more forest area to absorb CO_2 from the atmosphere)
- Sustainable agriculture (adopting practices that reduce emissions from agriculture and enhance soil carbon storage)

According to the Intergovernmental Panel on Climate Change (IPCC, 2024), the main strategies are transitioning to clean energy, implementing carbon pricing, enhancing energy efficiency, reforestation, and adopting sustainable agricultural practices. These strategies are estimated to achieve significant GHG reductions. Importantly, these strategies offer additional benefits beyond emissions reduction, such as reduced air pollution, lower energy costs, revenue generation, enhanced biodiversity, and improved soil health. Effective climate action supports broader sustainability objectives by:

- Reducing environmental degradation by lowering emissions and pollutants to protect ecosystems and biodiversity
- Enhancing resilience by building adaptive capacity to withstand climate impacts and natural disasters
- Promoting equity by ensuring fair distribution of resources and opportunities, addressing vulnerabilities of marginalized populations
- Supporting economic growth by fostering green industries, innovation, and sustainable livelihoods

According to the Sustainable Development Goals (SDG) Report 2023, several critical challenges remain across different SDGs (UN, 2023):

- Clean Water and Sanitation (SDG 6) aims to ensure the availability of water and sanitation for everyone. However, 2.2 billion people still lack access to safely managed drinking water. Moreover, 2.4 billion people reside in water-stressed regions, and since 1970, 81% of inland wetland-dependent species have declined.
- Affordable and Clean Energy (SDG 7) seeks to provide universal access to affordable, reliable, and sustainable energy. Despite progress, 675 million people still live without electricity, energy efficiency must more than double, and modern renewable energy powers only 30% of electricity production while remaining underutilized in the heating and transport sectors.
- Industry, Innovation, and Infrastructure (SDG 9) focuses on fostering innovation, sustainable industrialization, and building resilient infrastructure. In 2022, energy-related CO_2 emissions hit 36.8 gigatons. The global manufacturing growth rate dropped from 7.4% to 3.3%, driven by inflation, rising energy prices, supply chain disruptions, and an economic slowdown. While 95% of the global population has access to mobile networks (3G or higher), coverage drops to 82% in Sub-Saharan Africa and 68% in Oceania.

- Sustainable Cities and Communities (SDG 11) targets inclusive, safe, and sustainable urban settlements. Currently, 1.1 billion urban dwellers live in slums, with 2 billion more expected to join cities over the next 30 years. Only half of urban residents globally have convenient access to public transportation, and 75% of cities allocate less than 20% of their areas to public spaces, well below the recommended target of 45–50%. Air pollution is no longer confined to urban zones, as smaller towns also experience deteriorating air quality.
- Responsible Consumption and Production (SDG 12) promotes sustainable practices and patterns. High-income countries have a significantly larger ecological footprint, with a material footprint per capita of 24 tons compared to 2.5 tons in low-income nations. Despite calls to phase out fossil fuel subsidies, they nearly doubled due to global crises. Furthermore, 485 policies related to sustainable consumption and production have been introduced across 62 countries and the EU. On average, 120 kg of food is wasted per person annually.
- Climate Action (SDG 13) underscores the urgency of combating climate change. Global climate finance reached $803 billion annually, but developing countries require $6 trillion by 2030. Without deep and rapid greenhouse gas emission reductions (43% by 2030 and net-zero by 2050), global warming is expected to exceed 1.5°C by 2035 and reach 2.5°C by 2100. Sea-level rise has doubled over the past decade, and vulnerable regions face disaster-related mortality rates 15 times higher than others.
- Life Below Water and Life on Land (SDG 14 and 15) address the conservation of marine and terrestrial ecosystems. Forest loss, land degradation, and species extinction are accelerating, with hundreds of millions of hectares of productive land degraded annually. The planet faces one of the largest species extinction events (UN, 2023).

Figure 37

Worldwide GHG emissions include in different sectors [Data from (IEA, 2024c)]

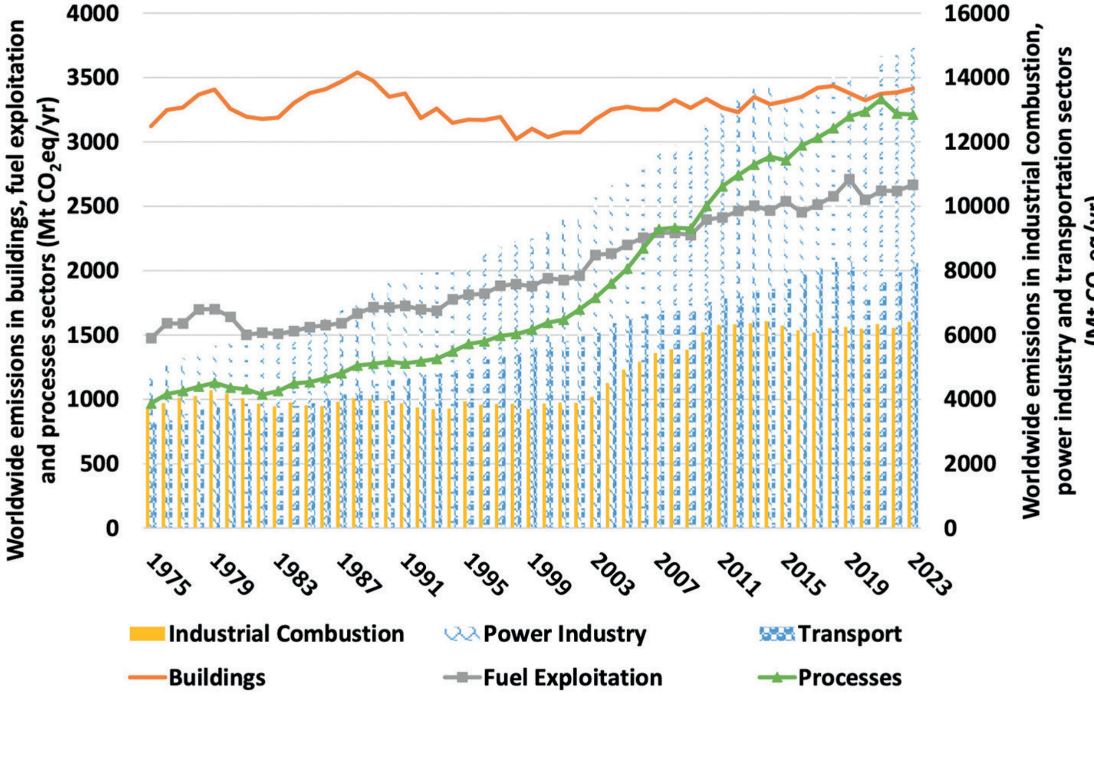
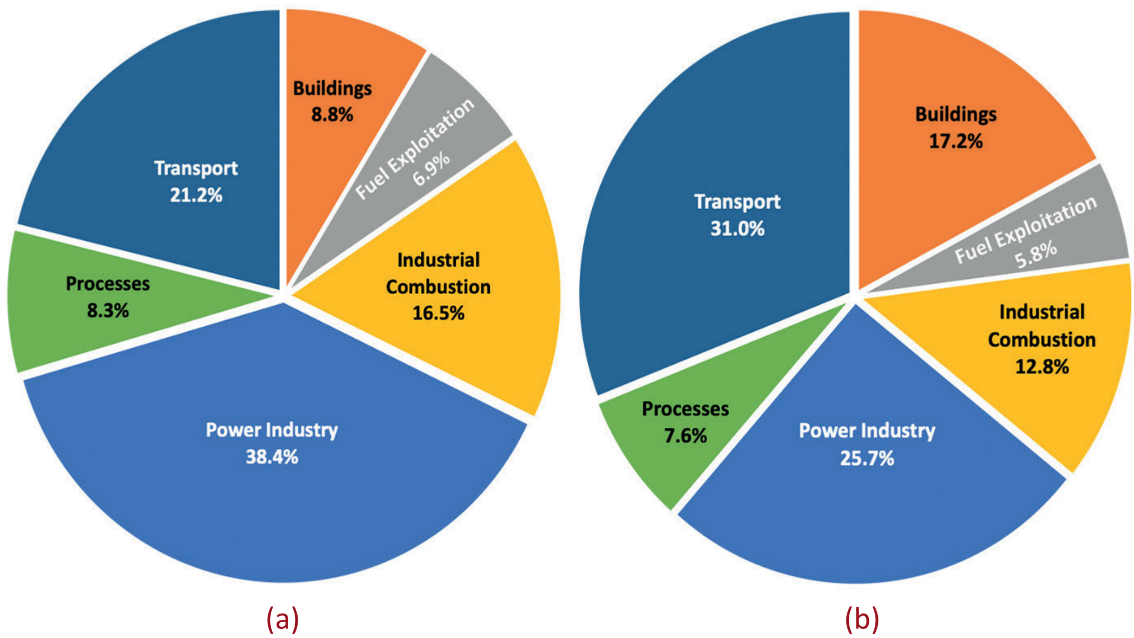


