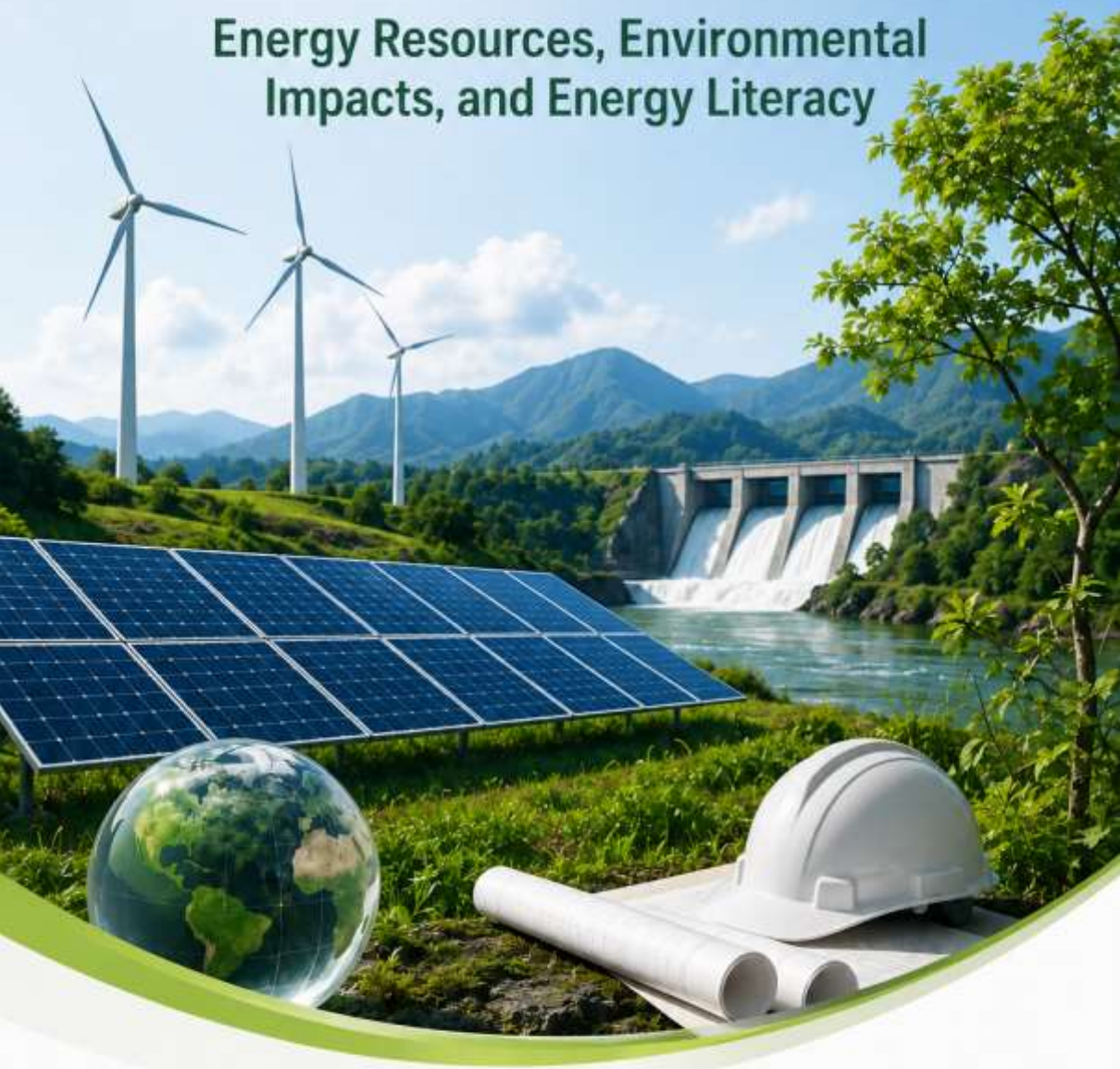
# ENERGY AND SUSTAINABILITY:

## Energy Resources, Environmental Impacts, and Energy Literacy



**Editor:**
**Prof. Dr. Hülya KARA SUBAŞAT**

All Sciences Academy

# ENERGY AND SUSTAINABILITY:
# Energy Resources, Environmental Impacts, and Energy Literacy

**Editor: Prof. Dr. Hülya KARA SUBAŞAT**

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***ENERGY AND SUSTAINABILITY***

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Editor: *Prof. Dr. Hülya KARA SUBAŞAT*

**Design:** All Sciences Academy Design
**Publication Date:** June 2026
**Publisher's Certificate Number:** 72273
**ISBN:** 978-625-8993-92-9
**Doi:** https://doi.org/10.5281/zenodo.21125290

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**Project Partners and Chapter Contributors**

This book was edited by Prof. Dr. Hülya Kara Subaşat. The preparation of the book also benefited from the academic, educational, and project-based contributions of the GREENLIGHT project team.

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## ACKNOWLEDGEMENTS AND PROJECT INFORMATION

This book has been prepared by drawing on the knowledge, experience, and educational outputs developed within the framework of the Erasmus+ project entitled **GREENLIGHT: Generating Renewable Energy Education Network Leading Initiatives for Green & Harmonious Tomorrows**

**Project number:** 2023-2-TR01-KA220-SCH-000180691

The GREENLIGHT project aims to develop innovative learning resources for teachers and students in the fields of renewable energy education, energy literacy, sustainability, and environmental awareness. This book seeks to expand the knowledge and experience generated within the project into an academic book format and to contribute to the fields of energy education, sustainability, and environmental awareness.

The editor gratefully acknowledges the academic, educational, and project-based contributions of the GREENLIGHT project team and chapter contributors. Their expertise, feedback, educational experience, project activities, and country-specific perspectives helped enrich the content, examples, and international dimension of this publication.

The views expressed in this publication are solely those of the editor and contributors. The European Union, the European Commission, and the Turkish National Agency cannot be held responsible for the content of this publication or for any use that may be made of the information contained herein.

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## PREFACE

Dear Readers,

Energy is one of the most fundamental issues shaping modern society. It affects daily life, industry, transportation, education, technology, and environmental policies. Beyond its technical dimension, energy also has environmental, economic, social, and ethical aspects. For this reason, understanding energy resources, energy transformations, and their impacts is essential for building a sustainable future.

This book has been prepared to present the relationship between energy and the environment in a clear, accessible, and scientifically reliable way. It introduces the basic concepts of energy, energy literacy, and the criteria used to evaluate energy resources, followed by a comparative discussion of renewable and non-renewable energy sources.

Renewable energy technologies such as solar, wind, hydropower, geothermal, marine and ocean energy, biomass, and biofuels are examined in terms of their operating principles, applications, advantages, limitations, and environmental impacts. Green hydrogen is also discussed as a complementary energy carrier that can support integrated renewable energy systems.

A central aim of this book is to promote energy literacy. Energy literacy involves not only acquiring knowledge, but also understanding the environmental and social consequences of energy use, comparing energy alternatives, making informed decisions, and supporting responsible actions for sustainability.

Clear language, comparative explanations, chapter summaries, and review questions have been included to support learning and critical thinking, and to encourage awareness of sustainable choices in everyday life. I hope this book will be a useful resource for students, teachers, academics, professionals, policy makers, and all readers interested in energy and environmental issues.

Prof. Dr. Hülya KARA SUBAŞAT

**ABSTRACT**

This book examines energy resources and their environmental impacts through the lens of sustainability and energy literacy. It aims to provide a clear, comparative, and scientifically grounded framework for understanding how energy is produced, transformed, used, and evaluated in relation to environmental responsibility and social decision-making. Rather than treating energy as a purely technical subject, the book emphasizes its environmental, economic, social, and educational dimensions. The book discusses non-renewable and renewable energy resources with attention to climate change, air pollution, energy security, life-cycle effects, social acceptance, cost, continuity, and just transition. Renewable energy technologies, including solar, wind, hydropower, geothermal, marine and ocean energy, biomass, and biofuels, are evaluated in terms of their opportunities, limitations, and planning requirements. Green hydrogen is also positioned as a complementary energy carrier that can support integrated renewable energy systems. Selected examples from Türkiye, Greece, Portugal, and North Macedonia further illustrate that energy transitions depend on local resources, infrastructure, policy priorities, and levels of social awareness. By combining scientific knowledge with sustainability awareness, the book seeks to strengthen energy literacy and support informed, responsible, and evidence-based decision-making. It emphasizes that energy issues should be approached not only through technical knowledge, but also through environmental responsibility, scientific thinking, social participation, and responsible decision-making.

*Keywords - Energy, environment, renewable energy, energy literacy, sustainability, climate change, energy efficiency, green hydrogen, integrated energy systems.*

# INTRODUCTION

Energy is one of the fundamental components of human life and modern societies. Lighting, heating, transportation, industrial production, agriculture, health services, communication technologies, and education systems largely depend on the use of energy. Many activities that appear ordinary in daily life are made possible through the use of different energy resources and the transformation of energy from one form into another.

Energy, however, is not only a technical issue. It is a multidimensional field with environmental, economic, social, political, and ethical aspects. Which energy resources are used, how these resources are produced, who has access to energy, and what kinds of environmental impacts arise from energy use are central questions for sustainable development. Therefore, understanding energy does not merely mean becoming familiar with electricity generation technologies; it also requires understanding the relationships among human activities, the natural environment, economic development, and social welfare.

Since the Industrial Revolution, the world economy has developed largely on the basis of fossil fuels such as coal, oil, and natural gas. These resources have provided significant opportunities for economic growth, urbanization, transportation, and industrial production. However, their intensive use has also led to major problems such as climate change, air pollution, ecosystem degradation, dependence on energy imports, and resource depletion (Energy Institute, 2024; Intergovernmental Panel on Climate Change [IPCC], 2023).

In response to these problems, renewable energy resources have gained increasing importance. Solar, wind, hydropower, geothermal energy, biomass, and marine-ocean energy offer important opportunities for lower-carbon and more sustainable energy systems. Green hydrogen produced using renewable electricity can also support these systems as a complementary energy carrier (International Renewable Energy Agency [IRENA], 2024). However, the energy transition does not simply mean replacing fossil fuels with renewable sources. Energy efficiency, storage technologies, smart grids, environmental planning, social awareness, financing, technological capacity, and just transition policies are also integral components of this transformation (International Energy Agency [IEA], 2024; International Labour Organization [ILO], 2016).

