GREENLIGHT:

Generating Renewable Energy Education Network – Leading Initiatives for Green & Harmonious Tomorrows

GREENLIGHT

Introduction to Energy and Sustainability

December 2024

2023-2-TR01-KA220-SCH-000180691

Avrupa Birliği tarafından finanse edilmektedir

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Introduction to Energy and Sustainability

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This e-book was written within the scope of the Erasmus+ project: “GREENLIGHT: Generating Renewable Energy Education Network – Leading Initiatives for Green & Harmonious Tomorrows” (2023-2-TR01-KA220-SCH-000180691)

Project Partners

TABLE OF CONTENTS

1. INTRODUCTION

Energy is an indispensable part of human life. Everything we do in our daily lives, from charging our phones to producing goods in factories, relies on energy[1]. Therefore, energy is a resource that must be available at every moment of life. Especially with the beginning of the Industrial Revolution, rapid population growth, widespread urbanization, and rising living standards have significantly increased the demand for energy.

When we examine today's global energy consumption, it becomes clear that a large portion of energy comes from fossil fuels. Fossil fuels such as coal, oil, and natural gas are energy sources formed from the fossilized remains of plants and animals that lived millions of years ago. However, the use of these resources has led to several serious problems. The first is energy dependence, especially for countries that do not have fossil fuel resources. Relying on other countries to meet their energy needs can create both economic and political difficulties[2]. The second issue is the rapid depletion of fossil fuel reserves. These resources are non-renewable, meaning that once they are used up, they take millions of years to be replaced[1]. The third and perhaps most important issue is the environmental damage caused by fossil fuels. The use of these fuels releases greenhouse gases into the atmosphere, contributing to global warming and thus climate change. Melting glaciers, rising sea levels and droughts are among the natural disasters resulting from these changes[3-1].

These challenges have led humanity to seek alternative energy sources. Environmentally friendly and sustainable renewable energy sources have recently begun to gain traction again. Historically, before the Industrial Revolution, energy primarily came from renewable sources such as wood, wind and water. However, with the Industrial Revolution, fossil fuels such as coal, oil and natural gas dominated energy use for many years. While the Industrial Revolution brought countless conveniences to humanity, the intensive use of fossil fuels significantly increased environmental damage[4].

The 1973 energy crisis brought renewable energy sources back into focus. During this period, the rapid increase in oil prices led countries to explore new energy alternatives. However, this interest was short-lived and eventually waned. As the environmental damage caused by fossil fuels increased and international agreements such as the Kyoto Protocol emphasized the seriousness of the problem, renewable energy sources have regained importance[5].Today, renewable energy is increasingly at the forefront due to its environmental friendliness and sustainability. Renewable energy sources include wind, solar, hydroelectric, geothermal and biomass energy, all of which can be used without harming the environment and are constantly renewed in nature. These types of energy not only help protect the environment, but also increase energy security. In recent years, technological advances have made renewable energy sources more efficient. Wind turbines now produce more electricity, solar panels last longer and energy storage systems minimize interruptions in energy supply[6].

This book aims to explain what renewable energy sources are, how they are produced, the technologies used and the impact of these types of energy on our environment. Understanding the energy sources of the future, managing our energy consumption responsibly for a sustainable world and improving our quality of life while protecting our environment are vital. Especially for young people like you, becoming aware of this area will contribute to building a cleaner world both today and in the future.

2. ENERGY AND ENVIRONMENT

2.1. Definition and Types of Energy

Energy is derived from the ancient Greek words “active” (“en”) and “work” (“ergon”), signifying “convertible to work”[7]. Fundamentally, energy refers to the capacity to perform work. It exists in various forms such as chemical, light, fossil, and electrical energy, all of which can be converted into one another. According to the Law of Conservation of Energy, energy cannot be created or destroyed but only transformed, maintaining a balance in a closed system [8].

2.2. Myths And Misconceptions About Energy

Despite its frequent use in daily life, energy is often misunderstood. Common misconceptions include:

- Energy can be “lost” or “destroyed”.
- Consumed energy changes irreversibly.
- Chemical energy can be “stored indefinitely”.

Energy …

- is not a description of a mechanism or anything ‘concrete’
- is not directly observable
- cannot be measure directly

These myths arise partly from insufficient education. Students may incorrectly perceive energy as a tangible material or misunderstand its abstract, physical nature. For example, energy is often incorrectly equated to a fuel-like substance that is “used up.” To counter these misconceptions, it is essential to provide clear explanations of energy's principles in schools and the public domain.

Governments globally emphasize renewable energy systems to transition toward low-carbon futures. Public perception significantly affects these efforts, with challenges including “NIMBY” (Not In My Backyard) attitudes and myths about renewable energy’s costs and reliability. Addressing these through education and transparent communication is crucial for fostering energy citizenship[9].

2.3. The Relationship Between Energy and Environment

Energy and environmental considerations are deeply intertwined. Historically, fossil fuels have driven industrial growth, but they have also led to significant environmental challenges, including greenhouse gas emissions, climate change, and ecological imbalances. These issues highlight the urgency of adopting sustainable energy practices. Renewable energy sources, such as solar and wind power, provide promising alternatives, reducing harmful emissions and fostering ecological balance[10].

Energy consumption is not only a technical matter but also a societal and economic concern. It is influenced by population growth, technological advancements, energy reserves, and environmental awareness[11].

Figure 1: Energy and transportation are major contributors to environmental impact

The global reliance on fossil fuels for energy has brought about severe environmental and economic challenges. Depleting fossil fuel reserves, energy import dependencies, and accessibility issues underscore the need for a transition. Additionally, emissions from fossil fuels drive global temperature increases and climate change, threatening energy security and sustainability[12].

Figure 2: Industrial activities cause pollution that disrupts ecological balance

Sustainability, as defined in the United Nations' 1987 Brundtland Report[13], refers to meeting present needs without compromising future generations' ability to meet their own. Achieving this balance necessitates prioritizing energy sources that minimize environmental harm. To align energy production with sustainability principles while supporting economic growth and protecting the environment, key measures include[14]:

Reducing the consumption of energy resources,

Encouraging and implementing energy saving,

Increasing energy efficiency with innovative technologies and policies.

By addressing these elements, it will be possible to align energy production with sustainability principles and ensure both economic growth and environmental protection.

Figure 3: Changes in energy use have shaped both society and nature.

Energy is indispensable in every facet of modern life, from daily activities to industrial production. As societies grow and evolve, energy production, sustainability, and economic development form a critical nexus shaping global progress. While energy is vital for development, its unchecked production and consumption have disrupted ecological balances and created global challenges. The increasing visibility of environmental problems, driven by rapid industrialization and urbanization, emphasizes the need for sustainable energy solutions[15].

Figure 4: A sustainable future requires harmony between energy and nature.

Environmental issues have become more pronounced since the mid-20th century due to population growth, rapid urbanization, and industrial activities. These changes have intensified air, water, and soil pollution, threatening ecological health and stability. Addressing these challenges requires integrated approaches that balance energy needs with environmental protection. Policies promoting renewable energy adoption and improving energy efficiency offer viable solutions, aligning with the dual goals of sustainability and economic growth[16].

2.3.1 Climate Change and Carbon Footprint

Global warming results from the greenhouse effect, where gases like carbon dioxide and methane trap heat in the Earth's atmosphere. Human activities, particularly energy production and consumption, significantly contribute to this phenomenon. The primary greenhouse gases include[17]:

- **Carbon Dioxide (CO_2):** Emitted by burning fossil fuels.
- **Methane (CH_4):** Produced from agriculture and waste management.
- **Nitrous Oxides (N_2O):** Released during industrial processes.
- **Fluorinated Gases:** Associated with refrigeration systems.

Even minor changes in greenhouse gas concentrations can disrupt climate systems, leading to rising temperatures, melting glaciers, and sea-level rise. Mitigating climate change requires reducing greenhouse gas emissions through:

- Renewable energy adoption
- Lowering energy consumption
- Promoting energy-efficient practices

Figure 5: Reducing our carbon footprint through public transport, energy efficiency, and renewable energy is key to fighting climate change.

Additionally, minimizing one's carbon footprint—the total greenhouse gases emitted by individual or collective activities—is critical. Practical strategies include[18]:

- Using public transportation
- Opting for energy-efficient appliances

2.3.2. Greenhouse Gas Effect

Global warming is the increase in air temperature in the parts of the atmosphere close to the earth's surface due to natural processes or human activities[19].

While some of the rays coming from the sun are reflected back by the atmosphere, a large part of them is absorbed by the earth and re-emitted into the atmosphere as long-wave rays. Gases in the atmosphere transmit solar rays at different rates depending on their properties. The increase in the density of these gases causes temperatures to rise in areas close to the earth's surface. This warming event in the atmosphere is called the "greenhouse effect"[20]. The increase in the amount of gases in the atmosphere, especially the concentration of greenhouse gases caused by human activities, leads to significant changes in the ecological balance. This situation is one of the main reasons for the environmental imbalances defined as climate change.

2.3.3. The Role of Human-Induced Greenhouse Gases and Energy Consumption

One of the main reasons for the human-induced greenhouse effect is that energy production methods and consumption amounts exceed the self-renewal capacity of nature. The increase in energy consumption leads to more intensive use of fossil fuels, increasing the amount of greenhouse gases released into the atmosphere[21]. Greenhouse gases do not prevent the sun's rays from entering the earth, but they absorb some of the long-wave rays reflected from the earth and reflect them back to the earth. This causes the atmosphere to warm. The main gases of the greenhouse effect are:

- Carbon dioxide (CO_2): Burning of fossil fuels, industrial activities and deforestation.

- Methane (CH_4): Agricultural activities, animal husbandry and waste management.

- Nitrogen oxides (N_2O): Fertilizer use and various industrial processes.

- Fluorinated gases: Industrial processes and cooling systems.

Figure 6: Industrial emissions are a major source of greenhouse gases.

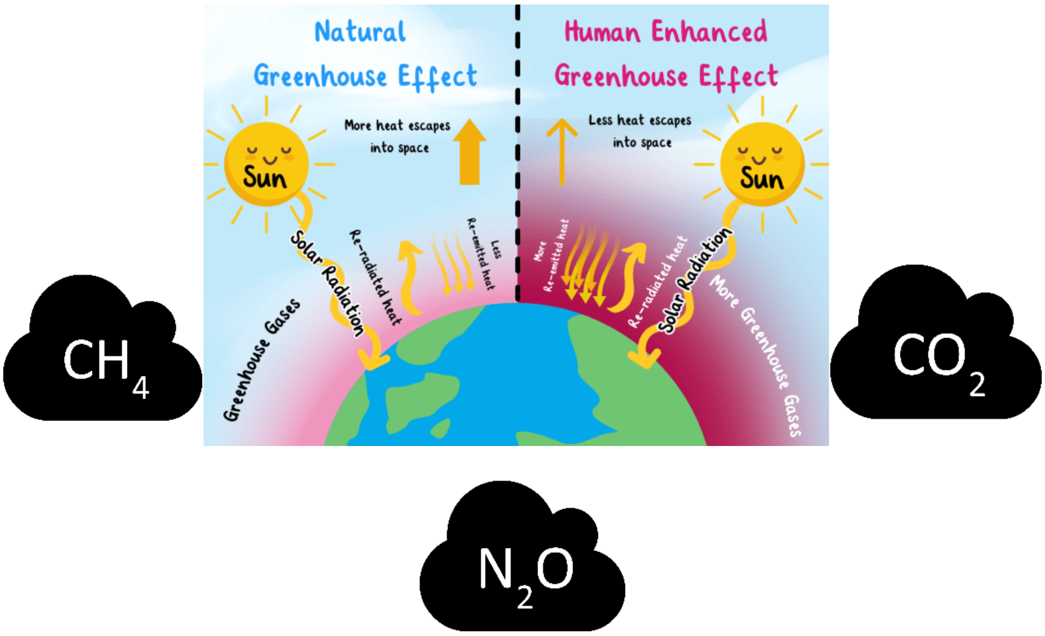


Figure 7: Human activities intensify the greenhouse effect and trap more heat.

The increase in the rate of greenhouse gases in the atmosphere causes average temperatures to rise, in other words, global warming. This situation leads to chain effects on the climate system. As a natural result of global warming, glaciers in high mountains and the poles are rapidly melting, which causes sea levels to rise. Due to increasing temperatures, many living species are losing their habitats and the ecosystem balance is disrupted. As the seas warm, carbon dioxide dissolved in water is released and mixed into the atmosphere. This further increases the greenhouse effect and creates a vicious cycle. Climate change caused by global warming can create very difficult living conditions for humanity and other living things. The general view of climate experts is that these changes can lead to major environmental disasters[22]. Problems that will arise especially in critical areas such as agriculture, water resources and energy supply threaten sustainable life. Controlling the increase in greenhouse gases, encouraging the use of renewable energy sources and reducing energy consumption are important in limiting the effects of global warming.

Carbon footprint refers to the total amount of carbon dioxide (CO2) and other greenhouse gases released into the atmosphere as a result of the activities of a person, community or organization. This concept includes emissions from energy consumption, transportation habits, consumed products and production processes. For example, when a person travel using their vehicle, travels by plane or uses electrical devices, they directly release carbon. In addition, the production of food and other products we consume can also increase our carbon footprint, because production processes usually require energy and greenhouse gases are released in these processes. In order to reduce our carbon footprint, minimize negative impacts on the environment and slow down global warming, it is of great importance to save energy, turn to renewable energy sources and develop more sustainable consumption habits.

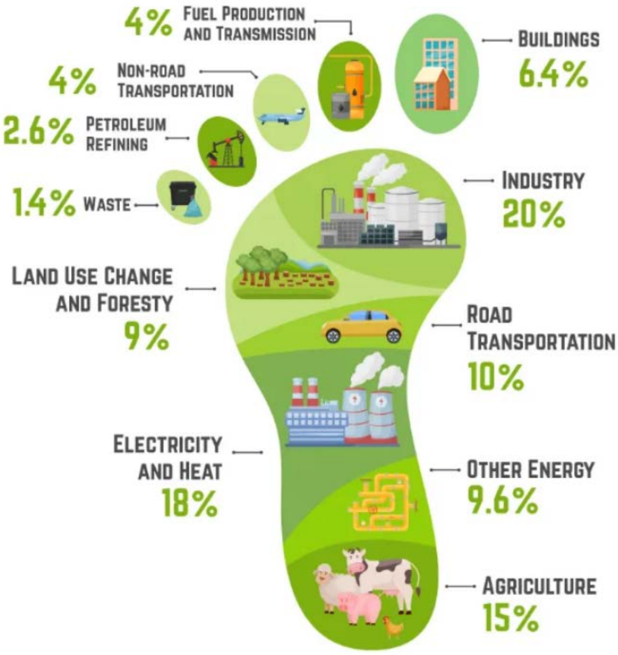


Figure 8: Our daily choices shape the size of our carbon footprint[23].

Renewable energy sources are one of the most effective solutions to reduce our carbon footprint[24]. Renewable energies obtained from natural sources such as sun, wind, water and geothermal have much lower carbon emissions compared to fossil fuels. When these sources are used, electricity production and other energy needs are met in a more environmentally friendly way because the release of greenhouse gases into the atmosphere is prevented. Renewable energy sources offer a more sustainable energy option in the long term because they are inexhaustible and do not harm the environment. In addition, renewable energy systems allow energy production on a local scale, thus reducing energy losses during transportation and transmission. Switching to renewable energy not only reduces the carbon footprint, but also minimizes environmental impacts and secures future energy needs. Therefore, the use of renewable energy sources is one of the most important steps to be taken in the fight against global warming and for a sustainable future[25].

2.4. Energy Efficiency and Sustainability

Energy efficiency refers to reducing energy consumption per unit of output without sacrificing performance. This approach optimizes energy use while supporting environmental sustainability. Key benefits include:

- Reduced greenhouse gas emissions
- Lower energy costs for households and industries
- Improved national energy security

Figure 9: Energy scarcity and climate change threaten both people and nature

Energy efficiency is an approach to provide less energy consumption per unit of product or service in all sectors such as industry, transportation, agriculture and housing without any reduction in production quantity and quality. This approach not only optimizes energy use, but also supports environmental sustainability and makes significant contributions to the protection of natural resources.

Energy efficiency applications reduce greenhouse gas emissions by reducing fossil fuel consumption and thus become an effective tool in combating climate change. In addition, while supporting the household economy by reducing individuals' energy costs, it also increases energy security by reducing energy imports throughout the country and contributes to the reduction of the current account deficit. On the other hand, energy efficiency encourages technological innovations and modernization processes. For example, replacing old equipment with more efficient and environmentally friendly technologies that consume high energy both improves production processes and facilitates the achievement of sustainable development goals[26]. Therefore, energy efficiency should be considered as one of the basic elements of development policies by providing environmental, economic and social benefits.

Figure 10: Energy efficiency and nature protection are keys to a sustainable future.

2.5. Renewable Energy Sources and Future Perspectives

Renewable energy sources, including solar, wind, hydroelectric, and geothermal energy, represent the cornerstone of sustainable energy policies. These sources offer numerous benefits:

- **Environmental Advantages:** Minimal greenhouse gas emissions.
- **Inexhaustibility:** Unlike fossil fuels, renewables are not depleted with use.
- **Local Energy Production:** Reduces energy losses during transmission.

Challenges remain, such as intermittent energy generation from solar and wind sources and the high initial costs of infrastructure. Despite these, advancements in storage technologies and supportive policies are making renewables increasingly viable[27].

The future of energy lies in transitioning from fossil fuel dependency to a system centered around renewable resources. By adopting innovative technologies, encouraging community involvement, and implementing effective policies, societies can secure a sustainable energy future for generations to come.

3. ENERGY RESOURCES

Energy sources can be broadly categorized into **non-renewable** and **renewable** based on their availability, usage, and regeneration capabilities. Understanding the characteristics of these resources is critical for addressing current and future energy demands sustainably.

Non-renewable energy sources are those that cannot be replenished within a short period and are consumed faster than they can regenerate. These sources are finite and will eventually be depleted. Non-renewable energy is primarily divided into two categories:

1. **Fossil Fuels:** These include coal, natural gas, and oil, which are formed from the remains of ancient plants and animals over millions of years. Despite their abundance and widespread use, fossil fuels are being consumed at a rate far exceeding their natural replenishment process.
2. **Nuclear Energy:** Derived from uranium or other radioactive elements, nuclear energy is another non-renewable source. While it does not produce greenhouse gases during energy generation, the raw materials used are limited and non-renewable.

The consumption of non-renewable energy sources poses challenges due to their finite nature, environmental impact, and the time required for their formation, which spans millions of years.

Renewable energy sources are resources that naturally replenish within short periods through ongoing natural processes. These sources are considered inexhaustible because they are continuously renewed by Earth's natural cycles.

Key renewable energy sources include[28]:

1. **Solar Energy:** Energy harnessed from sunlight using solar panels.
2. **Wind Energy:** Energy generated from wind through turbines.
3. **Hydropower:** Energy derived from moving water in rivers or dams.
4. **Biomass:** Organic material such as plant and animal waste used for energy.
5. **Geothermal Energy:** Heat energy sourced from beneath the Earth's surface.
6. **Ocean Energy:** Energy from tides, waves, and ocean currents.

Unlike fossil fuels and nuclear energy, renewable energy sources are environmentally friendly and sustainable. They do not face the same depletion concerns, as their availability is continuously replenished within natural cycles. Renewable energy has become a critical focus area due to its potential to reduce environmental harm, combat climate change, and ensure a sustainable energy future.

Figure 11: Non-renewable energy sources are limited and have significant environmental impacts.

4. NON-RENEWABLE ENERGY RESOURCES AND THEIR ENVIRONMENTAL IMPACTS

Non-renewable energy sources are those that cannot be replenished within a short period and are consumed much faster than they can regenerate. These sources are finite and will eventually deplete, making their sustainable management a critical challenge. Non-renewable energy sources primarily include **fossil fuels** such as coal, petroleum, and natural gas, as well as **nuclear energy** derived from radioactive materials like uranium and thorium[29].

4.1. Fossil Energy Sources

Fossil fuels are the most commonly used non-renewable energy sources in the world. They are formed from the remains of plants and animals that lived millions of years ago and were buried under layers of soil and rock. Over time, heat and pressure transformed these remains into coal, oil, and natural gas[30]. Fossil fuels are used to power vehicles, generate electricity, and run factories.

Coal: Coal is a solid black or brownish material made up mostly of carbon. It is the oldest fossil fuel and has been used for centuries to produce heat and energy. Coal is still widely used today, especially in power plants to generate electricity. However, burning coal releases harmful gases into the atmosphere, contributing to air pollution and climate change[31].

Figure 12: Coal, a widely used fossil fuel, varies in energy content and contributes to air pollution.

Oil (Petroleum): Oil is a liquid fossil fuel found in underground reservoirs. It is used to make products like gasoline, diesel, and jet fuel, which power vehicles and planes. Oil is also used to create products like plastic, asphalt, and chemicals. While oil is very useful, its extraction and transportation can cause environmental problems like oil spills, which harm wildlife and ecosystems[32].

Natural Gas: Natural gas is a clean-burning fossil fuel mainly made of methane. It is used for cooking, heating homes, and generating electricity. It burns cleaner than coal and oil, producing less pollution. However, natural gas can leak during transportation, and since methane is a powerful greenhouse gas, even small leaks can significantly impact the environment[33].

4.2. Nuclear Energy

Nuclear energy is produced from radioactive materials like uranium and thorium. It is created when atoms are split (a process called fission) or combined (a process called fusion) to release a large amount of energy. This energy is used to produce electricity in nuclear power plants. Nuclear power plants produce no greenhouse gases, making them cleaner than fossil fuels in terms of air pollution[34].

However, nuclear energy has its challenges. The waste produced by nuclear plants remains radioactive for thousands of years and needs to be stored carefully to avoid harming the environment or human health. Also, if something goes wrong at a nuclear power plant, it can lead to serious accidents that affect both people and nature[35].

4.3. Environmental Impacts

Non-renewable energy sources have been the main way we produce energy for a long time because they are reliable and can produce large amounts of power. However, they also have some major drawbacks:

Air Pollution: Fossil fuel combustion releases harmful pollutants, including particulate matter, carbon dioxide, sulfur dioxide, and nitrogen oxides. These pollutants contribute to respiratory and cardiovascular diseases, reduce air quality, and drive phenomena like acid rain and smog [36].

Water Pollution: Oil spills are among the most visible environmental disasters caused by non-renewable energy use. These spills devastate marine ecosystems, killing wildlife and damaging habitats. Additionally, runoff from coal mining and fracking operations often contaminates rivers, lakes, and groundwater with toxic substances[37].

Land Degradation: The extraction of coal, oil, and natural gas frequently involves land-intensive activities like open-pit mining and drilling. These processes destroy habitats, lead to deforestation, and cause soil erosion, leaving the land scarred and less productive for future use[38].

Climate Change: Greenhouse gas emissions from burning fossil fuels are the primary driver of global warming. Rising temperatures lead to melting ice caps, sea level rise, extreme weather events, and shifts in ecosystems that threaten biodiversity and human livelihoods[20].

Radioactive Waste: Nuclear energy generates radioactive waste that remains hazardous for thousands of years. Safe disposal requires highly secure facilities and long-term monitoring to prevent leaks into the environment. Mismanagement of radioactive waste can lead to contamination of soil and water, endangering both human and ecological health[39].

Why We Need to Find Alternatives: The problems with non-renewable energy sources have encouraged people to look for better solutions. Renewable energy sources like solar, wind, and hydropower are cleaner and won’t run out. Switching to these types of energy can help protect the planet for future generations[11].

4.4. Non-Renewable Energy Use in Global and European

Non-renewable energy sources remain the backbone of global energy systems, accounting for a significant portion of the world's energy consumption. Despite increasing awareness of their environmental impacts, the reliance on fossil fuels and nuclear energy persists due to their energy density, reliability, and existing infrastructure.

4.4.1. Non-Renewable Energy Use in Global

Globally, fossil fuels dominate the energy mix, contributing approximately 86% of total primary energy consumption[26]. Coal, oil, and natural gas are widely used across industrial, transportation, and residential sectors. Coal consumption is particularly high in emerging economies such as China and India, which together account for over 65% of global coal use. Oil remains critical for transportation, with the United States and Saudi Arabia among the largest consumers. Natural gas usage has seen a steady rise due to its lower emissions compared to coal, with Russia and the United States leading in production and consumption.

Nuclear energy, while accounting for a smaller share of global energy consumption, plays a crucial role in countries like the United States, France, and China. It is primarily used for electricity generation, offering a low-carbon alternative to fossil fuels.

Non-renewable energy sources remain the most widely used energy sources globally. As of 2024, fossil fuels account for over 80% of global energy consumption. However, due to their environmental impact and the risk of depletion, there is a global trend towards reducing dependency on these sources.

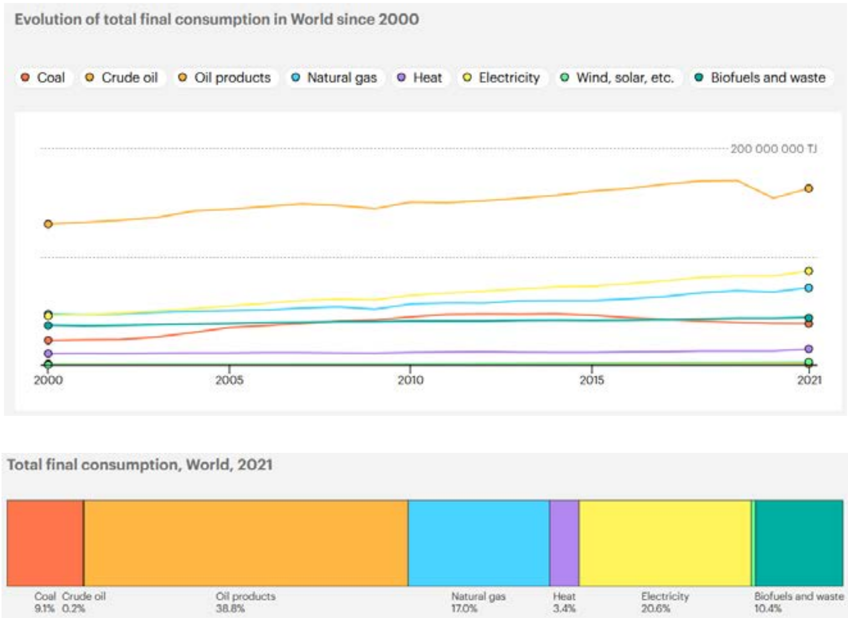


Figure 13: Final Consumption of Energy Sources Worldwide[40].

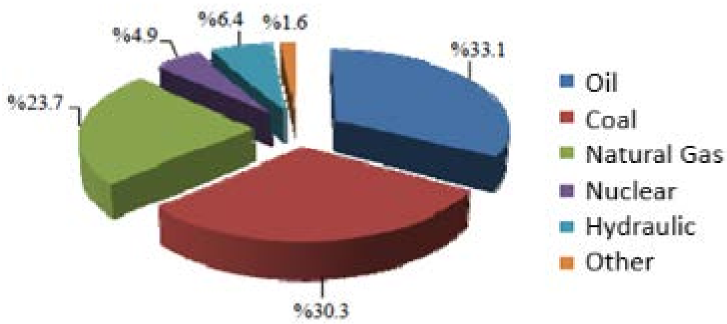


Figure 14: World primary energy use

4.4.2. Non-Renewable Energy Use in Europe

In Europe, non-renewable energy consumption has been gradually declining as countries transition to renewable energy sources and implement stringent climate policies. Nevertheless, fossil fuels still make up a substantial part of the energy mix. According to Eurostat (2021), oil accounts for approximately 34% of the EU's energy consumption, followed by natural gas at 25% and coal at 13%. Despite these figures, the EU has significantly reduced its coal usage over the past two decades, particularly in Germany and Poland, where coal was historically a dominant energy source.

Nuclear energy plays a pivotal role in Europe’s low-carbon energy strategy. France leads the continent in nuclear power, with over 70% of its electricity generated from nuclear plants. Other countries, including Sweden and Finland, also rely on nuclear energy, though several nations, such as Germany, have committed to phasing it out.

The European Union aims to reduce fossil fuel use and transition to renewable energy sources in line with its goal of becoming carbon neutral by 2050. Nuclear energy remains a significant energy source in some European countries[41].

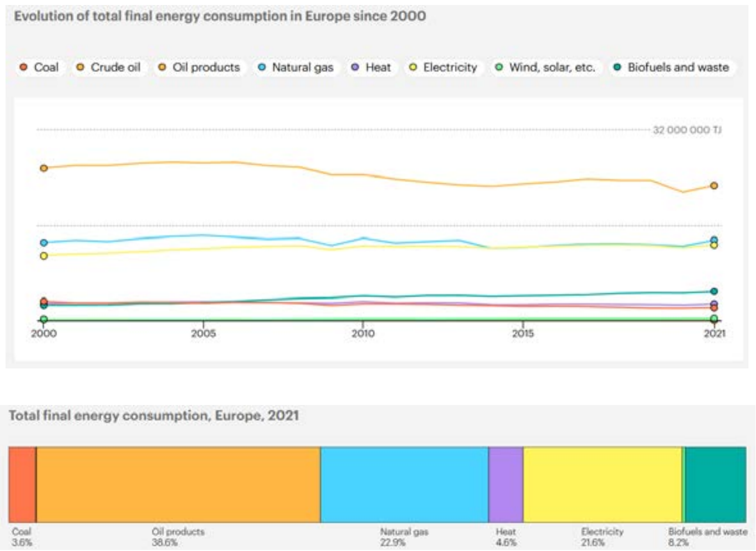


Figure 15: Final Consumption of Energy Sources in Europe[42].

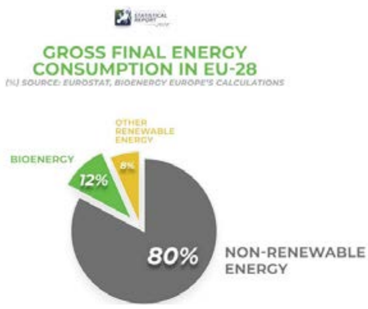


Figure 16: Gross final energy consumption in the EU-28[43].

Regional Disparities: The consumption of non-renewable energy varies significantly across regions. Northern and Western Europe have seen a more pronounced shift towards renewable energy, driven by strong government policies and public support for clean energy. Southern and Eastern Europe, however, remain more reliant on fossil fuels, largely due to economic constraints and slower adoption of renewable technologies[44].

Environmental and Policy Implications: The continued use of non-renewable energy sources in Europe and globally poses significant environmental challenges, including air pollution, water contamination, and greenhouse gas emissions. The European Union's Green Deal and other international agreements like the Paris Agreement aim to address these issues by reducing dependency on fossil fuels and increasing the share of renewables in the energy mix[45].

4.5. Non-Renewable Energy Use in Partner Countries

4.5.1 Non-renewable energy use in Türkiye

Türkiye is a country highly dependent on fossil fuels. Natural gas and oil imports constitute a significant portion of Türkiye's energy consumption. However, the increasing investments in renewable energy have begun to reduce the share of fossil fuels. In the realm of nuclear energy, projects such as the Akkuyu Nuclear Power Plant are contributing to the diversification of energy sources[46].

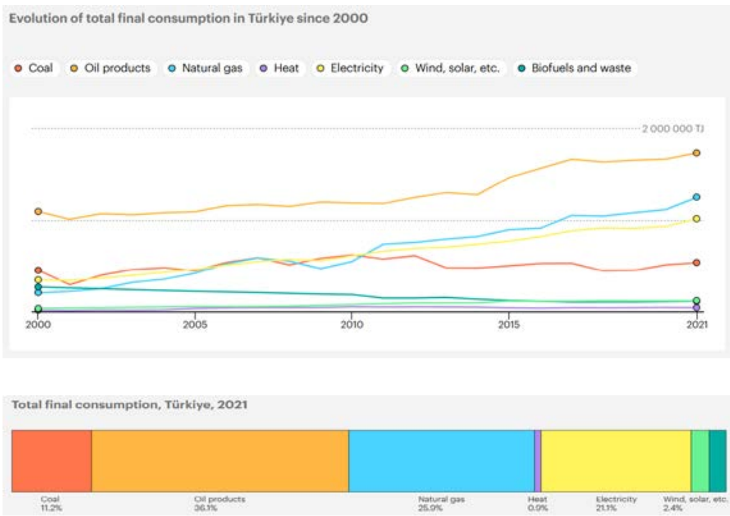


Figure 17. Final Consumption of Energy Sources in Türkiye[42].