Figure 37 shows global greenhouse gas (GHG) emission data based on the IEA Database from various sectors between 1975 and 2023. Here, CO_2 (fossil only), CH_4, N_2O, and F-gases are considered. Emissions in sectors selected for the graph have a significant increase during the years with the increase in worldwide population and energy requirements. These increases highlight the urgent need for decarbonization strategies across sectors, particularly in industrial combustion and power generation, to mitigate the impacts of climate change.

Future research and development should focus on (i) enhancing the efficiency and reducing the costs of renewable energy technologies, (ii) developing robust energy storage solutions to address, (iii) intermittency issues, (iv) considering smart grid technologies for energy distribution and consumption optimization, (v) exploring new renewable energy sources and innovative applications, and (vi) strengthening international collaboration to address global energy challenges.

Figure 38

Share of GHG emissions in different sectors in a) the world and b) European Union countries (Data from IEA-EDGAR, 2024)



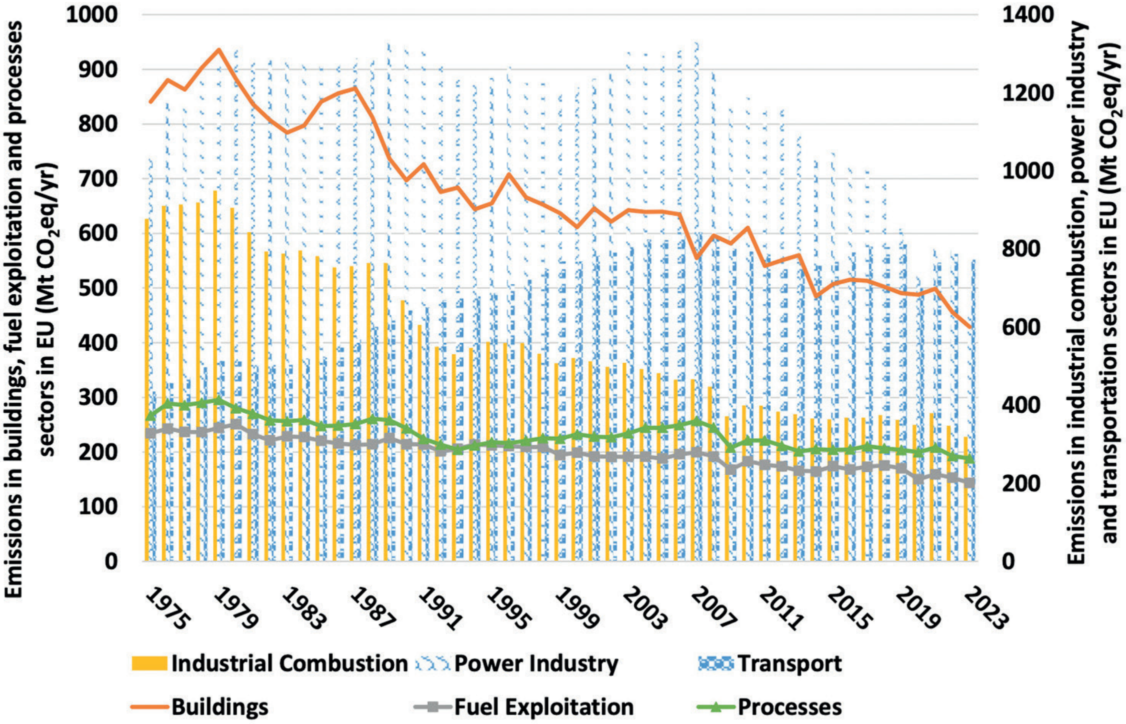
Due to human activities, energy production from fossil fuels, land use changes, environmental pollution, and climate change are happening very rapidly, biodiversity is being lost, the boundaries of the planet are being pushed are ecosystem services are weakened. The energy used should be based on renewable energy instead of fossil fuels, and GHG emissions should be reduced to net zero by 2050. Agricultural areas and soil degradation, water scarcity, and food crises due to climate change are imminent. The protection of agricultural areas and the spread of sustainable agricultural practices are important. The zero-waste principle should be adopted by moving from a linear economy to a circular economy. The waste should be recycled or converted into useful products and used. It is important to use recovered wastewater, treated organic waste, and treatment sludge as soil improvers in agriculture and landscape areas. Nuclear waste disposal is a manageable problem, there are operational facilities in Sweden, Finland, and the WIPP facility in the US. Nuclear waste disposal is controversial from a socio-political perspective and useful for opponents of nuclear energy.