When properly planned, renewable energy resources can reduce dependence on fossil fuels, lower greenhouse gas emissions, contribute to energy security, and support local development. Nevertheless, each resource has distinct advantages and limitations. Solar and wind energy require storage and grid planning because of their variable generation characteristics. Hydropower may affect water regimes, ecosystem balance, and local communities. Geothermal energy requires careful planning in terms of resource management, reinjection, and local environmental impacts. The

sustainability of biomass and biofuels depends on feedstock sources, land use, and life-cycle emissions. Hydrogen, on the other hand, is not a direct primary energy source; rather, it is an energy carrier whose environmental impact varies depending on the source from which it is produced (IEA, 2025; NREL, 2021).

For this reason, renewable energy resources should not be regarded as technologies that solve all energy and environmental problems on their own. A sustainable energy system requires a holistic approach in which different energy resources complement one another and in which energy efficiency, storage, smart grids, environmental impact assessment, and social participation are addressed together (IEA, 2024; IRENA, 2024).

Energy literacy becomes particularly important within this context. It can be understood as the capacity of individuals to understand energy, energy resources, energy transformations, and the environmental and social impacts of energy use. It is not limited to acquiring information about energy; rather, it is addressed in the current literature as a multidimensional competence that includes knowledge, attitudes, behavior, decision-making, sustainability awareness, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023).

Energy-related decisions appear in many areas of everyday life, including the efficiency of household appliances, transportation choices, heating and cooling habits, consumption patterns, waste management, and energy-saving practices in schools and workplaces. Yet energy systems are often invisible. It is not always easy to recognize which source electricity is generated from, what environmental costs are associated with a given fuel, under which conditions renewable energy technologies are more effective, or why energy efficiency matters (DeWaters et al., 2013; Santillán and Cedano, 2023).

Energy issues are also important areas of socio-scientific debate. Climate change, energy security, energy poverty, renewable energy investments, nuclear energy, the phase-out of fossil fuels, hydropower projects, the siting of wind turbines, and the impacts of biofuels on land use cannot be explained solely through technical calculations. These issues require scientific knowledge as well as ethical evaluation, evidence-based reasoning, comparison of different viewpoints, understanding of uncertainties, and participation in public decision-making processes (Sadler, 2004; Zeidler et al., 2005).

This book addresses energy resources through an accessible, comparative, and critical perspective by taking the relationship between energy and the environment as its point of departure. It evaluates energy resources not only in terms of their advantages, but also in terms of their limitations, environmental impacts, life-cycle consequences, and economic and social dimensions. In doing so, the book aims to support energy literacy and encourage informed, responsible, and evidence-based decision-making.

Educational approaches such as STEM education, inquiry-based learning, gamification, activities based on local environmental problems, and green skills are considered important tools for supporting energy literacy. Solar panels, wind turbines, hydroelectric systems, biomass applications, and hydrogen technologies are not only technical topics for students; they are also learning opportunities that encourage reflection on the environment, the economy, engineering, society, and the future (Hiğde, 2022; Mylonas et al., 2021; Vasconcelos et al., 2023).

The examples of Türkiye, Greece, Portugal, and North Macedonia show that the energy transition varies according to local conditions, including renewable energy potential, policy priorities, infrastructure capacity, and levels of social awareness (IEA, 2024; IRENA, 2024). Therefore, this book evaluates energy resources not only in terms of their general technical characteristics, but also through the educational and social dimensions that emerge in different contexts.

After the Introduction, the first chapter explains fundamental concepts related to energy, the environment, and energy literacy. The second chapter addresses decision-making criteria that can be used to evaluate energy resources. The third chapter examines non-renewable energy resources and their environmental impacts, while the fourth chapter analyzes the environmental, social, and systemic dimensions of the renewable energy transition. The fifth chapter discusses solar, wind, and hydroelectric energy, and the sixth chapter evaluates geothermal, marine and ocean, and bioenergy resources in detail. In the seventh chapter, renewable energy types are compared, green hydrogen is examined as a complementary energy carrier within integrated energy systems, and a general evaluation is provided through selected country examples. The conclusion presents the main findings of the book and their implications for energy literacy in an integrated manner.

The book is intended to provide readers with a balanced, accessible, and scientifically grounded resource on energy and the environment. While technical accuracy is maintained, attention has been paid to the clarity of the language used throughout the text. Tables, comparisons, learning objectives, chapter summaries, and discussion questions have been prepared to strengthen its usability as an educational material. The book is intended for school students, teachers, university students, academics, local decision-makers, professionals working in the fields of energy and the environment, and general readers interested in these issues.

The energy transition is possible not only through the development of new technologies, but also through conscious societies, sound policies, environmental sensitivity, scientific thinking, and a culture of responsible decision-making (IEA, 2024; UNESCO, 2020). This book aims to establish a knowledge-based, critical, and responsible basis for discussion on energy and environmental issues.

# CHAPTER 1: ENERGY AND ENVIRONMENT

Energy is a fundamental input that makes many domains possible, from everyday life to economic production and technological development. Lighting, transportation, heating, industry, agriculture, and communication technologies all depend on the use of energy. Therefore, energy is a multidimensional issue that must be addressed not only in terms of its technical characteristics, but also through its environmental and social consequences. Energy production and consumption create both direct and indirect effects on the natural environment. In particular, the intensive use of fossil fuels leads to major problems such as greenhouse gas emissions, air pollution, water and soil contamination, ecosystem degradation, and climate change (IPCC, 2023). In contrast, renewable energy resources offer important options for sustainable energy systems because they can generally provide lower greenhouse gas emissions throughout their life cycle (IRENA, 2024; NREL, 2021). The relationship between energy and the environment cannot be explained solely by the type of resource used. Production technology, conversion efficiency, level of consumption, access conditions, and the distribution of environmental costs within society are also decisive. Energy decisions should therefore be evaluated together with climate change, sustainability, energy security, and social justice (Schobert, 2002; Zecca and Chiari, 2010).

This chapter examines the concept of energy in relation to its types, transformations, efficiency, climate change, carbon footprint, and energy education. Its aim is to help readers evaluate energy not merely as a physical quantity, but as a systems issue connected to everyday life, the environment, and decision-making processes (Box 1.1).

Box 1.1. What will be learned in this chapter

| **Learning Objective** |
|---|
| Define energy as the capacity to do work and relate it to examples from everyday life. |
| Compare chemical, electrical, thermal, mechanical, light, and nuclear energy through examples. |
| Explain the law of conservation of energy and efficiency losses in energy transformations. |
| Evaluate knowledge, attitudes, behaviours, and decision-making dimensions related to energy together. |
| Discuss the effects of energy production and consumption on climate, air quality, ecosystems, and society. |
| Establish links among energy efficiency, carbon footprint, greenhouse gas emissions, and responsible consumption. |

### *1.1. Definition and Types of Energy*

Energy, in its broadest sense, is defined as the capacity to do work. In physical systems, energy may exist in different forms and can be transformed from one form into another. Thermal energy, light energy, chemical energy, mechanical energy, electrical energy, and nuclear energy are among these forms of energy (U.S. Department of Energy and American Association for the Advancement of Science [DOE and AAAS], 2017).

Energy is not directly visible in everyday life; rather, it is recognised through its effects. A light bulb producing light, a phone being charged, a vehicle moving, plants carrying out photosynthesis, or a wind turbine rotating are all associated with different types of energy and energy transformations. These examples show that the concept of energy should be understood in relation to both nature and technology (Tsegaw, 2018).

There are different forms of energy. Chemical energy is stored in the bonds of substances; food, batteries, and fuels are examples of this type. Electrical energy is associated with the movement of electric charges and is used in lighting, communication technologies, and household appliances. Thermal energy is related to temperature and the motion of molecules. Mechanical energy is associated with motion and position; bicycles, flowing water, and wind turbines can be given as examples. Light energy is carried by electromagnetic waves. Nuclear energy is the energy stored in the atomic nucleus (DOE and AAAS, 2017).

Table 1.1 shows that energy can exist in different forms and that these forms are often intertwined in everyday life. This distinction provides a basis for comparing energy resources in later chapters.

Table 1.1. Types of energy and examples from everyday life

| Type of Energy | Brief Explanation | Example from Everyday Life |
|---|---|---|
| Chemical energy | Energy stored in the bonds of substances. | Battery, fuel, food |
| Electrical energy | Energy associated with the movement of electric charges. | Lighting, phone charging, household appliances |
| Thermal energy | Energy associated with temperature and the motion of molecules. | Heater, stove, sunlight |
| Mechanical energy | Energy associated with motion and position. | Bicycle, wind turbine, flowing water |
| Light energy | Energy carried by electromagnetic waves. | Sunlight, lamp |
| Nuclear energy | Energy stored in the atomic nucleus. | Nuclear power plant, fusion reactions in the Sun |

### *1.2. Energy Literacy and Misconceptions about Energy*

Although energy is frequently used in everyday language, it is an abstract concept and may therefore lead to various misconceptions. Considering energy as a tangible substance, as something that completely disappears, or as merely electricity and fuel makes it difficult to evaluate energy resources, efficiency, and environmental impacts accurately (Wahlund and Palm, 2022). In this context, energy literacy refers to the competence to understand energy concepts and resources and to use this knowledge to make responsible decisions in everyday life and at the societal level. In the literature, this concept includes not only knowledge, but also attitudes, behaviours, critical thinking, and decision-making dimensions (DeWaters and Powers, 2011; DeWaters et al., 2013; DOE and AAAS, 2017).

Energy education should reduce these misconceptions and demonstrate that energy is a quantity that is transformed, transferred, stored, and produces environmental consequences in different systems. The most common misconceptions include the ideas that energy can disappear, that electricity and energy are the same thing, that renewable resources have no impact at all, or that energy efficiency simply means saving energy (Lee, 2016; Tatar and Oktay, 2007)..

Box 1.2 makes visible the difference between the everyday use of the concept of energy and its scientific meaning. This distinction facilitates a more accurate evaluation of energy resources and environmental impacts in subsequent topics.