4.5.2 Non-renewable energy use in Greece

Greece has historically relied heavily on fossil fuels, particularly oil and natural gas, for its energy needs. In 2023, oil accounted for 54% of the country's total energy supply. However, the nation has been actively reducing its dependence on lignite, a type of coal that has significantly contributed to carbon emissions. From 2005 to 2021, the share of lignite-fired electricity generation decreased from 60% to 10%, with plans to phase it out entirely by 2028. Concurrently, Greece is investing in natural gas infrastructure and expanding renewable energy sources to diversify its energy mix and enhance sustainability[47].

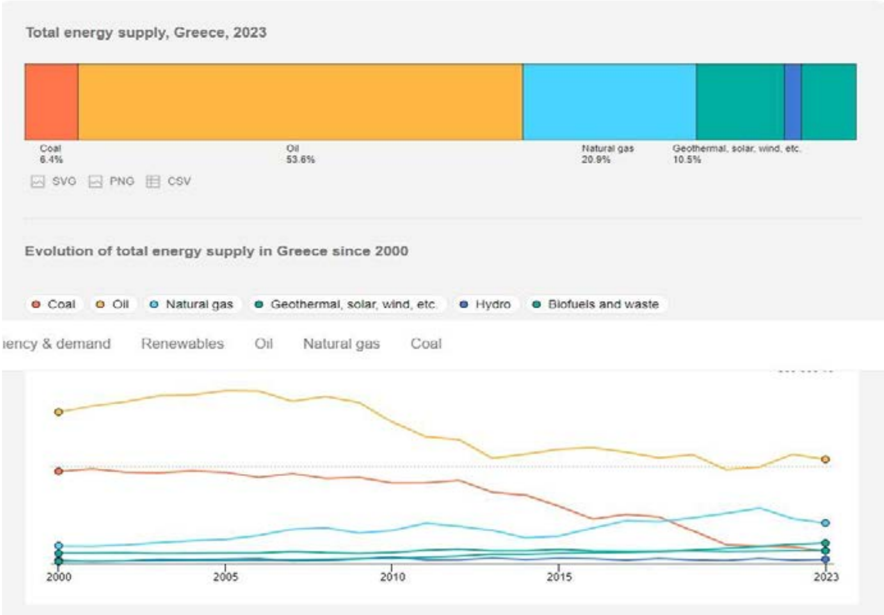


Figure 18. Total Consumption of Energy Sources in Greece[42]

4.5.3 Non-renewable energy use in Portugal

In 2000, about 78% of the energy consumed in Portugal was from coal and oil, while in 2023, the non-renewable sources represented just 64% of the global energy consumption in the country[48]. In 2023, Portugal was using 20% gas, whose consumption increased 87% compared with 2000, and 44% oil, with a decrease of 43% in the same period. Coal was banned, with the last coal power station closing in 2023.

Since 2000, Portugal has made significant strides in diversifying its energy mix, with a strong emphasis on renewable energy sources, supported by substantial investments in wind, hydro, and solar power, leading to a gradual but strong decline in the reliance on fossil fuels.

Over the past few years, the country has seen a notable shift toward cleaner and more sustainable energy production methods[48]. In 2022, Portugal was in the 4th place in the European Union, with a 61% share of electricity coming from renewable energy sources[49].

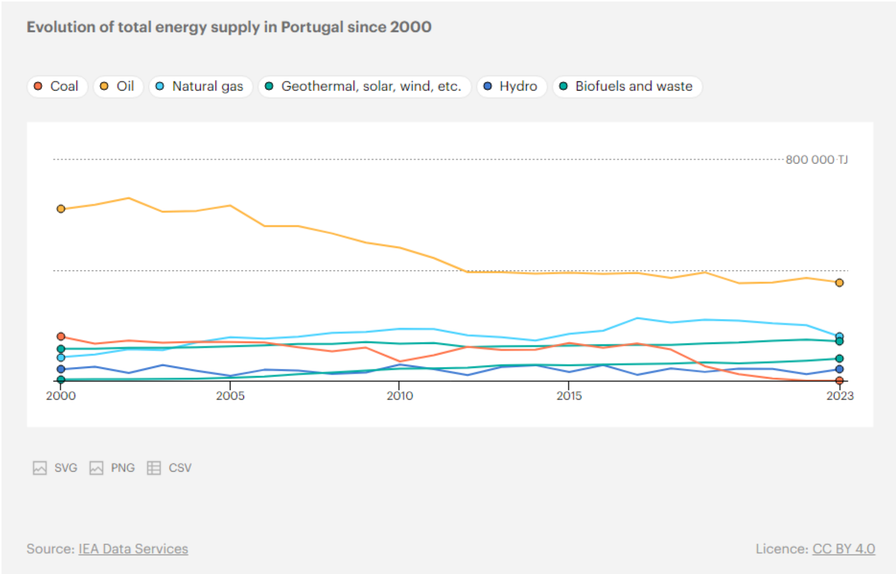


Figure 19: Evolution of total energy supply in Portugal since 2000[42].

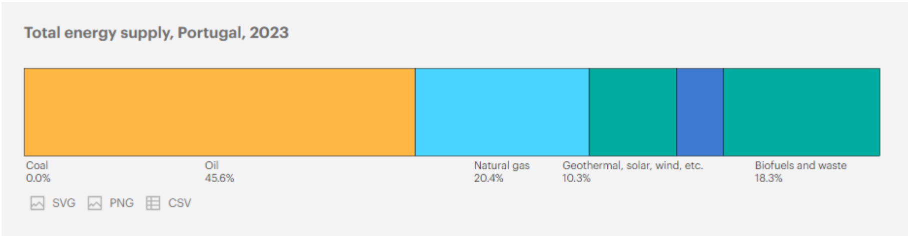


Figure 20: Total energy supply, Portugal 2023[42].

4.5.4 Non-renewable energy use in North Macedonia

North Macedonia's energy consumption is primarily derived from fossil fuels, with significant contributions from coal and oil. In 2022, coal accounted for 32.2% of the total energy supply, while oil contributed 44.6%. The country still depends heavily on coal-fired power plants for electricity generation, with 47% of total electricity production coming from coal in 2022. However, North Macedonia is undergoing a transition towards cleaner energy sources, with renewables and hydropower making up around 9.4% of the energy mix. Efforts to phase out coal by 2030 are underway, with an increasing focus on solar and wind energy to diversify the energy mix and reduce carbon emissions.

This overview highlights North Macedonia's ongoing efforts to reduce reliance on fossil fuels and transition to renewable energy sources while balancing the economic and infrastructure challenges posed by its heavy dependence on coal and oil[50].

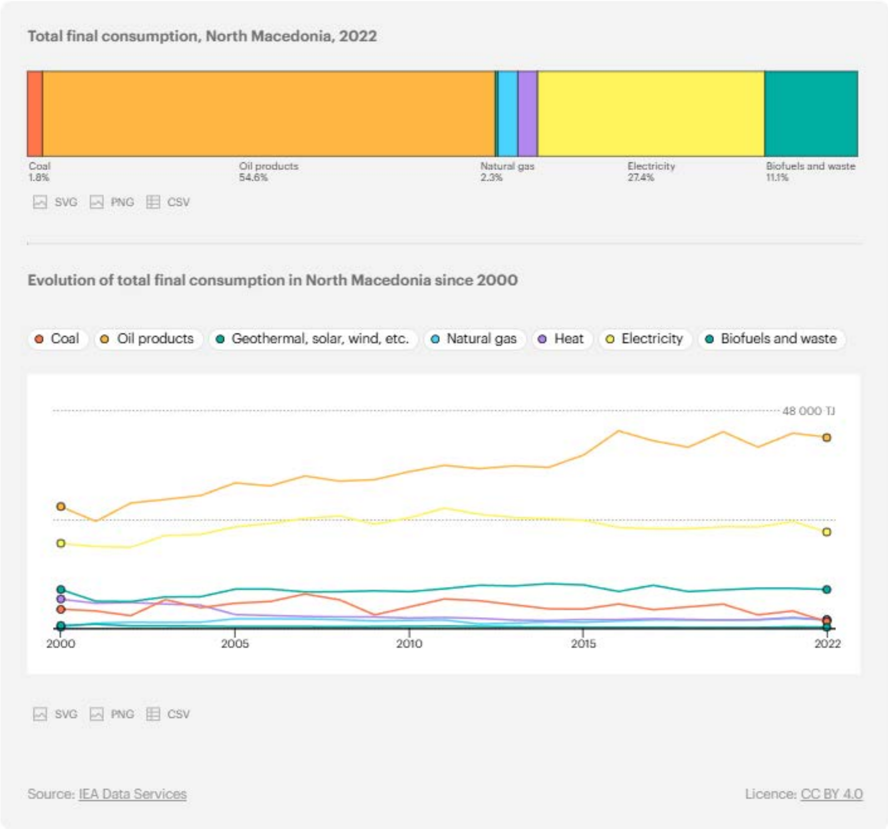


Figure 21:Final Consumption of Energy Sources in North Macedonia[42]

5. RENEWABLE ENERGY RESOURCES AND THEIR ENVIRONMENTAL IMPACTS

Renewable energy is vital for a sustainable future[51]. These energy sources, such as solar, wind, hydroelectric, biomass, and geothermal, are continuously replenished in nature, offering an alternative to finite resources. Each type harnesses natural processes, like sunlight, wind, or the Earth's heat, to generate power while minimizing carbon emissions and environmental harm. Although renewable energy reduces resource depletion and promotes energy independence, it faces challenges such as high initial costs, dependency on location and climate, and storage difficulties. This chapter delves into renewable energy technologies, their production, sustainability impacts, and real-world success stories[51].

5.1. Renewable Energy Use in Global

Fossil fuels, such as coal, oil, and natural gas, remain the largest source of energy in the world, supplying about 80% of all the energy we use[52]. Renewable energy sources, including solar, wind, hydropower, and biomass, have grown rapidly in recent years and now contribute around 20% of global energy consumption. Nuclear energy plays a smaller role, accounting for about 2.6% of the world's energy needs[53].

When it comes to producing electricity, renewable energy has made significant progress. In 2023, renewable sources generated over 30% of the world's electricity, marking a steady shift towards cleaner energy[54]. Hydropower leads the way as the most widely used renewable electricity source, followed by wind and solar power, both of which have grown quickly thanks to advancements in technology. For example, solar energy production increased by nearly 25% in just one year[55].

Despite these gains, fossil fuels still produce the majority of the world's electricity—about 60% in 2023[56]. The shift towards renewable energy is critical for a sustainable future. Cleaner energy sources reduce pollution, combat climate change, and ensure we have reliable energy for generations to come. However, this transition requires significant investment and global cooperation. While challenges remain, such as the need for better energy storage and more efficient technology, the progress made so far shows that renewable energy can play a key role in shaping a healthier planet.

Renewable energy sources have experienced rapid growth worldwide in recent years. The share of renewable energy in global energy consumption is increasing, and investments in these resources are growing rapidly. Total renewable electricity generation reached an all-time high in 2022, surpassing 8,500 TWh, which is more than 600 TWh (approximately 8%) higher than in 2021. This increase was primarily due to the growth in wind and solar photovoltaic (PV) production, both of which grew by approximately 270 TWh. Although hydroelectric power, the world's largest renewable electricity source, still saw a 70 TWh increase despite drought conditions affecting hydroelectric production in many regions including China, Europe, and the United States, the global share of renewable energy in electricity production rose to about 30%, up 1.5 percentage points from 2021. As of 2022, renewable energy sources account for approximately 30% of global energy production[54]. Notably, investments in solar and wind energy have been at the forefront of this growth.

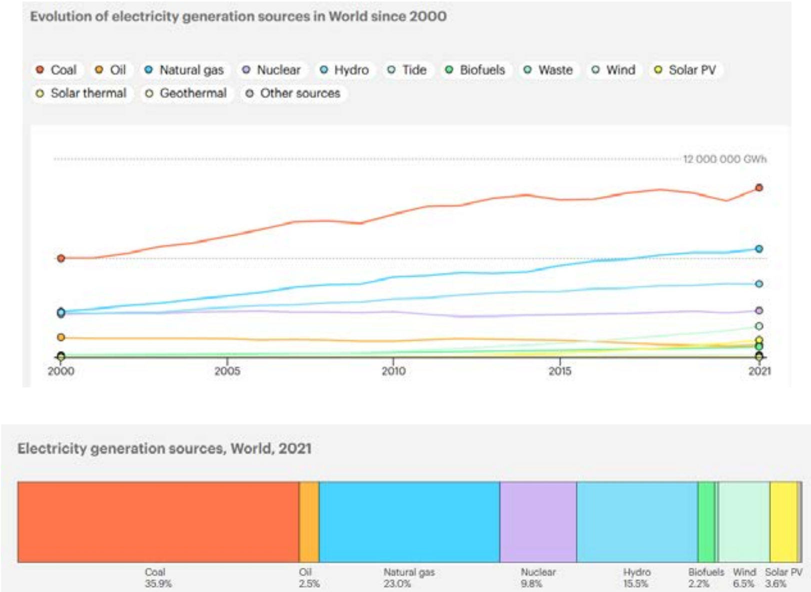


Figure 22: Electricity Generation Sources Worldwide[40]

5.2. Renewable Energy Use in Europe

Europe is one of the leading regions in the use of renewable energy sources. The European Union aims to source 32% of its energy consumption from renewable resources by 2030[57]. Countries such as Germany, Denmark, and Spain are global leaders in investments in wind and solar energy[57]. The positive impacts of renewable energy on the environment, climate, economy, and sustainability are driving the increased adoption of these energy sources. In 2022, renewable energy sources accounted for 41.2% of gross electricity consumption in the EU, an increase of 3.4 percentage points from 2021, and significantly ahead of other electricity generation sources such as nuclear (less than 22%), gas (less than 20%), or coal (less than 17%). Overall, the share of renewable energy sources increased by 5.7% from 2021 to 2022. Wind and hydroelectric power together constituted more than two-thirds of the total electricity generated from renewable sources (37.5% and 29.9%, respectively). The remaining third came from solar energy (18.2%), solid biofuels (6.9%), and other renewable sources (7.5%).

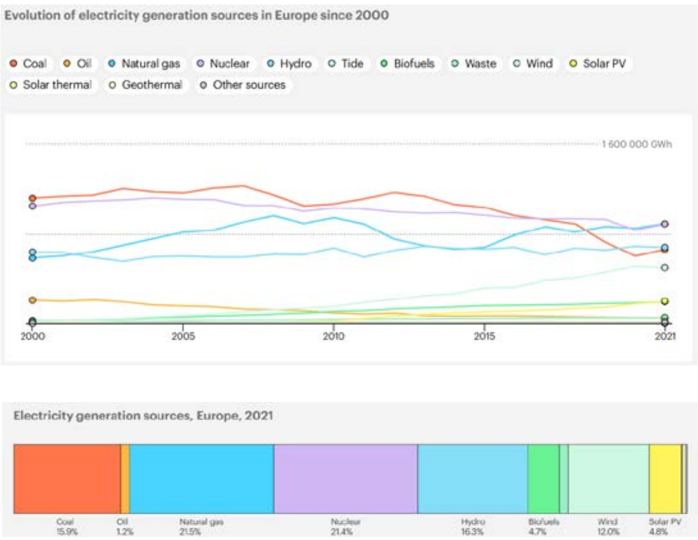


Figure 23: Electricity Generation Sources in Europe[42]

6. THE RENEWABLE ENERGY TYPES

6.1. Solar Energy

The Sun is the primary source of life on Earth and one of the most significant renewable energy sources[48]. In fact, many energy sources, including fossil fuels, ultimately derive their energy either directly or indirectly from the Sun. Located approximately 150 million kilometers away, the Sun is a massive sphere of hydrogen and helium. It generates an immense amount of energy through nuclear fusion reactions occurring in its core. In this process, hydrogen atoms fuse to form helium, releasing an enormous amount of energy. Although only a small fraction of the energy emitted by the Sun reaches the Earth, this amount is more than sufficient to meet the planet's energy demands.

The amount of solar energy reaching the Earth varies throughout the day and across the year.[58] This variation is primarily due to the Earth's rotation on its axis and its orbit around the Sun. Additionally, factors such as weather conditions, atmospheric composition, and latitude influence the amount of solar energy that reaches the surface.

Figure 24: Solar panels harness the Sun's energy to generate clean and renewable power

6.1.1. Solar Energy Conversions

A portion of the energy emitted by the Sun is absorbed by the Earth's atmosphere, while another portion is reflected back into space[59]. Approximately 71% of this energy is absorbed by the Earth's surface and utilized in various processes[60]. Solar energy can be converted into different forms of energy, either through naturally occurring processes or through methods developed by humans.

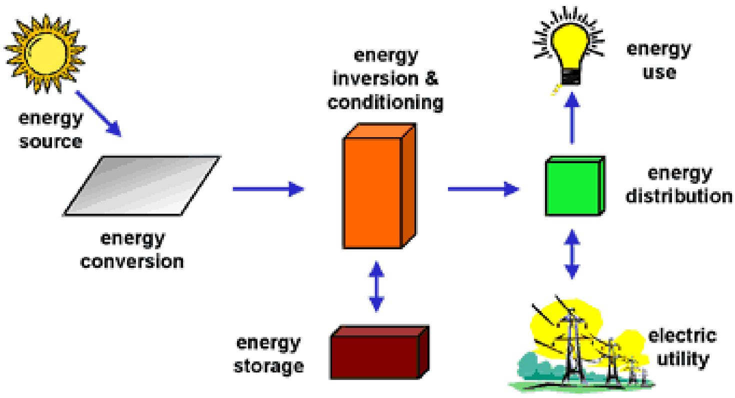


Figure 25: Solar energy undergoes conversion, storage, and distribution before reaching end-users as electricity[59].

a. Natural Conversions

Solar energy enables numerous natural processes, either directly or indirectly[58]:

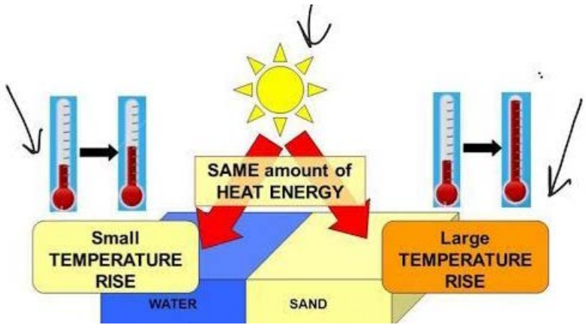


Figure 26: Different materials absorb solar heat differently, affecting temperature changes in nature

- **Heating of Soil and Water:** Solar radiation heats the soil and water, influencing air temperature and climate conditions.
- **Photosynthesis Process:** Plants utilize sunlight to produce food and release oxygen.
- **Water Cycle:** Solar heat drives the evaporation of water, leading to cloud formation and precipitation, sustaining the water cycle.
- **Wind and Wave Formation:** Temperature differences in the atmosphere generate winds, which in turn contribute to wave movement.
- **Natural Wildfires:** During dry periods, intense sunlight can trigger forest fires.

Figure 27 : Advanced technologies harness solar and wind energy to support both sustainability and innovation.

b. Artificial Conversions

Humans can utilize solar energy directly or indirectly through various technologies[61]:

- **Solar Collectors:** These devices capture solar radiation and use it for heating water or other heating systems.
- **PV Panels:** These panels convert solar energy directly into electricity.
- **Hydroelectric Energy:** Solar energy drives the water cycle, contributing to electricity generation from dams.
- **Wind Turbines:** Wind energy, created by temperature differences caused by the Sun, is harnessed to produce electricity.
- **Biomass Energy:** Plants store solar energy and are used for biofuel production.
- **Solar Architecture:** This involves designing buildings to maximize the efficient use of solar energy.

These various conversion processes of solar energy not only help maintain ecosystem balance in nature but also provide sustainable energy sources for human use.

6.1.2. Solar Energy Worldwide

The most efficient regions for utilizing solar energy are located between the latitudes of 35° North and 35° South, known as the "Solar Belt" of the Earth[62]. This region experiences high annual sunshine durations, and the solar energy potential ranges from 3.5 to 7 kWh/m^2[63]. Countries such as Spain, Italy, Greece, Türkiye, Egypt, Iran, China, Japan, the United States, and

Figure 28:The Solar Belt between 35°N and 35°S offers the highest global solar energy potential.

Australia are among those that can make the most use of solar energy.
Throughout human history, solar energy has been used in various ways:

- In the 4th century BC, the famous philosopher Socrates suggested that more windows should be added to the southern faces of houses to make better use of the Sun.
- In the 17th century, Galileo, by discovering lenses, pioneered efforts to focus solar energy.
- In 1860, research was conducted on collecting solar rays using parabolic mirrors and using them in steam engines.
- In the 1950s, solar energy systems began to spread in the United States and Japan, and the first photovoltaic (solar cell) panels were produced by Bell Telephone Laboratories.
- In 1984, the first large-scale solar power plant was established in Los Angeles, USA, reaching a capacity of 354 MW.
- In the 1990s, solar towers with capacities of 10 MW in California and 30 MW in Jordan were commissioned.
- In the 2000s, significant advancements were made in solar cell technology, and global solar energy production grew rapidly.

Today, solar energy plays a crucial role in the global energy transition. With the development of technology, the efficiency of solar panels has increased, and installation costs have decreased. As a result, many countries have started to use solar energy extensively[58].

6.1.3. Solar Energy in Partner Countries

6.1.3.1. Solar Energy in Türkiye

Türkiye is located within the Solar Belt and has an average of 2,640 hours of sunshine per year[64]. The annual solar radiation varies between 2.9 and 4.0 kWh/m² across different regions. According to the Türkiye Solar Energy Potential Atlas (GEPA), the regions with the highest solar potential are the Mediterranean Region and the area around Lake Van, while the regions with the lowest potential are the Black Sea and Marmara regions. As of February 2016, Türkiye had 313 solar power plants with a total installed capacity of 313 MW. The largest of these plants was the Konya Karatay Kızören Solar Power Plant, with a capacity of 18 MW. At that time, various incentive and support mechanisms were in place to increase the use of solar energy in Türkiye. The ministry aims for an annual increase of 5,000 MW in renewable energy capacity by 2035. Türkiye's solar energy potential and current installed capacity make a significant contribution to its energy independence and sustainability goals.

Figure 29: Southern and eastern regions of Türkiye have the highest solar energy potential.

6.1.3.2. Solar Energy in Greece

Greece, benefiting from its location within the Sun Belt, experiences high solar irradiance, with average global horizontal irradiation levels exceeding 1,500 kWh/m² annually. This favorable climate has propelled significant growth in the country's solar energy sector. In 2023, photovoltaics generated 19% of Greece's electricity, positioning the nation second globally in electricity production from solar energy[65]. By the end of 2024, Greece's cumulative installed photovoltaic capacity reached 9.6 GW, a substantial increase from 5.3 GW in 2022[66]. This rapid expansion is attributed to supportive policies, favorable climatic conditions, and a strong commitment to renewable energy. Looking ahead, Greece aims to achieve an 82% share of renewables in electricity generation by 2030, with solar energy playing a pivotal role in this transition.

A notable example of Greece's commitment to renewable energy is the transformation of Chalki, a small island in the Aegean Sea. As part of the "GR-eco Islands" national initiative, Chalki inaugurated a 1 MW solar park in November 2021, which now supplies clean energy to its approximately 300 permanent residents. The project involved the construction of a solar park and the establishment of an energy community, in which the municipality holds a 50% share. This initiative not only provides energy autonomy but also serves as a model for sustainable development across other Greek islands. The "GR-eco Islands" initiative reflects the Greek government's dedication to promoting green and digital transformation, aiming to decarbonize islands and enhance energy self-sufficiency through renewable energy and technological innovations.

Figure 30: Greece’s strong solar irradiance supports its leadership in solar energy production

6.1.3.3. Solar Energy in Portugal

The total annual average number of sun hours in Portugal ranges from a minimum of 2200 in the North to more than 3000 hours in the South, making the country suitable for a wide use of solar energy[67]. The southern part of the country is mainly flat, in contrast to the North, which explains why most of the biggest photovoltaic power stations are located in Ribatejo, Alentejo, and Algarve[68]. One of the largest facilities opened in 2023, “Central da Cerca”, located about 50 km north of Lisbon, has 310 thousand double-sided panels and will produce about 330 GWh

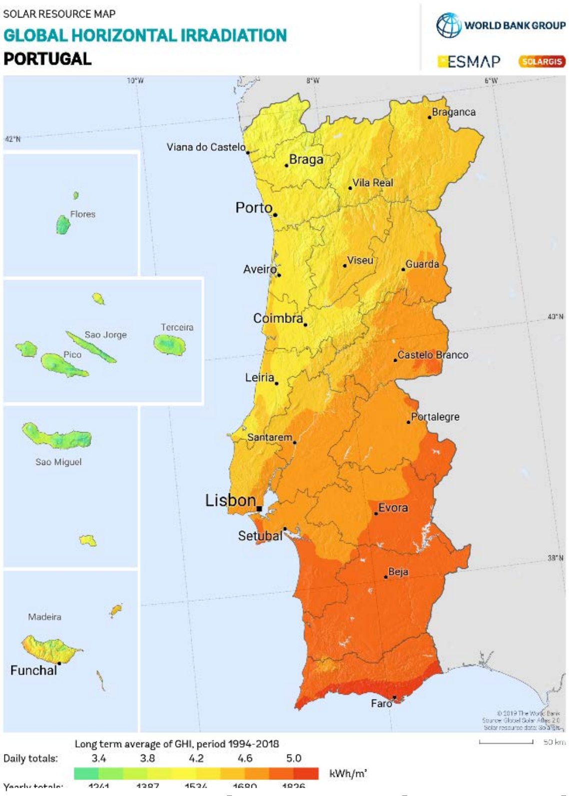


Figure 31: Southern Portugal receives the highest solar irradiation, making it ideal for large-scale solar power projects

per year. This energy will be enough to supply 100 thousand families and avoid the emission of at least 170 thousand tons of CO_2 each year.

According to the Portuguese official Agency of Energy (DGEG), 5.9 GW of the 20.8 GW renewable power used in the country comes from solar photovoltaic[69]. This value is more than twice the capacity installed by the end of 2022. In 2023, 1.1 GW of new solar power was added to the grid. By 2026, solar energy will surpass wind energy to become the second most important source concerning installed capacity.

Several new photovoltaic projects are being developed in Portugal. They are expected to be in force by the end of 2030, with the installed capacity increasing to around 9 GW. This means that by then, photovoltaic energy will become the main electricity production technology used in the country.

6.1.3.4. Solar Energy in North Macedonia

North Macedonia, located in the Balkan Peninsula, enjoys a favorable climate that provides significant solar energy potential. The country receives between 1,500 and 1,700 kWh/m² of solar radiation annually, making it an ideal location for solar energy development[67]. The highest solar energy potential is observed in the southern and eastern regions, which are characterized by abundant sunlight throughout the year.

As of 2023, North Macedonia's solar energy sector has made impressive strides. The country's installed solar capacity has reached around 200 MW, with key projects such as the Oslomej Solar Park, built on the site of a former coal mine, playing a critical role in advancing the country's renewable energy transition[70]. This project, along with others, is helping reduce the nation's dependence on fossil fuels, particularly coal, and increasing the share of renewables in its energy mix.

The government of North Macedonia has set ambitious renewable energy goals, targeting a 38% share of renewables in its energy mix by 2030[71], with solar energy playing a central role in this transition. To support this, the government is providing incentives and creating favorable policy frameworks to attract both large-scale investments and encourage residential solar installations.

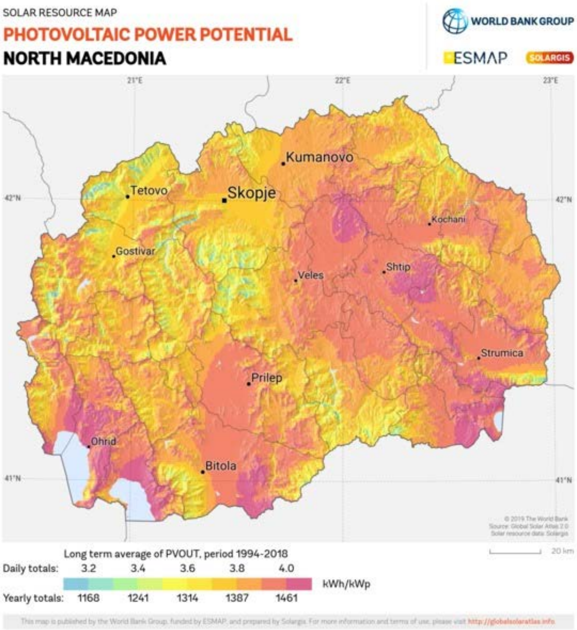


Figure 32: Southern and eastern North Macedonia offer the highest potential for solar power generation.

Notable examples of solar energy development in North Macedonia include the Skopje Solar Park, one of the country's significant solar power projects, and smaller-scale solar installations in rural areas[72]. These initiatives not only contribute to increased energy self-sufficiency but also help reduce CO_2 emissions, aligning with North Macedonia's broader environmental and climate goals.

With continued investment in solar energy, North Macedonia is well on its way to becoming a leader in the renewable energy sector in the Balkans, further diversifying its energy sources and promoting sustainability.

6.1.4. Positive and Negative Impacts of Solar Energy

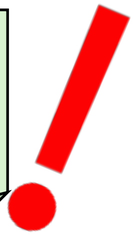
Advantages

- Solar energy is a renewable resource, meaning it can be used without depleting natural reserves. It is a sustainable option for meeting long-term energy needs.
- Solar energy production generates little to no greenhouse gas emissions, reducing air pollution and mitigating climate change.
- Once solar panels are installed, the maintenance and operating costs are relatively low compared to other energy sources.
- Solar energy reduces reliance on imported fossil fuels, contributing to energy security and independence.
- The growing solar industry provides job opportunities in manufacturing, installation, and maintenance, benefiting the economy.
- Solar systems can be deployed in a variety of settings, from residential rooftops to large-scale solar farms, allowing flexibility in production.

Disadvantages

- Solar energy production is dependent on sunlight, meaning it can be intermittent and unreliable during cloudy days or at night, requiring storage solutions or backup systems.
- The upfront cost of purchasing and installing solar panels can be high, despite long-term savings.
- Large-scale solar farms require significant land areas, which could potentially impact ecosystems or compete with agricultural land.
- Storing solar energy for use during non-sunny periods requires advanced battery technology, which can be expensive and still developing.
- The production and disposal of solar panels involve materials that may pose environmental challenges if not properly managed, such as rare earth elements and recycling issues.

While solar energy has great potential for a sustainable future, it is expected to become more widespread with technological advancements and cost reductions.



6.1.5. Technologies for Harnessing Solar Energy

Solar energy utilization technologies can be divided into two main categories[58]:

- This involves technologies that capture sunlight and convert it into thermal energy, typically for heating purposes.
- This includes photovoltaic systems that directly convert sunlight into electrical energy.

Additionally, in recent years, hybrid applications, such as Concentrated Photovoltaic (CPV) systems, have been developed, combining elements of both heat and electricity generation for more efficient energy production.

6.1.5.1. Heat Energy from the Sun

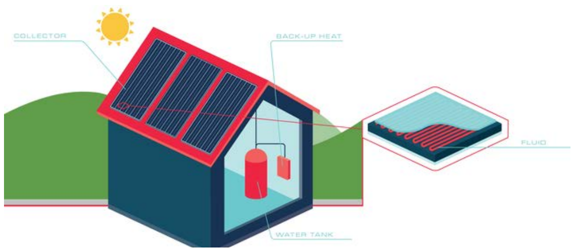


Figure 33: Solar collectors convert sunlight into heat for residential water heating.

This method captures sunlight and converts it into heat energy. Its areas of application are as follows[73]:

- **Solar Collectors:** Used for water heating in homes and industry.