The share of greenhouse gas (GHG) emissions across various sectors in both the world and European Union countries is given in Figure 38 (a) and (b). Globally, the power industry produces the most greenhouse gases, accounting for 38.4% of total emissions. In the European Union, the sectoral distribution is somewhat different. The power industry still holds a significant share at 25.7%, but transportation takes the lead at 31.0%. These values highlight the varying contributions of different sectors to global and regional GHG emissions, emphasizing the need for cleaner solutions and strict strategies for specific contexts.

Figure 39 shows the changes and trends in greenhouse gas (GHG) emissions from various sectors in the European Union countries from 1975 onward. While some sectors have shown a decline or stabilization in recent years, others continue to exhibit growth. Emissions from industrial combustion and the power industry demonstrate a notable decrease from their peaks in the early 2000s. This reflects the implementation of policies aimed at reducing emissions from these sectors, such as the promotion of renewable energy sources and energy efficiency measures. Emissions from buildings, fuel exploitation, and processes have shown more moderate changes, with some fluctuations observed. These trends highlight the complex dynamics of GHG emissions across different sectors within the European Union. While progress has been made in decarbonizing certain sectors, addressing the continued growth in transport emissions and maintaining the downward trajectory in other sectors is crucial for achieving climate targets.

Figure 39

GHG emissions in different sectors of European Union countries (Data from IEA-EDGAR, 2024)



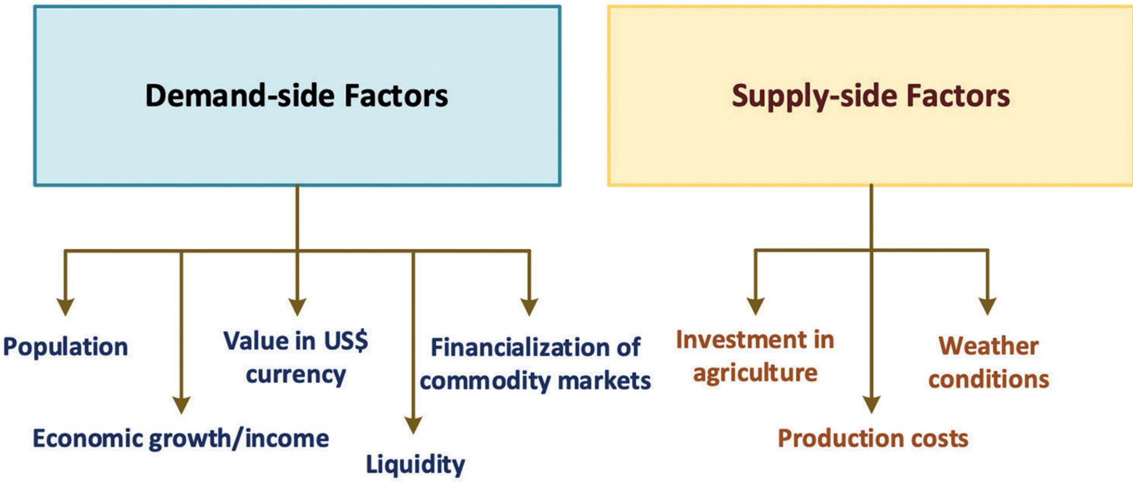
In conclusion, all energy sources and systems have some environmental impacts during production, installation, and decommissioning. Fossil fuel usage causes air pollution, greenhouse gas emissions, and habitat destruction. Renewable energy sources need more land use. Nuclear energy has notable risks. Life cycle assessments (LCA) allow for more consistent comparisons of energy technologies by measuring environmental burdens from cradle to grave. Comprehensive energy, cost, and environmental analyses should be performed for specific locations. Besides, advancements in technology are crucial for effective climate change mitigation. Innovations in (i) carbon capture and storage (ii) advanced nuclear reactors, (iii) hydrogen energy, (iv) electric vehicles (increasing the adoption of them to reduce emissions), and (v) smart grids are remarkable. Carbon (in CO_2 form) can be captured and stored in saline formations and injected into deep unused coal seams.

Energy and Agricultural Commodity Prices

Demand-side (such as population, economic growth/income, value of us dollar, global liquidity (inflation), financialization of commodity markets) and supply-side (such as investment in agriculture production costs, and weather conditions) factors play a role in the change of agricultural prices. Oil and agricultural prices affect each other through supply and demand and finance levels. Since agriculture uses a lot of energy, the price of oil directly affects the price of agricultural commodities (Nazlioglu, 2024).

Figure 40

The factors driving agricultural commodity prices [Modified from (Nazlioglu, S., 2019)]



The supply-side and demand-side variables that affect the price of agricultural commodities are shown in Figure 40. Several elements are examined in order to have a better understanding of what influences agricultural pricing. According to microeconomic theory, supply-side and demand-side factors influence a commodity's price.

In exploring the dynamics between energy prices and agricultural commodities, various modeling strategies provide a systematic framework for understanding these interactions. Long-term perspectives often rely on Computable General Equilibrium (CGE) models, while approaches that integrate both short-run and long-run dynamics, such as error-correction mechanisms and co-integration analyses, offer nuanced insights. Additionally, structural restrictions and Structural Vector Autoregressive (SVAR) models are essential for capturing complex interdependencies. Together, these tools help untangle the intricate economic relationships underpinning energy and agricultural price movements.

Understanding the flow of information and its predictive power is crucial for analyzing energy and agricultural markets. Conventional causality analyses serve as the foundation for this exploration, but advanced methods (such as those accounting for structural changes, non-linear relationships, and rolling window estimations) enhance predictive accuracy. Innovative approaches like causality-in-quantile and asymmetric causality shed light on varying price responses, while causality-in-variance analyses reveal volatility spillover effects. These diverse tools contribute to a comprehensive view of how price signals propagate across markets.

Synthesizing insights from different analytical approaches highlights the multifaceted nature of the relationship between energy and agricultural prices. Evidence suggests that agricultural commodity prices can be either neutral or sensitive to oil price fluctuations, depending on the context. Structural shifts in pricing dynamics further complicate these interactions, altering how commodity markets respond to external shocks. Recognizing these shifts is vital for developing policy frameworks that address market volatility and support sustainable agricultural and energy systems.

The implications of shifting causal linkages between energy and agricultural prices are profound, influencing market behavior under varying price regimes. For instance, low, moderate, and high price regimes each exhibit unique patterns of risk transfer, spillover effects, and opportunities for portfolio diversification and hedging. As the global economy transitions from fossil fuels to renewable energy sources, research methodologies must also evolve. The shift from traditional to modern methods reflects the growing complexity of market interdependencies and the influence of common factors across sectors.