Box 1.2. Common misconceptions about energy

| Common Misconception | Correct Explanation | Educational Emphasis |
|---|---|---|
| Energy disappears or is lost. | Energy is not destroyed; it is transformed from one form into another. However, usable energy may decrease, and energy is often dispersed into the environment as heat. | Conservation of energy and energy transformation should be taught together. |
| Energy is like a tangible substance. | Energy is not a concrete substance, but a physical quantity that describes the state of systems and their capacity to do work. | Energy should not be treated as synonymous with fuel or electricity. |
| When energy is consumed, it is completely used up. | Although everyday language refers to “energy consumption,” energy is not physically destroyed; it is transformed into less usable forms. | The phrase “energy consumption” should be explained as a decrease in usable energy. |
| Electricity is always clean energy. | The environmental impact of electricity depends on how it is generated. Electricity produced from coal does not have the same environmental impact as electricity produced from solar or wind energy. | The distinction between an energy carrier and an energy source should be made clear. |

| Common Misconception | Correct Explanation | Educational Emphasis |
|---|---|---|
| Renewable energy resources do not harm the environment at all. | Renewable energy resources generally have lower environmental impacts than fossil fuels; however, land use, material requirements, ecosystem effects, and recycling must also be considered. | The concepts of "low impact" and "no impact" should be distinguished. |
| Energy efficiency simply means using less energy. | Energy efficiency means performing the same task or providing the same service by using less energy. It does not necessarily reduce quality of life. | Efficiency, saving, and behavioural change should be addressed together. |
| Hydrogen is directly a clean energy source. | Hydrogen is mostly an energy carrier. Whether it is clean depends on how it is produced. Green hydrogen produced with renewable electricity can be low-emission. | The distinction between primary energy sources and energy carriers should be emphasised. |
| Biomass and biofuels are always carbon neutral. | The environmental impact of biomass and biofuels depends on feedstock, land use, transport distance, and production method. | A life-cycle approach should be used. |
| Solar and wind are unreliable because they are variable. | Solar and wind are variable resources; however, they can be integrated reliably into the energy system through storage, grid flexibility, resource diversity, and demand management. | Energy systems should be evaluated through the energy mix rather than a single source. |
| Energy problems can be solved only through new production technologies. | The energy transition is not only about production; it also requires energy efficiency, conservation, storage, grid management, social acceptance, and conscious consumption. | Energy literacy should include technical, environmental, and social dimensions together. |

### *1.3. Energy Transformations: Conservation, Efficiency, and Environmental Consequences*

One of the most fundamental properties of energy is that it cannot be created from nothing and cannot be completely destroyed. According to the law of conservation of energy, energy is transformed only from one form into another. In a light bulb, electrical energy is transformed into light and heat energy; in an automobile, the chemical energy of fuel is transformed into motion and heat; and in a solar panel, sunlight is transformed into electrical energy. Everyday life and energy technologies are based on these transformations. In wind turbines, the kinetic energy of air is first transformed into mechanical energy and then into electrical energy. In hydroelectric power plants, the potential and kinetic energy of water are converted into electrical energy through turbines. In geothermal systems, heat from the Earth's crust can be used directly for heating or for electricity generation. During transformation, part of the energy often disperses into the environment as heat

and becomes less usable. This situation shows that efficiency, storage, grid management, and technology choice are directly connected to environmental consequences (Maka and Alabid, 2022).

### *1.4. Energy Use and Environmental Impacts*

Industrialisation has largely been made possible by fossil fuels, which have provided significant advantages for production, transportation, and urbanisation. However, the same systems have also increased problems such as greenhouse gas emissions, air pollution, and pressure on ecosystems. The extraction, transportation, processing, and combustion of coal, oil, and natural gas affect both climate and the local environment through carbon dioxide, methane, nitrogen oxides, and various pollutants. For this reason, the impact of fossil fuels should be evaluated not only at the use stage, but also throughout the entire production chain. This approach also applies to renewable technologies. Raw material extraction, power plant construction, transmission lines, maintenance, waste management, and recycling processes can produce environmental consequences within the life cycle of energy systems (IEA, 2024; NREL, 2021).

Renewable energy resources generally have lower greenhouse gas emissions than fossil fuels and play an important role in combating climate change. Nevertheless, issues such as panel production, materials for wind turbines, aquatic ecosystems in hydroelectric projects, and land use in biomass should be included in the planning process (Abbasi et al., 2011). Energy demand increases with population growth, urbanisation, industrialisation, technological development, and rising living standards. Energy policies should therefore secure supply while also considering demand management and environmental impacts.

From a sustainability perspective, the main objective is to establish an energy system that meets today's energy needs without endangering the living conditions of future generations (World Commission on Environment and Development [WCED], 1987). In line with this objective, three main approaches come to the fore:

- Reducing energy consumption,
- Using energy more efficiently,
- Expanding low-carbon and renewable energy resources instead of fossil fuels.

When these three approaches are implemented together, environmental damage can be reduced and a safer energy system can be established (IRENA, 2024).

Figure 1.1 summarises how the relationship between energy demand and production methods shapes environmental consequences. Sustainable

energy policies should therefore focus not only on choosing new resources, but also on reducing demand and using energy efficiently.

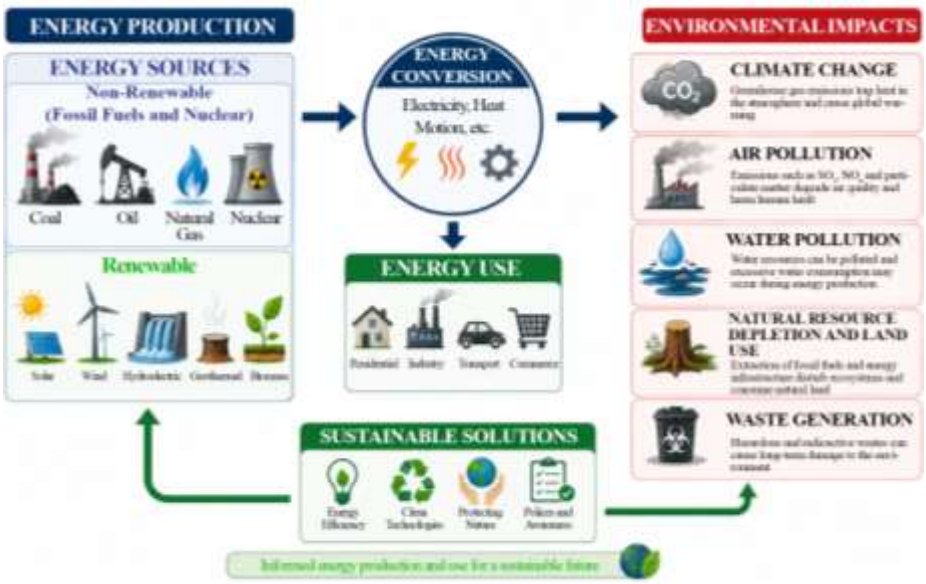


Figure 1.1. Basic relationship between energy production and environmental impacts

### *1.5. Climate Change and Carbon Footprint*

Climate change refers to long-term changes in the Earth's climate system. These changes may result in rising temperatures, changes in precipitation patterns, droughts, floods, sea-level rise, melting glaciers, forest fires, and an increase in extreme weather events. Although climate change can be influenced by natural processes, the main reason for the rapid change observed today is greenhouse gas emissions resulting from human activities (IPCC, 2023). A significant share of anthropogenic greenhouse gas emissions is related to energy production and consumption. The combustion of fossil fuels increases carbon dioxide emissions, while methane leaks, industry, transportation, agriculture, and waste management also contribute to total emissions.

Climate change has a two-way relationship with energy systems. On the one hand, fossil fuel-based energy production accelerates climate change. On the other hand, climate change can also affect energy systems. Droughts may reduce hydroelectric generation; heat waves may increase cooling demand; and extreme weather events may damage electricity transmission lines, energy infrastructure, and fuel supply chains. Therefore, energy systems must be planned in a way that is both low-carbon and resilient to climate risks.

Carbon footprint refers to the total amount of greenhouse gases released into the atmosphere as a result of the activities of an individual, institution, product, service, or society (Allegretti et al., 2022; Uydur, 2024). This concept includes not only direct energy consumption, but also transportation, diet, consumption habits, the production processes of goods used, waste generation, and supply chains. For example, the carbon footprint of a product is evaluated not only during its use, but also together with emissions generated during raw material extraction, production, transportation, packaging, use, and disposal stages. Individual behaviours are important in reducing carbon footprints; however, lasting outcomes require changes in energy infrastructure, urban planning, production technologies, public policies, and institutional practices together (Adewuyi and Awodumi, 2017).

The practices in Table 1.2 can help reduce environmental impacts in everyday life. However, the carbon footprint is related not only to individual preferences, but also to structural conditions.

Table 1.2. Example practices for reducing carbon footprint

| Area | What Can Be Done? | Possible Effect |
|---|---|---|
| Transportation | Public transport, cycling, walking, or car sharing can be preferred. | Fuel consumption and transportation-related emissions decrease. |
| Domestic energy use | LED bulbs, efficient appliances, and good insulation can be used. | Electricity and heating demand decrease. |
| Consumption habits | Long-lasting, repairable products with less unnecessary packaging can be preferred. | Production- and waste-related emissions decrease. |
| Diet | Local, seasonal, and lower-impact products can be preferred. | Environmental impacts from transport and production may decrease. |
| Waste management | Recycling, reuse, and waste reduction can be practised. | Resource consumption and waste-related emissions decrease. |
| Energy choice | Renewable energy resources can be preferred whenever possible. | Dependence on fossil fuels and greenhouse gas emissions decrease. |

### *1.6. Greenhouse Effect and Anthropogenic Greenhouse Gases*

The greenhouse effect is a natural process that enables the Earth to maintain temperature conditions suitable for life (Al-Ghussain, 2019). Some of the radiation from the Sun passes through the atmosphere and reaches the Earth's surface. The Earth's surface absorbs part of this energy and later emits it back into the atmosphere as heat. Greenhouse gases in the atmosphere retain part of this heat and help maintain the Earth's surface temperature (IPCC, 2023; United States Environmental Protection Agency [EPA], 2025). Without the natural greenhouse effect, the Earth would be a much colder planet. For

this reason, the greenhouse effect is not a negative process in itself. The problem is that human activities increase the amount of greenhouse gases in the atmosphere and disturb the natural balance by intensifying the greenhouse effect. Activities such as fossil fuel use, industrial processes, deforestation, agriculture, livestock production, and waste management increase greenhouse gas concentrations. This increase leads to more heat being retained in the atmosphere and causes global temperatures to rise.

Figure 1.2 illustrates the basic mechanism of the greenhouse effect and shows how greenhouse gases retain part of the heat emitted from the Earth's surface.