- **Solar Thermal Power Plants:** Concentrate sunlight using mirrors for large-scale energy production, driving steam turbines.

Figure 34: Solar thermal power plants use mirrors to generate electricity on a large scale.

- **Solar Ovens and Cookers:** Used for cooking in camping and rural areas.

Figure 35: Solar ovens harness the Sun's heat for cooking, especially in remote areas.

6.1.5.2. Direct Electricity Generation from the Sun

This method converts sunlight directly into electricity. The most commonly used technologies are:

- **PV Panels:** Panels that convert sunlight directly into electricity. They are used in rooftop systems, agricultural areas, and industry.

Figure 36: PV panels convert sunlight directly into electricity on rooftops and open areas.

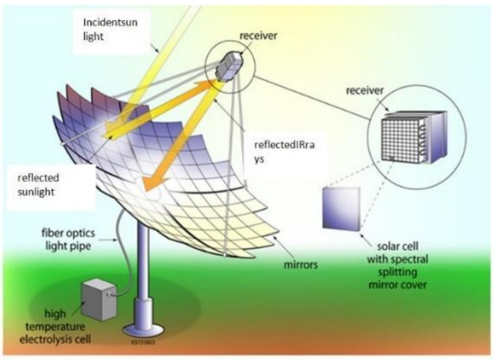


Figure 37: Concentrated photovoltaic systems use mirrors or lenses to boost solar power efficiency[74].

- **Concentrated Photovoltaic (CPV) Systems:** These systems concentrate sunlight onto small areas using lenses or mirrors, providing higher efficiency[74].

Solar energy technologies are becoming increasingly efficient and cost-effective thanks to advancements in material science and manufacturing techniques.

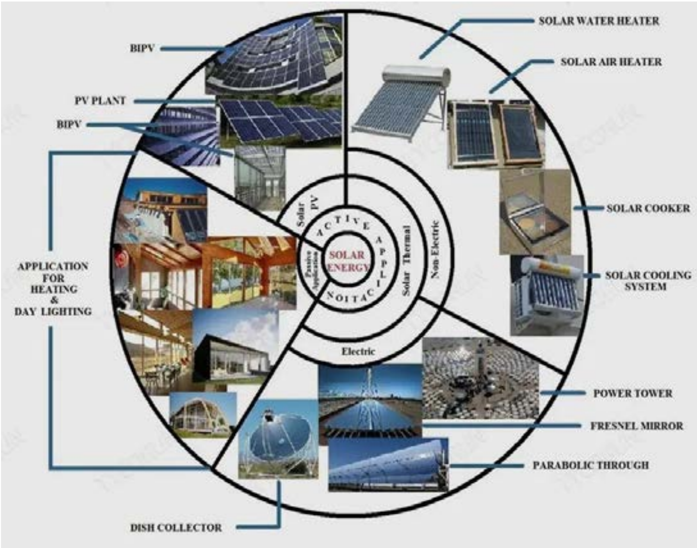


Figure 38: Solar thermal technologies serve diverse applications, from water heating to electricity generation[75].

6.1.5.3. Solar thermal energy technologies and applications

Solar thermal energy technologies collect sunlight to produce hot water, provide heating, and even generate electricity[75]. The most common application is the production of hot water using solar collectors, which are widely used in homes, industry, and agriculture. Thermal conversion systems are divided into three main groups according to the temperature used[76]:

a. Low-Temperature Thermal Applications (≤ 100°C)

These applications are used for processes that require low temperatures:

- Hot water production using flat-plate solar collectors (homes, hotels, sports facilities)
- Heat generation and storage with solar pools
- Water purification and desalination systems
- Heating and cooling of buildings
- Drying of agricultural products (fruit, vegetables, grain drying)
- Greenhouse heating systems
- Cooking with solar ovens

b. Medium-Temperature Thermal Applications (100-350°C)

These applications are used for processes that require higher temperatures:

- Hot water and heat production using vacuum tube solar collectors
- Industrial process heating systems
- Solar-powered cooling systems (cooling machines, air conditioners)

c. High-Temperature Thermal Applications (≥ 350°C)

These applications are used for electricity generation and heavy industrial processes:

- **Solar towers:** Concentrate sunlight at a single point using large mirrors to generate electricity through steam turbines.
- **Solar furnaces:** Enable the processing of materials such as metals and ceramics at high temperatures.
- **Ore smelting processes:** Used in metal production.

Through these technologies, solar energy can be effectively utilized both in daily life and in industry.

6.1.5.4. Methods of Electricity Generation from Solar Energy

One of the commonly used methods for generating electricity from solar energy is Concentrated Solar Power (CSP) systems. These systems include parabolic, tower, and dish systems. The use of solar collectors is particularly widespread in countries close to the equator. Countries such as the United States, Japan, France, Italy, Greece, and Israel actively utilize these systems. Even in countries like Sweden, where sunny days are limited, solar collectors are used to produce hot water[58].

Figure 39: “Concentrated Solar Power (CSP) systems use mirrors to focus sunlight and generate electricity efficiently.

Figure 40: Solar furnaces use parabolic reflectors to focus sunlight for cooking and heating.

a. Solar Furnaces

Solar furnaces are devices that collect sunlight using parabolic-shaped structures, converting it into heat. These systems are commonly used for cooking and water heating purposes. Solar furnaces are especially popular in countries such as Pakistan, India, China, and Kenya.

b. Solar collectors

Solar collectors, also known as "collectors," are systems that are classified into three groups based on their structural features:

1. **Flat-plate solar collectors**: These are the most common type of solar collectors, consisting of a flat absorber plate that absorbs sunlight and converts it into heat.
2. **Vacuum tube (tubular) solar collectors**: These collectors use vacuum tubes to minimize heat loss, improving efficiency, especially in colder climates.
3. **Non-glass solar collectors**: These systems do not use glass as a covering material but instead use other materials to capture solar energy.

These collectors are designed based on the circulation of water and can be produced as either naturally or pump-assisted circulating, and can have either open or closed-loop systems.

1. Flat Collectors

Flat collectors collect solar energy and transfer it to a fluid as heat. The fluid can be water, air or a different fluid. Air collectors lose more heat than liquid collectors. Therefore, they are used in heating residential and commercial buildings and drying processes. Liquid collectors are preferred in heating large buildings, industrial heating processes and cooling of buildings.

The structure of a flat-surface collector consists of three parts:

1. An absorber plate with high absorption capacity
2. Glass or plastic cover placed in front of the absorber plate
3. Collector case made of metal, impregnated wood or plastic

Figure 41: Flat-plate collectors absorb solar energy and transfer it to a fluid for heating.

2. Vacuum Tube Collectors

Vacuum tube collectors are systems designed using vacuum glass tubes. They have two intertwined tube structures and the air between the tubes is removed to create a vacuum environment. In this way, heat losses are minimized and energy efficiency is increased. The tubes are coated with a special surface to better absorb the sun's rays and convert them into heat. Thanks to their round structure, the sun's rays always come to the surface at a right angle, which provides more energy production compared to flat collectors.

Figure 42: Vacuum tube collectors reduce heat loss, increasing efficiency in colder climates.

3. Glassless Solar Collectors

Glassless solar air collectors are solar air heating systems with a metal absorber surface that does not have a glass or similar cover on it. The most commonly used type of these systems, also known as SolarWall, is the "Air-Leaked Solar Collector" application. These collectors are used in commercial buildings, industry, agriculture and livestock sectors,

Figure 43: Glassless collectors like SolarWall heat air directly and are used in industrial applications.

and also in industrial processes to heat the outside air needed.

They are usually mounted on the exterior walls of buildings in order to better capture the low sun angle in the winter months and to benefit from the sun rays reflected from the snow surface.

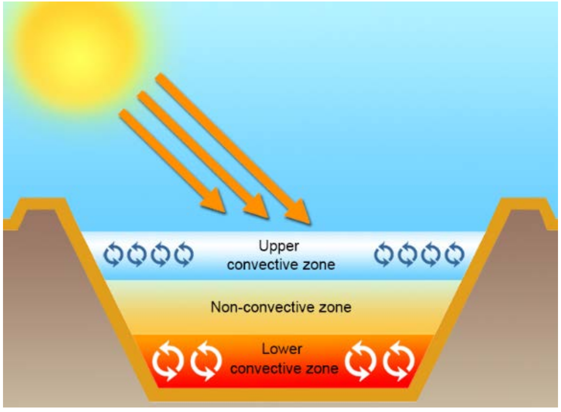


Figure 44: Solar pools store solar heat in salt-layered water, reaching temperatures up to 90°C[77].

c. Solar Pools

Solar pools are systems that collect and store solar energy as heat[77]. The bottom of these pools, which are usually 5-6 meters deep, is made black to better absorb the sun's rays. The water temperature in solar pools can reach up to 90°C. There are layers with different salt ratios in the pool. While the water is colder in the upper parts due to the low salt ratio, the water remains warmer in the lower parts due to the higher salt ratio. The hot water in the lower part can be used for direct heating purposes or can be used for electricity generation. The efficiency of solar pools is approximately 20%. These systems are widely used especially in countries such as Israel, the USA and Australia. For example, there are solar pools with a capacity of 150 kW and 5 MW in Israel, 400 kW in the USA and 15 kW in Australia.

d. Solar Chimney

Solar chimney systems create air currents using solar energy and convert this movement into electrical energy. A large structure covered with transparent surfaces absorbs the sun's rays and heats the air inside more than the outside temperature. The heated air rises through a sloping roof and is directed to the chimney. The hot air reaching the chimney moves at a speed of approximately 15 m/s and rotates the wind turbine placed there, generating electricity.

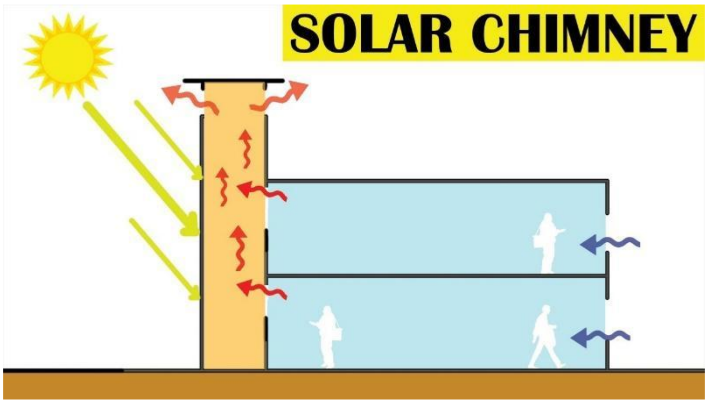


Figure 45:Solar chimneys use heated air to drive turbines and generate electricity.

e. Solar Water Distillation Systems

Obtaining drinking water using solar energy is an environmentally friendly and economical method. Especially in coastal areas where sunlight is intense, seawater purification can be carried out easily and efficiently. Two basic methods are used to convert seawater into drinking water. In the first method, evaporation, freezing, crystallization and filtration are applied for salt separation. In the second method, electrodialysis, extraction, ion exchange and diffusion techniques are used. The simplest water distillation system is the greenhouse type distillation system. In this system, the bottom of the distiller is designed in black to better absorb sunlight. The upper part is arranged in an airtight manner and inclined to the channel where fresh water will be collected. The sunlight passing through the glass surface heats the water in the distiller and causes it to evaporate. The rising water vapor condenses on the glass surface and turns into water droplets and slides down the inclined surface and accumulates in the collection container. The hotter the water, the higher the distillation efficiency. When the outside temperature drops, the condensation process accelerates, producing more fresh water[78].

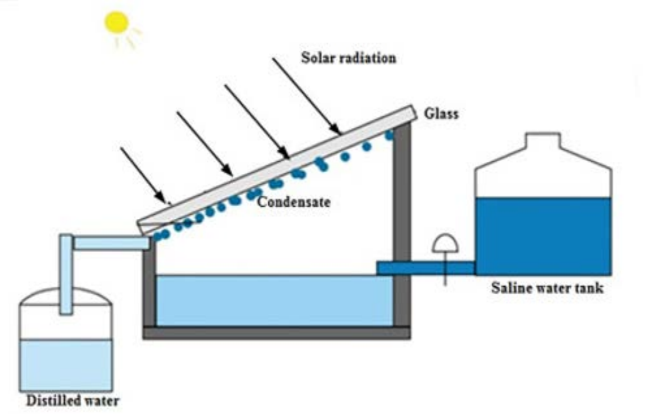


Figure 46: Solar distillation systems purify saline water using the Sun's heat[78].

6.1.5.5. Passive Heating and Cooling of Residences with the Sun

The angular change of sun rays throughout the year is an important factor in building designs[79]. Since sun rays are more vertical in the summer and more horizontal in the winter, architectural solutions have been developed to suit this situation. Structures that prevent sun rays from entering the interior in the summer and allow them to enter the interior at the maximum level in the winter increase energy efficiency[80].

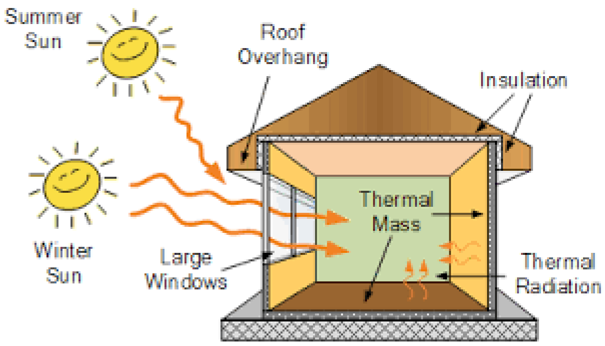


Figure 47: Passive solar design maximizes sunlight in winter and provides shading in summer to improve energy efficiency[79].

If you are located in the northern hemisphere, the southern facades of buildings benefit more from sunlight during the winter months. Therefore, the positioning of windows and the design of shading systems are of great importance. In addition, the insulation method called "insulation" keeps homes warm by reducing heat loss in the winter and keeps them cool in the summer, reducing the need for cooling. Such passive design methods contribute to both the environment and the budget by reducing energy consumption.

a. Solar Greenhouse Heating

Temperature control in greenhouse farming is of great importance for healthy plant growth and high yields. The high cost of heating with fossil fuels has increased the tendency towards alternative energy sources. In recent years, the use of solar energy in greenhouse heating has become widespread. The plastic or glass coverings of greenhouses are designed to take in the maximum amount of sunlight. The incoming sunlight is absorbed by the soil, converted into heat and kept inside. In this way, the temperature in the greenhouse is maintained and a suitable environment is provided for the development of plants. Greenhouses heated with solar energy offer a low-cost and environmentally friendly solution.

Figure 48: Solar dryers use heated air to naturally and efficiently dry agricultural products.

b. Sun Drying

Solar energy is used as a natural and economical method for drying various materials. The drying process is carried out by keeping it under direct sunlight (open air drying) or by passing air heated by the sun over the product. Systems in which the drying process is carried out by moving the air heated by solar energy are called solar dryers. These systems can be used in many different areas from food products to agricultural materials. Solar drying methods are preferred because they are low cost and provide drying while preserving product quality.

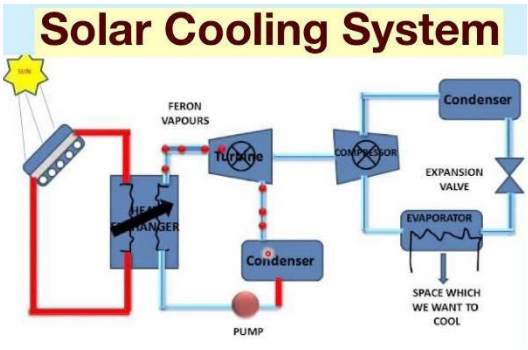


Figure 49: Solar cooling systems provide eco-friendly solutions for refrigeration and air conditioning.

c. Solar Cooling

Solar energy cooling systems are used in areas such as food preservation, ice production, cooling of buildings and indoor air conditioning. Cold storages, tourist facilities and summer houses are among the common areas of use of these systems. Solar energy cooling can be carried out with different methods. Among these methods, the absorption cooling system is the most widely used. It is preferred due to its high efficiency and simplicity of working principle. In this system, the solution heated by solar energy is vaporized through certain stages and condensed again to provide cooling. These systems operating with solar energy offer an environmentally friendly alternative by reducing dependence on fossil fuels.

6.1.5.6. Concentrator solar power systems (CSP) and electricity generation

It is possible to generate electricity from solar energy by thermal methods thanks to concentrator systems. These systems enable high temperatures to be reached by concentrating the sun's rays at a certain point or line. Concentrator thermal systems can be linear or point-type and generate electricity using steam turbines with the Rankine cycle and gas turbines with the Stirling or Brayton cycle. The heat obtained from the sun is transferred to the power generation system either directly by steam generation or through substances such as hot oil and molten salt. Since temperatures between 200°C and 1500°C can be achieved with these systems, it is possible to generate electricity using thermodynamic power cycles. Since nuclear and thermal power plants are also based on similar principles today, there is extensive experience in the application of CSP systems. In addition, CSP systems can be supported by fossil fuels such as natural gas or solid fuels when sunlight is insufficient. An important advantage of CSP systems is that they can store solar energy in the form of heat. This feature, unlike PV (photovoltaic) systems, offers the opportunity to make the energy supply uninterrupted. For this reason, CSP systems are also called "Solar Thermal Power Plants".

In terms of electricity production, the following classification can be made for concentrating systems:

1. Linear Concentrators
a. Parabolic Trough Collectors

Parabolic trough collectors are systems that reach high temperatures by concentrating the sun's rays along a line. The inner surface of the collectors is covered with a reflective material and directs the rays to a pipe located at the focal point. Oil is usually used as a heat transfer fluid in the pipe. This fluid heats up to 350-400°C and is used for electricity generation in power plants. Efficiency is increased thanks to the mobile systems that follow the sun's rays.

Figure 50: Parabolic trough collectors focus sunlight onto a central tube to produce high-temperature heat for electricity generation.

b. Fresnel Mirror Condensers

Fresnel mirror concentrators are a system that concentrates linear solar radiation to achieve high temperatures[81]. They operate similarly to parabolic trough collectors, but use many small, movable mirrors with a flatter surface. These mirrors track the sun on a single axis and direct the rays to the collector at the top. They are seen as an economical alternative due to their low production costs. They are used in Nevada Solar One, California SEGS Plant and various plants in Spain.

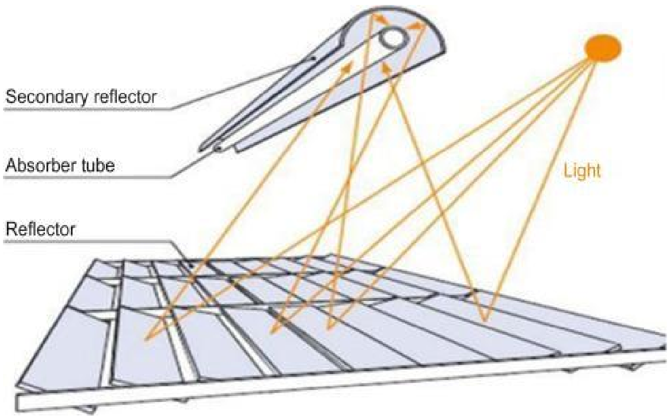


Figure 51: Fresnel mirror concentrators use flat, adjustable mirrors to direct sunlight to an absorber tube for thermal power production[81].

2. Point Concentrators

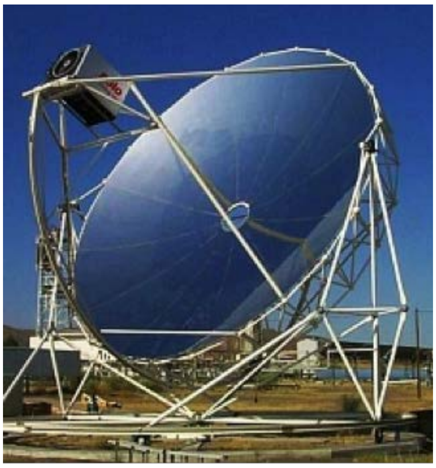


Figure 52: Fresnel mirror concentrators use flat, adjustable mirrors to direct sunlight to an absorber tube for thermal power production.

a. Parabolic Dish Systems

These systems consist of reflectors in the shape of a dish that follow the sun throughout the day and concentrate the rays at the focal point. The sun's rays are directed to the focal point with the help of computer-controlled mirrors called heliostats. The liquid in the absorbent pipe here heats up to 600-700°C. This heat is converted into electrical energy by steam turbines.

b. Central Receiver Systems

Central receiver systems have a tower-type structure. The system is based on large mirrors (heliostats) directed at the tower[82]. These computer-controlled mirrors continuously reflect the sun's rays to the receiver at the top of the tower. The heat transfer fluids, such as molten salt, in the receiver reach temperatures of 350-600°C. This heat energy is used to generate electricity with the help of steam turbines.

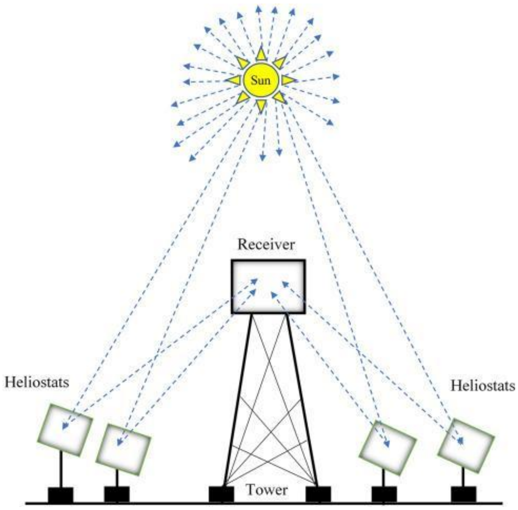


Figure 53: Parabolic dish systems track the sun and focus its rays to generate high-temperature heat for power production[82].

6.1.5.7. Systems and applications that generate electricity directly from solar rays

a. PV cells and panels

Systems that produce electricity directly from solar energy are called **PV systems**[83]. The basic building blocks of these systems are PV cells. When sunlight hits the surface of PV cells, electric current is produced. However, a single cell can produce a very low amount of direct current (DC). For higher electricity production, these cells are connected in series or parallel to form PV panels[84].

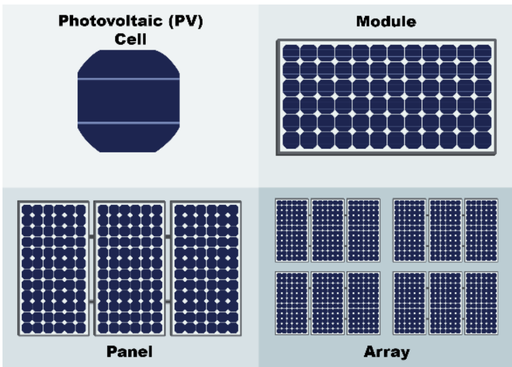


Figure 54: PV systems are built from PV cells, combined into modules, panels, and arrays to generate electricity[83].

The most important advantages of photovoltaic systems are:

- They are durable and require little maintenance because they have no mechanical moving parts.
- They operate silently and do not emit harmful gases into the environment.
- They have a long service life.
- They can be designed in different powers from small microwatt levels to megawatt levels.

However, a large area is needed to install a high-efficiency system. The International Energy Agency Photovoltaic Power Systems Program (IEA-PVPS) has divided photovoltaic systems into four main groups:

Photovoltaic Systems

Domestic Independent Photovoltaic Power Systems

They are systems that work independently of the grid.

They are used for residences or small residential areas.

The energy produced is stored in batteries and used when needed.

Non-Domestic Independent Photovoltaic Power Systems

Used in areas where there is no electricity grid or where transportation is difficult.

The energy produced can be consumed directly or stored in batteries.

It is widely preferred in agricultural irrigation systems, communication towers and rural areas.

These are systems that operate in conjunction with the grid.

They are used to meet the electricity needs of various residential or commercial buildings. The excess energy produced can be transferred to the grid, thus reducing users' electricity bills.

Central Grid-Connected Photovoltaic Power Systems

Produce electricity with large-scale solar power plants.

Also known as "solar fields".

The energy produced is transferred directly to the electrical grid and distributed to a wide range of users.

b. Domestic PV Systems

Domestic PV systems are systems that meet the energy needs of homes by converting sunlight into electrical energy. Excess electricity produced by solar panels can be transferred to the city grid and energy can be taken from the grid when needed[85].

Figure 55: Domestic PV systems convert sunlight into electricity, powering homes and transferring excess energy to the grid.

Features:

- There is no need for energy storage, because excess energy is sent directly to the grid.
- DC electricity produced by the panels is converted to AC by inverters and becomes usable at home.
- Power capacity can vary between 1 kW and 50 kW.
- Dual meters are used: One measures the electricity drawn from the grid, the other measures the electricity given to the grid.
- Electronic control devices provide safety by shutting down the system in the event of a possible fault.

Components of domestic PV systems:

Solar panels: Provides energy production according to need.
Inverter: Converts DC electricity to AC electricity used in the home.
Electronic control devices: Ensures system safety and stops the system in case of malfunctions.
Meters: Monitors energy production and consumption.

Domestic PV systems offer an **environmentally friendly** and economical energy source, reducing dependence on fossil fuels and promoting sustainable energy use.

c. Off-Grid PV Systems

Off-grid PV systems are used to meet energy needs in areas where access to the electricity grid is difficult or impossible. These systems convert solar energy directly into electrical energy and make it possible to provide energy at all hours of the day with storage solutions. The electricity produced is stored in batteries to be used when sunlight is insufficient[86].

The areas of use of independent PV systems are quite wide:

- Indoor and outdoor lighting
- Rural radio, telephone and wireless systems
- Communication stations
- Protection of oil pipelines
- Telemetric measurements in electricity and water distribution systems
- Meteorological observation stations
- Agricultural irrigation systems
- Forest watchtowers
- Medicine and vaccine cooling systems
- Earthquake and weather observation stations
- Lighthouses
- Operating devices in areas far from the electricity grid
- First aid, alarm and security systems
- Traffic warning systems
- Military systems
- Electric vehicles
- Space studies

Figure 56 :Hybrid PV systems combine solar panels with batteries and the grid to ensure continuous and reliable power supply.

d. Hybrid Connected Systems

In hybrid PV systems, also called hybrid connected systems, there are other systems that produce electricity in addition to the panels. The primary electricity producer is the panels. In addition, there may be a system that produces renewable energy, such as a wind turbine or diesel generator, that provides secondary energy to the system.

e. Photovoltaic Cells and Panels

Photovoltaic cells are solar cells made of semiconductor materials that convert sunlight directly into electrical energy. They can be square, rectangular or circular. When light falls on solar cells, an electrical voltage is generated at their ends. The efficiency of the cells can vary between 5% and 32% depending on their structure. To obtain higher power, cells are connected in series or in parallel to form solar panels (solar modules). The energy produced by these panels can range from a few watts to megawatts. Solar cells have a long life because they convert solar energy directly into electrical energy and can operate without the need for an additional electronic circuit[87].

f. Materials Used in PV Cells

PV cells are made of special materials to generate electricity. The most commonly used material is crystalline silicon[88,89]. Crystalline silicon cells are divided into two groups: single crystal silicon and multi-crystal silicon. These materials provide an efficiency between 14% and 19% when converting sunlight into electricity. In addition, materials such as amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium selenide (CIS) are also used. Amorphous silicon is used in thin film technology and its efficiency is between 4% and 8%. Cadmium telluride is cheaper and more efficient than other thin film cells. CIS provides the highest efficiency among thin film technologies. New generation PV cells include concentrator PV cells and organic PV cells. In concentrator PV cells, sunlight is collected with lenses or mirrors and made stronger. Organic PV cells are

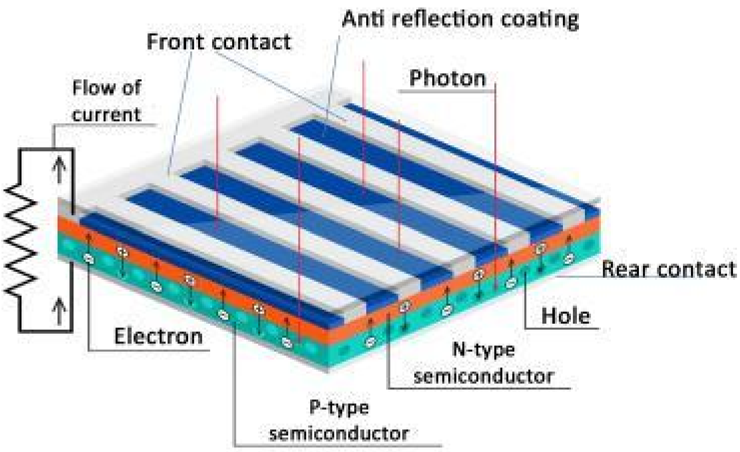


Figure 57: PV cells convert sunlight into electricity using semiconductor layers, where photons create electron-hole pairs and generate current[89].

produced from flexible materials such as plastic or polymer. PV cells have two different layers called n-type and p-type for their operation. These layers allow electrical charges to move. When sunlight falls on this cell, an electric current is created inside and thus energy is produced.

6.2. Wind Energy

Wind energy is a renewable energy source that comes from the sun. While the sun's rays heat the earth, they cannot deliver the same amount of heat to every region[90]. When the air warms up, it rises and is replaced by cooler air. This movement creates pressure differences in the atmosphere, creating wind. Wind is the air current that moves from high-pressure air masses to low-pressure air masses. A very large amount of energy reaches the earth from the sun in an hour, and a small part of it turns into wind. Wind energy is actually the energy of the sun converted into kinetic energy. Wind energy is a continuously occurring and inexhaustible energy source that occurs naturally. It also does not emit harmful gases like fossil fuels and is environmentally friendly.

Figure 58: Wind turbines convert the kinetic energy of moving air, originally driven by the Sun’s heating of the Earth, into clean, renewable electricity.

6.2.1. Wind Energy in the World

The oldest machine that uses wind energy is the windmill. It is thought to have been used in Alexandria approximately 3000 years ago. It is known that the Turks established windmills in 640 and that they spread to Europe with the Crusades. According to written documents, windmills were used between Afghanistan and Iran in 644 AD. Windmills were used in China to irrigate rice fields between 750-850. While the windmills used in the East had a vertical axis, they were developed by making them horizontal in the West. The first horizontal axis windmill was used in the Kingdom of Normandy in 1180[91]. Machines that used wind energy were developed in the Netherlands in the early 18th century and in Germany in the late 19th century. In 1850, American windmills with multiple wings and wind guides began to be used. The use of wind energy in terms of electricity generation developed after the first power plant was established in New York in 1882.

Figure 59: Windmills, the earliest machines powered by wind energy, have evolved from ancient vertical-axis designs in Asia to horizontal-axis turbines in Europe, eventually leading to modern wind power used worldwide for electricity generation.

Wind energy was first used to generate electricity in Denmark in 1891. In the 1910s, electricity use became widespread in large cities, but wind energy remained in the background due to the economics of petroleum-based fuels at the time. Wind energy began to develop rapidly in the 1990s and became widespread in America and Europe. For many years, Germany was the country with the largest installed wind energy capacity in the world, but in 2008, the USA surpassed Germany. In 2010, China made a major breakthrough and took first place. China is followed by the USA, Germany, India, Spain, England, France, Canada and Denmark.

6.2.2. Wind Energy in Partner Countries

6.2.2.1. Wind Energy in Türkiye

Although Türkiye is not among the top countries in the world in terms of wind energy capacity, it is one of the leading countries in terms of potential. It is among the top countries in terms of wind energy potential, especially in Europe. Türkiye's wind energy potential has been calculated as 48,000 MW, taking into account regions where winds exceed 7.5 m/s at 50 meters above the ground. The first studies on wind energy in Türkiye began with academic research. Ankara University in 1960, METU and Ege University in 1970, and TÜBİTAK-MAM in 1980 conducted studies in this field. The Electrical Power Resources Research Administration (EİE) affiliated with the Ministry of Energy and Natural Resources began its work on wind energy in 1981, and a branch office was established in this field in 1989. Within the scope of the Türkiye Wind Atlas Project, observation stations were established in various regions and Türkiye's wind map was drawn.