Looking forward, research must adapt to address emerging questions driven by market interdependence and structural changes. The transition from oil to electricity engines and the integration of advanced modeling techniques are pivotal in capturing the evolving nature of these relationships. By identifying and analyzing common factors influencing both energy and agricultural markets, future studies can provide actionable insights for policymakers and market participants. This forward-looking approach ensures that research remains relevant in a rapidly changing global landscape.

11.3. Economic Development and Hydrogen Age

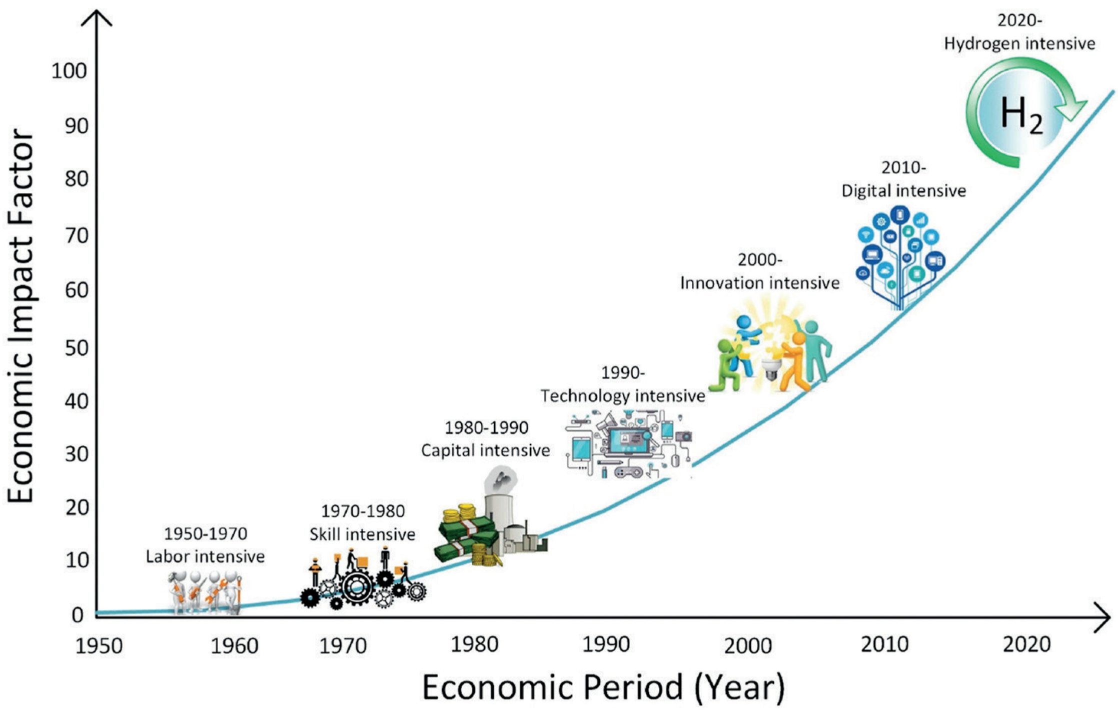
Since the beginning of the industrial revolution around 1760, we have seen significant changes in the ways that we produce, transform, store, transport, transfer, and use energy. In many industries where steam engines were introduced, coal was the primary factor taken into account in energy calculation. Coal was used extensively in these engines. Following the oil era, when gasoline became a necessary commodity, natural gas has since entered the energy equation for many nations. Although these three hydrocarbon products have greatly benefited humans, they have also harmed the ecosystems of all other living things, including people.

This is not to say that skill development initiatives stopped; rather, they continued with new aspects. The capital-intensive era of the 1980s had more economic impact because of investments and capital-based projects in a variety of industries, from agriculture to industry. The economic impact of this period was more than three times greater than that of the labor-intensive period. The technology-intensive era that followed, which began in the 1990s, contributed to the increased economic effects on industrialized nations as a result of the technologies they created.

An essential graph illustrating the economic development eras following the 1950s and their levels of economic influence is presented in Figure 41. It is seen that the first post-World War II period was a thorough, labor-intensive one with little economic consequence. This time frame lasted into the 1970s. The period that followed the labor-intensive one was a skill-intensive one, during which more skilled workers were ready to enter the local workforce to do higher-quality projects more quickly and efficiently. This time frame roughly corresponded to the 1970s and 1980s.

Such advanced technologies spurred economic development and helped those nations become truly technologically advanced, which led to more welfare and, consequently, many revenues from the increased exports of their technology goods, services, etc. The 2000s were a time of intense innovation, with many developed nations seizing the chance to differentiate themselves from other nations by improving the quality of their goods, services, etc., thereby taking the lead in the global market and having a bigger economic impact. With digital technology, goods, services, etc., the digitally intense time was presumably typical for developed nations and gave them a distinct edge in developing their smart gadgets, smart materials, and ultimately smart goods and services.

Figure 41
A schematic illustration of economic impact factors to indicate economic periods [Taken from (Dincer, I., 2023)]



12. Conclusions

This report provides an overview of the various subjects of energy technologies. It covers the basic physics of energy, its historical development, and the laws and practices influencing its use. In addition to reviewing conventional and renewable energy sources like solar, wind, hydro, geothermal, and nuclear power, the report addresses fundamental thermodynamic concepts. It investigates cutting-edge technologies like fuel cells, energy storage devices, and hydrogen energy.

The report covers the important topics of alternative fuels, district energy systems, energy conservation, and smart grids. Lastly, it examines how energy is used in different areas and its effects on the economy, environment, and society. All energy sources and systems have their benefits, effects, and challenges. A comprehensive comparison and discussion are provided. In conclusion, the effects and usage of energy sources can be summarized as follows:

- Coal is widely utilized for heat in industry. It is burned to obtain the heat required for electricity and power. However, problems are faced such as gray smog, CO_2 and acid rain, mercury (bioaccumulation), difficulties in mining, and respiratory (asthma) (EPA, 2024).
- Crude oil/petroleum has wide usage in transportation and industry by combusting it in an internal combustion engine, or chemical industry. However, problems are faced such as brown smog (NOx, Ozone, VOCs), difficulties in drilling, Spills, CO_2 emissions, and respiratory (asthma). While Russia and Saudi Arabia are the biggest producers, the US is the biggest consumer (IEA, 2024a).
- Natural gas is utilized for residential and industrial purposes (such as cooking and heating); in transportation (to produce power), and in power stations (to produce electricity) by burning it in a boiler or combustion chamber. However, problems are faced such as CO_2 emissions (as in all fossil fuel usage), hydraulic fracturing (fracking), possible water contamination, pipeline leaks, and explosions.
- Nuclear energy is utilized for electricity production by using uranium to provide heat to the steam turbine. It has nearly zero emissions. Also, it does not cause cancer, birth defects, radiation poisoning, or death unless an accident occurs. However, some problems are faced such as toxic, radioactive waste disposal and thermal pollution. France owns the highest share in electricity, US most installed capacity (INL, 2024).
- Hydroelectric power is used for electricity. Potential energy is utilized to spin water turbines. However, some problems are faced such as evaporation and sediment behind dams, and habitat alteration for river species. For instance, reservoirs can breed mosquitoes. Norway has the highest share in electricity, Canada has the most installed capacity, and China has the largest dam in the world (Three Gorges) (IEA, 2024b).
- Wind energy turns blades which turn turbines and electricity is produced by a wind turbine. Flat planes, mountains, and offshore. However, some problems are faced such as noise and aesthetics. Also, wind turbines could cause bird deaths. Denmark has the highest percentage, and the US has less than 10% in total capacity.
- Solar energy is harvested for heating (by concentrated solar power) and electricity (by PV panels). However, some problems are faced such as toxins and huge amounts of waste from PVs. Germany leads the world in solar energy.