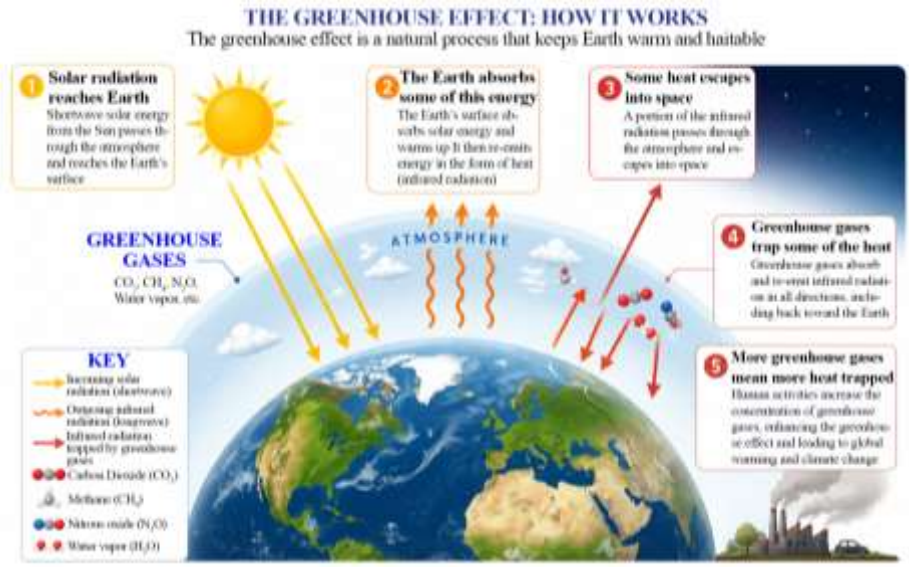


Figure 1.2. Basic functioning of the greenhouse effect

In summary, the problem is not the existence of the natural greenhouse effect, but its strengthening through human activities. As greenhouse gas concentrations increase, risks such as rising temperatures, drought, extreme precipitation, forest fires, and sea-level rise become greater. Energy systems play a central role in this process. Because fossil fuels used in electricity generation, transportation, industry, and buildings increase emissions, the energy transition is one of the main areas of climate policy.

The main greenhouse gases include carbon dioxide, methane, nitrous oxides, and fluorinated gases (Table 1.3). These gases differ in their sources, atmospheric lifetimes, and effects on climate. Carbon dioxide is the most common result of fossil fuel use. Methane remains in the atmosphere for a shorter time but has a strong heat-trapping effect in the short term. Nitrous oxides are particularly associated with agriculture and certain industrial

processes. Fluorinated gases mostly arise from refrigeration systems, air-conditioning technologies, and specific industrial applications (EPA, 2025).

When energy demand is met by fossil fuels, emissions increase. Therefore, demand management, efficiency, and the transition to low-carbon resources should be considered together in efforts to combat climate change (IPCC, 2023). Emission reduction requires transformation not only in electricity generation, but also in transportation, industry, agriculture, buildings, and consumption habits. This transformation can also provide additional benefits in terms of air quality and energy security (EPA, 2025; IEA, 2024).

Table 1.3. Main greenhouse gases and their sources

| Greenhouse Gas | Main Sources | Climate Significance |
|---|---|---|
| Carbon dioxide, $CO_2$ | Fossil fuel use, industry, transportation and deforestation | One of the most important components of anthropogenic greenhouse gas emissions. |
| Methane, $CH_4$ | Agriculture, livestock, waste, leaks from natural gas and oil systems | Has a strong heat-trapping effect in the short term. |
| Nitrous oxide, $N_2O$ | Fertiliser use, agricultural activities and some industrial processes | Can remain in the atmosphere for a long time and contributes to climate change. |
| Fluorinated gases | Refrigeration systems, air-conditioning technologies and some industrial applications | Although emitted in lower quantities, they can create strong greenhouse effects. |

### *1.7. Energy Efficiency and Sustainable Consumption*

Energy efficiency is the capacity to perform the same task or provide the same service by using less energy. In other words, energy efficiency aims to reduce energy consumption while maintaining quality of life, production level, or service quality. More efficient lighting systems, well-insulated buildings, high-efficiency electrical appliances, efficient motors, public transportation systems, and smart energy management practices can be given as examples of energy efficiency.

Energy efficiency is one of the most effective instruments of sustainable energy policy. Providing the same service with less energy can reduce fossil fuel use, greenhouse gas emissions, and energy costs.

Energy efficiency and energy saving are related concepts, but they do not mean the same thing. Energy saving refers to behaviours aimed at reducing energy consumption. For example, turning off unnecessary lights, unplugging unused devices, or choosing to walk short distances are forms of energy saving. Energy efficiency, by contrast, includes technological or structural improvements that provide the same service with less energy (Abas et al., 2015). For example, using an LED bulb instead of an incandescent bulb,

choosing a high energy-class appliance instead of an old refrigerator, or heating a well-insulated building are examples of energy efficiency (Table 1.4).

Table 1.4. Difference between energy saving and energy efficiency

| Concept | Explanation | Example |
|---|---|---|
| Energy saving | Reducing energy consumption through behaviour. | Turning off unused lights |
| Energy efficiency | A technological or systemic improvement that enables the same task to be performed with less energy. | Using LED bulbs |
| Sustainable consumption | Using resources consciously with consideration for future generations. | Reducing unnecessary consumption and choosing durable products |

Energy efficiency is especially important in buildings, transportation, industry, agriculture, and domestic consumption. In buildings, thermal insulation, efficient heating-cooling systems, natural lighting, and high energy-performance building designs can reduce energy demand. In transportation, public transport, electric vehicles, fuel-efficient engines, bicycle lanes, and urban planning are important. In industry, efficient motor systems, waste heat recovery, process improvements, and energy management systems can provide substantial energy savings.

Sustainable consumption means making decisions by considering the environmental and social consequences of energy use. Not only the price of a product, but also the energy used in its production, its raw materials, transport distance, lifetime, repairability, and recycling opportunities are important.

This transformation may begin with individual choices, but it also requires support from institutions and policies. Schools, municipalities, public institutions, and businesses can contribute to the process through efficient buildings, public transport investments, energy labels, standards, renewable energy applications, and education programmes (Table 1.5).

In summary, a sustainable energy transition is not limited to changing production resources. Reducing energy demand, using existing energy efficiently, and meeting the remaining demand with low-carbon resources should be considered together.

Table 1.5. Example practices for improving energy efficiency

| Area | Practice | Expected Contribution |
|---|---|---|
| Lighting | Use of LED lighting and motion sensors | Reduces electricity consumption. |
| Buildings | Thermal insulation, double glazing, and efficient heating-cooling systems | Reduces heating and cooling demand. |
| Household appliances | Preference for appliances with high energy efficiency | Reduces energy costs in the long term. |
| Transportation | Public transport, cycling, walking, and car sharing | Reduces fuel consumption and emissions. |
| Industry | Efficient motors, waste heat recovery, and energy management | Reduces energy intensity in production. |
| Schools | Energy monitoring, student projects, and awareness activities | Strengthens energy literacy. |

### *1.8. Energy Education for a Sustainable Future*

Energy education enables students and society to make sense of the concepts discussed in this chapter. Today, such education should include not only physical concepts, but also issues such as climate change, renewable energy, efficiency, sustainable consumption, and equitable access to energy. In this context, energy literacy is the main goal that combines knowledge with decision-making skills. Energy-literate individuals can compare different resources, discuss environmental impacts, and make more conscious choices in everyday life (Ayata et al., 2024; DeWaters et al., 2013; Leite et al., 2026; Ramachandran et al., 2024; Santillán and Cedano, 2023).

Energy issues provide powerful learning opportunities for science education, environmental education, STEM, and sustainability education. Examples such as electricity generation, fuel use, heating and cooling, transportation, and energy consumption in school buildings make it easier to connect abstract concepts with everyday life (Hiğde, 2022; Mylonas et al., 2021; Vasconcelos et al., 2023).

Energy education is also a suitable domain for socioscientific discussions. Decisions such as installing a wind turbine in a region, constructing a hydroelectric power plant, using nuclear energy, or producing biofuels involve not only technical knowledge, but also environmental impacts, economic costs, social acceptance, and ethical questions. Such discussions can improve students' ability to think with evidence and evaluate different views (Sadler, 2004; Zeidler, 2014).

The STEM approach supports energy literacy through experimentation, design, and data analysis. Building a solar panel model, designing a wind turbine, constructing a simple hydroelectric setup, or measuring a school's energy consumption can help students understand both scientific concepts and the processes of developing sustainable solutions.

Therefore, effective energy education should position students not as passive recipients of information, but as active participants who observe, collect data, propose solutions, and discuss the consequences of energy decisions.

Energy education is not limited to the school environment. Families, municipalities, media, museums, science centres, environmental organisations, and local governments can contribute to more informed public participation in energy debates by supporting access to reliable information (DOE and AAAS, 2017; Ramachandran et al., 2024).

For a sustainable future, the main goal of energy education is not only to encourage individuals to save energy, but also to enable them to evaluate energy systems within the framework of scientific knowledge, environmental sensitivity, technological innovation, and social responsibility (Table 1.6).

Table 1.6. Example activities that can be used in energy education

| Activity | Purpose | Skills Developed |
|---|---|---|
| Measuring energy consumption at home or school | To make energy use visible | Data collection, analysis, awareness |
| Designing a solar panel model | To understand the working principle of solar energy | Design, problem solving, STEM skills |
| Building a wind turbine model | To understand the mechanical-electrical transformation of wind energy | Experimentation, engineering thinking |
| Calculating carbon footprint | To evaluate the environmental impacts of everyday life | Responsible decision-making |
| Discussion comparing energy resources | To identify the advantages and limitations of different resources | Critical thinking, use of evidence |
| Project on a local energy problem | To relate energy issues to society | Participation, research, solution development |

### *1.9. Chapter Summary and Discussion Questions*

This chapter examined the relationship between energy and the environment through fundamental concepts. Types of energy and examples from everyday life provided a conceptual basis for the comparison of resources in subsequent chapters.

Energy transformations are fundamental to many systems, including renewable energy technologies. Because efficiency losses may occur during transformations, energy efficiency has central importance for sustainability. Energy literacy was addressed not only as knowledge of energy concepts, but also as the ability to evaluate environmental, economic, and social consequences, make evidence-based decisions, and develop responsible behaviour.

The relationship of fossil fuels with greenhouse gas emissions, air pollution, ecosystem degradation, and health problems was explained. It was

also emphasised that renewable resources, although generally lower-impact, should be evaluated in terms of life cycle and local conditions.
Climate change, carbon footprint, and the greenhouse effect were examined in connection with energy systems. It was shown that demand management, energy efficiency, transition to low-carbon resources, and sustainable consumption should be addressed together.

Finally, energy education was described as a powerful learning field for science education, environmental education, STEM, and socioscientific discussions. This approach can help individuals evaluate energy decisions more consciously.