The regions with the highest wind energy potential in Türkiye are as follows:

1. Marmara Region
2. Aegean Region
3. Western Black Sea Region
4. Central Anatolia Region
5. Southeastern Anatolia Region
6. Eastern Anatolia Region

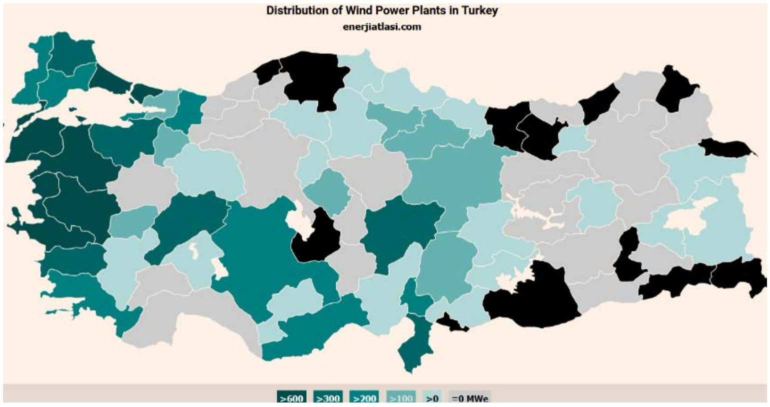


Figure 60:Map showing the distribution of wind power plants across Türkiye by installed capacity (MW).

An important step in wind energy in Türkiye was the establishment of the first wind farm in Germiyan village of Çeşme district of İzmir in 1998. This power plant, which contains three turbines with a capacity of 500 kW each, has a total power of 1.5 MW. Many wind power plants have been put into operation since the 2000s. In line with the 2023 targets of the Ministry of Energy and Natural Resources, it is planned to increase the installed power in wind energy to 20,000 MW, solar energy to 5,000 MW and geothermal energy to 1,000 MW. These targets show that wind energy is one of the most developed areas among renewable energy sources in Türkiye. Among the studies carried out to achieve these targets is the Wind Power Monitoring and Forecast Center project, jointly carried out by the Ministry of Energy and Natural Resources and the General Directorate of Space and Meteorology of TÜBİTAK. The system developed within the scope of this project is planned to be applied in a wider area.

Figure 61: Wind turbines generate electricity from kinetic wind energy, offering a clean and renewable energy source.

6.2.2.2. Wind Energy in Greece

Greece has made significant strides in harnessing wind energy, with its installed wind power capacity reaching 5,226 MW by the end of 2023, up from 1,000 MW in 2010. This growth reflects the country's commitment to expanding renewable energy sources.

The regions with the highest wind energy potential include Central Greece, particularly the prefecture of Evia, which had an installed capacity of 548 MW by the end of 2012, accounting for 31.3% of the nation's total wind power at that time. Additionally, the Aegean islands and parts of Northern Greece have been identified as areas with substantial wind resources[92].

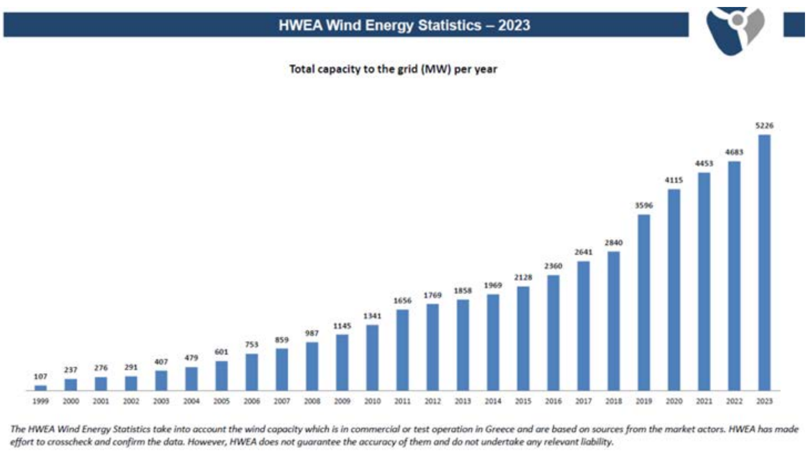


Figure 62: The chart shows Greece’s annual wind power capacity growth from 1999 to 2023, reaching a total of 5,226 MW[92].

Looking ahead, Greece aims to further enhance its wind energy capacity, with projections indicating annual onshore wind capacity additions of approximately 400 MW from 2024 to 2030. This planned expansion aligns with the country's broader strategy to increase the share of renewables in its energy mix, contributing to energy security and environmental sustainability[93].

Moreover, Greece is actively participating in regional collaborations to promote renewable energy. In 2023, a total of 153 wind turbines were newly installed across Greece. This was 85 turbines more than the number installed during the previous year. In September 2024, Greece, along with eight other southern European Union member countries, pledged to transform the Mediterranean region into a renewable energy hub, focusing on offshore wind and solar energy projects. This initiative underscores Greece's dedication to leveraging its geographic advantages for sustainable energy development.

6.2.2.3. Wind Energy in Portugal

Wind energy had an exceptional growth in Portugal from 2000 to 2015, reaching an installed capacity of more than 5 GW. From 2015 on, investment in windfarms slowed down. By the end of 2023, the total installed capacity was 5.9 GW, mainly in onshore facilities. It was the second source of electricity production, just below hydroelectric power, with an installed capacity of 8.2 GW. In April 2024, 267 wind farms and 2908 wind turbines were in force.

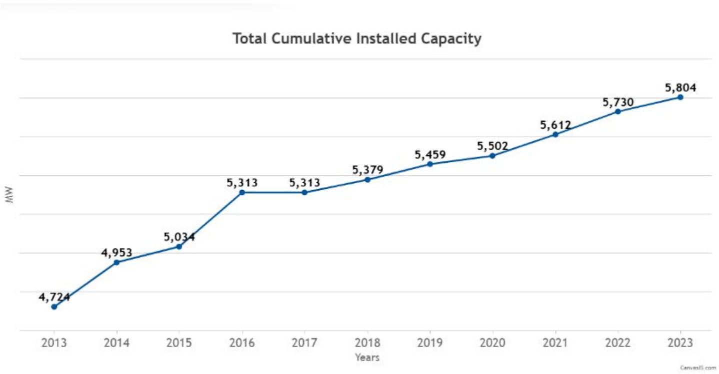


Figure 63: Portugal's wind energy capacity steadily increased, reaching 5.8 GW by 2023, with further growth expected by 2030.

According to the last version of the National Program for Energy and Climate (PNEC), by 2030, there should be more than 4.1 GW of onshore capacity and 2 GW in offshore structures. The Portuguese Atlantic Coast has a huge potential for offshore structures, leading to plans to install up to 10 GW in the medium term.

As a curiosity, the project WindFloat Atlantic was the world's first semi-submersible floating offshore wind farm, which started operating. It is based on the 2 MW WindFloat1 prototype, which operated successfully between 2011 and 2016 near Póvoa de Varzim (north of Portugal).In 2024, wind energy represented nearly 40 % of all the electricity produced in Portugal[94].

6.2.2.4. Wind Energy in North Macedonia

North Macedonia, a country striving for a sustainable energy transition, has been actively developing its wind energy sector as part of its broader commitment to reducing reliance on fossil fuels. While historically dependent on coal, the government has set ambitious targets to increase the share of renewables to 50% by 2030 and phase out coal by 2035. Among these efforts, wind energy is emerging as a crucial pillar of the country's renewable energy strategy[95].

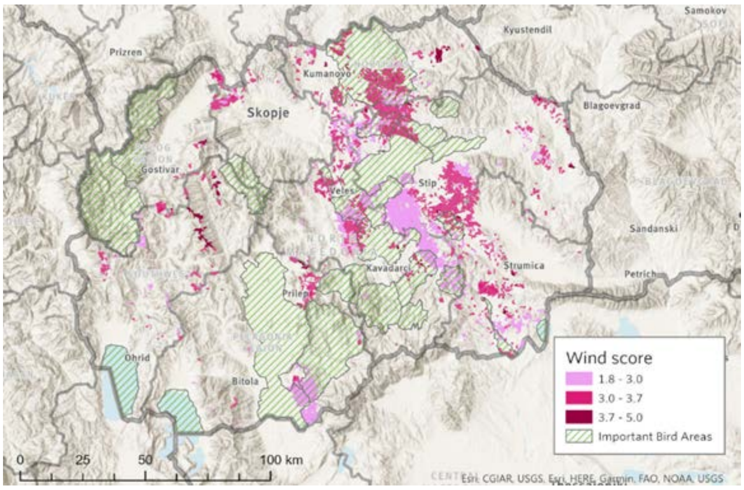


Figure 64: North Macedonia's wind score map highlights regions with strong wind energy potential, supporting the country's clean energy transition[95].

The country’s first and most significant wind power project, Bogdanci Wind Farm, marked the beginning of large-scale wind energy utilization[96]. Located in southeastern North Macedonia, Bogdanci was chosen for its consistent wind speeds, averaging 7 meters per second at a height of 100 meters. The project was initiated by Elektrani na Severna Makedonija (ESM), the state-owned energy company, and supported through financing from the European Bank for Reconstruction and Development (EBRD).

Bogdanci Wind Farm – A Landmark Project
The first phase of Bogdanci Wind Farm became operational in 2014, comprising 16 turbines with a total installed capacity of 36.8 MW. The farm generates approximately 100 GWh of electricity annually, supplying power to over 16,000 households. Recognizing the success of the project, a second phase was planned, aiming to add an additional 14 MW, bringing the total capacity to 50 MW.

The success of Bogdanci demonstrated the feasibility of wind energy in the country and paved the way for further investments and new projects.

Building on this momentum, North Macedonia has launched several new wind power projects that will significantly boost capacity in the coming years. The most important project worth emphasizing is the upcoming Alcazar Energy’s 400 MW Wind Farm – The Largest in the Balkans (Planned, National Level)

Capacity: 400 MW
Investment: Over $500 million
Developer: Alcazar Energy, a major renewable energy company
Expected Start: 2025

Impact: More than doubles the country’s wind power capacity, transforming North Macedonia into a regional leader in wind energy
This massive 400 MW wind project will be the largest wind energy development in the Western Balkans, aligning with North Macedonia’s long-term goal of energy independence and carbon neutrality.

North Macedonia’s diverse topography and geographic positioning create ideal conditions for wind energy in several key regions:

- Southeastern Region – Strong wind currents in Bogdanci, Gevgelija, Valandovo
- Northeastern Region – Promising wind speeds in Kriva Palanka and Kumanovo

– Pelagonia Region – High wind energy potential near Bitola and Prilep

Wind speeds across these areas range between 5.5 and 8.5 m/s, providing optimal conditions for continuous energy generation.

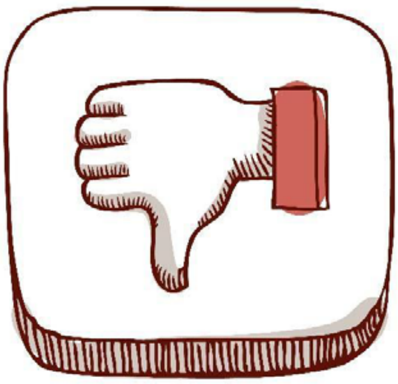
6.2.3. Positive and Negative Impacts of Wind Energy

Both positive and negative effects of wind energy use are discussed. Although wind turbines have some environmental damage, they are generally accepted to be a beneficial and sustainable energy source for the environment[97].

Advantages

- It is renewable and clean. Wind is a naturally and continuously occurring energy source. Turbines do not emit any gas while operating, do not pollute the environment and prevent the spread of greenhouse gases that increase global warming.
- It does not require raw materials. Wind is freely available in the atmosphere and does not create external dependency.
- It offers a cost advantage. Although the installation cost is high, it is an economical solution in the long term because the operating and maintenance costs are low. Today, it has become competitive with other energy sources.
- It takes up little space. Wind turbines do not require large areas. Moreover, the lands where the turbines are installed can be used for agricultural and animal husbandry activities.
- The installation time is short. Wind power plants can be commissioned in a shorter time than traditional power plants.
- It can be applied at different scales. Systems of different sizes can be installed, from small, independent turbines to large wind farms.

Disadvantages



- Initial investment cost is high. It requires high costs for the production, transportation and installation of turbines.
- Energy production is irregular. Since the wind speed is not constant, the amount of energy produced varies. Inadequate wind during times of high demand or, conversely, excessive energy production can cause problems.
- It can cause noise pollution. The sounds made by turbines while they are operating can be disturbing, especially in areas close to residential areas.
- It can be dangerous for birds and other living things. Turbine blades can pose a risk to migratory birds and some wild animals.
- It can create electromagnetic interference. Turbines can interfere with some radar systems and affect radio and television signals.

- Problems can occur with electrical transmission lines. Wind power plants are generally installed in areas where the wind is strong but electrical transmission lines are weak. This can make it difficult to transport the energy produced.

6.2.4. Areas of Use of Wind Energy

Wind energy has been used in many areas throughout history, from agricultural activities to electricity generation[52,98]. It generally has three main areas of use. In mechanical applications, wind energy has been used in processes such as water pumping (especially for agricultural irrigation), grain milling and processing of agricultural products (such as cutting, mowing, oil extraction). In electricity generation, it is evaluated in two different ways: grid-connected and grid-independent systems. While the electricity generated by large-scale wind power plants can be transferred to the national grid, electricity can be provided by small-scale wind turbines in rural areas where there is no electricity grid. In heat energy generation, the electricity generated by wind turbines can be used in heating systems or ventilation systems. In addition, wind energy is used in different areas, both inside and outside buildings. While it is used in agricultural irrigation systems, sea lighthouses, airport runway lights and other signaling systems outside buildings, individual electricity generation can be provided by ventilation and cooling systems inside buildings and rooftop wind turbines.

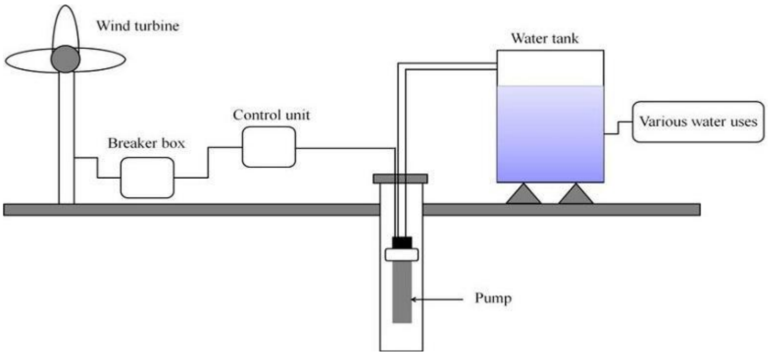


Figure 65: This diagram illustrates the use of wind energy for water pumping, showcasing its application in agricultural irrigation and rural water supply[98].

6.2.5. Wind Turbines

Wind turbines are machines that convert the kinetic energy of the wind into electrical energy. This conversion process begins with the wind turning the turbine blades, producing mechanical energy. The blades convert the mechanical energy into rotational motion, which is converted into electrical energy by the generator[99].

Wind turbines are divided into three groups according to the position of their rotation axes relative to the ground. Horizontal axis wind turbines are the most commonly used turbines and have their main shaft parallel to the ground. They are often preferred in large-scale wind farms.

Figure 66: Horizontal axis wind turbines are the most widely used type, ideal for large-scale wind farms and high energy production.

Vertical axis wind turbines have their main shaft perpendicular to the ground and can use wind from any direction. They are more common in small-scale applications and urban areas.

Figure 67: Vertical axis wind turbines can capture wind from any direction and are suitable for urban or small-scale applications.

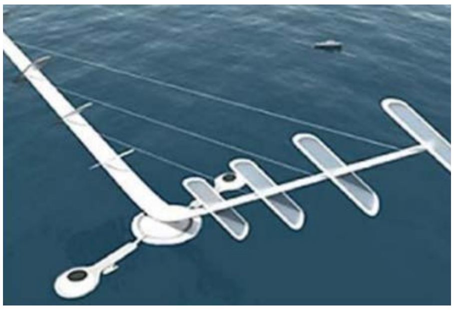


Figure 68: Inclined axis wind turbines are a hybrid design that combines the advantages of horizontal and vertical systems, often used in experimental offshore setups.

Inclined axis wind turbines combine the features of horizontal and vertical axis turbines, but are a rare design type. In addition, wind turbines are classified according to their speed, power capacity, number of blades, wind effect, gear mechanisms and installation location. Which turbine to use is determined by the wind characteristics of the region and the purpose of use.

6.2.5.1. Offshore Wind Turbines

Efficient use of offshore wind energy is of great importance for the wind energy market. Although wind turbines mounted on the seabed are generally preferred in areas close to the coast, these systems can cause problems such as noise, visual pollution and affecting ship traffic. For this reason, studies on floating platform wind turbines are increasing[100].

Figure 69: Offshore wind turbines are installed in marine environments to harness stronger, more consistent winds, significantly boosting electricity generation capacity.

Offshore winds have less turbulence than onshore winds. This allows for higher wind speeds, allowing for more electricity to be produced. Given that the power generated increases as the cube of the wind speed, the generation capacity increases significantly even when only a few kilometers away from land. For example, in an area where the average wind speed is 28 km/h, it is possible to generate 60% more electricity than in an area where the speed is 22 km/h. This shows the critical importance of the speed factor in generating electricity from wind power.

Today, offshore wind turbines are adapted from land-based turbines and made resistant to sea conditions. In this process, the robustness of the turbines is increased by designing tower structures resistant to wave loads. In addition, the gear system and electrical components are strengthened with special protection methods against the corrosive effects of sea water. Special access systems are added to ensure easy access to the platform for maintenance personnel, while security measures are increased with emergency switches. The outer surfaces of the turbines are coated with special paints resistant to sea water to make them long-lasting, and warning lights and eye-catching colors are used for aircraft. In addition, additional security measures are taken to ensure that marine vehicles can notice the turbines in foggy weather.

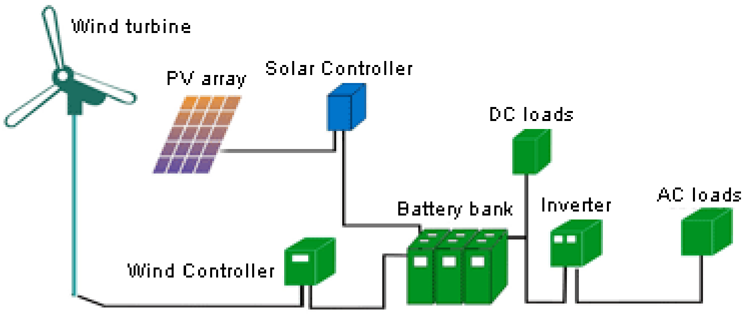


Figure 70:Hybrid systems combine solar and wind energy to provide more stable and continuous power, especially in off-grid areas with variable weather conditions.

6.2.5.2. Solar and Wind Hybrid Systems

Today, photovoltaic solar energy and wind energy systems that operate independently of the grid are increasingly being used on a larger scale. Especially in regions where access to the grid is difficult or uneconomical, independent solar and wind energy systems offer an important solution[101]. However, wind and solar energy are energy sources that vary daily, monthly and annually. Due to their low energy density, they may be insufficient to provide continuous and uninterrupted power. For example, solar energy systems may not be able to produce enough electricity on cloudy days, while wind energy systems cannot provide continuous power due to changing wind speeds throughout the year. This situation makes energy storage systems necessary to ensure continuity of energy production. Wind energy operates with higher efficiency in the winter months, while solar energy operates with higher efficiency in the summer months. The risk of being without electricity increases in the summer when only wind energy is used, and in the winter when only solar energy is used. For this reason, hybrid systems where solar and wind energy are used together provide more stable energy production than when they are used alone. In addition, the complementary operation of these two energy sources reduces the need for energy storage and helps the system become more efficient.

6.3. Hydroelectric Energy

Hydroelectric energy is one of the oldest and most widely used types of energy among renewable energy sources[62]. Hydroelectric energy, which is an energy source from the sun, is formed as a result of the natural water cycle. Water in rivers, lakes and seas evaporates with the heat of the sun, moves with the effect of the wind and condenses in the atmosphere and returns to the earth as rain or snow. These precipitations provide nutrition to streams, causing the moving water to be a continuous source of energy. Hydroelectric energy is obtained by converting the kinetic and potential energy of water flowing from a certain height into mechanical energy by means of turbines and then into electrical energy by means of generators[28]. Hydroelectric power plants not only produce electricity, but also play an important role in many areas such as providing drinking water, agricultural irrigation, reducing flood risk and aquaculture.

Figure 71:Hydroelectric energy transforms the power of flowing water into electricity through turbines and generators, contributing to both energy production and water management.

6.3.1. Classification of Hydroelectric Power Plants

Hydroelectric power plants are classified according to their installed power potential, head height, energy production characteristics, construction methods and the characteristics of the water source where they are installed[102]. There are classifications that vary from country to country, especially for mini and micro hydroelectric power plants. In general, power plants that produce up to 10 MW of power are considered small-scale hydroelectric power plants.

Table 1: Types of power plants according to installed capacity

Type of Power Plant	Installed Power (kW)
Micro	0.1 – 100
Mini	101 – 1000
Small	1001 – 10000
Large	Greater than 10000 kW

While large hydroelectric power plants are among the classical renewable energy sources, small hydroelectric power plants are considered in the group of new and renewable energy sources. The size limit of small hydroelectric power plants may vary from country to country. For example, while the upper limit of small hydroelectric power plants in Canada and the USA is 50 MW, it is determined as 10 MW in Europe.

Other Classifications of Hydroelectric Power Plants:

1. Hydroelectric Power Plants According to Head Height
    - Low-head power plants: These are power plants with a head height of less than 15 meters. They are usually installed on flat or low-sloping lands, on rivers with high flow rates. Kaplan turbines are used.
    - Medium-head power plants: The head height varies between 15-50 meters. Kaplan or Francis turbines are used.
    - High-head power plants: These are power plants with a head height of over 50 meters. They are mostly located in mountainous and rugged terrains. Francis or Pelton turbines are used.
2. Hydroelectric Power Plants According to the Energy They Produce
    - Continuous energy producing power plants (Base power plants): They produce uninterrupted energy.
    - Power plants that operate during the times when energy is needed the most (Peak power plants): They are activated when demand is high.
3. Hydroelectric Power Plants According to Their Construction Methods
    - Underground power plants
    - Semi-buried power plants
    - Above ground power plants
4. Hydroelectric Power Plants According to the Water Source They Are Installed
    - River power plants
    - Canal power plants
    - Dam power plants
    - Pumped reservoir power plants

6.3.2. Hydroelectric Energy in the World

Hydroelectric energy is considered one of the most important renewable energy sources worldwide[103]. Annual precipitation is approximately 119 thousand km³, 60% of which evaporates and 40% reaches lakes and seas through streams. In total, approximately 19% (9 thousand km³) of 47 thousand km³ of water is economically and technically usable.

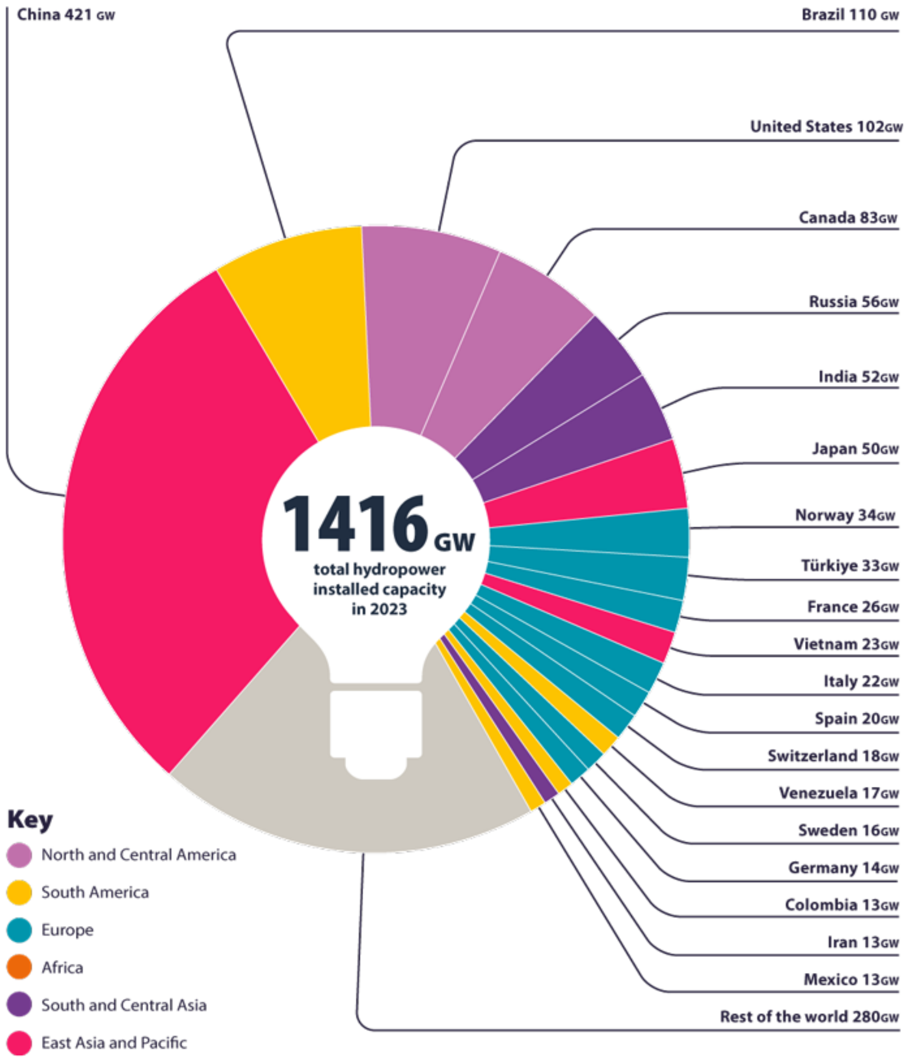


Figure 72: Total installed hydropower capacity reached 1416 GW in 2023, led by China (421 GW), Brazil (110 GW), and the United States (102 GW), highlighting the global shift towards sustainable energy[103].

However, only a small portion of hydropower is used effectively worldwide. Most of the unused potential is in Latin America, Asia and Africa. Especially in developing countries, it is aimed to evaluate this potential more efficiently by installing new hydroelectric power plants.

6.3.3. Hydroelectric Energy in Partner Countries

6.3.3.1. Hydroelectric Energy in Türkiye

The energy produced in small hydroelectric power plants in Türkiye varies depending on the precipitation pattern. The amount of precipitation in our country varies according to the regions and seasons. Although Türkiye is not rich in terms of hydroelectric potential, it is among the countries that can be self-sufficient by using its water resources effectively. Dam construction in Türkiye dates back to prehistoric times. The first dams were built by the Hittites in 1300 BC and the Urartians in 1000 BC. In the Republican period, the first dam was the Çubuk Dam, built in 1930 to meet the drinking water needs of Ankara[104]. The Electrical Power Resources Research Administration was established in 1932 to determine and research suitable energy sources for electricity production. In 1950, Türkiye's installed electrical power was 408 MW and its hydroelectric capacity was only 18 MW. However, a significant increase was achieved in the number of hydroelectric power plants until the 1970s. The development of hydroelectric energy in Türkiye gained momentum with the establishment of the Turkish Electricity Authority in 1970. With TEK, the construction of power plants by official institutions and municipalities was stopped and a transition to an interconnected system was provided throughout the country. During the same period, the private sector was involved in the construction of hydroelectric power plants. With the law enacted in 1984, the participation of the private sector in electricity production was encouraged with the Build-Operate-Transfer model.

Figure 73: Hydroelectric Energy in Türkiye (2024).

In order to regulate the hydroelectric energy market, the Energy Market Regulatory Authority was established in 2001 and the authorities of electricity production, transmission and distribution were transferred to this institution. After 2003, the "Water Use Regulation" was published to encourage private sector investments, and the Renewable Energy Law was enacted in 2005. With the regulations made in 2011, the installation of small-scale micro and mini hydroelectric power plants was facilitated. Türkiye has the capacity to build all types of hydroelectric power plants in terms of technology. One of the best examples of this is the Atatürk Dam and Hydroelectric Power Plant, which was largely built by domestic companies. Our country has the necessary technology and investor potential for the installation of small and medium-scale hydroelectric power plants. Especially compared to large-scale hydroelectric power plants, small hydroelectric power plan projects, which can be built faster and have fewer legal/financial obligations, are attracting more attention from the private sector. Today, the number of hydroelectric power plant projects carried out by the private sector within the framework of the Electricity Market Law No. 4628 is approximately 1,595. However, the increase in private sector investments has also brought with it some problems. The uncontrolled transfer of many streams to the private sector through "Water Usage Rights Agreements" has created risks that could lead to deterioration in water quality and increases in water prices. Therefore, it is important to develop more balanced policies in the use of hydroelectric energy, considering sustainability and public interest.

As of the end of 2024, Türkiye's total installed capacity has reached 115,975 MW, 32,203 MW of which consists of hydroelectric power plants. This value corresponds to approximately 27.8% of the total installed capacity. The number of hydroelectric power plants is also striking. As of the end of December 2024, there are a total of 784 HES in Türkiye; 617 of them are fluvial type and 147 are dam type.

6.3.3.2. Hydroelectric Energy in Greece

Greece’s mountainous terrain and numerous rivers create ideal conditions for hydropower. With an estimated annual potential of 80 TWh, the country has long utilized water resources, beginning modern hydropower development in the early 20th century. As of 2023, hydropower made up 13% of Greece’s installed capacity and 10% of total power generation, reaching 3,427 MW. Despite its potential, output varies due to seasonal and climatic fluctuations, including droughts and uneven rainfall. Greece has made big strides in hydropower development over the years. The establishment of the Public Power Corporation (PPC) in the 1950s played a key role in expanding the country’s energy sector, with hydropower at the core of this growth. In the following decades, Greece continued investing in renewables, with hydropower being a major contributor to the energy mix[105]. However, as energy demand grew, the country diversified, increasing its reliance on natural gas and expanding into wind and solar power.

Country	Electricity Generation			
	Hydro [GWh]	Total [GWh]	Hydro/Total %	Main Energy Source
European Union (28)	38,018	3,253,125	12%	Nuclear, Coal, Gas
Albania	7782	7782	100%	Hydro
Norway	144,005	149,333	96%	Hydro
Iceland	13,471	1855	73%	Hydro
Austria	42,919	68,336	63%	Hydro
Switzerland	36,689	63,172	58%	Hydro, Nuclear
Sweden	62,137	156,01	40%	Nuclear, Hydro
North Macedonia	1897	5629	34%	Coal, Hydro
Bosnia and Herzegovina	5641	17,767	32%	Coal, Hydro
Serbia	11,521	39,342	29%	Coal, Hydro
Portugal	16,909	60,28	28%	Hydro, Coal, Gas, Wind
Romania	18,536	65,103	28%	Hydro, Goal, Nuclear, Gas
Turkey	67,231	273,695	25%	Coal, Gas, Hydro
Slovak Republic	4606	26,934	17%	Nuclear, Hydro, Coal
Russia	18,664	1,090,973	17%	Gas, Nuclear, Coal, Hydro
Spain	39,865	274,671	15%	Nuclear, Gas, Wind
Italy	44,257	289,032	15%	Gas, Hydro, Coal
France	64,889	555,621	12%	Nuclear
Greece	5565	54,438	10%	Coal, Gas
Bulgaria	4568	45,243	10%	Coal, Nuclear
Ukraine	9304	164,494	6%	Nuclear, Coal
Germany	26,135	647,231	4%	Coal, Gas, Nuclear, Wind
United Kingdom	8354	339,399	2%	Gas, Nuclear
Poland	2322	166,568	2%	Coal

Figure 74: Hydroelectric Energy in Greece[105].

In recent years, Greece has promoted small and medium-scale hydropower to enhance energy security. Market liberalization and regulatory support have boosted private investment, especially in remote mountainous regions. However, concerns remain about the environmental impact on river ecosystems, biodiversity, and local communities. As of 2024, Greece's installed capacity is around 18,000 MW, with hydropower contributing 3,427 MW from about 250 plants. While hydropower remains important, the government aims to balance energy growth with environmental sustainability, managing resources to meet future demands while protecting water systems.

6.3.3.3. Hydroelectric Energy in Portugal

In Portugal, like in most countries, small hydroelektrik structures to transform water movement or potential energy into useful energy have been used for thousands of years.