Nomenclature

CO_2	Carbon dioxide
ex	Total specific exergy (kJ/kg)
$\dot{E}x$	Exergy transfer rate (kW)
$\dot{E}x_D$	Exergy destruction rate (kW)
$\dot{E}x^Q$	Thermal exergy rate (kW)
EJ	Exajoules
h	Enthalpy (kJ/kg)
H_2	Hydrogen
H_2O	Water
$\dot{m}$	Mass flow rate (kg/s)
$\dot{Q}$	Heat transfer rate (kW)
s	Specific entropy (kJ/kgK)
$\dot{S}_{gen}$	Entropy generation rate (kW/K)
O_2	Oxygen
T	Temperature (K)
$\dot{W}$	Power production rate (kW)
MJ	Megajoules

Abbreviations

AI	Artificial intelligence
AC	Alternating current
AGR	Advanced gas-cooled reactor
BIPV	Building-integrated photovoltaics
BWR	Boiling water reactor
CAES	Compressed air energy storage
CCUS	Carbon capture, utilization, and storage
COP	Coefficient of performance
CPV	Concentrated photovoltaic
CSP	Concentrated solar power
DC	Direct current
DSG	Direct steam generator
EA&P	East Asia and Pacific
EES	Engineering Equation Solver
EPR	European pressurized water reactor
FNR	Fast neutron reactor
GF	Greenization factor
HER	Hydrogen evolution reaction
HP	High pressure
HRS	Hydrogen refueling stations
HRSG	Heat recovery steam generator
HTGR	High-temperature gas-cooled reactor
IEA	International Energy Agency
IoE	Internet of Energy
ISCC	Integrated solar-based combined cycle
LAES	liquid air energy storage
LFP	lithium-iron-phosphate

LMIC	Lower-middle-income countries
LP	Low pressure
LWGR	Light water graphite reactor
ME&NA	Middle East and North Africa
MIC	Middle-income countries
MP	Medium pressure
OER	Oxygen evolution reaction
OTEC	Ocean thermal energy conversion
PCM	Phase change materials
PEM	Polymer electrolyte membrane
PHS	Pumped hydro storage
PHWR	Pressurized heavy water reactor
PVs	Photovoltaics
PWR	Pressurized water reactor
RCP	Representative concentration pathways
SDG	Sustainable development goals
SMES	Superconducting magnetic energy storage
SMR	Small modular reactors
SVAR	Structural vector autoregressive
TES	Thermal energy storage
toe	Ton of oil equivalent
UMIC	Upper-middle-income countries
UTES	Underground thermal energy storage
VAWTs	Vertical axis wind turbines

Greek letters

η	Efficiency

Subscripts and superscripts

0	Initial
b	Boundary
CC	Combustion chamber
Comp	Compressor
Cond	Condenser
d	Destruction
EL	Electrolyzer
en	Energy
ex	Exergy
GT	Gas turbine
in	Inlet, input
out	Outlet, output
P	Pump
r	Reversible
ST	Steam turbine
s	Source
sep	Separator

References

ACES DELTA. (2024). *Advanced Clean Energy Storage Hub project*. Available at: https://aces-delta.com.

ACS. (2024a). *American Chemical Society. Development of the Pennsylvania Oil Industry.* Available at: https://www.acs.org/education/whatischemistry/landmarks/pennsylvaniaoilindustry.html

ACS. (2024b). *The Keeling Curve*. Available at: https://www.acs.org/education/whatischemistry/landmarks/keeling-curve.html.

Al-Ashouri, A., Köhnen, E., Li, B., Magomedov, A., Hempel, H., Caprioglio, P., Márquez, J.A., Morales Vilches, A. B., Kasparavicius, E., Smith, J. A. & Phung, N. (2020). Monolithic perovskite/silicon tandem solar cell with> 29% efficiency by enhanced hole extraction. *Science, 370*(6522), 1300-1309.

Alma, M. H. (2024). *Alternative Fuels*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

ASCE. (2024). *American Society of Civil Engineers. Vulcan Street Plant*. Available at: https://www.asce.org/about-civil-engineering/history-and-heritage/historic-landmarks/vulcan-street-plant.

ASME. (2024). T*he American Society of Mechanical Engineers.* Vulcan Street Power Plant. Available at: https://www.asme.org/about-asme/engineering-history/landmarks/29-vulcan-street-power-plant.

Ašmontas, S. & Mujahid, M. (2023). Recent progress in perovskite tandem solar cells. *Nanomaterials, 13*(12), p.1886.

Atakhanova, Z. (2024a). *Economic and Social Dimensions of Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Atakhanova, Z. (2024b). *Economic and Social Dimensions of Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Aydin, M. E. (2024). *Environment and Sustainability Dimensions of Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Baba, A. (2024a). *Energy and Innovation*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Baba, A. (2024b). *Renewable Energy Sources.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Baba, A., Sözbilir, H., Sayık, T., Arslan, S., Uzelli, T., Tonkul, S. & Demir, M. M. (2022). Hydrogeology and hydrogeochemistry of the geothermal systems and its direct use application: Balçova-Narlidere geothermal system, İzmir, Türkiye. *Geothermics, 104*, 102461.

Balikci, A. (2024a). *History of Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Balikci, A. (2024b). *Energy Policies and Strategies*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

BBC. (2024). *The origins of the Industrial Revolution*. Available at: https://www.bbc.co.uk/bitesize/articles/z6kg3j6.

Bestmag. (2024). '*World's largest flow battery' connected to the grid in China*. available at: https://www.bestmag.co.uk/worlds-largest-flow-battery-connected-to-the-grid-in-china/

Boeing. (2024). *777-200, 777-200ER, and 777-300 general arrangement*. Available at: https://www.boeing.com.