***Discussion Questions***

1. Why should energy be evaluated not only as a technical issue, but also as an environmental and social issue?
2. Which examples from everyday life can be used to explain the law of conservation of energy?
3. What is the difference between energy saving and energy efficiency? Why is this distinction important?
4. Although renewable energy resources are considered more environmentally friendly than fossil fuels, why are they not completely impact-free?
5. Can carbon footprint be explained only by individual behaviour? Why?
6. How can climate change affect energy systems?
7. Why is energy literacy not limited to having knowledge only?
8. Which practices can be implemented to improve energy efficiency in a school?
9. Which environmental and social factors should be considered when evaluating a wind turbine or hydroelectric power plant project?
10. How can energy education improve students' responsible decision-making skills for a sustainable future?

# CHAPTER 2: ENERGY RESOURCES

Energy resources are natural resources and transformed forms of energy that people use to meet needs such as heating, lighting, transportation, industry, agriculture, and communication. In this chapter, these resources are examined not only by name, but also in terms of their functions within the energy system and their sustainability implications (DOE and AAAS, 2017; Energy Institute, 2024).

Energy resources are commonly classified as renewable and non-renewable. This distinction provides a useful starting point for learning; however, sustainability cannot be explained by renewal rate alone. Production technology, life-cycle impacts, infrastructure requirements, system flexibility, cost, energy security, and social acceptance are also part of the decision-making process (IRENA, 2024; Wüstenhagen et al., 2007).

This chapter extends the basic concepts discussed in Chapter 1 within the context of energy resources. Its purpose is to provide readers with a comparative evaluation framework before moving to the detailed discussion of non-renewable and renewable resources in Chapters 3 and 4.

Throughout the chapter, environmental impact, life cycle, cost, continuity, energy security, technological feasibility, social acceptance, and fair access are considered together. This approach makes it possible to evaluate resources not through a simple positive-negative distinction, but within an evidence-based and multidimensional decision-making process (DeWaters et al., 2013; Ramachandran et al., 2024; Sovacool and Dworkin, 2015).

This chapter discusses the classification of energy resources, the distinction between primary and secondary energy, energy carriers, major resource groups, decision-making criteria, energy security, social acceptance, and a sustainable energy mix (Box 2.1).

Box 2.1. What will be learned in this chapter

| **Learning Objective** |
|---|
| Distinguish renewable and non-renewable resources according to their basic characteristics. |
| Explain the concepts of primary energy, secondary energy, and energy carrier with examples. |
| Evaluate energy resources in terms of environmental impact, cost, continuity, energy security, and social acceptance. |
| Discuss not only the use phase of an energy resource, but also its impacts from production to waste management. |
| Relate issues such as domestic resources, import dependence, price vulnerability, and energy poverty to energy decisions. |
| Design a balanced energy mix by considering the strengths and limitations of different resources. |

### *2.1. Basic Classification of Energy Resources*

Energy resources can be classified according to different criteria, such as their form in nature, renewal rate, area of use, role in the energy system, environmental impact, and economic cost. In this book, the basic distinction is made between non-renewable and renewable energy resources; however, this distinction is only the first step (DOE and AAAS, 2017; IEA, 2024).

Non-renewable energy resources are resources that exist in limited quantities in nature and are not regenerated within a short period from the perspective of human life. Coal, oil, natural gas, and uranium are included in this group. Although high energy density and developed infrastructure provide important advantages, issues such as climate change, air pollution, ecosystem pressure, external dependence, safety, and waste management must be considered (International Atomic Energy Agency [IAEA], 2024).

Renewable energy resources are resources that can be renewed continuously or within short periods through natural processes. Solar radiation, wind, flowing water, geothermal heat, biomass, and marine-ocean movements are included in this group. Although they are important for low-carbon energy systems, they should also be evaluated together with land use, material requirements, variable generation, ecosystem effects, recycling, and social acceptance (NREL, 2021; Wüstenhagen et al., 2007). Figure 2.1 shows that energy resources can be examined in two main groups. However, classification should not be interpreted as an absolute good-bad distinction; the suitability of resources varies according to the context of use, technology, site selection, cost, and environmental and social consequences.

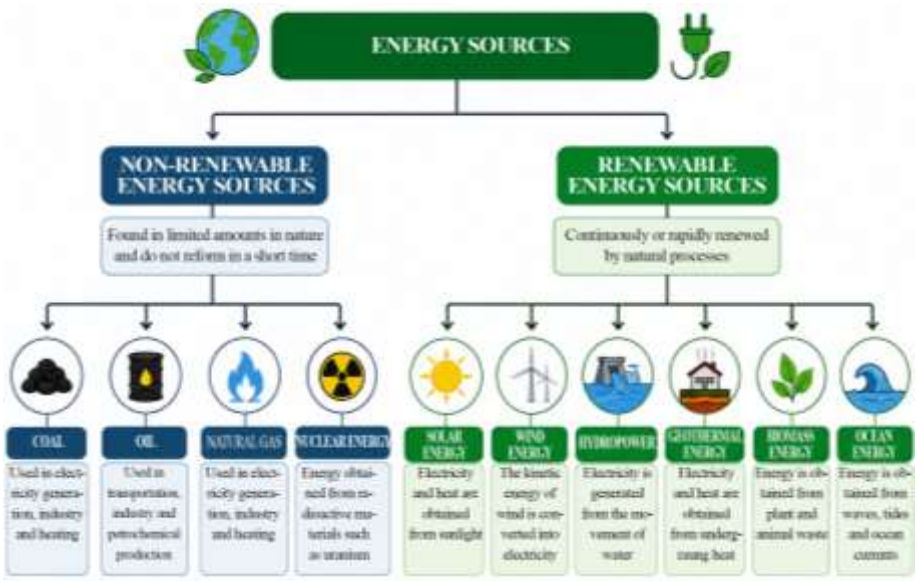


Figure 2.1. Basic classification of energy resources

Table 2.1 compares non-renewable and renewable energy resources in terms of resource status, examples, environmental impacts, energy security, continuity, technological needs, and sustainability. However, energy planning should not be based only on resource type. Technology, scale, local conditions, cost, infrastructure, and social impacts are also decisive. Therefore, the rest of this chapter examines energy resources within a broader decision-making framework.

Table 2.1. Comparison of non-renewable and renewable energy resources

| Characteristic | Non-renewable Energy Resources | Renewable Energy Resources |
|---|---|---|
| Resource status | Limited and not renewed in a short period. | Renewed continuously or within a short period through natural processes. |
| Examples | Coal, oil, natural gas, uranium | Solar, wind, hydropower, geothermal, biomass, ocean energy |
| Environmental impact | Fossil fuels may cause high greenhouse gas emissions and pollution. | Generally, have lower greenhouse gas emissions; however, they may have local environmental impacts. |
| Energy security | May create import dependence. | May support production based on local resources. |
| Continuity | Depends on stocks and reserves. | Depends on the natural conditions of the resource; some may produce variable output. |
| Technological need | Existing infrastructure is widespread. | Storage, smart grids, and flexible energy systems may be required. |
| Sustainability | Limited in the long term and environmentally problematic. | Can contribute to sustainable energy systems when properly planned. |

### *2.2. Primary Energy, Secondary Energy, and Energy Carriers*

In order to evaluate energy resources, it is necessary to understand the concepts of primary energy, secondary energy, and energy carrier in addition to the renewable-non-renewable distinction. These concepts help explain the conversion chain from the acquisition of energy in nature to its delivery to the end user (DOE and AAAS, 2017; IEA, 2024).

Primary energy refers to resources found directly in nature that have not yet been converted into another form of energy. Coal, oil, natural gas, uranium, solar radiation, wind, flowing water, geothermal heat, and biomass can be given as examples of primary energy resources (DOE and AAAS, 2017).

Secondary energy is the form of energy obtained by converting primary energy resources. Electricity is the most common example. Electricity can be generated using coal, natural gas, hydropower, wind, or solar energy; therefore, the environmental impact of electricity depends on which primary resources and technologies are used to generate it (IEA, 2024).

An energy carrier is an intermediate form of energy that enables energy to be transported from one place to another or stored for later use. Electricity and hydrogen are important energy carriers in this respect. Whether

hydrogen is a low-carbon option depends more on its production method than on hydrogen itself (IEA, 2024; IRENA, 2024).

This distinction is important in energy decisions so that the concepts of resource, technology, and carrier are not confused. For example, the environmental impact of an electric vehicle cannot be explained only by the absence of tailpipe emissions; the electricity generation mix, battery production, and charging infrastructure should also be considered (IEA, 2024; NREL, 2021).

Table 2.2 summarises the distinction between primary energy, secondary energy, and energy carriers. This distinction is important for energy literacy because the terms resource, conversion technology, and energy carrier are sometimes confused in energy-related debates. In decision-making, the questions "which resource?", "which technology?", "which conversion pathway?", and "which end use?" should be considered together (DeWaters et al., 2013; Ramachandran et al., 2024).

Table 2.2. Examples of primary energy, secondary energy, and energy carriers

| Concept | Explanation | Examples |
|---|---|---|
| Primary energy | An energy resource found directly in nature. | Coal, oil, natural gas, solar radiation, wind, water, geothermal heat, biomass |
| Secondary energy | Obtained through the conversion of primary energy. | Electricity, gasoline, diesel, some biofuels |
| Energy carrier | Facilitates the transportation, storage, or end use of energy. | Electricity, hydrogen, synthetic fuels |

### *2.3. Non-renewable Energy Resources: General Evaluation*

Non-renewable energy resources have played a decisive role in the development of modern economies. Coal, oil, natural gas, and nuclear energy have long been major options in areas such as electricity generation, transportation, industry, and heating (Energy Institute, 2024; Jyothi et al., 2023; Smith et al., 2019). This section provides a general evaluation of non-renewable resources as a basis for decision-making; their detailed environmental impacts are discussed in Chapter 3.

High energy density, storability, and compatibility with existing infrastructure are prominent strengths of non-renewable resources. Coal, oil, and natural gas have provided flexibility to energy systems as transportable fuels. Nuclear energy is also discussed among low-carbon options because it does not directly burn fossil fuels during electricity generation; however, uranium supply, radioactive waste, safety, and social acceptance require careful planning (Energy Institute, 2024; IAEA, 2024).

By contrast, the combustion of fossil fuels creates major problems in terms of greenhouse gas emissions, air pollution, and health impacts (EPA, 2025; IPCC, 2023). In addition, stages such as coal mining, oil extraction, natural gas production, pipelines, and refinery processes can affect water, soil, and ecosystems. Therefore, non-renewable resources should be evaluated not

only according to the use phase, but also by considering the entire life cycle (NREL, 2021).