The construction of big dams to control water fluxes and/or for hydroelectric production of electricity began by the end of the 19th century but became significant in the mid-20th century. In 2007, Portugal launched the National Program for Dams with High Hydroelectric Potential (PNBEPH), which led to a substantial increase in the country's installed capacity.

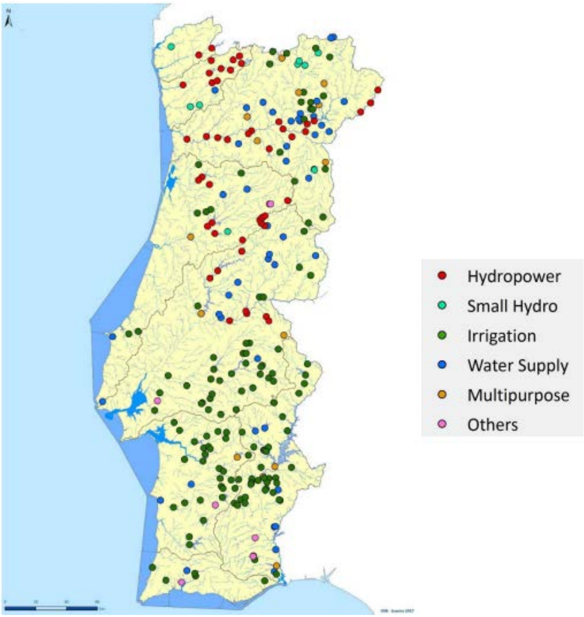


Figure 75: Hydroelectric Energy in Portugal (2024).

Even if the country has 260 big dams (more than 15 m height or 10-15 m height and 1 hm^3 of capacity), most of them are dedicated to agriculture, water regulation and other activities. Actually, Portugal has 42 hydroelectric power plants (> 10 MW), and about 8.2 GW of total installed capacity, from which about one third is due to pumping systems. Due to the strong asymmetries in orography and precipitation patterns between the North and the South of Portugal, the dams for hydroelectric use are mostly located in the north of the country. With the explosive growth of other forms of renewable energies in the last two decades, hydroelectric power plants became even more important once they could contribute to the stabilization of the electricity grid, in particular after the closing of all the coal-based power plants in Portugal.

Although the total contribution of hydroelectric power to the country's electricity supply depends, each year, on meteorological conditions, it represents around 30 % of all the electricity consumed in Portugal.

Figure 76: Alqueva Dam, Portugal – One of the largest dams in Europe, generating hydropower and supporting irrigation.

One of the largest dams in Portugal is the Alqueva dam (figure), built on the Guadiana River and inaugurated in 2004. It gave rise to the largest artificial lake in Europe and allows the irrigation of immense agricultural areas in the south of Portugal. It has an installed hydroelectric power of 240 MW. The largest hydroelectric plant in Portugal is the Gouvães dam, on the Torno River, in the Douro River basin, with 880 MW of installed capacity.

6.3.3.4. Hydroelectric Energy in North Macedonia

North Macedonia's mountainous terrain and rivers offer strong potential for hydroelectric power, with an estimated 8.863 TWh of theoretical resources annually. However, current production is around 1.2 TWh, highlighting significant untapped capacity.
The development of hydroelectric power in North Macedonia includes the Mavrovo Hydropower System, one of the largest in the country. It consists of three plants—Vrutok, Vrben, and Raven—with a combined capacity of 200 MW and an annual production of around 445 GWh. Another key facility is the Tikveš Hydroelectric Power Station on the Crna River. Operating since 1968, it has a capacity of 113 MW and plays a significant role in the country's hydroelectric output.

Figure 77:Key Hydropower Plants in North Macedonia – A map showing major facilities like Tikveš, Vrutok, and Globočica[106].

North Macedonia is modernizing its hydroelectric infrastructure, with €36.2 million in financing agreements signed in February 2023 for the rehabilitation of six major plants: Vrutok, Vrben, Raven, Tikveš, Globočica, and Špilje[106]. These plants represent about 85% of the country's hydroelectric capacity and contribute 20% of total electricity production. The government has also awarded a concession for the Čebren Hydroelectric Plant, a 333 MW pumped storage facility on the Crna River. This project aims to boost renewable energy capacity and improve energy storage and distribution flexibility. Since 2010, over 100 small hydropower plants have become operational in North Macedonia, highlighting the country's commitment to diversifying its renewable energy sources.

The government is encouraging investments in the energy sector, particularly in the design, construction, and operation of new hydroelectric plants. This strategy supports North

Macedonia’s goals of improving energy security, reducing fossil fuel reliance, and achieving renewable energy targets. In conclusion, hydroelectric power is a key element of North Macedonia's energy strategy. By modernizing existing facilities and developing new projects, the country seeks to fully tap into its hydroelectric potential, ensuring a sustainable and resilient energy future.

6.3.4. Positive and Negative Impacts of Hydroelectric Energy Use

One of the biggest advantages of hydroelectric power plants is that they do not produce air polluting emissions like fossil fuel thermal power plants. Hydroelectric power plants are among the clean energy sources because they do not release any waste or harmful gases while operating[107]. In addition, thanks to hydroelectric power plants:

Advantages

- Agricultural irrigation can be provided,
- Floods can be prevented,
- Water resources can be managed more efficiently,
- Water quality in the region can be increased,
- Aesthetic ponds and water reservoirs can be created.

However, hydroelectric power plants also have some negative environmental effects. Dam construction can cause ecosystem changes by flooding large areas. This can affect the vegetation and animal life in the area. In addition:

Disadvantages

- Large-scale dams can change the climate of the region and cause microclimates,
- Changing the direction of streams can reduce the productivity of agricultural lands,
- It can cause problems such as coastal erosion and depletion of water resources.

For these reasons, environmentally friendly Small Hydroelectric Power Plants have become more preferred than large hydroelectric power plants. SHPs:

It has lower investment costs,
- It can be built in a short time,
- It has lower maintenance and operating costs,
- It has limited environmental impact compared to large hydroelectric power plants,
- It contributes to the local economy by meeting the electricity needs in rural areas.

However, Hydroelectric Power Plants can also have negative effects on the ecosystem. Therefore, it is of great importance that projects are designed and implemented in a way that does not disrupt the natural balance.

6.4. Geothermal Energy

Geothermal energy is derived from the Greek words geo (ground) and therme (heat) and means "ground heat"[108]. This energy source is found in the form of hot water, steam or mineral fluids formed by the effect of high temperatures in the inner layers of the earth at different depths of the earth's crust[73]. There are very high temperatures in the earth's inner structure, especially in the magma layer. Thanks to heat conduction, the temperature increases as you go towards the lower layers of the earth's crust. This natural heat source causes the water underground to heat up and various geothermal areas to form. Geothermal energy is obtained by using hot water or steam directly or indirectly. Some geothermal sources do not contain water or steam; instead, high-temperature rocks called hot dry rocks are evaluated for energy production. A process called reinjection is applied to ensure the sustainability of geothermal systems in the long term. In this method, the water or steam extracted from underground is pumped back underground and the natural cycle is maintained. Geothermal energy is widely used in direct heating systems, industrial processes and electricity generation[24,109].

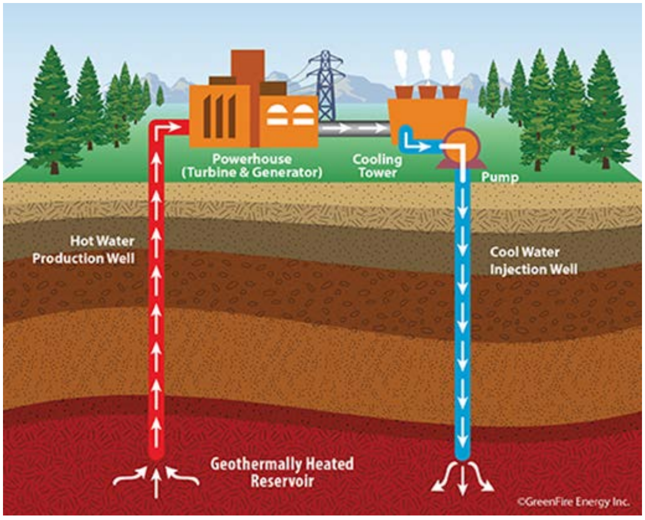


Figure 78: Geothermal power plants extract heat from underground reservoirs, using hot water or steam to generate electricity and reinjecting cooled water to sustain the cycle[108].

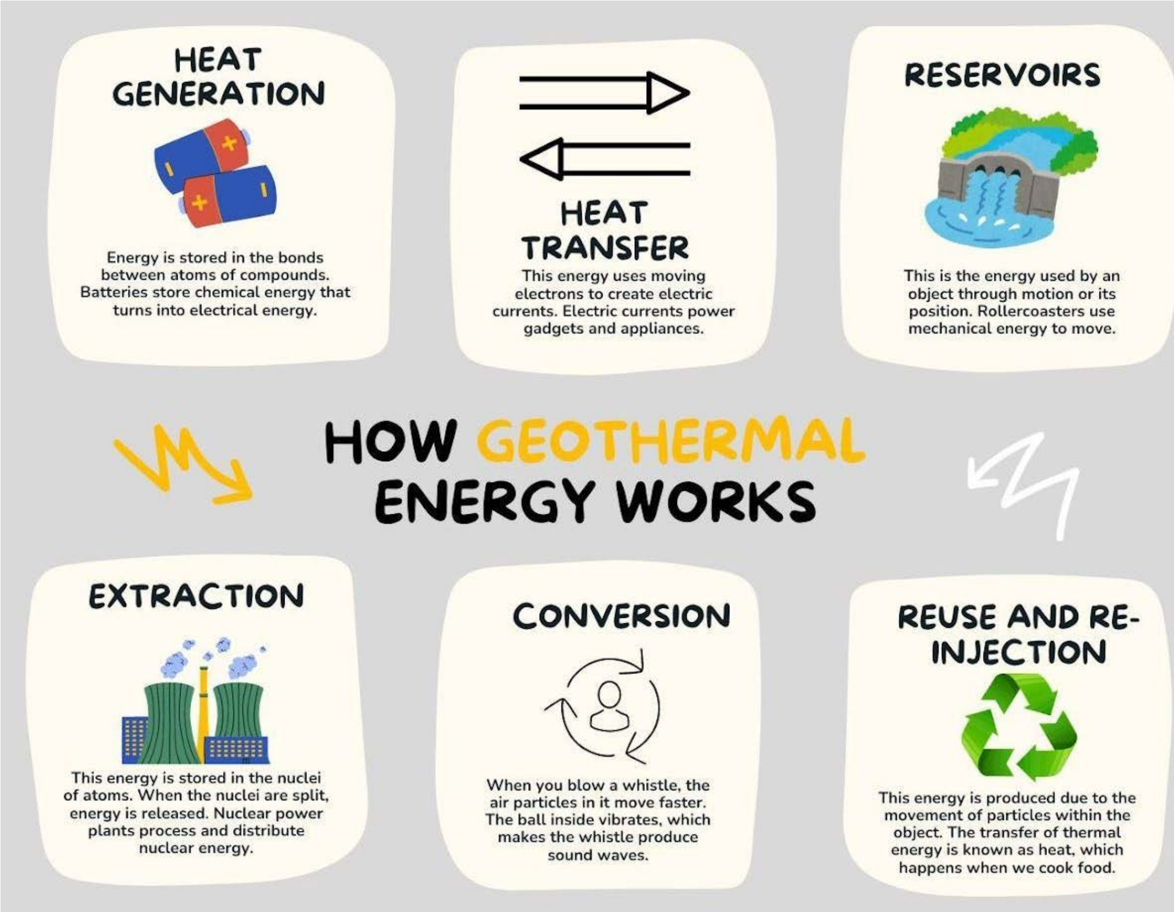


Figure 79: This infographic explains geothermal energy from heat extraction to conversion, reuse, and reinjection, highlighting its sustainable and renewable nature[109].

6.4.1. Geothermal Energy in the World

There are many geothermal areas around the world and these areas are called geothermal zones. Geothermal zones are generally located in areas where tectonic movements are intense and volcanic activity is seen[110]. The most important geothermal zones are:

Figure 80: Geothermal energy is produced in volcanic and tectonic zones worldwide, with major plants in the U.S., Indonesia, and the Philippines.

- **Andean Volcanic Belt:** Argentina, Chile, Bolivia, Peru, Ecuador, Colombia and Venezuela
- **Alpine-Himalayan Belt:** Thailand, Burma, China, Tibet, India, Pakistan, Iran, Türkiye, Greece, Yugoslavia and Italy
- **East African Rift System:** Djibouti, Ethiopia, Kenya, Uganda, Tanzania, Malawi and Zambia
- **Central American Volcanic Belt:** Panama, Costa Rica, Nicaragua, El Salvador and Guatemala

Geothermal energy has been used since the earliest ages of human history. During the ancient Roman period, geothermal resources were used in baths and heating systems[110]. The first use of geothermal energy in electricity production took place in Italy in 1904. The world's first commercial geothermal power plant was established in Italy in 1911. After a long time, the second industrial geothermal power plant was put into operation in New Zealand in 1958. From the 1950s to the 2000s, electricity production from geothermal energy increased by 17% and thermal (heating) use by 87%. Today, the evaluation of geothermal energy resources is becoming increasingly widespread and many countries are trying to use this clean and renewable energy source more effectively.

As of 2024, the global geothermal energy production capacity has reached a total of 16,873 MW. This capacity was achieved with the contribution of 35 countries. With the commissioning of 14 new facilities and expansion of existing capacities during the year, a total increase of 389 MW was achieved. The top 10 countries in terms of installed geothermal energy capacity were recorded as the United States (3,937 MW), Indonesia (2,653 MW), Philippines (1,984 MW), Türkiye (1,734 MW), New Zealand (1,207 MW), Kenya (985 MW), Mexico (976 MW), Italy (944 MW), Iceland (755 MW) and Japan (740 MW).

6.4.2. Geothermal Energy in Partner Countries

6.4.2.1. Geothermal Energy in Türkiye

Türkiye is a country rich in geothermal resources as it is located in the Alpine-Himalayan belt. The total geothermal potential of our country is estimated to be approximately 62,000 MW. Of this potential, 31,500 MW is suitable for direct use and 1,734 MW for electricity generation. Türkiye ranks first in Europe and fourth in the world with this capacity. The first heat energy use using geothermal resources in Türkiye began in 1964 with the heating of the Park Hotel in Balıkesir-Gönen[111]. Today, nearly 15 thousand houses in İzmir are heated with geothermal energy. After 2000, studies on geothermal energy in Türkiye have accelerated, and direct usage areas such as thermal tourism, greenhouse farming and central heating of houses have become widespread.

There are nearly 1,000 geothermal resources in our country, and 11 regions stand out as efficient in terms of electricity generation:

- **Aydın-Germencik** (232 °C)
- **Manisa-Salihli Göbekli** (182 °C)
- **Çanakkale-Tuzla** (174 °C)
- **Aydın-Salavatlı** (171 °C)
- **Kütahya-Simav** (162 °C)
- **İzmir-Seferihisar** (153 °C)
- **Manisa-Salihli Caferbey** (150 °C)
- **Aydın-Yılmazköy** (142 °C)
- **İzmir-Balçova** (136 °C)
- **İzmir-Dikili** (130 °C)

Figure 81:Türkiye ranks 4th globally in geothermal electricity with 1,734 MW capacity, mainly concentrated in the Aegean region.

Türkiye has significant potential in geothermal energy and is ranked 4th in the world with an installed capacity of 1,734 MW as of 2024. There are approximately 1,000 geothermal resources in the country in the form of natural outlets and at different temperatures, and the total discovered geothermal potential is calculated as 62,000 MW. Türkiye aims to increase the share of geothermal in its total installed electrical energy capacity to 8% by 2053 and to meet all residential heating use from geothermal energy.

6.4.2.2. Geothermal Energy in Greece

Greece, located in the Mediterranean-Volcanic Belt, is rich in geothermal resources, with an estimated total geothermal potential of around 5,000 MW. These resources are concentrated in areas with volcanic activity and tectonic movement, such as the Aegean Islands and parts of the mainland. Despite this considerable potential, Greece has not fully exploited its geothermal resources compared to other countries with similar geological conditions[112]. Geothermal energy use in Greece began in the 1980s, with the establishment of district heating systems in areas like Lesvos Island and Agios Nikolaos on Crete[113]. Over the years, geothermal applications have expanded to include residential heating, agricultural processes (such as greenhouse farming), and thermal tourism. Currently, Greece has about 50 known geothermal fields, with significant resources on islands like Milos, Nisyros, and Santorini, as well as in the northern and central parts of the mainland. Notably, the Milos Island field can reach temperatures of up to 300 °C, while the Nisyros field is an important resource for both direct-use applications and potential electricity generation. As of 2023, Greece's installed geothermal capacity is approximately 160 MW, with the majority being used for direct applications, such as heating. While Greece is a leader in geothermal direct use in Europe, its electricity generation from geothermal remains limited. However, the country is actively exploring the potential for geothermal electricity generation, particularly in high-temperature fields. The Greek government has identified geothermal energy as a critical component of its renewable energy strategy and aims to significantly increase its contribution to the national energy mix. This includes plans for new geothermal plants and expanding geothermal heating infrastructure.

By 2030, Greece intends to enhance the share of geothermal energy in its overall energy capacity, contributing to the decarbonization of its energy sector and bolstering energy security. Despite the substantial geothermal potential, there is still considerable room for growth in harnessing geothermal energy for electricity generation, and the country is working to better utilize this resource as part of its sustainable energy future.

Figure 82: Greece has around 5,000 MW geothermal potential, with 160 MW installed—mainly for heating—while exploring electricity generation projects.

6.4.2.3. Geothermal Energy in Portugal

In mainland Portugal, geothermal energy is widely distributed, primarily used for low-enthalpy applications (<150ºC), including balneotherapy, heating for spaces and greenhouses, drying wood, fruits, vegetables, and aquaculture. However, the Azores archipelago, a group of nine volcanic islands, is the main area where geothermal energy is more developed due to its volcanic origin and location at a tectonic plate boundary, providing great geothermal potential.

São Miguel Island is particularly famous for using geothermal energy in local activities, such as cooking the traditional dish "Cozido das Furnas" in geothermal-heated holes. Beyond leisure activities, geothermal energy is also employed for commercial purposes. Geothermal power plants on the islands of São Miguel and Terceira account for about 25% of the electricity consumed in the archipelago.

Figure 83: In Portugal, geothermal energy is mainly used for heating on the mainland, while in the Azores it supplies 25% of the islands' electricity.

The first experimental geothermal power plant was built in 1980 at Pico Vermelho on São Miguel Island. The largest plants include Pico

Vermelho (13 MW), Ribeira Grande (16.6 MW), and Pico Alto (4.7 MW) on Terceira Island. There is an ongoing expansion project at Pico Vermelho to double its capacity to 24 MW by exploring new geothermal sources.

The Portuguese government has introduced a "Strategic Plan for Geothermal Energy," aiming to increase the number of geothermal systems on the mainland by tenfold by 2033 and to quintuple the amount of geothermal energy extracted by that time.

6.4.2.4. Geothermal Energy in North Macedonia

North Macedonia, located along the geothermal zone stretching from Hungary through Italy to Greece, has significant geothermal potential, especially with its low-temperature systems. Medium and high-temperature resources, however, remain largely unexplored. Historically, the country has utilized geothermal energy for district heating, greenhouse farming, and spa tourism. For example, the Kočani Valley, known for its thermal springs with water temperatures ranging from 70-80°C, supports local agriculture and heating. However, the development of geothermal energy has stagnated over the past three decades due to a lack of investment and disputes over ownership rights to geothermal resources. Geothermal energy in North Macedonia has the potential to contribute approximately 10 MW to the national energy mix, but this potential is largely untapped, with most current uses focused on direct applications instead of electricity generation[114,115].

Legend:
1-Baniče/Tetovo
2-Dobrevo/Zletovo
3- Drvoš-Baldovci/Strumica
4-Gorničet/Gevgelija
5-Istibanja/Vinica
6-Zdravevci/Kratovo
7- Rakliš/Radoviš
8-Sabota Voda/Veles
9- Smokvica/Gevgelija
10-Strnovec/Staro Nagoričane
11-Toplec-Dojran
12-Topli dol & Mrežičko- R'žanovo/ Kavadarci
13- Volkovo/Skopje

Figure 84:North Macedonia has rich low-temperature geothermal resources mainly used for heating, agriculture, and spa tourism, but electricity generation remains untapped[115].

The underutilization of geothermal energy in North Macedonia presents a valuable opportunity to diversify the country’s energy sources and improve energy security. With investments in the exploration and development of geothermal resources, North Macedonia could reduce its reliance on fossil fuels and adopt more sustainable energy practices. Additionally, revitalizing the spa tourism sector, which has faced a decline due to underinvestment, could boost economic growth and attract international visitors.

In conclusion, while North Macedonia has considerable geothermal potential, unlocking this capacity requires strategic investments, policy support, and technological advancements. By addressing these challenges, the country can effectively utilize geothermal energy for heating, agriculture, and potentially electricity generation, paving the way for a more sustainable and diversified energy future.

6.4.3. Positive and Negative Impacts of Geothermal Energy

Geothermal energy is considered as a sustainable and renewable energy source through reinjection method. It has significant advantages and disadvantages[116].

Advantages

It provides suitable conditions for thermal applications in the sector and is a clean energy source.

- It is a source that reduces external dependency on energy.
- It is lower cost than conventional energy sources and is ready to use.
- It is easy to establish production facilities in the region where the source is located and the need for facility space is low.
- Continuous energy production is possible regardless of weather conditions.
- There is no risk of explosion or fire.
- Greenhouse gas emissions of geothermal power plants are quite low.

Disadvantages

- The minerals contained in geothermal fluid can cause water and soil pollution.
- If appropriate precautions are not taken, it can cause environmental problems such as temperature changes and noise.
- If the chemical components contained in geothermal fluid are not managed properly, they can harm the environment.
- Geothermal energy is difficult to transport over long distances and can usually be transmitted up to a maximum of 100 km.

6.4.4. Areas of Use of Geothermal Energy

Geothermal resources are divided into three groups according to their temperature:

- Low temperature fields (20-70 °C)
- Medium temperature fields (70-150 °C)
- High temperature fields (150 °C and above)

While low and medium temperature geothermal resources are generally used for thermal applications, high temperature resources are evaluated in an integrated manner in electricity generation and thermal applications. Electricity generation is also possible from medium temperature fluid.

6.4.5. Types of Geothermal Energy Use

Geothermal energy usage areas are examined in two main groups[117]:

Figure 85: Geothermal energy is used directly for heating, agriculture, and tourism, and indirectly for electricity generation, depending on the source temperature[117].

Direct Use

- Central heating systems (city heating, greenhouse heating, residential heating)
- Thermal tourism (thermal springs, spa centers, health cure centers)
- Drying agricultural products
- Hot water fish farming
- Snow and ice melting (on roads and airports)
- Mineral and mineral production

Indirect Use

- Electrical energy production

The areas of use of geothermal energy vary depending on the temperature of the source. Today, geothermal resources are used worldwide for thermal tourism purposes. Thermal springs, spa centers, bath and swimming facilities are among the most common applications[118]. In addition, geothermal energy is used to clear roads and airports of snow and ice in countries such as the USA, Switzerland, Japan, Iceland and Argentina. Geothermal resources are also used in agricultural production and industrial areas.

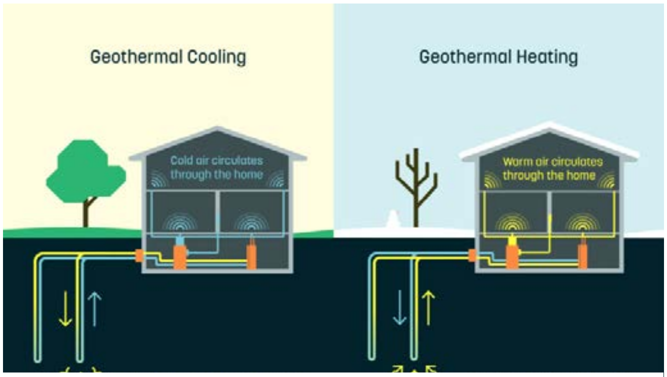


Figure 86: Geothermal central heating uses underground heat to warm homes efficiently, with minimal heat loss and sustainable reinjection systems.

6.4.6. Geothermal Energy Applications

6.4.6.1 Residential Heating (Central Heating System)

Geothermal energy is a widely used energy source for heating homes[119]. Depending on economic conditions, geothermal fluid is transported to buildings via central heating systems. When transported using specially insulated pipes, the temperature loss is quite low (approximately 0.1–0.3 °C/km). In central heating systems where geothermal fluid is used, hot water or steam drawn from wells is transmitted to the heating center via the main line. Here, the heat of the geothermal fluid is transferred to the circulation water circulating in the buildings by means of heat exchangers. The geothermal fluid, whose heat is taken, is reinjected back into the underground, ensuring sustainable use.

6.4.6.2. Ground and Water Source Heat Pump

Geothermal heat pumps are based on the principle that the temperature in the lower layers of the earth's crust is relatively constant throughout the year[120]. In these systems, low-temperature geothermal fluid is used as a heat carrier or, in areas with little groundwater, the heat of rocks is utilized[121]. For ground and water source heat pumps, wells are generally drilled at a depth of 100-200 meters. These systems are used for various purposes such as hot water supply, space heating and cooling. They are especially preferred for energy saving in residences, commercial buildings and industrial facilities.

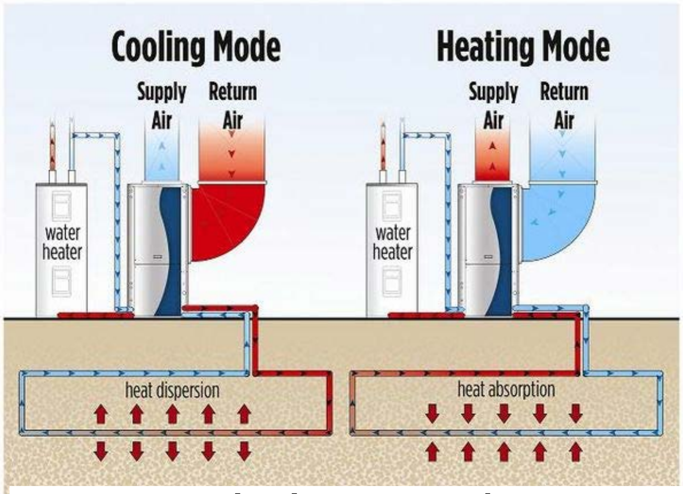


Figure 87:Ground and water source heat pumps use stable underground temperatures for efficient year-round heating and cooling[120].

6.4.6.3. Greenhouse Heating

Geothermal energy is a widely used method for heating greenhouses. Greenhouse heating systems vary depending on the heating technique used[122]. The most suitable sources for greenhouse heating with geothermal energy are shallow, superficial geothermal sources with a temperature of 25-60°C. Such sources offer an economical option because their excavation, operation, pumping and maintenance costs are lower. Geothermal heating improves temperature control in greenhouses, increases plant productivity and provides environmental benefits by reducing fossil fuel consumption.

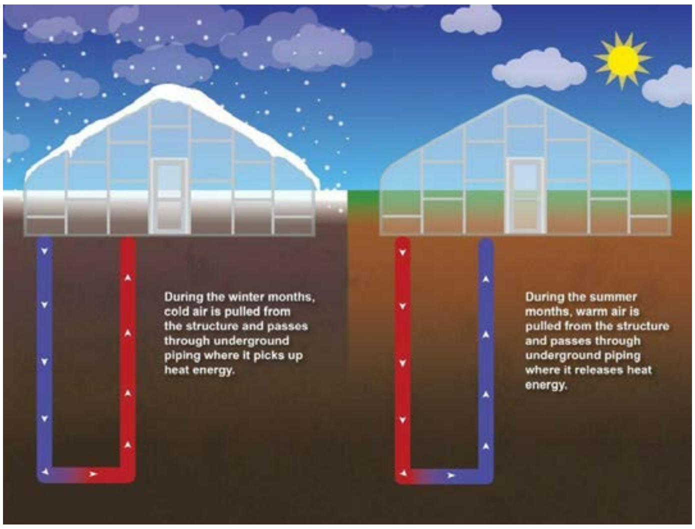


Figure 88: Geothermal energy provides efficient, eco-friendly heating for greenhouses, boosting crop yield year-round.

6.4.6.4. Electricity Production from Geothermal Energy

Geothermal power plants generate electricity using steam turbines, as in thermal power plants. Depending on the temperature and composition of the geothermal fluid, electricity is generated through three different systems[123]:

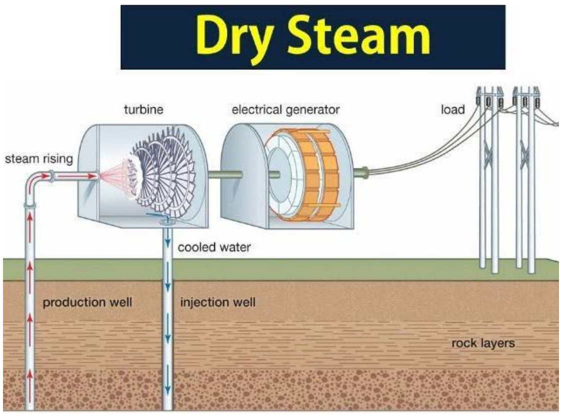


Figure 89: Dry steam power plants use underground steam directly to drive turbines and generate electricity.

1. Dry Steam Power Plants: In this method, the superheated steam (approximately 1500°C) coming out of the underground is directed directly to the turbines to produce electricity[123].

2. Flash Steam Power Plants: The pressure of the hot fluid taken from the source is reduced by separators and water and steam are separated. The steam obtained is used in turbines to produce electricity, while some of the water is sent back underground[123].

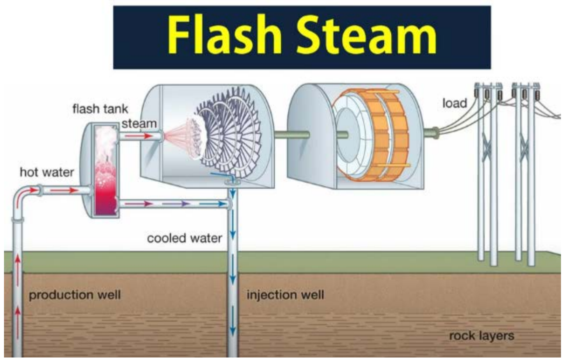


Figure 90:In flash steam systems, high-pressure hot water is depressurized to produce steam that drives the turbine.

3. Binary Cycle Power Plants: It is a method used to benefit from low temperature geothermal resources. In this system, the hot geothermal fluid heats a second fluid and vaporizes it, and the vaporized second fluid is used in turbines[123].

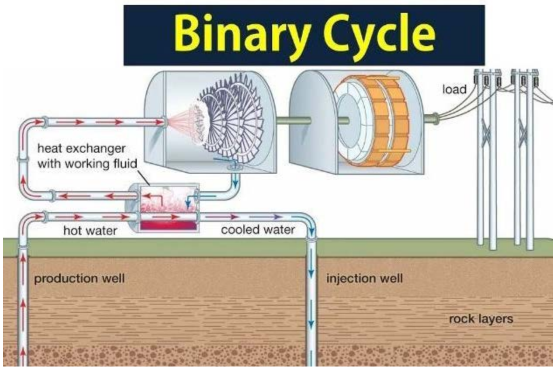


Figure 91: Binary cycle power plants transfer heat from geothermal fluid to a secondary fluid with a lower boiling point, which vaporizes and powers a turbine.

In dry steam power plants, the fluid extracted from underground is usually a mixture of saturated steam and liquid. If the steam ratio is high, the steam is separated and directed directly to the turbines. If the steam ratio is low, the pressure is reduced (by spraying method) and some of the fluid is vaporized, thus generating electricity.

6.5. Sea-Ocean Energies

Figure 92: Ocean energy systems harness power from waves, tides, and currents to generate electricity, using underwater cables to deliver it to shore[125].