Britannica. (2024). *Oil Spill*. Available at: https://www.britannica.com/science/oil-spill

Carlowicz, M. (2021). *NASA Earth Observatory. Satellites View California Oil Spill*. Available at: https://appliedsciences.nasa.gov/our-impact/news/satellites-view-california-oil-spill.

CDIAC. (2024). *Carbon Dioxide Information and Analysis Center*. Available at: https://www.eea.europa.eu/data-and-maps/data-providers-and-partners/carbon-dioxide-information-and-analysis.

Çevik, U. (2024a). *Physics of Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Cevik, U. (2024b). *Nuclear Energy.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Colpan, C. O. (2024a). *Fuel Cells*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Colpan, C. O. (2024b). *Energy Storage Systems and Applications.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Colpan, C. O., Cruickshank, C.A., Matida, E. & Hamdullahpur, F. (2011). 1D modeling of a flowing electrolyte-direct methanol fuel cell. *Journal of Power Sources, 196*(7), pp.3572-3582.

Colpan, C. O., Nalbant, Y. & Ercelik, M. (2018). *4.28 Fundamentals of fuel cell technologies*. In Comprehensive energy systems (ed. by Ibrahim Dincer).

Cormack, Z., & Kurewa, A. (2018). The changing value of land in Northern Kenya: The case of Lake Turkana Wind Power. *Critical African Studies, 10*(1), 89-107.

Dincer, I. (2016). Exergization. *International Journal of Energy Research, 40*, 1887-1889.

Dincer, I. & Acar, C. (2017). Innovation in hydrogen production. *International Journal of Hydrogen Energy, 42*(22), 14843-14864.

Dincer, I. & Aydin, M. I. (2023). New paradigms in sustainable energy systems with hydrogen. *Energy Conversion and Management, 283*, 116950.

Dincer, I. (2020). Covid-19 coronavirus: closing carbon age, but opening hydrogen age. *International Journal of Energy Research, 44*(8), 6093.

Dincer, I. (2023). Hydrogen 1.0: a new age. *International Journal of Hydrogen Energy, 48*(43), 16143-16147.

Dincer. I. (2024a). *Fundamental Principles and Concepts in Thermodynamics*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Dincer. I. (2024b). *Hydrogen Energy and Related Technologies.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Dincer, I., & Rosen, M. A. (2021). *Thermal energy storage: Systems and applications*. 3rd Edition. Wiley.

DOE OSTI. (2024). *U.S. Department of Energy. Office of Scientific and Technical Information*. Available at: https://www.osti.gov/opennet/manhattan-project-history/People/Scientists/enrico-fermi.html.

El-Emam, R.S., Dincer, I., Zamfirescu, C. (2017). Greenization Factor as a Sustainability Measure for Energy Systems. In Zhang, X., Dincer, I. (eds) *Energy Solutions to Combat Global Warming. Lecture Notes in Energy*, vol 33. Springer.

Ember. (2023). *Ember, Energy Institute. Carbon intensity of electricity generation*. Available at: https://ourworldindata.org/grapher/carbon-intensity-electricity.

Ember. (2024a). *Energy Institute - Statistical Review of World Energy 2024.* Share of electricity production by source, World. Available at: https://ourworldindata.org/grapher/share-elec-by-source

Ember. (2024b). *Electricity generation from nuclear. Share of electricity production by source, World*. Available at: https://ourworldindata.org/grapher/nuclear-energy-generation.

Ember. (2024c). *Energy Institute - Statistical Review of World Energy 2024. Electricity generation from hydropower.* Available at: https://ourworldindata.org/grapher/hydropower-consumption.

Ember. (2024d). *Energy Institute - Statistical Review of World Energy 2024. Share of electricity production by source, World.* Available at: https://ourworldindata.org/grapher/per-capita-electricity-generation.

Energy Institute. (2024a). *Statistical Review of World Energy*. Available at: https://ourworldindata.org/energy-production-consumption.

Energy Institute. (2024b). *Statistical Review of World Energy.* Available at: https://ourworldindata.org/grapher/electricity-prod-source-stacked.

Energy Institute. (2024c). *Statistical Review of World Energy.* Available at: https://ourworldindata.org/grapher/share-elec-by-source.

EPA. (2024). *U.S. Environmental Protection Agency. Summary of the Atomic Energy Act*. Available at: https://www.epa.gov/laws-regulations/summary-atomic-energy-act.

ETC. (2024). *Edison Tech Center*. Available at: https://edisontechcenter.org/NYC.html

EU EHO. *European Hydrogen Observatory.* Clean Hydrogen Partnership. Available at: https://observatory.clean-hydrogen.europa.eu/about-us.

Genc, N. (2024). *Smart Grid*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Gipe, P. & Möllerström, E. (2022). An overview of the history of wind turbine development: Part I-The early wind turbines until the 1960s. *Wind Engineering, 46*(6), pp.1973-2004.

Ground Report. (2024). *Who invented solar energy? The history of solar power*. Available at: https://groundreport.in/energy/who-invented-solar-energy-the-history-of-solar-power-7609312.

Hepbasli, A. (2010). *Energy Efficiency and Management System: Approaches and Applications.* Schneider Electric Energy Efficiency Series 1. Esen Offset Publisher. ISBN:978-9944-5084-6-9.

Hepbasli, A. (2024). *Energy Conservation and Efficiency Aspects.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Highview Power. (2024). Available at: https://highviewpower.com/

Humphrys, E. (2020). *Hydroelectricity in Canada in the Canadian Encyclopedia.* Available at: https://www.thecanadianencyclopedia.ca/en/article/hydroelectricity

IAEA. (2024). *Power Reactor Information System (PRIS)*. Available at: https://www.iaea.org/resources/databases/power-reactor-information-system-pris

IEA-EDGAR. (2024). *Emissions Database for Global Atmospheric Research. Community GHG Database.* Available at: https://edgar.jrc.ec.europa.eu/report_2024.

IEA. (2024a). *Policies database.* Available at: https://www.iea.org/policies.

IEA. (2024b). *Hydroelectricity.* Available at: https://www.iea.org/energy-system/renewables/hydroelectricity.

IEA. (2024c). *Greenhouse Gas Emissions from Energy Highlights, IEA, Paris*. Available at: https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy-highlights.

INL. (2024). *Idaho National Laboratory. The U.S. Department of Energy's Office of Nuclear Energy. Idaho National Laboratory*. Available at: https://inl.gov/ebr/

IPCC. (2024). *Intergovernmental Panel on Climate Change*. Available at: https://www.ipcc.ch/reports.