From the perspective of energy security, the situation of non-renewable resources varies from country to country. Countries with domestic resources may gain an advantage in supply security, whereas import-dependent countries may face price fluctuations, geopolitical risks, and external dependence. This situation shows that the economic and political dimensions of energy resources are as important as their technical characteristics (Energy Institute, 2024; IEA, 2024).

Therefore, when evaluating non-renewable energy resources, it is not sufficient to consider only short-term costs or the convenience of existing infrastructure. Climate impacts, air quality, health costs, reserve limitations, waste management, external dependence, and the social consequences of the phase-out of fossil fuels should be considered together (IPCC, 2023; ILO, 2015).

### *2.4. Renewable Energy Resources: General Evaluation*

Renewable energy resources are gaining increasing importance for low-carbon and more sustainable energy systems. Solar, wind, hydropower, geothermal, biomass, and marine-ocean energy are considered within this scope (Neha and Rambeer, 2021). This section provides a general evaluation of renewable resources before the detailed discussion of specific renewable energy technologies in the following chapters.

The most important advantage of renewable resources is that they generally have lower life-cycle greenhouse gas emissions than fossil fuels (NREL, 2021). They can also support production based on local resources, reduce dependence on energy imports, and contribute to the diversification of energy systems (IRENA, 2024).

However, renewable energy resources are not uniform or problem-free options. Solar and wind energy can produce variable output; hydropower projects can affect river ecosystems; biomass requires sustainable feedstock management; and geothermal energy depends on local environmental conditions. Therefore, site selection, grid integration, storage, material use, recycling, and social acceptance should be evaluated together (IRENA, 2024; Wüstenhagen et al., 2007).

For this reason, the evaluation of renewable resources should be based on a balanced approach that acknowledges their low-carbon advantage while also making local environmental and social impacts visible.

Table 2.3. Major energy resources, energy carriers, and areas of use

| Energy Resource | Resource Type | Common Areas of Use |
|---|---|---|
| Coal | Non-renewable | Electricity generation, industry, heating |
| Oil | Non-renewable | Transportation, industry, petrochemical products |
| Natural gas | Non-renewable | Electricity generation, heating, industry |
| Nuclear energy | Non-renewable | Electricity generation |
| Solar energy | Renewable | Electricity generation, water heating, small-scale systems |
| Wind energy | Renewable | Electricity generation |
| Hydropower | Renewable | Electricity generation, storage, and system balancing |
| Geothermal energy | Renewable | Electricity generation, heating, greenhouse cultivation |
| Biomass energy | Renewable | Heat, electricity, biogas, and biofuel production |
| Marine and ocean energy | Renewable | Electricity generation, research and pilot applications |
| Hydrogen | Energy carrier | Industry, transportation, energy storage, fuel cells |

Table 2.3 shows that energy resources play different roles in different sectors. However, the area of use of a resource does not automatically mean that it is the most appropriate option. Suitability is determined together with local potential, cost, infrastructure, environmental impact, continuity, and social acceptance criteria (IEA, 2024; IRENA, 2024).

### *2.5. Criteria for Evaluating Energy Resources: A Decision-Making Framework*

Comparing energy resources is not limited to classifying them as renewable or non-renewable. Real energy decisions are multi-criteria decisions. The appropriate option for a country, municipality, school, or household may vary according to geographical conditions, infrastructure, cost, environmental goals, energy demand, and social expectations (IEA, 2024; WCED, 1987). Environmental impact is one of the most fundamental criteria; however, this impact is not limited to emissions produced during energy generation. Stages such as raw material extraction, production, transportation, installation, operation, maintenance, dismantling, and waste management should also be evaluated within the life cycle. Therefore, whether an energy resource is 'clean' can be understood only by examining all processes together (NREL, 2021). Cost is also a multidimensional criterion. The cost of an energy option is not determined solely by the initial investment cost of a power plant; fuel, maintenance, grid connection, storage, backup capacity, environmental damage, and social impacts should also be considered. Therefore, costs that appear low in the short term may create higher environmental or social costs in the long term (IEA, 2024; IRENA, 2024).

Continuity and energy security are important for the reliable operation of energy systems. While some resources can provide dispatchable generation, some renewable resources produce variable output depending on weather conditions. This situation requires grid flexibility, storage, demand management, and resource diversity (IEA, 2024; IRENA, 2024).

Social acceptance and fair access should also be part of the decision-making process. Even if an energy project is technically feasible and economically appropriate, it may become controversial if it negatively affects local communities' living spaces, agriculture, tourism, or cultural values. Sustainable energy decisions should question not only how much energy is produced, but also for whom, where, at what cost, and with what social consequences it is produced (Sovacool and Dworkin, 2015; Wüstenhagen et al., 2007).

Table 2.4 shows that energy resources should not be evaluated in a one-dimensional manner. Instead of presenting a single resource as absolutely superior, the decision-making framework opens discussion about which combination of resources is more sustainable and feasible in a specific context.

Table 2.4. Decision-making framework for evaluating energy resources

| Criterion | Explanation | Importance for Decision-Making |
|---|---|---|
| Environmental impact | Greenhouse gas emissions, air-water-soil impacts, and ecosystem pressure | A fundamental criterion for climate targets, environmental protection, and public health. |
| Life cycle | Raw material extraction, production, transportation, installation, operation, dismantling, and waste management | Makes it possible to see all impacts of the resource, not only the use phase. |
| System cost | Installation, operation, fuel, maintenance, grid, storage, and external costs | Affects energy prices, investment decisions, and long-term feasibility. |
| Continuity and flexibility | The ability of a resource to provide regular production and the system's adaptation to variable generation | Important for electricity system reliability and supply-demand balance. |
| Energy security | The ability to provide the resource continuously, accessibly, and economically | Can reduce external dependence, price vulnerability, and supply risks. |
| Technological feasibility | Technology maturity, local capacity, maintenance, and operating requirements | Determines whether a resource can be installed and sustained in practice. |
| Infrastructure need | Grid connection, storage, transportation, transmission, and distribution requirements | Influences the speed, cost, and system compatibility of the energy transition. |
| Social acceptance | The attitudes of local communities, institutions, and society toward the project | Critical for the feasibility and long-term success of projects. |
| Fair access | Secure, affordable, and inclusive access to energy | Important for energy poverty, regional inequality, and just transition. |

### *2.6. Energy Security, Feasibility, and Social Acceptance*

Energy security means that energy can be provided continuously, reliably, accessibly, and economically (Bhattarai, 2022). A country's energy security depends on its domestic resources, import dependence, the resilience of its energy infrastructure, price stability, and resource diversity (IEA, 2024). High dependence on non-renewable energy resources may create external dependence and price vulnerability, especially for energy-importing countries. Fluctuations in oil and natural gas prices can affect energy costs and economic planning. Renewable resources can support local production; however, they may also create new planning requirements such as variable generation, grid flexibility, and storage needs (Energy Institute, 2024; IEA, 2024).

Technological feasibility is also a decisive factor in the use of energy resources. High solar or wind potential in a region is not sufficient on its own. In order to use this potential, appropriate technology, investment, maintenance capacity, grid connection, land-use planning, and institutional arrangements are required (IRENA, 2024). Social acceptance is becoming increasingly important for the feasibility of energy projects. Projects may affect local communities' living spaces, the natural environment, agricultural production, tourism, or cultural heritage. Therefore, participation, transparency, local benefit-sharing, and environmental impact assessment are important (Sovacool and Dworkin, 2015; Wüstenhagen et al., 2007).

Energy literacy connects energy security and social acceptance. Individuals with accurate information can evaluate energy projects more soundly; however, for acceptance to strengthen, decision-making processes must also be fair, participatory, and trustworthy (DeWaters et al., 2013; Ramachandran et al., 2024).

### *2.7. Sustainable Energy Mix and Decision-Making*

The selection of energy resources may vary according to countries' geographical conditions, economic structures, technological capacities, energy demands, and policy goals. For example, solar energy may be a stronger option in regions with high sunshine duration, wind energy in coastal and open areas with high wind potential, and geothermal energy in regions with suitable geological conditions (IRENA, 2024). In terms of sustainability, three main dimensions should be considered together in energy decisions. The environmental dimension includes impacts on climate, air, water, soil, and ecosystems. The economic dimension includes issues such as investment, operation, energy prices, and external dependence. The social dimension is related to access to energy, just transition, health, employment, local participation, and social acceptance (WCED, 1987).

A sustainable energy system does not only mean increasing renewable resources. Energy efficiency, consumption habits, energy storage, smart grids, demand management, the transformation of transportation, and clean technologies in industry are also parts of this process (IEA, 2024; IRENA,

2024). Therefore, to establish a sustainable energy system, different resources and technologies should be evaluated as complementary rather than relying on a single resource. When designing an energy mix, short-term supply security and long-term climate and environmental goals should be considered together. This approach provides a basis for the more detailed evaluation of different resource groups in the following chapters.

### *2.8. Evaluation from the Perspective of Energy Literacy*

The classification of energy resources is one of the fundamental topics of energy literacy. However, energy literacy is not limited to knowing the names of resources. Energy-literate individuals should be able to evaluate resources together with their environmental impacts, economic costs, contributions to energy security, social consequences, and life-cycle effects (DeWaters et al., 2013; Ramachandran et al., 2024).

From this perspective, energy resources offer a strong learning area for science and environmental education. Students can examine options such as coal, oil, natural gas, nuclear energy, solar, wind, hydropower, geothermal, biomass, and hydrogen beyond the level of definition and within a comparative decision-making process (DeWaters et al., 2013; DOE and AAAS, 2017).

Energy resources are also suitable for socioscientific discussions. Issues such as the pace of coal phase-out, the use of natural gas as a transition fuel, the role of nuclear energy, the ecosystem effects of hydropower projects, or the site selection of wind turbines require the joint discussion of scientific knowledge and social values (Sadler, 2004; Zeidler, 2014).

Classroom activities related to energy resources can be supported through practices such as preparing comparative tables, examining country energy profiles, developing energy scenarios, calculating carbon footprints, evaluating local energy projects, and designing an energy mix. In these activities, students can make evidence-based evaluations by using the decision-making criteria presented in Section 2.5.

Box 2.2 provides a classroom activity that helps students apply the decision-making criteria presented in Section 2.5 to the design of an energy mix. Such activities make the topic of energy resources more concrete for students. They also demonstrate that energy literacy includes not only knowledge, but also analysis, evidence-based evaluation, discussion, and responsible decision-making skills.