There are various methods of obtaining energy from the seas and oceans[124,125]. These methods are:

- Surface Evaporation Energy
- Current Energy
- Salinity Gradient Energy
- Temperature Gradient Energy
- Tidal Energy
- Wave Energy

However, considering today's technology and economic conditions, it is not possible to produce energy efficiently from marine energies other than wave and tidal energy[126]. Therefore, the most widely used sources among sea-ocean energies are wave and tidal energy.

6.5.1. Sea-Ocean Energies in the World

Figure 93: The Rance Tidal Power Plant in France, with a capacity of 240 MW, is one of the world’s first and largest tidal energy projects, operating with a 750-meter dam.

The use of sea and ocean energies dates back to ancient times. The first known tide mill was operated by the Romans in 537 AD. Today's tide power plants are based on the principles of the law of gravitation, as explained by Newton in the 17th century.

In order to generate electricity from tidal movement, dam structures are built in areas where tidal amplitude is high. One of the most important examples of this system is the Rance Tidal Power Plant in France. This plant has a power of 240 MW and a 750-meter-long dam.

Another large-scale power plant is the 254 MW Sihwa Lake Power Plant in South Korea, which was completed in 2011[127]. The idea of using wave energy to generate electricity has been discussed since the 1700s. However, in the 20th century, wave energy was first used in electricity generation in San Francisco and California, USA.

Figure 94: Located in South Korea, the Sihwa Lake Tidal Power Plant is the world's largest tidal power facility with a capacity of 254 MW, completed in 2011.

The world's first large-capacity power plant built using modern wave energy technologies was built on the Isle of Islay off the west coast of Scotland, with a capacity of 500 kW. As of 2023, the total installed capacity of global ocean energy projects is set at 527 MW. Approximately 50% of these projects are in Asia and 45% in Europe.

6.5.2. Sea-Ocean Energies in Partner Countries

6.5.2.1. Sea-Ocean Energies in Türkiye

Türkiye has significant potential in terms of sea and ocean energy. Wave energy, in particular, stands out as a significant resource in increasing our country's energy diversity. According to measurements made in Türkiye's seas, there is an annual technical wave energy potential of approximately 50 TWh. The regions with the highest potential are concentrated especially on the coastline between İzmir and Antalya. Therefore, the regions between Antalya and İzmir (Finike-Dalaman) are considered the most suitable places for electricity generation from wave energy. Studies have also gained momentum for offshore wind energy projects in Türkiye.

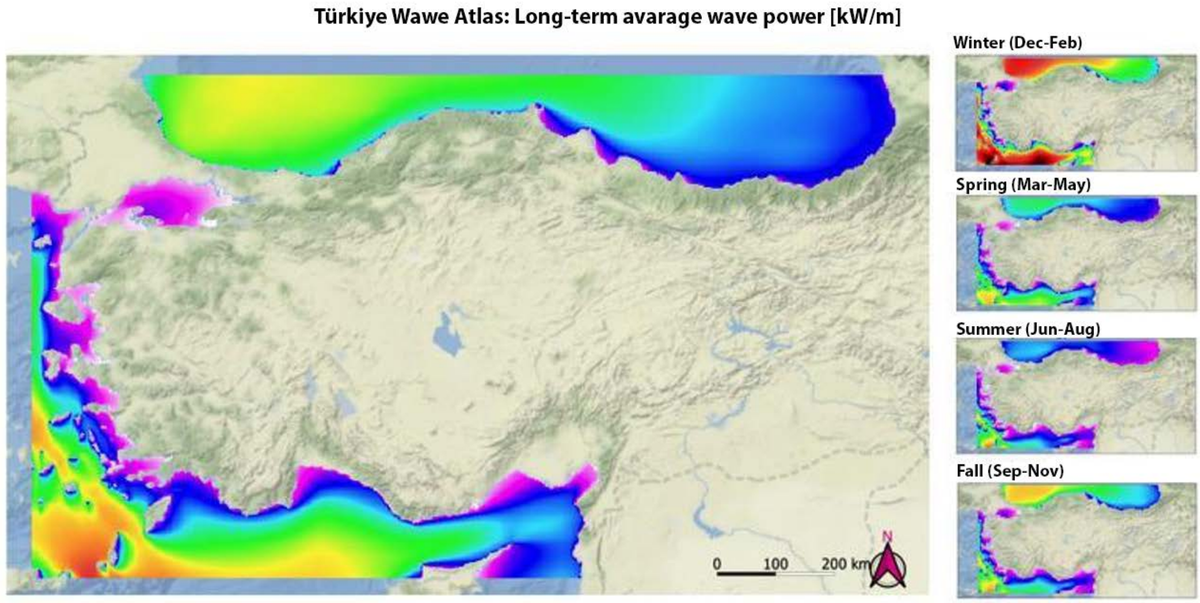


Figure 95: Wave energy potential is highest between Izmir and Antalya.

According to the "Türkiye Offshore Wind Energy Roadmap" report prepared by the World Bank, there is a total technical offshore wind energy potential of 75 GW in Türkiye's territorial waters. The report predicts that 7 GW of offshore wind energy capacity can be reached by 2040[128]. Although commercial projects related to marine energy are still limited in Türkiye, various research and experimental projects are being conducted at the academic level. In particular, in a project carried out by the Ministry of Energy and Natural Resources in 2007 on wave energy, barges were used where the vertical movement of waves was converted into electrical energy by generators, and 5 kWh of electricity was generated with this system, meeting the energy needs of two houses. As a result, various studies are being conducted by both public institutions and the private sector to evaluate Türkiye's marine and ocean energy potential. The start of technical studies on offshore wind energy projects in 2024 in particular will be an important step in terms of diversifying our country's renewable energy resources and increasing energy supply security.

6.5.2.2. Sea-Ocean Energies in Greece

Greece has significant potential for developing sea and ocean energy, especially in wave energy and offshore wind. The country’s long coastline and favorable geographical conditions make it an ideal location for marine renewable energy projects. Greece’s wave energy potential is particularly remarkable, with studies estimating an annual technical potential of around 35 TWh. The Aegean Sea, especially around the Cyclades Islands and the southern Peloponnese, offers the highest wave energy potential, making these areas ideal for wave energy development to support electricity generation and Greece’s renewable energy goals. Offshore wind energy is also gaining attention, with Greece’s Exclusive Economic Zone (EEZ) in the Aegean and Ionian Seas providing excellent conditions for wind farms. The National Renewable Energy Action Plan estimates the country’s offshore wind potential at up to 22 GW. In recent years, various offshore wind projects have been proposed, with the government allocating areas in the Aegean Sea for their development. These projects are essential for meeting Greece’s renewable energy targets and improving energy security. The government has also introduced regulatory reforms to streamline permitting and attract private investment in marine energy.

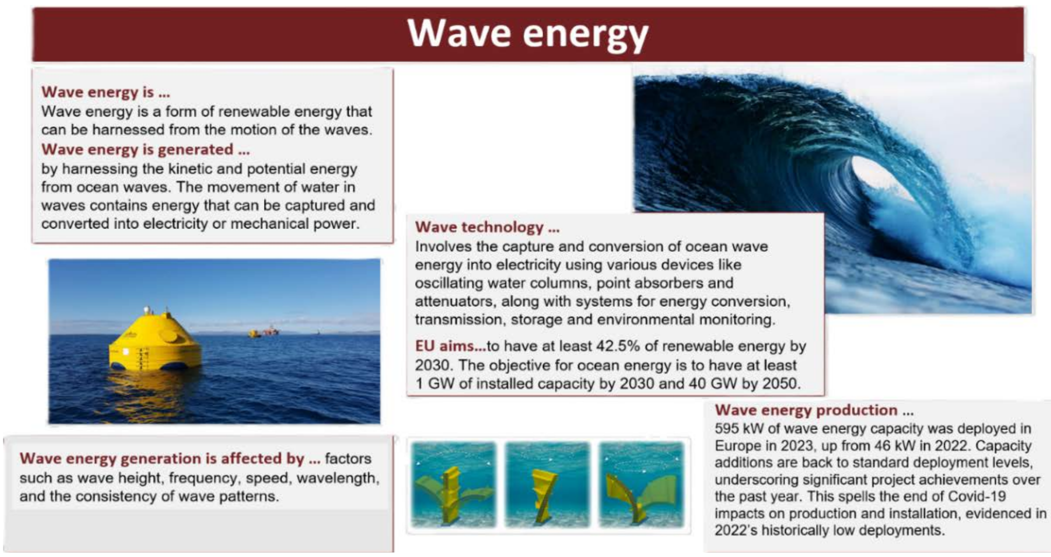


Figure 96: Greece has high wave energy potential, especially in the Aegean Sea, and aims to expand marine renewables like wave and offshore wind energy.

Greece is still in the early stages of developing commercial marine and ocean energy projects, though several research and pilot initiatives are underway. The country's participation in international collaborations and EU-funded projects is advancing the technological and economic feasibility of sea energy. The Ministry of Environment and Energy is supporting studies on the environmental impacts and technological innovations required for efficient wave and offshore wind energy harnessing[129]. Greece plans to significantly expand its marine energy capacity over the next two decades, making it a crucial part of the country's transition to a more sustainable energy system.

In conclusion, Greece is well-positioned to leverage its sea and ocean energy potential, especially through wave and offshore wind energy. With ongoing research, regulatory support, and investments in technology, Greece is expected to become a key player in advancing marine renewable energy in the Mediterranean, contributing to both national and regional energy sustainability.

6.5.2.3. Sea-Ocean Energies in Portugal

Portugal has been exploring wave energy for over 50 years, with pioneering academic work starting in the 1970s. Currently, energy projects in this area are limited to wave energy for electricity production, excluding offshore wind farms. The country benefits from its extensive 800 km western coastline, which offers favorable conditions for harnessing wave energy. The "Central do Pico" project in Porto Cachorro, Pico Island, Azores, was the first research and demonstration wave energy plant in the world connected to the electrical grid. It began studies in 1986 and started operating in 1999, using oscillating water column technology and a turbine developed in Portugal. The plant closed in 2018, and there have been attempts to reactivate it since then.

Portugal has also implemented wave energy projects in the northern (Aguçadoura) and central (Peniche) areas. Despite its immense potential, wave energy development has faced technological and maintenance challenges, resulting in limited installed power capacity. Between 2017 and 2019, an experimental tidal current system was installed on the southern coast, using energy from river currents in an estuary, but the potential of this resource is considered low. Wave energy development in Portugal is part of several national plans, including the National Plan for Energy and Climate (PNEC 2030), with significant growth expected in the coming years[130].

Figure 97: Portugal has developed several wave energy projects along its coast, including Aguçadoura, Peniche, and the Azores, contributing to innovation in marine renewables.

6.5.2.4. Sea-Ocean Energies in North Macedonia

Since North Macedonia is a landlocked country, it does not have direct access to sea or ocean energy sources such as wave, tidal, or offshore wind energy[131]. As a result, there are currently no marine energy projects, research initiatives, or infrastructure developments related to sea and ocean energy within the country. The country's renewable energy efforts are instead focused on hydropower, solar, wind, and geothermal resources.

While North Macedonia does not have the geographical characteristics to exploit sea-based energy sources, it is actively developing its renewable energy sector through substantial investments in wind and solar power. These efforts are aimed at diversifying the country's energy mix, enhancing energy security, and contributing to environmental sustainability.

6.5.3. Positive and Negative Impacts of Sea-Ocean Energy

Sea and ocean energy stands out as a sustainable and environmentally friendly energy source[132]. These types of energy are considered inexhaustible resources thanks to the continuation of waves as long as the wind blows and tidal movements as long as the gravitational force between the Earth and the Moon exists. However, these systems have some advantages as well as various difficulties and disadvantages.

Advantages

- Wave and tidal energy is an unlimited energy source provided by nature.
- Since there is no fossil fuel consumption, greenhouse gas emissions are close to zero.
- Marine energy plants make a positive contribution to global warming by reducing carbon emissions.
- Marine energy systems are generally durable structures and can continue to produce energy for many years.
- Tidal dams can prevent floods by acting as breakwaters in the regions where they are located.
- Since they are built in the sea, they do not have a direct impact on the land ecosystem and protect agricultural lands.
- Marine energy can increase energy supply security by reducing external dependency.
- Touristic facilities can be built around power plants on the sea.
- It can act as a lagoon and create a suitable environment for the reproduction of certain species.
- Due to the intense waves in the winter months, more production can be made during periods when energy demand increases.

Disadvantages

- Since wave and tidal movements are not constant, energy production can be irregular.
- Marine energy plants have higher installation costs than other renewable energy sources.
- Turbines can change the migration routes of marine organisms and negatively affect coastal ecosystems.
- Facilities built close to the shore can create aesthetic concerns and noise pollution.
- Power plants built far from the shore can negatively affect ship traffic and fishing.
- They can block the flow of streams into the sea and cause water accumulation.
- Turbines spinning in the water can pose a physical risk to marine organisms.

6.5.4. Wave Energy

Wave energy is a renewable energy source that occurs as a result of the movement of the wind on the sea and ocean surface. Wave energy plants operate with systems placed on the sea surface or seabed. Turbines that rotate with the movement of the waves produce electricity through a generator. In addition to electricity production, wave energy can also be used in different areas such as hydrogen production[133].

Although the use of wave energy is limited worldwide, it is primarily evaluated by the USA, Portugal and some European countries.

Wave motion occurs as a result of the friction of the wind with the sea surface. Different systems have been developed to obtain energy from this motion:

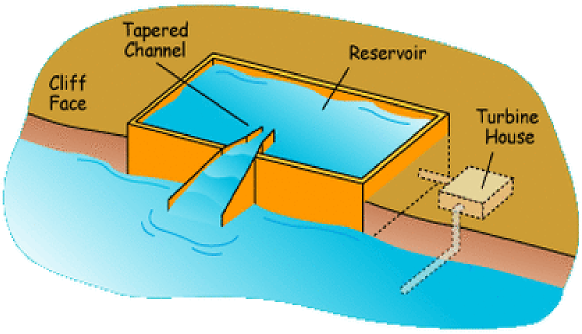


Figure 98: Canal system[134].

• **Canal systems:** Creates potential energy by directing water to reservoirs[134].

• **Hydraulic pump systems:** Floating systems that work with wave motion.

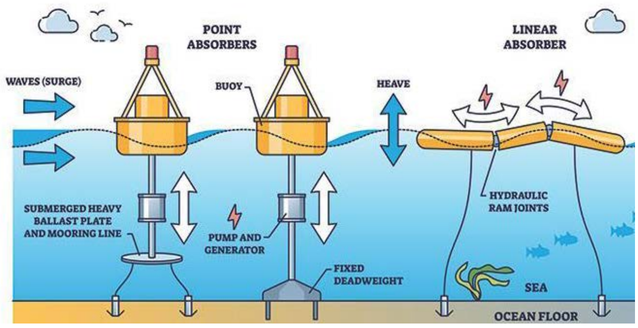


Figure 99: Hydraulic pumpl system.

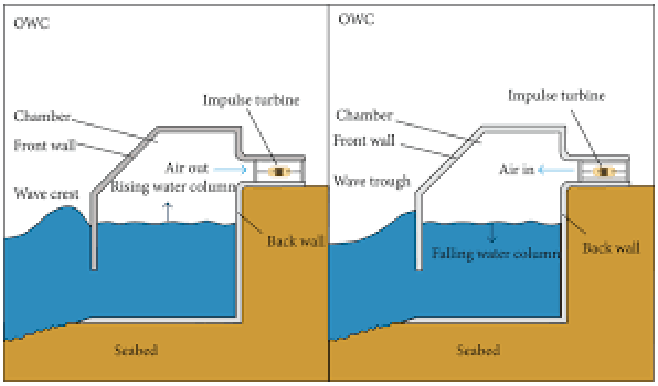


Figure 100: Oscillating water column (OWC) systems[135].

• **Oscillating water column (OWC) systems:** These are mechanisms that produce electricity by compressing air[135].

These systems convert wave energy into mechanical energy and then into electrical energy for use. Wave energy conversion systems are divided into two main groups:

1. **Active systems:** Generate mechanical energy directly from wave motion. Examples: Duck and The Raft systems.
2. **Passive systems:** Generate electricity by converting wave energy into hydraulic lift and then into potential energy. Examples: Oscillating Water Column (OWC) and TAPCHAN (shrinking channel system).

Wave energy systems should be designed considering the wave force and sea conditions in the installation areas. An ideal system should be resistant to changes in wave direction, have short-term energy storage capacity and be able to balance changes in energy production.

6.5.4.1. Wave Energy Conversion Systems

Wave energy conversion systems are divided into three groups according to their installation areas[136]:

1. Systems Installed on the Shoreline:

They are constructed as fixed or buried on the shore.

Since wave power is lower on the shore, energy efficiency is low.

2. Near Shore Type Applications:

They are positioned at depths of 15-25 meters.

Oscillating Water Column (OWC) systems are widely used.

3. Off-shore Type Applications:

They are installed at depths of 40 meters and above.

They are suitable for high wave regimes.

They require long electrical cables to transfer energy to the shore.

Pelamis System: It is a system that operates a generator and produces electricity with the movement of hydraulic oil in hydraulic cylinders.

6.5.5. Tidal Energy

The regular rise and fall of water on the surface of the sea and ocean due to the gravitational pull of the Sun and the Moon is called tides. When this periodic movement is used to generate electricity, tidal energy is obtained[137].

Figure 101: “Tidal movements are converted into electrical energy using turbines, providing a renewable power source.

Electricity can be generated using tidal energy in two main ways:

1. Tidal Current Mills: They have been used for centuries in North America and Europe to produce mechanical energy. They are systems that obtain energy directly from current motion[137].

Figure 13: Tidal current mills convert the kinetic energy of tidal flows into mechanical power, historically used for grinding grain.

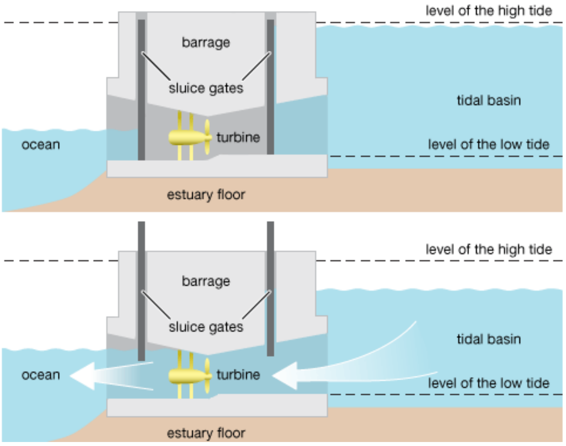


Figure 103: A tidal barrage uses sluice gates and turbines to generate electricity from the difference in sea levels during high and low tides[138].

2. Tidal Dams: Similar to the dam system in hydroelectric power plants. When the sea level rises during the tide, the gates are opened and the dam is filled with water[138]. When the tide goes down, the backflow of water turns the turbines and generates electricity.[137]

With the developing technology, tidal turbines have also started to be used. These turbines are placed between land and an island or between two islands in areas where tidal currents are strong and produce energy through the movement of water. These turbines placed under the sea work similarly to wind turbines and convert the kinetic energy of water into mechanical energy and then into electrical energy[137].

Figure 104: Modern tidal turbines operate like underwater wind turbines, converting tidal currents into electrical energy[138].

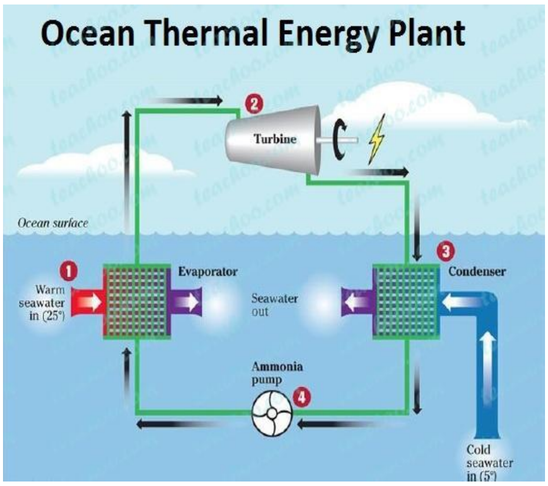


Figure 105: OTEC systems generate electricity by using the temperature difference between warm surface water and cold deep seawater[139].

6.5.6. Ocean Thermal Energy

Most of the radiation from the sun is absorbed by the seas and oceans and stored as heat[139]. This causes a temperature difference between the ocean surface and the deep waters. The surface waters of the ocean are generally warmer, while the deep waters are colder. This temperature difference can be used to produce energy[140].

The Ocean Thermal Energy Conversion (OTEC) system is a method that aims to generate electricity from the temperature difference between the ocean surface and its depths[140]. This concept was described by the French biophysicist Jacques Arsène d'Arsonval in 1881.

How does the OTEC system work?

- Hot water from the ocean surface is used to vaporize a liquid with a low boiling point (such as ammonia).
- The steam turns a turbine to produce electricity.
- This steam is then condensed using the cold deep waters of the ocean and the system is turned back on.

OTEC systems can be implemented in three different ways:

1. **Closed Loop OTEC:**

A liquid with a low boiling point (for example, ammonia) is used.
The hot water vaporizes this liquid, turning the turbines and producing energy.
The liquid is then re-condensed with cold deep water, continuing the system.

2. **Open Loop OTEC:**

Hot water on the ocean surface is taken directly to a low-pressure area and vaporized.
The steam turns a turbine, producing electricity.
It is then condensed by cold water and returned to liquid form.

3. **Hybrid OTEC:**

It is a combination of closed and open loop systems.
The advantages of both methods are used to increase efficiency.

OTEC is an environmentally friendly and sustainable energy source. However, the system is expensive to install and can only be applied in tropical ocean regions where the temperature difference is significant[140].

6.6. Biomass Energy

Biomass is an energy source consisting of biological and non-fossil organic matter. Plants convert solar energy into chemical energy through photosynthesis, and this energy can be converted into biomass energy through plant and animal waste[48].

Figure 106: Biomass energy is derived from renewable organic materials, transforming biological waste into sustainable power.

Biomass sources are divided into two: traditional and modern:

- Traditional biomass includes biomass sources used for domestic purposes such as wood, dung and agricultural waste.
- Modern biomass is a type of biomass based on advanced technologies such as specially grown energy plants, urban and industrial waste and biogas production.

Biomass energy can be obtained from many different sources such as food industry residues, forest residues, aquatic and terrestrial plants, animal waste and city waste. These materials are renewable and can be regenerated in a short time[48].

Advantages

●It has the potential to be an important source of energy supply.

●It provides environmental benefits by reducing greenhouse gas emissions.

●It increases energy security by reducing fossil fuel imports.

●It supports economic development in rural areas and creates employment.

●It reduces waste management problems and ensures more efficient use of resources.

Disadvantages

●Biomass energy has a lower energy density than fossil fuels, which means more material needs to be used.

●Using trees and plants as fuel can lead to deforestation and ecosystem degradation if done uncontrolled.

●Burning biomass can release pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and fine particles.

●Plants grown for biomass production require large amounts of water. This can put pressure on water resources.

- Agricultural land used for energy production can compete with food production and cause food prices to increase.
- Storing and transporting biomass raw materials can be more laborious and costly than fossil fuels.
- Losses can occur during the conversion of biomass to energy, and some technologies are still under development.

Biomass energy has an important place in renewable energy systems as a sustainable and environmentally friendly energy source.

6.6.1. Biomass Resources

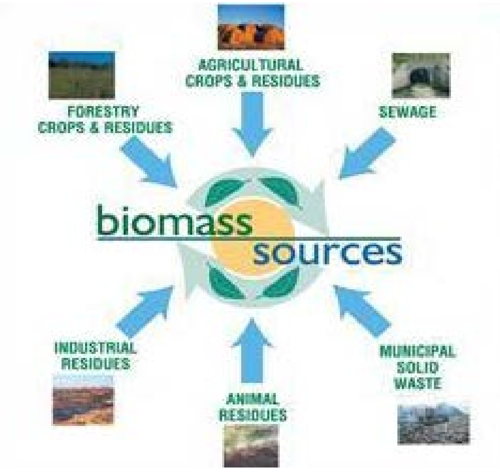


Figure 107: Biomass energy can be produced from a wide range of sources, including agricultural, forest, industrial, and urban organic waste[141].

Biomass resources that can be used in energy production can be divided into four main groups[141]:

1. **Forest Products:**

Fast growing tree species (willow, poplar, eucalyptus, etc.)
Forest residues (wood chips, sawdust, pruning residues, etc.)

- **Agricultural Products:**

Plants grown for energy (miscanthus, reed, sorghum, etc.)
Plants containing oil, starch and sugar (corn, sugar cane, etc.)
Animal feces and slaughter residues

- **Industrial Waste:**

Agro-industrial wastes
Forest products and paper industry wastes

- **Urban Waste:**

Grass, leaves, park and garden waste
Sewage sludge
Organic household waste

6.6.1.1. Energy Plants

With the increasing importance of renewable energy sources, special plants that can grow in all types of soil conditions have begun to be grown for energy production. Sorghum, corn, tobacco, industrial hemp, miscanthus, sweet broom, sugar cane and various wild grasses are among the energy plants.

Main features of energy plants:

- They are known as C4 plants and are resistant to drought.
- They have the capacity to efficiently convert sunlight into energy.
- They have a high capacity to absorb carbon dioxide (CO_2) from the air, thus playing an important role in combating global warming.
- They are used in various biofuel and energy production and provide high efficiency.

6.6.2. Biomass Conversion Processes and Technologies

Different methods are applied to convert biomass into energy. These processes can be grouped into three main groups[141]:

1. Physical Operations:

1. **Dewatering and drying:** The moisture content of biomass is reduced, allowing it to be burned more efficiently.
2. **Size reduction:** By the process of grinding or shredding, biomass is broken into small pieces.
3. **Density increase:** By pressing or pelletizing, the volume of biomass is reduced, making it easier to transport and store.
4. **Separation:** The process of separating the different components present in the biomass is carried out.

2. Thermochemical Processes:

1. **Direct combustion:** Biomass is burned directly, providing heat or electricity generation.
2. **Gasification:** Gases such as hydrogen (H_2), carbon monoxide (CO) and methane (CH_4) are obtained from high-temperature biomass.
3. **Pyrolysis:** In a high temperature and oxygen-free environment, biomass is broken down to obtain products such as bioyal, biogas and biochar.
4. **Liquefaction:** Biomass is converted into liquid fuels by special processes (biodiesel, bioethanol, etc.).

3. Biochemical Processes:

1. **Fermentation:** Biomass containing sugar is broken down by microorganisms to produce biofuels such as bioethanol.
2. **Anaerobic fermentation:** Biogas (methane, CO_2) is produced by the breakdown of organic wastes by microorganisms in an oxygen-free environment.
3. **Mechanical extraction:** Physical squeezing or pressing is applied to produce biofuels from vegetable oils.

Figure 108: Proper waste management enables the recovery of materials and reduces environmental impact through recycling and energy conversion.

6.6.3. Waste Management

Wastes are substances that are formed as a result of human activities and cannot be used directly. These substances, which have the potential to harm the environment, can cause the ecological balance to deteriorate and endanger human health when not managed with appropriate methods.

Solid wastes are divided into two main groups: harmful and harmless:

1. **Harmful Wastes:** These are wastes that may harm human health and the environment and must be disposed of with special processes. These can be toxic, flammable, or have corrosive properties. For example, chemical wastes, batteries, medical wastes fall into this group.
2. **Harmless Wastes:** It consists of organic and inorganic substances that do not directly harm the environment and human health. Domestic and natural waste is in this category.

In addition, there are different types of solid waste according to their source:

1. **Domestic Waste:** Organic and inorganic garbage, ashes, old furniture, etc.
2. **Industrial Waste:** Metal, plastic, chemical and production residues from industrial facilities.
3. **Commercial and Institutional Waste:** Waste from offices, schools, restaurants, and stores.
4. **Municipal Waste: Waste** collected from street cleaning, parks and gardens.
5. **Special Waste:** Wastes that contain hazardous components and require special disposal (e.g. paint, batteries, medical wastes).
6. **Agricultural Wastes: Organic** wastes, fertilizers and animal wastes from agricultural activities.

6.6.3.1. Waste Management Systems

Waste management may differ according to the living habits of the society and the geographical characteristics of the region. However, the main goal is to dispose of waste without harming the environment and to reuse it as much as possible. For this, various methods are applied[142]:

1. **Waste Reduction:** Environmental impacts and costs are reduced by taking measures to prevent waste generation from the very beginning.
2. **Recycling:** It is ensured that materials such as plastic, glass, metal, paper are separated and recycled.
3. **Waste Recycling: Converting** waste into a different energy source by biological, chemical or physical methods (e.g. biogas production).
4. **Recycling:** Making wastes reusable by undergoing some processes.
5. **Landfill: Controlled** burial of non-recyclable wastes in private areas.

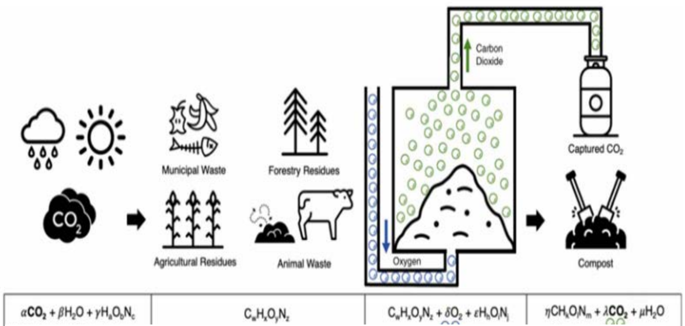


Figure 109: Composting transforms organic waste into nutrient-rich humus, contributing to carbon cycling and soil enrichment[143].

6.6.3.2. Composting

Composting is an environmentally friendly recycling method that decomposes biological waste through natural processes and makes it beneficial to the soil[143]. In this process, organic waste is broken down by microorganisms under aerobic conditions and turns into a substance called humus, rich in plant nutrients.

It reduces the amount of waste and relieves the burden of landfills.
It increases soil fertility and meets the need for natural fertilizers.
It offers an alternative that does not harm the environment by reducing the use of chemical fertilizers.

The composting process usually takes place in four stages:

1. **Initial Phase (1-3 days):**
   Microorganisms begin to decompose organic waste.
   The temperature rises rapidly.
2. **High Decomposition Phase (10-100 days):**
   Complex components such as fats, cellulose and lignin are broken down.
   The temperature exceeds 40°C and harmful microorganisms are destroyed in the process.
3. **Stabilization Phase (10-100 days):**
   Decomposition slows down, the temperature begins to drop.
   Organic compounds are transformed into simpler forms.
4. **Maturation Phase (1-6 months):**
   The compost becomes completely stable and ready for use.
   It can be used in agriculture and horticulture as a nutrient-rich soil conditioner.

Proper composting becomes more efficient by maintaining a balance of moisture, oxygen, and carbon-nitrogen. Natural fertilizer production can be easily carried out by using biological materials such as domestic organic wastes, park and garden

Figure 110: Biofuels are renewable energy sources produced from biological materials, offering a sustainable alternative to fossil fuels[144].

6.7. Biofuels

Biofuels are renewable fuels derived from biological sources[144]. Unlike fossil fuels such as oil, coal, and natural gas, biofuels are sustainable energy sources and are less disruptive to the carbon cycle[145].

Biofuels are divided into three groups according to their physical state as solid, gas and liquid:

- **Solid biofuels:** Briquettes, pellets, biochar, charcoal.
- **Gas biofuels:** Syngaze, biogas, biohydrogen.
- **Liquid biofuels:** Biodiesel, bioethanol, biomethanol, biodimethylether, biooil.

Biofuels are divided into four generations according to their production processes and sources of raw materials[146]:

1. First Generation Biofuels (2000-2010)

- It is produced from foodborne agricultural products (corn, sugar cane, soy, etc.).
- It includes fuels such as biodiesel and bioethanol.
- It can be used in existing engines, but it has been criticized for its impact on food supplies.

2. Second Generation Biofuels (2010-2030)

- It is produced from non-food sources of biomass (agricultural and forestry waste, woody plants).
- Fuels such as biodiesel and bioethanol are obtained using lignocellulosic biomass.
- It is more advantageous in terms of sustainability, but production costs are high.