Stocker, T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (eds.). (2013). *IPCC Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IRENA. (2024a). *Renewable capacity statistics: Total solar capacity. International Renewable Energy Agency*. Available at: https://ourworldindata.org/grapher/installed-solar-pv-capacity

IRENA. (2024b). *Renewable capacity statistics: Total wind capacity. International Renewable Energy Agency.* Available at: https://ourworldindata.org/grapher/cumulative-installed-wind-energy-capacity-gigawatts.

IRENA. (2024c). *Renewable capacity statistics: Installed geothermal energy capacity. International Renewable Energy Agency.* Available at: https://ourworldindata.org/grapher/installed-geothermal-capacity

Koca, A. (2024). *Energy Materials.* New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Leverenz, R., Gerhard, L. & Göbel, A. (2004). *The European Pressurized Water Reactor.* A safe and competitive solution for future energy needs.

Long, K. R., Van Gosen, B. S., Foley, N. K. & Cordier, D. (2012). *The principal rare earth elements deposits of the United States: A summary of domestic deposits and a global perspective* (pp. 131-155). Springer Netherlands.

Lund, J. W. (2004). *100 years of geothermal power production*. GHC Bulletin.

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L., Lamarque, J. F., Matsumoto, K., Montzka, S. A., Raper, S. C., Riahi, K., & Thomson, A. G. J. M. V. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic change, 109*, 213-241.

MENR. (2024). *Republic of Türkiye, The Ministry of Energy and Natural Resources, Türkiye*. Available at: https://enerji.gov.tr/.

Midilli, A. (2024a). *Waste to Energy Options*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Midilli, A. (2024a). *District Energy Systems*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

Nafion. (2024). *NafionTM Membranes.* Available at: https://www.nafion.com/en/

NASA. (2024). *The National Aeronautics and Space Administration*. Available at: https://ntrs.nasa.gov/search.

National Grid. (2024). *The history of energy in the United States.* Available at: https://www.nationalgrid.com/stories/energy-explained/history-energy-united-states.

Nazlioglu, S. (2019). Oil and agricultural commodity prices. In U. Soytaş & R. Sarı (Eds.), *Routledge Handbook of Energy Economics* (pp. 385-395, Chapter 26). Routledge.

Nazlioglu, S. (2024). *Energy and Agricultural Commodity Prices*. New Energy Technologies Summer School, August 18-23, 2024. Turkistan, Kazakhstan.

NECP. (2024). *National energy and climate plans*. Available at: https://commission.europa.eu/energy-climate-change-environment/implementation-eu-countries/energy-and-climate-governance-and-reporting/national-energy-and-climate-plans_en.

NEI. (2024). *The Nuclear Energy Institute*. Nuclear Fuel. Available at: https://www.nei.org/fundamentals/nuclear-fuel

NOAA. (2024). *National Oceanic and Atmospheric Administration*. Available at: https://www.noaa.gov/tools-and-resources.

NSIDC. (2024). *National Snow and Ice Data Center*. Available at: https://nsidc.org/data/explore-data.

O'hayre, R., Cha, S. W., Prinz, F. B., & Colella, W. (2016). *Fuel cell fundamentals*. John Wiley and Sons.

Okonkwo, P. C., Ige, O. O., Uzoma, P. C., Emori, W., Benamor, A. & Abdullah, A. M. (2021). Platinum degradation mechanisms in proton exchange membrane fuel cell (PEMFC) system: A review. *International journal of hydrogen energy, 46*(29), 15850-15865.

Oktay, Z. & Dincer, I. (2009). Exergoeconomic analysis of the Gonen geothermal district heating system for buildings. *Energy and Buildings, 41*(2), 154-163.

Othman, R., Dicks, A. L. & Zhu, Z. (2012). Nonprecious metal catalysts for the PEM fuel cell cathode. *International Journal of Hydrogen Energy, 37*(1), 357-372.

PPIAF. (2024). *Global Infrastructure Hub*. Available at: https://www.gihub.org/connectivity-across-borders/case-studies/itaipu-hydroelectric-dam.

REN21. (2024). *Renewables 2024 Global Status Report collection, Renewables in Energy Supply.* Available at: https://www.ren21.net/gsr-2024/modules/energy_supply/01_global_trends/03_investment_and_finance.

Ritchie, H., Rosado, P., & Roser, M. (2024). *Energy Production and Consumption*. Available at: https://ourworldindata.org/energy-production-consumption.

Ruppel, C. D. (2011). Methane hydrates and contemporary climate change. *Nature Education Knowledge, 2*(12), 12.

Shymkent Oil. (2024). *Shymkent Refinery.* Available at: https://www.shymkentoilrefinery.kz/sor/en/bu-refining-en/index.html.

SI. (2024). *Swedish Institute*. Available at: https://sweden.se/climate/sustainability/energy-use-in-sweden.

Solarpaces. (2024). *100 MW CSP Tower operating in 700 MW DEWA project in Dubai*. Available at: https://www.solarpaces.org/100-mw-csp-tower-operating-in-700-mw-dewa-project-in-dubai.

Sorgulu, F., Ozturk, M., Javani, N. & Dincer, I. (2023). Experimental investigation for combustion performance of hydrogen and natural gas fuel blends. *International Journal of Hydrogen Energy, 48*(88), 34476-34485.

Statista. (2024). *Average annual Brent crude oil price from 1976 to 2024*. Available at: https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/

TCS. (2024). *Trade Commissioner Service. Cleantech market in Costa Rica.* Available at: https://www.tradecommissioner.gc.ca/costa-rica/market-reports-etudes-de-marches.

Tüpraş. (2024). *Izmit Refinery.* Available at: https://www.tupras.com.tr/en/about-us.

UN. United Nations. (2023). *The Sustainable Development Goals Report 2023: Special Edition*. Available at: https://unstats.un.org/sdgs/report/2023.

Unex. (2024). *Floating Solar Power Plant.* Available at: https://blog.unex.net/en/blog/photovoltaic-installations/unex-in-europes-most-innovative-floating-solar-power-plant.

UNFCCC. (2018). *The Paris Agreement. United Nations Framework Convention on Climate Change.* Available at: https://unfccc.int/process-and-meetings/the-paris-agreement.

US DOE. (2024a). *Multijunction III-V Photovoltaics Research*. Available at: https://www.energy.gov/eere/solar/multijunction-iii-v-photovoltaics-research.

US DOE. (2024b). *Stable Thermochemical Salt Hydrates for Energy Storage in Buildings.* Available at: https://www.energy.gov/eere/buildings/articles/stable-thermochemical-salt-hydrates-energy-storage-buildings.

US EIA. (2024a). *Energy Information Administration*. Available at: https://ourworldindata.org/grapher/change-energy-consumption.

US EIA. (2024b). *Energy Information Administration.* Available at: https://ourworldindata.org/grapher/primary-energy-cons.