Box 2.2. Classroom activity suggestion: Designing an energy mix for a country

| Activity Stage | Description |
|---|---|
| Aim | To enable students to evaluate different energy resources using decision-making criteria. |
| Implementation | Students propose an energy mix for a fictional country according to energy needs, geographical conditions, economic opportunities, and environmental targets. |
| Analysis | Each resource is scored in terms of environmental impact, life cycle, system cost, energy security, continuity, infrastructure need, and social acceptance. |
| Discussion | The question 'Is it more sustainable to rely on a single energy resource or to use different resources together?' is discussed. |
| Outcome | Students understand that energy planning includes technical, environmental, economic, and social dimensions together. |

### *2.9. Chapter Summary and Discussion Questions*

This chapter has examined energy resources not only through their names or technical characteristics, but also within the decision-making process. The renewable-non-renewable distinction is a basic starting point; however, the sustainability of a resource should be evaluated together with technology, local conditions, life-cycle impacts, cost, energy security, and social acceptance criteria.

The distinction among primary energy, secondary energy, and energy carriers is important for the correct understanding of energy systems. The environmental impacts of carriers such as electricity and hydrogen depend on the resources and technologies through which they are produced.

Non-renewable resources can provide advantages such as high energy density and existing infrastructure; however, they have important limitations regarding climate, air quality, waste management, and external dependence. Renewable resources offer strong options for low-carbon transformation; nevertheless, they require planning in terms of site selection, variable generation, ecosystem impacts, material use, and social acceptance.

From the perspective of energy literacy, the main goal is to enable individuals to compare different resources together with their environmental, economic, and social consequences and to participate consciously in sustainable energy decisions.

### *Discussion Questions*

1. Why is it important to classify energy resources as renewable and non-renewable? Why is this classification not sufficient on its own?
2. What is the difference between primary energy, secondary energy, and an energy carrier?
3. Why does the environmental impact of electricity depend on the resource mix used to generate it?

4. Why does whether hydrogen is a low-carbon energy carrier depend on its production method?
5. What are the strengths of non-renewable energy resources and their limitations in terms of sustainability?
6. Why should renewable energy resources not be considered completely problem-free?
7. Why is the life-cycle approach important when evaluating an energy resource?
8. What kind of relationship can be established among energy security, cost, and environmental impact?
9. Why are social acceptance and local participation important in energy projects?
10. Why should different resources be used together for a sustainable energy system?

# CHAPTER 3: NON-RENEWABLE ENERGY RESOURCES AND THEIR ENVIRONMENTAL IMPACTS

Non-renewable energy resources are resources that exist in limited quantities in nature and cannot be regenerated within time spans that are short from the perspective of human life. Coal, oil, natural gas, and uranium used in nuclear energy production are evaluated within this group. These resources have historically played a decisive role in the development of industrialization, transportation, urbanization, and electricity generation (DOE and AAAS, 2017; Energy Institute, 2024; Jyothi et al., 2023).

Their widespread use has been shaped by high energy density, storability, compatibility with existing infrastructure, and the ability to provide continuous supply. Coal is used in electricity generation and industry, oil in transportation, and natural gas in electricity generation, heating, and industry, while nuclear energy is regarded in some countries as an option for large-scale electricity generation without burning fossil fuels (IAEA, 2024; IEA, 2022).

By contrast, non-renewable resources are associated with problems such as climate change, air pollution, water and soil pollution, waste management, occupational safety, import dependence, and social acceptance. Therefore, they should be evaluated not only in terms of generation capacity or short-term cost, but also together with criteria such as environmental impact, life cycle, system cost, energy security, infrastructure dependence, and just transition (IEA, 2024; ILO, 2016; IPCC, 2023).

Box 3.1. What will be learned in this chapter

| Learning Objective |
|---|
| Explain the basic characteristics of coal, oil, natural gas, and nuclear energy. |
| Compare these resources in terms of energy density, infrastructure compatibility, cost, environmental impact, and safety. |
| Discuss the environmental impacts that occur during extraction, transportation, conversion, consumption, and waste management. |
| Explain the influence of fossil fuel imports, price fluctuation, and dependence on existing infrastructure on energy decisions. |
| Evaluate the contributions and limitations of approaches such as carbon capture, methane reduction, and energy efficiency. |
| Evaluate the effects of the fossil fuel phase-out process on workers, local communities, and consumers. |

This chapter discusses fossil fuels, nuclear energy, environmental impacts, transition technologies such as carbon capture and methane reduction, global and European trends in the use of non-renewable energy, and selected country examples. The aim is to apply the decision-making

framework developed in Chapter 2 to non-renewable resources and to discuss their place in the energy transition in a balanced manner (Box 3.1).

### *3.1. Fossil Energy Resources*

Fossil energy resources consist of coal, oil, and natural gas. These fuels, which were formed through the transformation of organic remains that lived millions of years ago under pressure and temperature underground, have long been the main energy inputs in areas such as electricity generation, transportation, industry, heating, and petrochemicals (Energy Institute, 2024; Singh et al., 2020). High energy density, portability, storability, and compatibility with existing infrastructure made fossil fuels a powerful option in the processes of industrialization and economic growth. However, these historical advantages are now being re-evaluated together with environmental costs and energy security risks (Energy Institute, 2024; IEA, 2024).

The role of fossil fuels in the energy system should be discussed together with climate impacts, air pollution, the environmental consequences of extraction and transportation processes, price volatility, import dependence, and the need for a just transition (IPCC, 2023; ILO, 2016; Sovacool and Dworkin, 2015).

#### *3.1.1. Coal*

Coal is historically one of the fundamental energy resources of industrialization. It is used in electricity generation, certain industrial processes such as iron and steel production, and heating. Because of its high carbon content, it releases a significant amount of carbon dioxide when burned; for this reason, it is considered one of the most problematic fossil fuels in terms of climate change (IPCC, 2023; Energy Institute, 2024).

Coal combustion is important not only in terms of carbon dioxide emissions, but also in terms of air pollution. Sulfur dioxide, nitrogen oxides, particulate matter, and heavy metals can create adverse effects on human health and ecosystems (EPA, 2025). Especially when filtration and emission control systems are insufficient, coal use may be associated with respiratory diseases, cardiovascular problems, and acid rain. Coal mining also creates significant environmental impacts. Open-pit mining can alter land structure and vegetation, while underground mining involves risks such as occupational safety, methane accumulation, and mining waste. Therefore, the role of coal in energy systems should be evaluated together with climate, health, and local environmental costs, in addition to economic cost (EPA, 2025; ILO, 2016; IPCC, 2023).

#### *3.1.2. Oil*

Oil is a critical fossil fuel, especially for the transportation sector. It is used in the production of gasoline, diesel, jet fuel, and various petrochemical products. Road transport, aviation, maritime transport, and

some industrial processes still depend heavily on petroleum products (Energy Institute, 2024; IEA, 2024; Singh et al., 2020).

One of the most important advantages of oil is its high energy density and ease of transportation. These characteristics have made oil indispensable for the transportation sector for a long period. However, the extraction, transportation, refining, and combustion of oil carry environmental risks. Oil spills can damage marine and coastal ecosystems. Refinery processes may cause air and water pollution. The combustion of petroleum products can lead to carbon dioxide, nitrogen oxides, and particulate matter emissions (EPA, 2025; IPCC, 2023). The concentration of oil resources in certain regions creates risks of external dependence and price volatility for importing countries. Therefore, electric vehicles, biofuels, public transportation, energy efficiency, and alternative fuels are among the options for reducing oil dependence in transportation (IEA, 2024; IRENA, 2024).

### *3.1.3. Natural Gas*

Natural gas is a fossil fuel composed mainly of methane and used in electricity generation, heating, industry, and some transportation applications. Because it can produce lower carbon dioxide emissions during combustion than coal, it is considered in some energy policies as a 'transition fuel' from coal to renewable resources (IEA, 2024; Moore et al., 2014). The environmental impact of natural gas is not limited to carbon dioxide emissions during combustion. Methane leakage may occur during extraction, processing, transportation, and distribution. Although methane remains in the atmosphere for a shorter time than carbon dioxide, it has a strong heat-trapping effect in the short term; therefore, leakage must be considered when evaluating the climate impact of natural gas (EPA, 2025; IEA, 2024a).

Natural gas also has a two-sided character in terms of energy security. On the one hand, it can provide more flexible electricity generation than coal and can balance variable renewable resources. On the other hand, high dependence on imported natural gas can create price volatility and geopolitical risks. Therefore, the role of natural gas should be considered as temporary, carefully planned, and compatible with a low-carbon transition (IEA, 2024, 2024a).

Table 3.1. Main fossil fuels and their areas of use

| Fossil Fuel | Basic Characteristic | Main Areas of Use | Key Environmental Risk |
|---|---|---|---|
| Coal | Solid fossil fuel with high carbon intensity | Electricity generation, industry, heating | High $CO_2$ emissions, air pollution, mining impacts |
| Oil | Liquid fuel with high energy density | Transportation, petrochemicals, industry | Spills, air pollution, greenhouse gas emissions |
| Natural gas | Gas fuel dominated by methane | Electricity generation, heating, industry | $CO_2$ emissions and methane leakage |

Table 3.1 summarises the main characteristics, common areas of use, and key environmental risks of coal, oil, and natural gas. The table shows that fossil fuels differ in their physical form and areas of use, but they share important environmental concerns such as greenhouse gas emissions, pollution, and extraction-related impacts.

### *3.2. Nuclear Energy*

Nuclear energy is the release of energy stored in the atomic nucleus through controlled nuclear fission and its use in electricity generation (Rabilloud, 2013). Uranium is generally used as fuel in nuclear power plants. Because uranium is a limited mineral, nuclear energy is not accepted as a renewable energy resource (DOE and AAAS, 2017; IAEA, 2024). Nuclear energy may have low carbon dioxide emissions because it does not directly burn fossil fuels during electricity generation. For this reason, some countries evaluate nuclear energy in terms of low-carbon electricity generation and supply security. Unlike variable resources such as solar and wind, nuclear power plants can provide dispatchable and continuous electricity generation (IAEA, 2024; IEA, 2022).

However, nuclear energy has limitations such as radioactive waste management, high investment cost, long construction time, and complex safety regulations (Table 3.2). The long-term safe storage of spent nuclear fuel requires careful planning from technical, economic, and social perspectives (IAEA, 2024; IEA, 2022).