3. Third Generation Biofuels (2030 and beyond)

- It is produced from algae and genetically improved plants.
- It offers higher yields and has a lower impact on food production.
- Advanced biotechnological methods are required for its production.

4. Fourth Generation Biofuels (2030 and beyond)

- They are known as carbon negative biofuels.
- It is produced using genetically modified microorganisms.
- Environmental impacts are minimized with carbon capture and storage (CCS) technologies.

Biofuels have lower carbon emissions compared to fossil fuels and offer a sustainable energy solution as they are produced from renewable sources. In addition, it reduces dependence on imported fuels by increasing energy independence and contributes positively to agriculture and rural development. However, the effects of biofuels on food production are controversial, and the widespread use of these fuels depends on the development of sustainable production models. The main challenges to the widespread use of biofuels are the higher production costs than fossil fuels, the necessity of considering environmental impacts such as biodiversity and land use, and the high technological investment and infrastructure requirements. For this reason, it is of great importance to shape energy policies with a focus on sustainability in order for biofuels to be an effective alternative energy source in the long term.

6.7.1. Biorefinery Technology

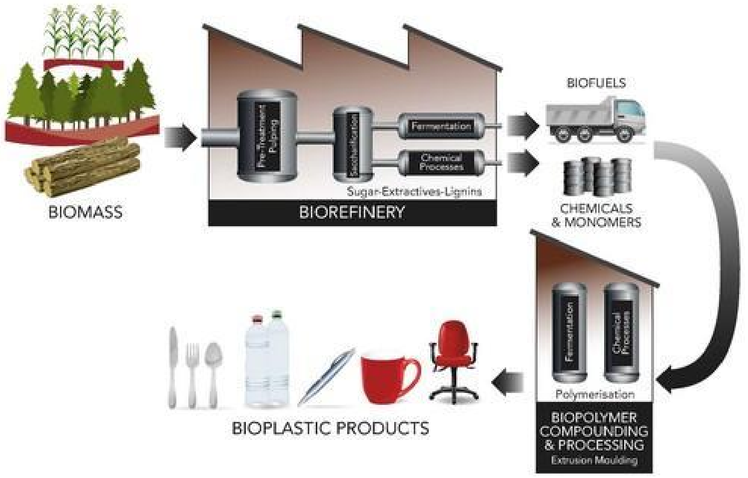


Figure 111: Biorefineries convert biomass into biofuels, bioplastics, and valuable chemicals through integrated chemical and biological processes[148].

Biorefinery technologies include methods that ensure sustainability and efficient use of renewable energy sources in the biofuel production process[147]. Biorefineries, which are similar to oil refineries in terms of their basic structure, differ from traditional refineries in that they use biomass as raw material and operate under milder conditions. In this way, production is achieved with lower energy consumption, solid waste formation is prevented and the amount of wastewater is significantly reduced[147].

Biorefineries are based on a model that supports the production of biofuels, bioenergy and biomaterials by working in integration with agricultural enterprises[148]. The key components of this model are[147]:

- **Agricultural Production:** Cultivation of energy crops and provision of biomass resources.
- **Logistics: Creation** of appropriate logistics systems for the collection, transportation and processing of raw materials.
- **Harvesting and Waste Management:** Collection and evaluation of plant wastes.
- **Densification and Storage:** Pre-treatment of the raw material to make it suitable for the processing process.
- **Biorefinery Processing Processes:** Converting biomass into fuel and other biomaterials through chemical and biochemical conversion processes.
- **Product Storage and Distribution:** Distribution of the resulting biofuel, energy, and other by-products.
- **Evaluation of By-Products: Storage** and distribution of animal feed and manure generated in the biorefinery process.

> In order for biorefineries to be economically viable, logistics processes need to be optimized and raw material transportation and storage costs need to be reduced.

Biorefineries transform biomass into different products such as biofuels, biochemicals, and biomaterials by putting them through various physical, chemical, and biochemical transformation processes. In these processes, it is of great importance that biorefineries are flexible and have the ability to process different raw materials. As in oil refineries, the fact that biorefineries have a variety of raw materials increases resistance to economic fluctuations by ensuring continuity in production.

The fact that biorefineries are not only limited to biofuel production, but also include co-generation applications such as electricity and heat generation is an important factor that increases efficiency. This integrated approach supports the development of the biofuels sector and enables energy production to become more sustainable.

6.7.2. Biofuel Technology in the World

Among the most widely used biofuels in the world are bioethanol, biodiesel and biogas. One of the most successful examples of biofuel production and use is Brazil[149]. Since the oil crisis of the 1970s, Brazil has been using ethanol as a liquid biofuel for transportation. Biogas production is widespread throughout the world, with small-scale plants in India and China, and medium and large-scale plants in Europe. The USA, on the other hand, converts biomass into energy and uses it in electricity generation.

Biofuel Applications

- **Denmark**: Solid biofuels, especially wood briquettes and pellets, are produced from imported wood.
- **Finland**: By increasing the use of biomass, it meets 25% of its energy consumption from biomass.
- **France**: Wood and industrial waste are used as biomass sources and are used in energy production.
- **Netherlands**: There is a large amount of wood waste, which is made into pellets and exported to Sweden, Germany and Belgium.
- **Spain**: Waste from agricultural production is used in the production of biofuels.
- **Sweden**: Forest industry by-products, energy crops and straw are used in the production of biofuels. The country meets 16% of its energy needs from biofuels.
- **Canada**: Aims to provide 50% of its energy consumption from energy forestry by 2050. The U.S. and Canada are planning energy forestry projects with fast-growing tree species without interfering with food production.
- **Ireland**: Energy forestry is considered in peatlands.

A compound annual growth rate (CAGR) of 9.55% is projected over the 2024-2031 forecast period. In 2023, the biofuel industry employed 16,599 people. During the 2023-2024 period, U.S. ethanol exports reached a record 6.6 billion liters (1.75 billion gallons). During this period, Canada was the largest importer, accounting for 37% of U.S. ethanol exports. Europe is paying more attention to biodiesel production. This is directly related to the geographical structure of the continent and the characteristics of the agricultural products grown. While ethanol production is more widespread globally, biodiesel production has increased at a faster rate in recent years.

6.7.3 Biofuel Technology in Partner Countries

6.7.3.1. Biofuel Technology in Türkiye

Türkiye has significant potential in renewable energy production with its rich biomass resources. Biomass obtained from agriculture, forestry and animal waste is used for energy production. As of 22024, Türkiye's total installed electricity capacity reached 115,353 megawatts, 59% of which was provided by renewable energy sources. The installed capacity of biomass power plants reached 2,125 megawatts, constituting 1.8% of the total[150]. Bioethanol production has been on the agenda in Türkiye at various times since the 1930s. There are legal regulations in Türkiye that encourage the use of bioethanol and biodiesel.

6.7.3.2. Biofuel Technology in Greece

Greece has significant potential for biofuel production, supported by its rich agricultural and forestry resources[151]. Biomass from crop residues, forestry by-products, and organic waste plays a central role in biofuel production, positioning Greece well to boost its renewable energy capacity. According to reports from the Ministry of Environment and Energy, Greece's biomass resources, including olive oil mill waste and agricultural residues, hold considerable promise for biofuel production. As of 2023, Greece's installed bioenergy capacity, which includes biofuels, exceeds 800 megawatts, contributing significantly to the country's renewable energy generation.

The primary biofuels produced in Greece are bioethanol and biodiesel, both derived from domestic agricultural products such as wheat, corn, and rapeseed. Bioethanol production has been a key sector in Greece since the early 2000s. Several bioethanol plants are located in agricultural regions, where bioethanol is produced from cereals and other crops. These plants play a crucial role in meeting Greece's energy needs and reducing greenhouse gas emissions. Greece has also seen growth in the biodiesel sector, producing biodiesel from agricultural waste, especially olive oil mill residues, a by-product of Greece's large olive oil industry. Multiple biodiesel production facilities are in operation, producing fuel for both domestic consumption and export. These biofuels are often used as additives in transportation fuels, helping to reduce the carbon footprint of the transportation sector. The Greek government has implemented various policies to support biofuel production, including subsidies and tax exemptions for biofuels derived from domestic agricultural products. Bioethanol and biodiesel blends are mandated for use in the transportation sector, with specific percentages set for inclusion in gasoline and diesel fuels. However, the biofuel sector faces challenges, particularly high production costs and reliance on government subsidies. Moreover, competition with other renewable energy sources, such as solar and wind energy, has sometimes slowed the growth of biofuel production.

Looking ahead, Greece aims to expand its biofuel production capacity to meet the European Union's renewable energy targets. The country intends to further develop its biofuel sector by utilizing its agricultural output to produce cleaner, more sustainable fuels, reducing dependence on fossil fuels. Biofuels are expected to remain a key part of Greece's renewable energy strategy, contributing to the country's energy security and environmental goals.

6.7.3.3. Biofuel Technology in Portugal

Portugal has shown a strong commitment to the energy transition, with biofuels playing a key role in this process. In line with the European Union's goals, the country has invested in biofuel production and usage to reduce greenhouse gas emissions and diversify energy sources. Biodiesel remains the most widely used biofuel, primarily produced from vegetable oils such as rapeseed and soy, as well as an increasing amount of used cooking oil (UCO). Encouraging UCO use supports the circular economy and reduces dependence on imported raw materials, while biodiesel blending in diesel is essential for meeting renewable energy targets in transport. Bioethanol, produced from sugar-rich biomass like beet and corn, plays a smaller role but has growth potential through research and new technologies. Additionally, biogas production from organic waste—such as agricultural residues, urban waste, and wastewater treatment plant sludge—has gained importance, contributing to electricity and heat generation and holding potential for injection into the natural gas grid. Portugal also participates in European initiatives for developing biojet fuel, a promising alternative for sustainable aviation.

Portugal's biofuel policies align with EU directives, particularly the National Energy and Climate Plan 2030 (PNEC 2030), which sets ambitious targets for biofuel incorporation in transport. The government has actively promoted UCO collection and processing and recently approved the Action Plan for Biomethane 2024-2040 (PAB). This strategic plan focuses on creating and consolidating a biomethane market to reduce GHG emissions and support economic decarbonization by leveraging local resources and decreasing reliance on imported natural gas. Biodiesel (FAME) production remains the main focus of Portugal’s biofuel industry, with a significant increase in UCO usage. Data from DGEG indicates a continuous rise in national biofuel production, while biofuel imports have also grown, reflecting increasing demand and the need to supplement domestic production.The following figure shows the evolution of total biofuel production (FAME and HVO) between 2016 and 2023:

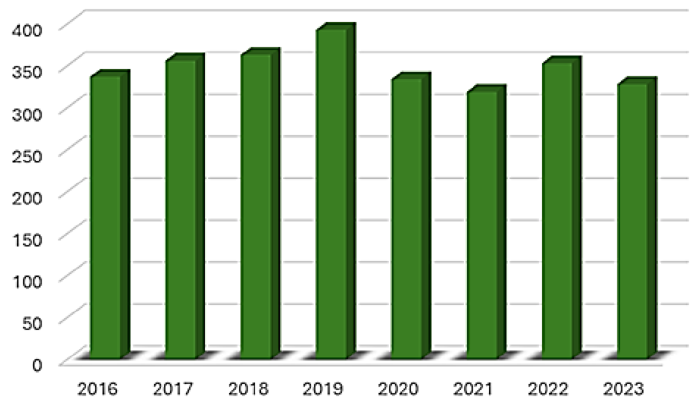


Figure 112: Evolution of national biofuel production between 2016-2023 (in kton)

From 2021 onwards, there was a significant increase in biofuel imports compared to previous years. Data from 2016 to 2023 show this growing trend, although the 2023 values are still provisional.

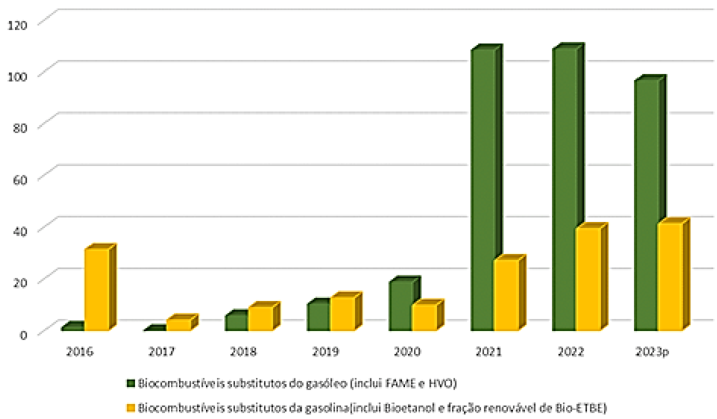


Figure 113: Evolution of biofuel imports between 2016-2023 (in kton).

Portugal's biofuel sector faces several challenges, including reducing dependence on imported raw materials, minimizing the environmental impact of energy crop production, and developing infrastructure for biogas and biojet fuel. However, there are also significant opportunities, such as expanding the use of advanced biofuels derived from waste and non-food biomass, investing in biogas and green hydrogen, and fostering collaboration between universities, research centers, and industry. The recently approved Action Plan for Biomethane 2024-2040 (PAB) further creates new opportunities by promoting biomethane infrastructure, encouraging innovative business models, and strengthening the circular economy.

The National Biofuels Strategy (ENB) provides key guidelines for the sector, emphasizing sustainability and innovation. Research and development efforts have explored alternative raw materials, such as algae and forest residues, to enhance biofuel production. Additionally, increasing environmental awareness among consumers has led to greater demand for biofuels, further driving the sector’s growth.

6.7.3.4. Biofuel Technology in North Macedonia

North Macedonia has begun exploring renewable energy sources, including biofuels, to diversify its energy mix and improve sustainability[152]. However, as of 2020, the country reported no production of biofuels and bioliquids, indicating that this sector is still in its early stages. Despite the underdevelopment of biofuels, North Macedonia has made significant progress in bioenergy, particularly through biogas projects. A key example is the 2-MW biogas plant in Lozovo, which began operations in December 2022. This facility, equipped with two MWM TCG 2020 V12 gas engines, supplies electricity to approximately 4,000 households, representing a meaningful step forward in the country’s efforts to embrace sustainable energy production.

North Macedonia's energy supply remains heavily dependent on fossil fuels, with oil and coal accounting for 45% and 32% of the total energy supply, respectively, in 2022. This dependency highlights the urgent need for diversification through renewable energy sources. While biofuel production is still underdeveloped, the country possesses abundant biomass resources, such as wood from fruit trees and other agricultural residues, which offer significant potential for future bioenergy production. In 2023, the primary production of biomass from these sources was recorded at 1.924 thousand tons of oil equivalent (TOE). With the right investments and support, North Macedonia can further develop its biofuel and biomass sectors, creating a more diverse, sustainable, and resilient energy system.

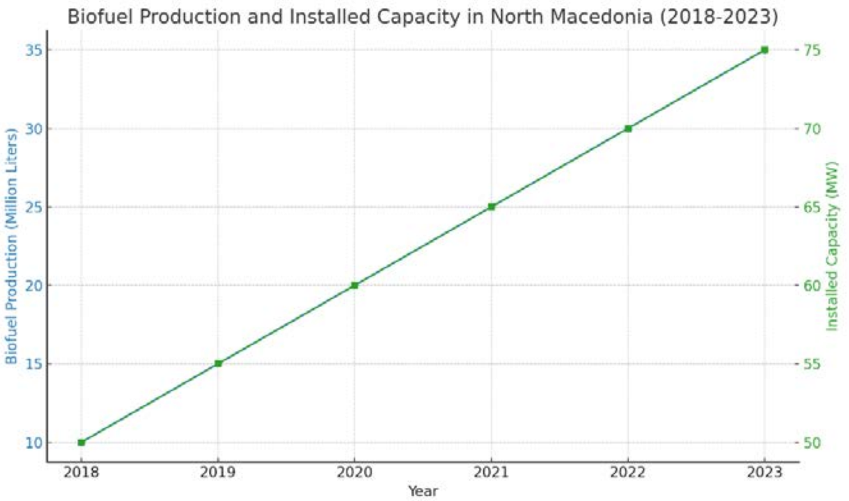


Figure 114: Biofuel production and installed capacity in North Macedonia have shown steady growth, reflecting the country's gradual shift towards renewable energy.

To further promote bioenergy, companies like SERVODAY are introducing innovative biomass solutions in North Macedonia. These include portable pellet production units and advanced biomass boiler feeding systems, aiming to enhance efficiency and fuel flexibility in the energy and manufacturing sectors.

While biofuel technology is still emerging in North Macedonia, the development of biogas plants and the utilization of biomass resources indicate a growing commitment to renewable energy. Continued investment and technological innovation are essential to fully harness the potential of biofuels and bioenergy in the country's energy landscape.

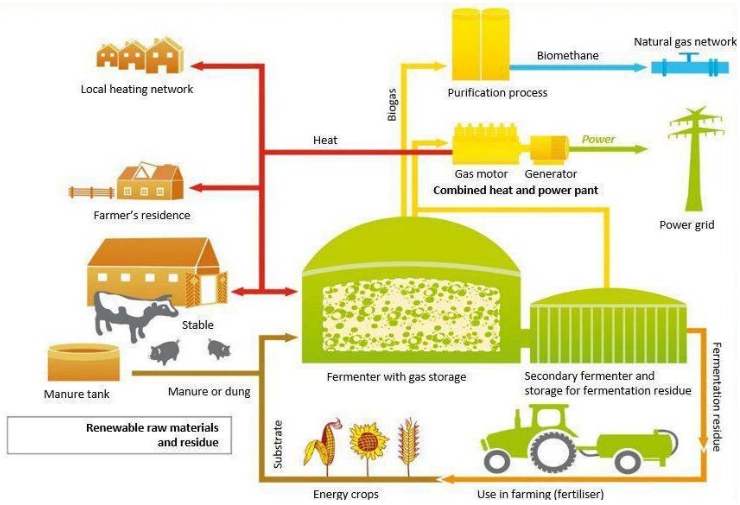


Figure 115: "Biogas plants convert organic waste into heat, electricity, and biomethane, while producing fertilizer as a by-product for agricultural use[153].

6.7.4. Biogas Technology

Biogas is a type of gaseous biofuel that is widely used all over the world[153]. Its main advantage is that all kinds of organic waste can be converted into energy. Wastes that may be harmful to human health and the environment are converted into biogas by fermentation in an oxygen-free environment[154].

Uses of Biogas:

- Heat generation (e.g. in stoves and heating systems)
- Electricity generation (in motors or cogeneration systems)
- Use as fuel (integrated into biogas engines or natural gas systems)

In addition, the sludge generated during biogas production can be used as fertilizer in agricultural production.

Biogas Plants:

- Small-scale plants are common in Asia, and the production of fermented fertilizers from animal and vegetable waste is often at the forefront.
- Medium and large-scale facilities are preferred in Europe and it is aimed to both dispose of domestic, industrial and agricultural wastes and convert them into energy.

6.7.4.1. Biogas production

Organic waste is used for biogas production. These are[154]:

- Animal manure (cattle, sheep, poultry)
- Plant production waste
- Forest and paper industry waste
- Textile industry waste
- Food industry waste (milk, yeast, chocolate, beverage production, etc.)
- Agricultural industrial waste (oil, sugar factories, etc.)
- City solid waste
- Sewage waste

Energy crops and algae can also be harnessed for high-efficiency biogas production.

Biogas is a flammable gas mixture obtained by decomposing organic wastes by microorganisms in an oxygen-free environment. In the process[154]:

Methane (CH_4): It is the most important component of biogas and constitutes its energy source.
Carbon dioxide (CO_2): It is a natural by-product of the process.
Hydrogen sulfide (H_2S) and nitrogen (N_2): May be present in small amounts depending on the type of waste.

Figure 116: Methane (CH_4) is the primary energy-rich component of biogas, produced through anaerobic digestion of organic waste.

The methane content determines the energy value of biogas. However, methane cannot be liquefied at low pressures like LPG; It needs a pressure of 280-350 bar to liquefy.

Biogas production depends on the chemical and physical properties of the wastes used . Important factors include:

- Type and composition of waste (animal, vegetable, domestic, etc.)
- The amount of foreign matter (soil, stone, metal, etc.)
- Particle size (smaller pieces ferment faster)
- Moisture content and organic matter content
- Generator (reactor) design (volume, insulation, mixing and heating systems)
- Fermentation temperature and pH balance

6.7.5. Bioethanol Technology

Bioethanol is a fuel of biological origin that was developed due to the depletion of fossil fuels and the need to reduce greenhouse gas emissions. It is the most widely used biofuel in the world and is used as an alternative motor fuel, especially mixed with gasoline[155].

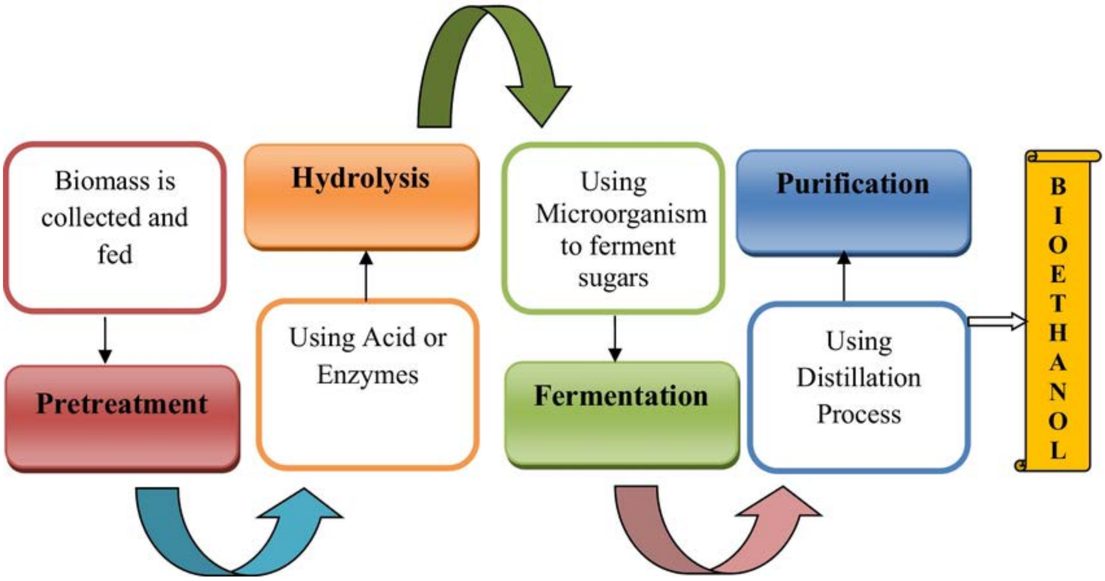


Figure 117: Bioethanol is produced by converting biomass into fermentable sugars, followed by microbial fermentation and distillation[155].

Ethanol is a compound formed as a result of the fermentation of sugars by yeasts. Cereals, sugar crops, and starch-containing plants are the most common sources of bioethanol production. In addition, cellulosic materials such as trees, grasses and household waste can also be used to obtain bioethanol. However, the production of bioethanol from cellulosic materials is more complex and costly compared to the production directly from agricultural products containing sugars and starches. Therefore, technological advances are needed for more efficient production methods.

Products such as corn, sugar beet and sugar cane, which are used for the production of bioethanol, are also staple food sources. For example, in the U.S., a large portion of corn production is used for bioethanol. This leads to an increase in corn prices around the world and competition between food production and energy production.

In order to prevent this problem, alternative sources should be used in bioethanol production instead of agricultural products with food value. These include lignocellulosic plants with no food value and agricultural residues (unused parts such as stems, roots). Thus, both energy needs can be met and food safety is protected.

6.7.6. Uses of Bioethanol

Bioethanol can be evaluated in different ways in various energy systems[156]:

- It can be used directly as an alternative motor fuel.
- It can act as a fuel additive by mixing with gasoline in certain proportions.
- It can be used as an energy source in fuel cells.
- It can be used as a raw material in the production of biodiesel.

Gasoline and Diesel Blends of Bioethanol

Fuel types containing bioethanol in different proportions are used around the world:

Gasoline with added alcohol (contains up to 5% alcohol).
Gasohol (10% ethanol, 90% gasoline blend).
E85 (a mixture containing 85% ethanol, 15% gasoline).

Advantages

Among the important advantages of bioethanol are the following:

- It is a sustainable fuel because it is produced from renewable resources.
- It contributes to energy security by reducing oil dependency.
- It offers an environmentally friendly option by reducing greenhouse gas emissions.
- By increasing the octane number, it helps the fuel burn more efficiently and cleanly.
- It improves engine performance and does not harm nature thanks to its biodegradability.

6.7.6.1 Bioethanol production

The production of bioethanol is carried out by passing lignocellulosic biomass through certain stages. This process consists of four basic steps. The first step is the separation of lignin, hemicellulose and cellulose by pretreating the biomass. This stage involves the breakdown of biomass to make the hydrolysis process more efficient. In the second step, cellulose and hemicellulose are decomposed into monomer sugars by enzymes or chemical methods. In the third stage, the sugars obtained are fermented with the help of microorganisms such as yeast and converted into ethanol. In the last stage, ethanol is condensed by distillation and purification processes[157].

In biomass used in ethanol production, the pretreatment stage is very important. This stage involves cleaning the biomass, separating it according to its size, and making it more accessible in the biochemical processes that proceed. Mechanical and physical processes applied during pretreatment disrupt the internal structure of biomass and increase sugar yield. Each type of raw material (e.g., softwood, corn cob or bagasse) needs different pretreatment methods to achieve optimal yields.

In facilities where bioethanol is produced from molasses and dark syrup, dark syrup and molasses are fed into the fermentation tank together with yeast. After the fermentation process is completed, bioethanol is obtained by performing distillation, rectification (dewatering) and separation processes, respectively.

6.7.7. Biodiesel Technology

Biodiesel is a clean and renewable energy source developed as an alternative to petroleum-based diesel fuels[158]. It can be used directly or as an additive in diesel engines. The commercialization of biodiesel in many countries is supported by improvements in product quality and increased customer satisfaction[159]. Biodiesel production and use are regulated by international standards such as ASTM D6751 (American Society for Testing and Materials) and European standard EN 14214.

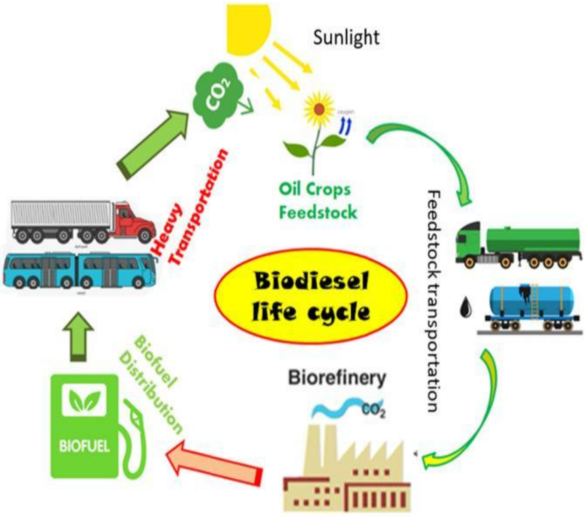


Figure 118: Biodiesel Life Cycle: From feedstock growth to biofuel distribution[159].

6.7.7.1. Oil Sources Used in Biodiesel Production

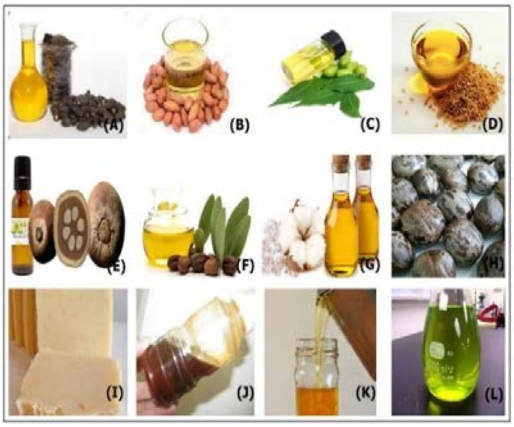


Figure 119:Biodiesel can be produced from various oil sources including vegetable oils, waste oils, animal fats, and algae-based lipids[160].

Different types of oil can be used for the production of biodiesel[160]:

- **Vegetable oils**: Agricultural oil sources such as palm, safflower, rapeseed, soy.
- **Recovery oils**: By-products from the vegetable oil industry (such as soap stock, scrap oil).
- **Urban and industrial waste oils**: Waste oils such as brown grease and black grease.
- **Animal fats**: Fats of animal origin, such as tallow, fish oil, and poultry oil.
- **Waste vegetable oils**: Used cooking oils (such as yellow grease).
- **Algae**: It is also possible to produce biodiesel from microalgae with a high oil content.

The use of these resources increases the sustainability of biodiesel and contributes to the utilization of waste.

Biodiesel can be used in engines in pure form (B100) or mixed with diesel in certain proportions:

B5: A mixture of 5% biodiesel and 95% diesel.
B20: A mixture of 20% biodiesel and 80% diesel.
B50: A mixture of 50% biodiesel and 50% diesel.
B100: 100% biodiesel is the purest type of biodiesel used without additives.

Low-ratio biodiesel blends (B5, B20) can be used in standard diesel vehicles without requiring engine modification, while high-ratio biodiesel (B50, B100) may require adaptation of some engine systems.

Advantages

There are many benefits to the use of biodiesel:

- It is a sustainable fuel because it is produced from renewable resources.
- It reduces dependence on petroleum-derived fuels.
- It offers an environmentally conscious option by drastically reducing carbon emissions.
- Since it does not contain sulfur, it reduces the release of harmful gases.
- It has high engine lubrication and improves engine performance.
- Thanks to its high flash point, it provides safe transportation and storage.
- It is biodegradable and non-toxic, does not harm nature.
- Its calorific value is very close to diesel and there is no significant loss in engine performance.
- Since it has a high cetane number, it provides more efficient combustion.

6.7.7.2. Biodiesel production

One of the main problems in the production of biodiesel is the high viscosity of the oils used[161]. Therefore, the viscosity needs to be reduced before it can be used as a motor fuel. To achieve this, thermal and chemical treatments are applied to the oils. In heat treatment, which is the simplest method, oils are heated before they are introduced into the fuel system to reduce their viscosity. However, this method can lead to various problems, especially when used on mobile devices.

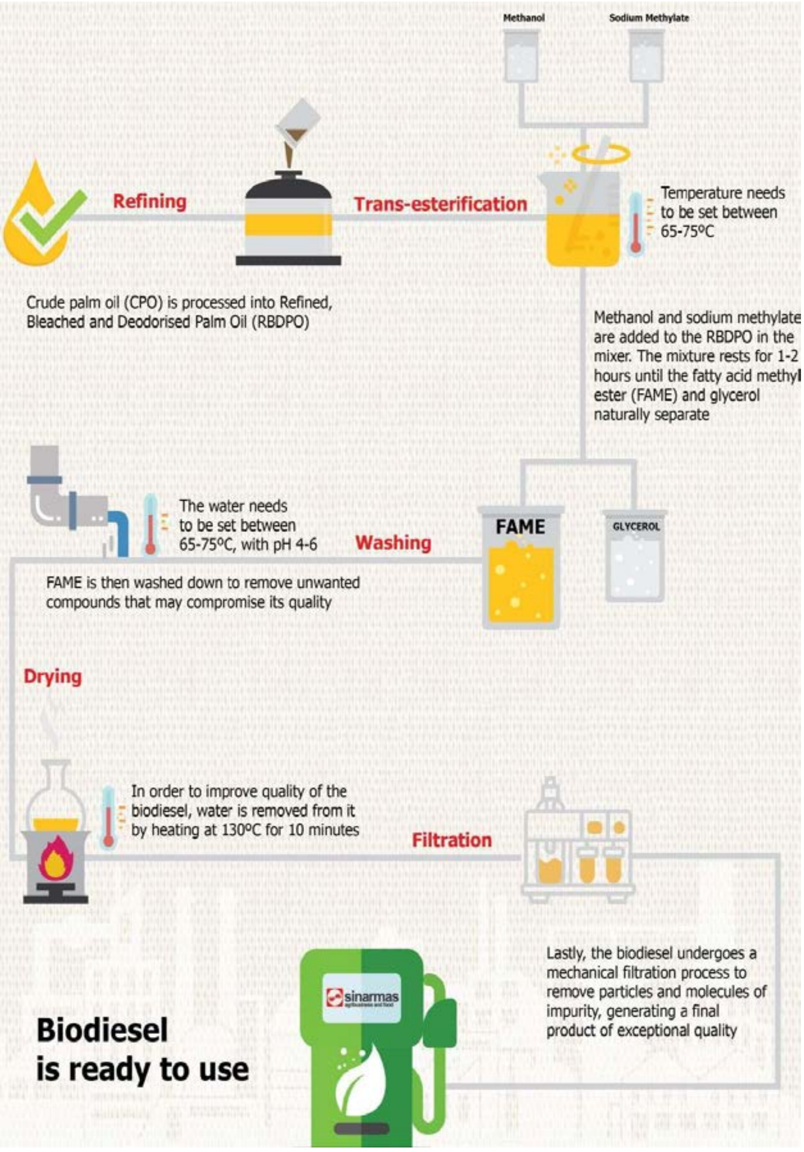


Figure 120: Biodiesel is produced via transesterification, where oils react with alcohol in the presence of a catalyst, followed by refining, washing, drying, and filtration to obtain fuel-grade biodiesel[162].