US EIA. (2024c). *U.S. Energy Information Administration.* Available at: https://www.eia.gov/

US NRC. (2024). *U.S. Nuclear Regulatory Commission. Pressurized-water reactor (PWR)*. Available at: https://www.nrc.gov/reading-rm/basic-ref/glossary/pressurized-water-reactor-pwr.html.

US NREL. (2024). *Data and Tools. The National Renewable Energy Laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.* Available at: https://www.nrel.gov/research/data-tools.

Valiante, G. (2019). *Lac-Mégantic Rail Disaster.* Available at: https://www.thecanadianencyclopedia.ca/en/article/lac-megantic-rail-disaster.

Williams, K. J. (1992). Deptford Power Station: A Century in Power: History of the world's oldest large HVAC generating station. *IEEE Power Engineering Review, 12*(6), 26.

World Bank. (2024a). *Share of the population with access to electricity. World Development Indicators.* Available at: https://ourworldindata.org/grapher/share-of-the-population-with-access-to-electricity.

World Bank. (2024b). *Share of the population with access to basic services, World. World Development Indicators*. Available at: https://ourworldindata.org/grapher/access-to-basic-service.

World Bank. (2024c). *Commodity Markets*. Available at: https://www.worldbank.org/en/research/commodity-markets.

WNA. (2024). *World Nuclear Association. Outline the History of Nuclear Energy.* Available at: https://world-nuclear.org/information-library.

WPR. (2024). *World Population Review.* Available at: https://worldpopulationreview.com/country-rankings/vegetable-production-by-country.

TUBA-New Energy Technologies Summer School Program

Ahmet Yesevi University
Turkistan, Kazakistan

August 18-23, 2024

Sunday, August 18, 2024

14:00-17:00	**Registration**
18:00-20:00	**Get Together and Welcoming Dinner**

Monday, August 19, 2024

9:00-9:20	**Opening Talks**
9:20-10:00	**History of Energy (Prof. Dr. Abdulkadir Balıkçı)**
10:00-10:40	**Physics of Energy (Prof. Dr. Uğur Çevik)**
10:40-11:30	**Fundamental Principles and Concepts in Thermodynamics (Prof. Dr. İbrahim Dinçer)**
11:30-12:10	**Traditional Energy Sources (Prof. Dr. Zauresh Atakhanova, Nazarbayev University)**
12:10-14:00	**Lunch Break**
14:00-14:50	**Nuclear Energy (Prof. Dr. Uğur Çevik)**
14:50-15:40	**Renewable Energy Sources (Prof. Dr. Alper Baba)**
15:40-16:30	**District Energy Systems (Prof. Dr. Adnan Midilli)**
16:30-17:00	**Break**
17:00-18:30	**Panel Discussion on "Challenges, Opportunities and Future Directions in Energy Sector"**

Moderator: Prof. Dr. Adnan Midilli
Panelists: Prof. Dr. Alper Baba
Prof. Dr. Abdulkadir Balikci
Prof. Dr. Uğur Çevik
Prof. Dr. İbrahim Dinçer
Student Participant

18:30	**Closing Remarks**

Tuesday, August 20, 2024

9:30-10:20	**Environment and Sustainability Dimensions of Energy (Prof. Dr. Mehmet Emin Aydın)**
10:20-11:10	**Hydrogen Energy and Related Technologies (Prof. Dr. İbrahim Dinçer)**
11:10-12:00	**Fuel Cells (Prof. Dr. Can Özgur Çolpan)**
12:00-14:00	**Lunch Break**
14:00-18:00	**Free Time/Social Hours/Visits to Historical Sites**

Wednesday, August 21, 2024

9:30-10:20	**Energy Storage Systems and Applications (Prof. Dr. Can Özgur Çolpan)**
10:20-11:10	**Energy Materials (Prof. Dr. Atıf Koca)**
11:10-12:00	**Smart Grid (Prof. Dr. Naci Genç)**
12:00-14:00	**Lunch Break**

14:00-14:50	**Energy Conservation and Efficiency Aspects (Prof. Dr. Arif Hepbaşlı)**
14:50-15:40	**Energy Policies and Strategies (Prof. Dr. Abdulkadir Balıkçı)**
15:40-16:20	**Break and Free Discussion**
16:20-17:10	**Waste to Energy Options (Prof. Dr. Adnan Midilli)**
17:10-18:00	**Alternative Fuels (Prof. Dr. M. Hakkı Alma)**

Thursday, August 22, 2024

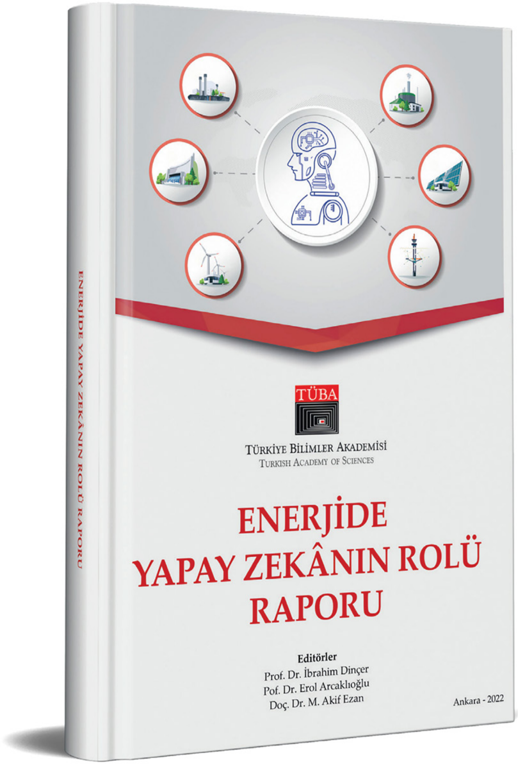
9:30-10:20	**Energy and Innovation (Prof. Dr. Alper Baba)**
10:20-11:10	**Economic and Social Dimensions of Energy (Prof. Dr. Zauresh Atakhanova)**
11:10-11:40	**Energy and Agricultural Commodity Prices (Prof. Dr. Şaban Nazlıoğlu)**
11:40-13:00	**Panel Discussion on "Economic, Environmental, Social, Political, Ethical Dimensions of Energy"**

Moderator: Prof. Dr. Mehmet Emin Aydın
Panelists: Prof. Dr. M. Hakkı Alma
Prof. Dr. Alper Baba
Prof. Dr. Abdulkadir Balıkçı
Prof. Dr. Şaban Nazlıoğlu
Student Participant

13:00-14:30	**Lunch Break**
14:30-18:00	**Free Time/Social Hours/Visits to Historical Sites**

Friday, August 23, 2024

9:30-12:30	**Tours to Facilities**
12:30-14:30	**Lunch Break**
14:30-18:00	**Closing Remarks for the Program**



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