Chemical treatments are commonly preferred to reduce viscosity. Among these, the most effective and common method is **the transesterification** method[161]. In this process, vegetable or animal fats are reacted with an alcohol to obtain biodiesel and glycerin as a by-product. In simpler terms, large-molecule oils react with small-molecule alcohols to turn into a more fluid liquid that can be used as motor fuel[162].

There are different alcohol and catalyst options in the transesterification reaction. Methanol and ethanol are the most commonly used alcohols. Acidic, basic or enzymatic catalysts can be preferred as catalysts. However, **basic catalysts** are usually more advantageous because[161]:

- It provides higher yields.
- It is less corrosive.
- The reaction time is shorter.
- Acidic catalysts increase the cost of production because they require special acid-resistant tanks.

Basic Catalyst Biodiesel Production Stages:

1. **Mixing Catalyst and Alcohol**
   Usually, sodium hydroxide (NaOH) or potassium hydroxide (KOH) is used as a catalyst. The catalyst is dissolved in alcohol with the help of a mixer and made ready for the reaction.

2. **Reaction**
   The prepared catalyst-alcohol mixture is taken into the reactor with oil, which is the raw material of biodiesel. The reactor is kept closed to prevent alcohol loss. The reaction temperature is kept slightly above the boiling point of the alcohol (about 70°C) and the processing time can vary between 1 and 8 hours.

3. **Separation**
   As a result of the reaction, two main products are formed: biodiesel and glycerin. Since glycerin is denser than biodiesel, it can be separated by the action of gravity. Centrifuges can be used in some plants to provide faster separation.

4. **Removal of Alcohol**
   After the separation of glycerin and biodiesel, the remaining alcohol is removed by evaporation (flash evaporation) or distillation. In some systems, after this stage, the mixture is neutralized and the end products are treated before separation.

5. **Neutralization of Glycerin**
   It contains glycerin, which is a by-product, unused catalyst and soap. These components are neutralized with an acid and stored as crude glycerin. Salts formed during neutralization can be left in glycerin or recovered. With the purification process, glycerin with a purity of 80-88% can be obtained and presented to the industry. Glycerin with a purity of 99% can be produced by applying special processes, which can be used in the pharmaceutical and cosmetic industries.

6. **Washing and Storage of Biodiesel**
   The biodiesel, separated from the glycerin, is washed with warm water and dried to remove the catalyst and soaps remaining in it. The final product is a liquid with a bright amber color and a viscosity close to that of diesel fuel. In some systems, colorless biodiesel can be produced by applying distillation in the final stage[163].

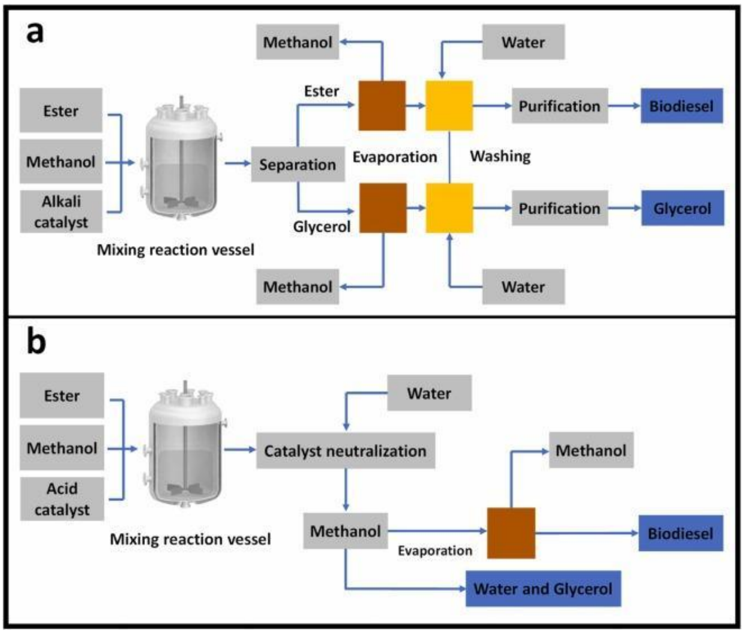


Figure 121: The biodiesel production process varies based on the catalyst used: alkaline catalysts offer higher yields and faster reactions, while acid catalysts require longer processing but can handle high free fatty acid content[163].

6.8. Hydrogen Energy

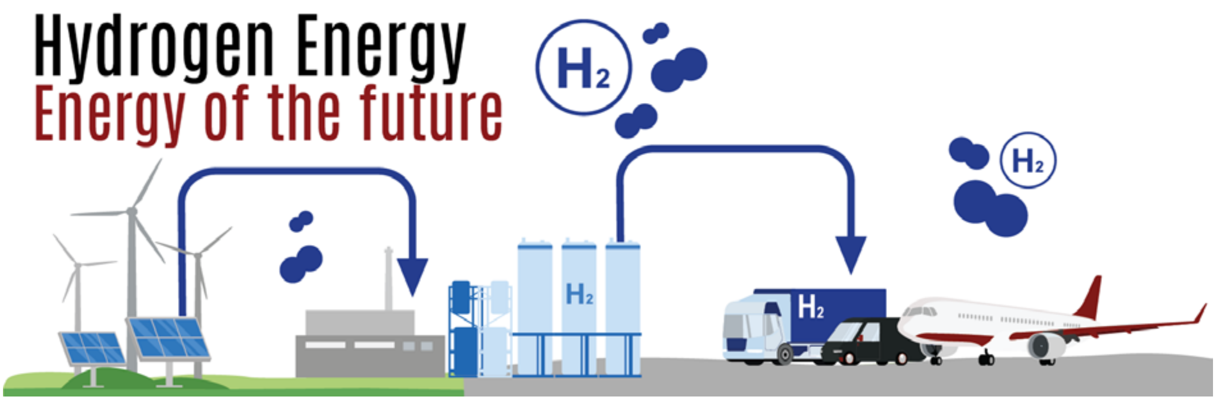


Figure 122: Hydrogen is a clean and renewable energy carrier produced from water using solar and wind power, enabling sustainable solutions in transportation and industry[164].

The word hydrogen is derived from the Greek words hydro, meaning *"water"*, and genes, meaning *"formation"*. Hydrogen is the lightest and most abundant element in the universe[164]. Hydrogen is found in water, plants, animals, and many chemical compounds on Earth. However, it is not found in pure form in nature. While it is found in the atmosphere in a very small amount of gaseous form, it is usually found combined with other elements. In nature, some microorganisms can produce hydrogen. Also, plants produce oxygen and carbohydrates from light, water, and carbon dioxide by photosynthesis. Technologically, hydrogen can be produced from sources such as water, biomass, and fossil fuels. The most environmentally friendly method is to obtain hydrogen by breaking down the water molecule. If this process is done using renewable energy sources such as solar or wind energy, hydrogen becomes a completely clean fuel. Hydrogen is a colorless, odorless gas that is 14 times lighter than air. It becomes liquid at very low temperatures[165]. It is used as rocket fuel in space exploration because it is light and has a high energy-carrying capacity. Hydrogen is highly chemically active and combines easily with other elements. When it reacts with oxygen, water vapor is formed, and a large amount of energy is released in the process. That's why hydrogen is used as a clean and powerful energy source.

Hydrogen can be used to generate energy in internal combustion engines or fuel cells. It does not pollute the environment, as only water vapor is formed as a result of combustion. Hydrogen can also be converted directly into electrical energy. The fuel cells that provide this allow hydrogen and oxygen to react chemically to produce electricity. This system is used in car engines, home energy systems and spacecraft. Hydrogen is considered an environmentally friendly fuel because it does not emit carbon as a result of combustion. Today, when fossil fuels are used, carbon dioxide (CO_2) and harmful gases are released into the atmosphere, leading to climate change and air pollution. Whereas, hydrogen is called green energy because it only produces water. If solar, wind or water energy is used instead of fossil fuels in hydrogen production, it can become a sustainable and clean energy source for the world. Today, our energy needs are largely met from fossil fuels such as coal, oil and natural gas. However, these resources are limited and harm the environment. That's why scientists think hydrogen could be the main source of energy in the future. Hydrogen provides a great advantage because it can be produced from ubiquitous water. The hydrogen cycle works by splitting water into hydrogen and oxygen to produce energy and then turning that hydrogen back into water. This process is one of the cleanest ways to produce energy without harming nature.

In the future, a transition to a carbon-free energy system can be achieved with the more widespread use of hydrogen energy. This means cleaner air, sustainable energy, and less reliance on fossil fuels.

6.8.1. Hydrogen Production

Hydrogen is not found in pure form in nature, so energy must be used to obtain it. The energy sources used in hydrogen production can be fossil fuels (coal, oil, natural gas), nuclear energy, and renewable energy sources (solar, wind, biomass, water, geothermal, wave and tidal energy). Using these sources, hydrogen production is carried out by different methods[166].

Chemical, thermochemical and electrochemical methods are used to produce hydrogen. Today, the most widely used methods are techniques that enable hydrogen to be obtained from fossil fuels. However, renewable energy-supported methods that do not harm the environment are also gaining more and more attention.

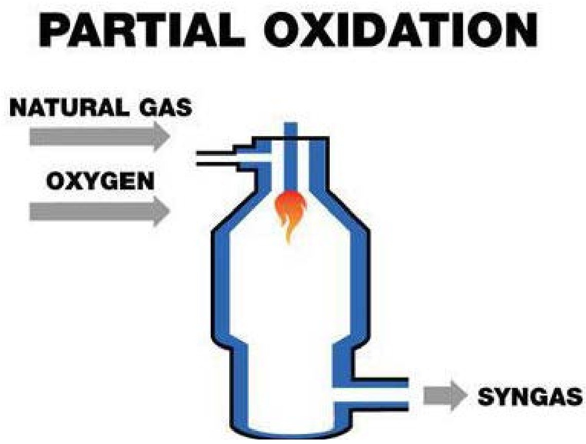


Figure 123: In the POX method, natural gas reacts with limited oxygen at high temperatures to produce syngas, a hydrogen-rich gas mixture[166].

2. Auto-Thermal Reforming (ATR)

This method produces hydrogen by combining both heat-requiring (endothermic) and heat-releasing (exothermic) reactions[167]. It creates a more efficient production process by allowing the environment to heat up spontaneously. ATR is one of the methods that provides high yields in hydrogen production.

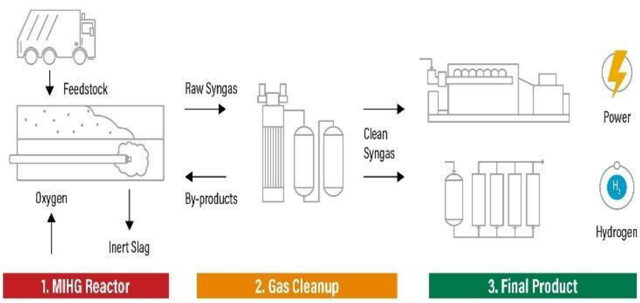


Figure 125: Gasification converts feedstock into hydrogen-rich syngas through high-temperature processing, followed by gas cleanup for power and hydrogen production[168].

Oxidation Oxide (POX – Partial Oxidation)

In this method, hydrocarbons (e.g., natural gas) react with small amounts of oxygen to form hydrogen, carbon monoxide, and other gases. The process takes place at very high temperatures and usually does not require a catalyst. Some of the gases produced are burned during the process, ensuring the continuity of the system[166].

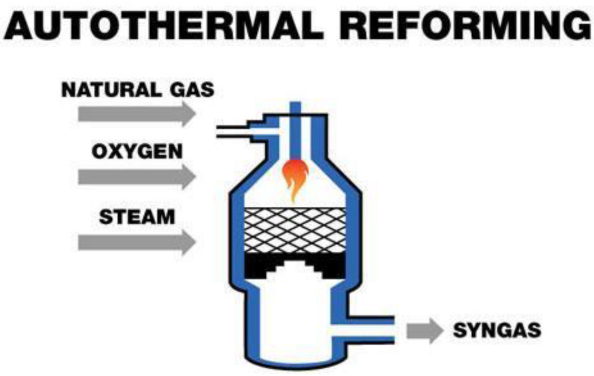


Figure 124:Autothermal reforming combines steam reforming and partial oxidation to produce hydrogen-rich syngas efficiently[167].

3. Gasification

Gasification produces hydrogen by processing substances such as coal or biomass under high temperature and pressure[168]. During this process, gases such as hydrogen, carbon monoxide and methane are released. If biomass is used, it is important to remove moisture to increase yields.

4. Pyrolysis

Pyrolysis allows hydrogen to be obtained by breaking down organic substances by exposing them to high temperatures in an oxygen-free and waterless environment. It is generally used for the purpose of evaluating organic wastes and takes place at low temperatures[169].

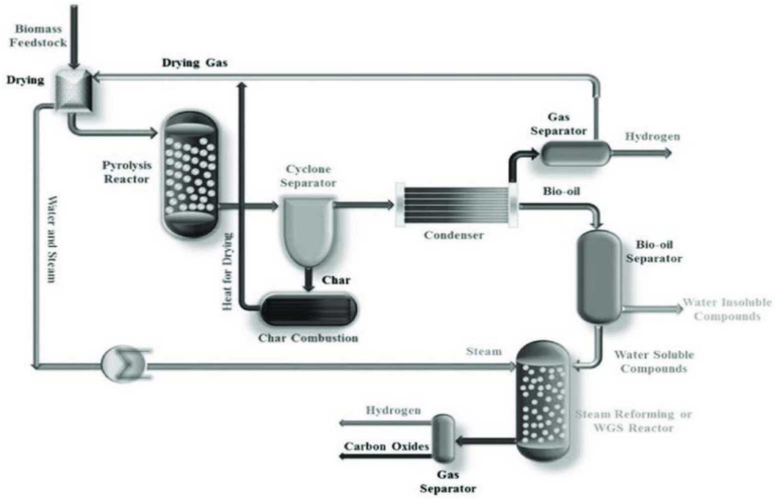


Figure 126:Pyrolysis converts biomass into hydrogen by thermally decomposing it in an oxygen-free environment, followed by gas separation and steam reforming[169].

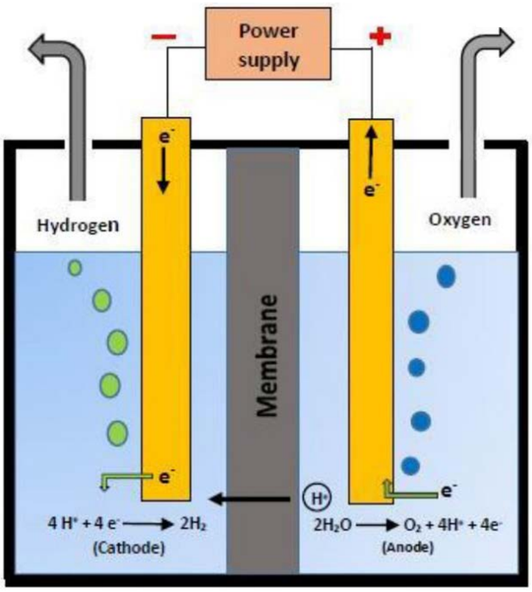


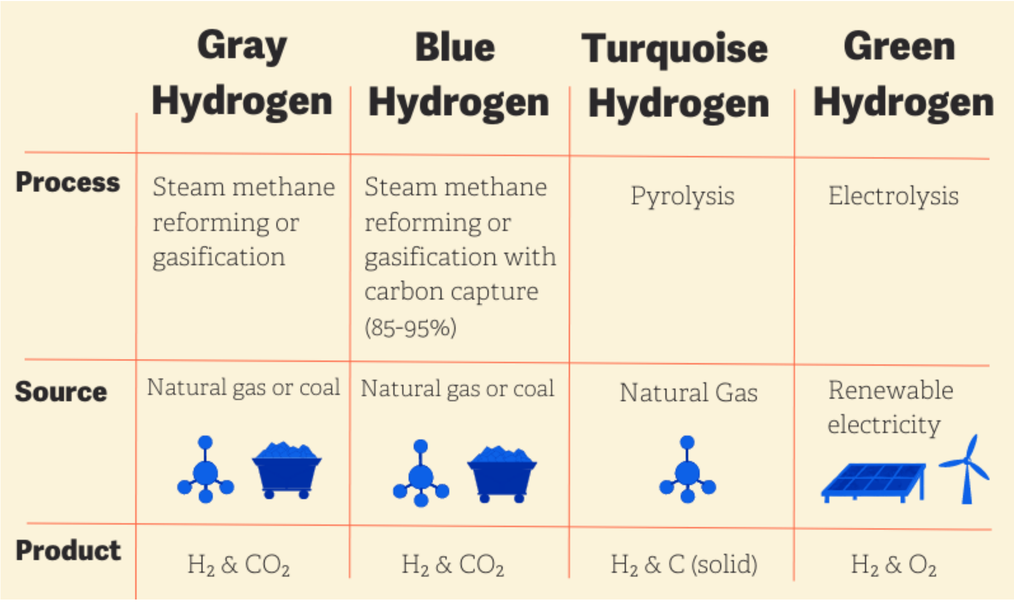
Figure 127: Electrolysis splits water into hydrogen and oxygen using electrical energy, producing clean hydrogen without carbon emissions[170].

5. Electrolysis

Electrolysis is the process of splitting water molecules into hydrogen and oxygen using electric current[170]. This method becomes an environmentally friendly and sustainable method of hydrogen production, especially when combined with renewable energy sources such as solar and wind. Hydrogen produced by electrolysis is a clean and carbon-free energy source.

6.8.2. Green Hydrogen

Green hydrogen is a type of hydrogen that is produced with renewable energy sources without harming the environment. This is much more environmentally friendly compared to fossil fuels, as there are no carbon emissions during production. Renewable energy sources such as solar energy, wind energy, and biomass are used for the production of green hydrogen[171].



	Gray Hydrogen	Blue Hydrogen	Turquoise Hydrogen	Green Hydrogen
Process	Steam methane reforming or gasification	Steam methane reforming or gasification with carbon capture (85-95%)	Pyrolysis	Electrolysis
Source	Natural gas or coal	Natural gas or coal	Natural Gas	Renewable electricity
Product	H_2 & CO_2	H_2 & CO_2	H_2 & C (solid)	H_2 & O_2

Figure 128: Hydrogen is classified by production method: green hydrogen is the cleanest form, generated via electrolysis using renewable energy without carbon emissions[171].

Four main energy sources play a role in the production of green hydrogen:

1. **Heat energy** – It can be obtained from fossil fuels or renewable energy sources.
2. **Electrical energy** – It is used in the electrolysis process by providing it from sources such as solar panels and wind turbines.
3. **Photon energy** – It is used in the production of hydrogen directly from sunlight.
4. **Biochemical energy** – Organic substances are enabled to produce hydrogen through natural processes.

6.8.2.1. Hydrogen Production from Solar Energy

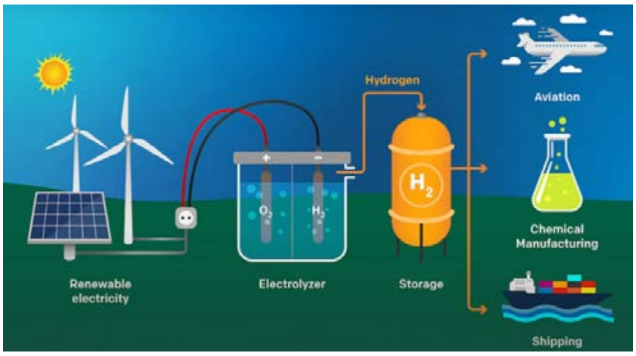


Figure 129: Solar-powered electrolysis enables green hydrogen production for use in aviation, shipping, and chemical industries.

There are four basic methods for producing hydrogen using solar energy: photovoltaic, thermal energy, photo-electrolysis and bio-photolysis. Solar energy can be used in the production of hydrogen by converting it into electricity or heat through various systems[172]. PV systems produce hydrogen by electrolysis of water by converting sunlight directly into electricity. Solar collectors and concentrated solar energy (CSP) systems, on the other hand, help to obtain hydrogen through thermochemical processes by producing high temperatures. The photo-electrolysis method allows water to decompose into hydrogen and oxygen using sunlight directly, while in the bio-photolysis process, some microorganisms produce hydrogen naturally using sunlight.

6.8.3. Purification of Hydrogen

Various purification methods are used to obtain only pure hydrogen in the gas mixtures that emerge during hydrogen production. These methods increase the purity of hydrogen, allowing it to be used more efficiently and safely[173].

- **Pressure Swing Adsorption (PSA):** The hydrogen in the gas mixture is purified by passing it through special filters. This method is one of the most widely used methods for obtaining high-purity hydrogen.
- **Gas Filtration (Membrane Technology):** Separation is done by filtering hydrogen molecules through special membranes (membranes). This method is energy-efficient and quick.
- **Adsorption:** Solid surfaces attract certain gases, allowing hydrogen to be separated from other gases.
- **Absorption:** Chemical solutions help purify hydrogen by retaining certain gases.
- **Distillation: Hydrogen** is separated by taking advantage of the differences in the boiling points of different gases.

> Thanks to these methods, high purity hydrogen can be obtained and used more efficiently in fuel cells, industrial processes and energy systems.

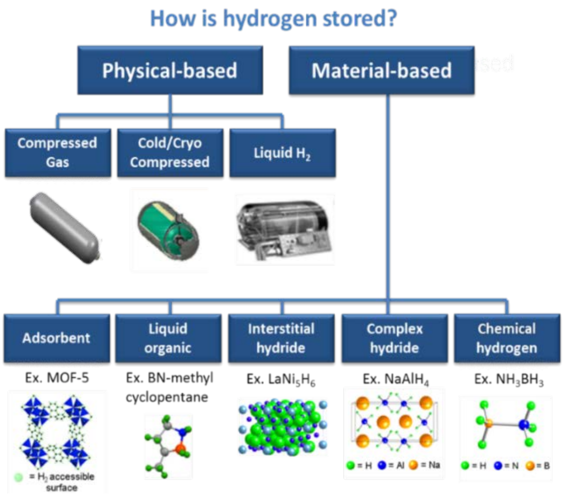


Figure 130: Hydrogen can be stored physically as gas or liquid, and materially through chemical bonding or solid-state hydrides for efficient and safe energy use[174].

6.8.4. Storage of Hydrogen

Efficient storage of hydrogen is of great importance for sustainable energy systems. Since hydrogen gas is very light and low density, special techniques have been developed to store a sufficient amount of energy. Hydrogen is usually stored in three different ways[174]:

1. **Storage as Gas:** Hydrogen can be stored in high-pressure cylinders. Metal tanks or durable glass fiber-wrapped tanks ensure the safe transport of hydrogen.
2. **Storage as Liquid:** Hydrogen is cooled down to -253°C to make it liquid. This method allows more hydrogen to be stored in less volume, but requires extra energy to maintain low temperatures.
3. **Chemical Storage:** It can be stored by binding with chemical compounds such as hydrogen, ammonia or boron hydride. When necessary, hydrogen gas is obtained again by separating from these compounds.

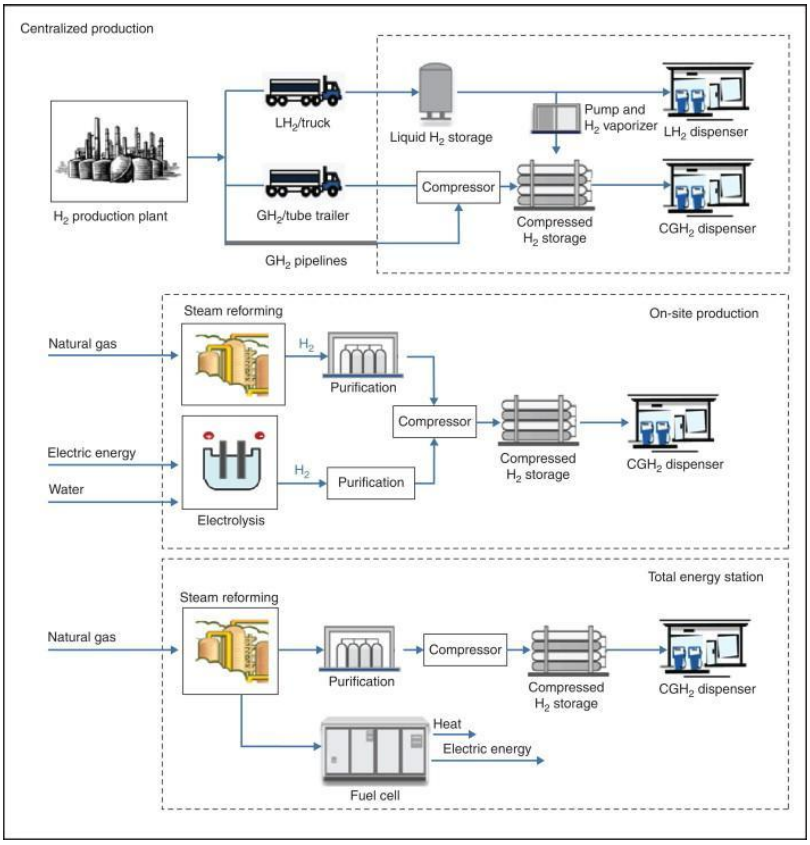


Figure 131: Hydrogen can be produced centrally or on-site, then distributed via pipelines, tankers, or dispensers after compression and storage[175].

6.8.5. Transmission and Distribution of Hydrogen

Once hydrogen has been produced, it needs to be delivered safely and efficiently to the point of use. For this, pipelines, tankers and special transport systems are used[175].

- **Transportation by Pipelines:** Hydrogen can be transported by pipelines directly from the place of production to the points of consumption. Existing natural gas pipelines can be adapted to transport hydrogen in some cases.
- **Transportation by Tankers:** Liquid hydrogen can be transported by specially insulated tankers. This method facilitates the transport of hydrogen over long distances.
- **Transport by Chemical Compounds:** Hydrogen can be transported more safely and efficiently by storing it in compounds such as ammonia or methanol. Hydrogen can then be separated from these compounds again.

To ensure the widespread use of hydrogen, it is important to increase the number of supply stations and improve safety standards. The proliferation of refueling points, especially for hydrogen-powered vehicles, will contribute to the growth of the hydrogen economy.

6.8.6. Fuel Cells

Fuel cells directly generate electricity as a result of the electrochemical reaction of hydrogen and oxygen. This system is the opposite of electrolysis of water to produce hydrogen and oxygen. In fuel cells, hydrogen is used as fuel, and only water is released as a result of the reaction. Therefore, fuel cells are an environmentally friendly and highly efficient energy production technology[176]. A fuel cell is basically made up of three main components:

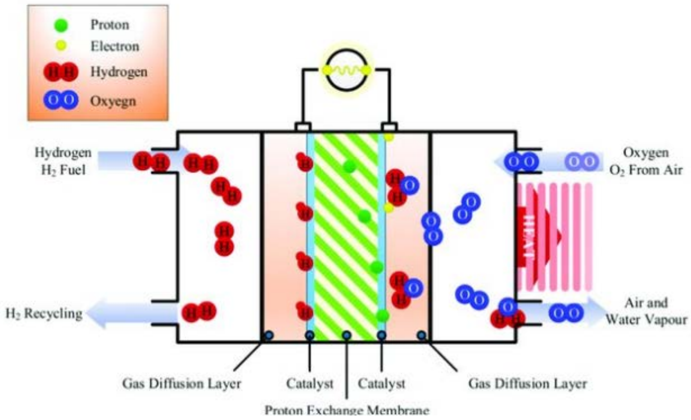


Figure 132: Fuel cells generate electricity through the electrochemical reaction of hydrogen and oxygen, producing only water as a by-product[176].

- **Anode (negative electrode):**
  Hydrogen is oxidized here and broken down into protons and electrons.
- **Cathode (positive electrode):** Oxygen combines with electrons here to form water.
- **Electrolyte:** It allows protons to move between the anode and cathode.

The electrons resulting from this process move in the external circuit and produce electrical energy. Fuel cells can run non-stop when hydrogen is continuously supplied.

Fuel cells are divided into different categories based on the electrolyte material used and the operating temperature:

Polymer Electrolyte Membrane Fuel Cell (PEMFC): Operates at low temperature, suitable for portable devices and vehicles.

Alkaline Fuel Cell (AFC): Used in spacecraft, it is highly efficient.

Phosphoric Acid Fuel Cell (PAFC): Operates at medium temperature, suitable for large-scale power generation.

Solid Oxide Fuel Cell (SOFC): It works at high temperature, it is preferred in industrial applications.

Molten Carbonate Fuel Cell (MCFC): It is used in power plants that require high temperatures.

Direct Methanol Fuel Cell (DMFC): Uses liquid methanol, suitable for portable electronic devices.

Zinc Air Fuel Cell (ZAFC): It is used in lightweight and portable energy solutions.

Proton Ceramic Fuel Cell (PCFC): It works efficiently at high temperatures.

Fuel cells have a wide range of uses, from electric vehicles to portable power systems to large power plants.

6.8.7. Trigeneration (Electricity-Heat-Hydrogen)

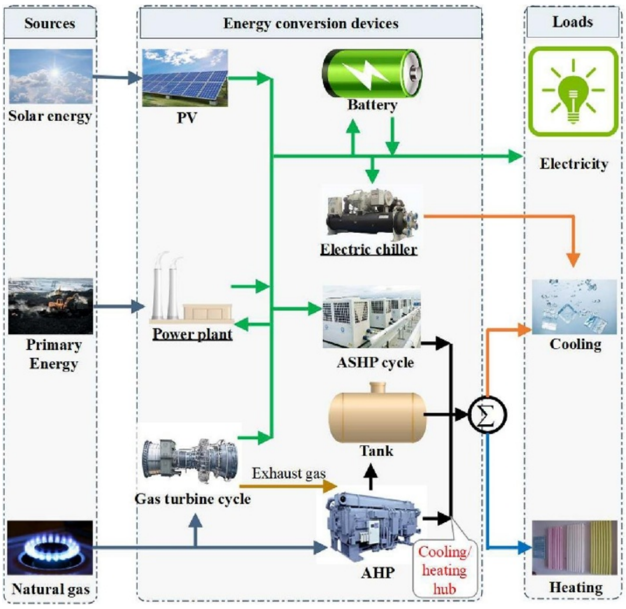


Figure 133: Trigeneration systems integrate electricity, heat, and hydrogen production, enhancing energy efficiency through renewable sources and smart energy management[177].

Trigeneration is an energy technology that enables the production of electricity, heat and cooling within the same system. While conventional cogeneration systems only generate electricity and heat, trigeneration systems can additionally produce cooling or hydrogen[177].

Trigeneration systems based on renewable energy sources offer great advantages in terms of sustainable energy production. For example:

- **Electricity generation:** The system can generate electricity through generators using hydrogen or natural gas as fuel.
- **Heat recovery:** The waste heat generated during production can be used to heat buildings or industrial plants.
- **Hydrogen production:** Excess energy can be used to produce hydrogen by electrolysis of water. This hydrogen can be stored and used as fuel.

These systems help reduce carbon emissions while increasing energy efficiency. Trigeneration technology, which is widely used especially in large facilities, hospitals and industrial enterprises, plays an important role in creating a more sustainable energy infrastructure in the future.

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