Safety and risk perception are also decisive in nuclear energy projects. Although modern power plants have advanced safety systems, major accidents in the past have increased social concerns. Therefore, projects should be evaluated not only from an engineering perspective, but also in terms of risk management, emergency planning, transparent communication, and social acceptance (IAEA, 2024; Sovacool and Dworkin, 2015).

Table 3.2. Advantages and limitations of nuclear energy

| Dimension | Advantage | Limitation |
|---|---|---|
| Carbon emissions | Direct $CO_2$ emissions are low. | Fuel mining, construction, and waste management create life-cycle impacts. |
| Electricity generation | Provides continuous and dispatchable electricity generation. | Construction periods are long and investment costs are high. |
| Energy security | Can support fuel stockpiling and resource diversification. | Uranium is limited and may create external dependence. |
| Waste management | Waste volume may be lower than in some other sources. | Radioactive waste requires long-term safe storage. |
| Social acceptance | Can be included in low-carbon energy debates. | Concerns about accidents, safety, and waste can create social opposition. |

For these reasons, evaluating nuclear energy from the perspective of sustainability requires a balanced approach. Advantages such as low-carbon

electricity generation and supply security should be considered together with radioactive waste, cost, project duration, safety, and social acceptance (Table 3.2) (IAEA, 2024; IEA, 2022).

### *3.3. Environmental Impacts of Non-renewable Energy Resources*

The environmental impacts of non-renewable energy resources vary according to resource type, technology, production method, emission control systems, and local conditions. These impacts should be evaluated using a life-cycle approach, that is, by considering all stages from resource extraction to transportation, conversion, consumption, and waste management. For fossil fuels, the most fundamental impact is the contribution of greenhouse gases such as carbon dioxide and methane to climate change (EPA, 2025; IPCC, 2023).

Air pollution is another important impact (Sharma et al., 2013). During the combustion of fossil fuels, pollutants such as particulate matter, sulfur dioxide, and nitrogen oxides may be released. These pollutants can cause problems such as respiratory diseases, cardiovascular diseases, acid rain, and ecosystem degradation (EPA, 2025).

Water and soil pollution are also among the important consequences (Ivanova et al., 2022; Masood et al., 2020). Oil spills can damage marine ecosystems; coal mining and waste storage processes can disrupt soil structure. Oil and natural gas extraction can place pressure on water resources, while in nuclear energy production, the safe management of radioactive waste is of critical importance (EPA, 2025; IAEA, 2024).

The environmental impacts of non-renewable energy resources can also affect local communities. In mining regions, land loss, health risks, occupational safety problems, and economic dependence may occur. Oil and natural gas infrastructures may affect coastal areas, marine ecosystems, and local livelihoods. In nuclear power plants, risk perception, waste storage, and emergency planning may create social debates (ILO, 2016; Sovacool and Dworkin, 2015).

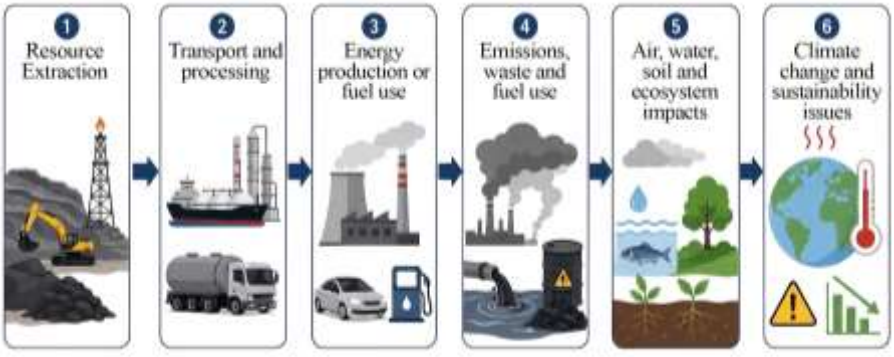


Figure 3.1. Environmental impact chain of non-renewable energy resources

Figure 3.1 shows that the environmental impacts of non-renewable energy resources do not arise only during the energy generation stage. All stages, including resource extraction, transportation, conversion, consumption, and waste management, can create environmental consequences; therefore, evaluation should be conducted using a life-cycle approach (Table 3.3).

Table 3.3. Main environmental impacts of non-renewable energy resources

| Impact Area | Relationship with Fossil Fuels | Relationship with Nuclear Energy |
|---|---|---|
| Climate change | $CO_2$ and methane emissions contribute to climate change. | Direct $CO_2$ emissions during electricity generation are low. |
| Air pollution | Particulate matter, $SO_2$, and $NO_x$ emissions may occur. | Air pollutant emissions are low during normal operation. |
| Water use and pollution | Mining, drilling, refinery, and thermal power plant processes may affect water resources. | Cooling water demand and radioactive waste management are important. |
| Soil and land impacts | Mining, pipelines, and infrastructure may affect land use. | Power plant sites, waste storage, and security zones require planning. |
| Waste management | Ash, mining waste, oil sludge, and refinery wastes may be generated. | Radioactive waste must be stored safely for long periods. |
| Social impact | Health, local economy, employment, and displacement effects may occur. | Risk perception, emergency planning, and social acceptance are important. |

### *3.4. Carbon Capture, Methane Reduction, and Transition Technologies*

The transition away from fossil fuel-based systems is a long and complex process. In some countries, electricity generation, industry, heating, and transportation still depend heavily on fossil fuels. For this reason, transition technologies and management tools aimed at reducing emissions are discussed during the energy transition (IEA, 2024).

Carbon capture, utilization, and storage technologies aim to capture carbon dioxide produced during the combustion of fossil fuels or industrial processes before it is released into the atmosphere and to store it underground or use it in some industrial processes. These technologies are discussed especially in sectors that are difficult to electrify directly, such as cement, iron and steel, and chemicals. However, carbon capture technologies should not be seen as a stand-alone solution because of high cost, energy demand, storage safety, and long-term monitoring requirements (IEA, 2020; IEA, 2024b). Reducing methane emissions is also important for limiting short-term climate impacts. Detecting leaks in natural gas systems, improving pipelines, limiting methane release in oil and gas production, and managing methane at waste sites are the main practices in this area. Because methane has a strong greenhouse effect in the short term, reducing leaks is important for climate policies (EPA, 2025; IEA, 2024a).

Transition technologies can contribute to the energy transition; however, if they are used in a way that makes fossil fuel dependence permanent, they create sustainability risks. Therefore, energy efficiency, renewable energy investments, electrification, storage, grid flexibility, and sustainable consumption should be planned together (IEA, 2024; ILO, 2016; IRENA, 2024).

Table 3.4 summarises selected approaches for reducing fossil fuel-related emissions. These approaches can support the energy transition, but they should be evaluated together with long-term decarbonisation goals, renewable energy investments, energy efficiency, electrification, and just transition policies.

Table 3.4. Selected approaches for reducing fossil fuel-related emissions

| Approach | Purpose | Point to Consider |
|---|---|---|
| Energy efficiency | To perform the same task with less energy | It is one of the most effective and low-cost mitigation pathways. |
| Fuel switching | To shift from coal to lower-emission resources | It may be a temporary solution; in the long term, a transition to low-carbon resources is necessary. |
| Reducing methane leaks | To reduce leaks in natural gas systems | Measurement, monitoring, and maintenance capacity are required. |
| Carbon capture and storage | To capture and store $CO_2$ emissions | High cost, energy demand, and storage safety are important. |
| Transition to renewable energy | To reduce fossil fuel use | Grid, storage, and planning requirements must be addressed. |
| Electrification | To shift transportation, heating, and industry to electricity | Electricity must be generated from low-carbon resources. |

### *3.5. Use of Non-renewable Energy at the Global and European Scales*

The global energy system has long developed on the basis of fossil fuels. Coal, oil, and natural gas still have significant shares in global energy consumption. Oil is widely used in transportation, coal and natural gas in electricity generation, and natural gas in heating and industry in many countries (Energy Institute, 2024).

Although the share of renewable energy resources has increased in recent years, the phase-out of fossil fuels is not proceeding at the same pace in every country. Countries' energy infrastructures, levels of economic development, domestic resources, import dependence, industrial structures, and policy preferences determine the speed of the energy transition. Therefore, the energy transition is an unequal and multidimensional process at the global level (IEA, 2024; IRENA, 2024).

In Europe, climate policies, energy security concerns, and renewable energy investments have created important steps toward reducing dependence on fossil fuels (Adewuyi and Awodumi, 2017). In many countries, targets to reduce or end coal-fired electricity generation have come to the fore, while oil

and natural gas remain important in transportation, industry, and heating. Therefore, for Europe, the energy transition requires the joint implementation of renewable capacity, energy efficiency, building transformation, electric transportation, storage, grid infrastructure, and just transition policies (IEA, 2024; IRENA, 2024; ILO, 2016).

### *3.6. Use of Non-renewable Energy in Selected Country Examples*

Türkiye, Greece, Portugal, and North Macedonia have different starting points regarding non-renewable energy resources. The role of fossil fuels, import dependence, coal phase-out policies, renewable energy potential, and approaches to nuclear energy vary from country to country (IEA, 2024; IRENA, 2024).

In Türkiye, oil, natural gas, and coal have significant shares in energy consumption. External dependence on oil and natural gas is one of the main issues in terms of energy security. Türkiye is also increasing renewable electricity generation and aims to diversify resources through nuclear energy (Furuncu, 2016). Therefore, the key issue is to ensure energy security while reducing dependence on fossil fuels, increasing renewable capacity, and strengthening energy efficiency (Energy Institute, 2024; IEA, 2024; IRENA, 2024).

Greece has historically stood out with electricity generation based particularly on lignite. In recent years, it has developed policies to reduce coal-fired electricity generation and increase renewable resources (Panagopoulou, 2023). The energy transition of islands, natural gas infrastructure, renewable investments, and electricity interconnections are important issues. In the lignite phase-out process, just transition policies are also important for local economies and employment (Energy Institute, 2024; IEA, 2024; ILO, 2016).
Portugal is one of the countries that has ended coal-fired electricity generation. Nevertheless, oil and natural gas remain important for transportation, industry, and the energy system. Investments in wind, solar, hydropower, storage, and grid flexibility stand out in the energy transition (Seminario-Córdova and Rojas-Ortega, 2023). This example shows that coal phase-out is an important step, but broader policies are required to reduce fossil fuel dependence (Energy Institute, 2024; IRENA, 2024).

In North Macedonia, coal, oil, and natural gas occupy an important place in the energy mix. Coal phase-out and the transition to renewable energy are important policy areas for the country. The use of former coal sites for solar energy projects, modernization of energy infrastructure, and increasing renewable electricity generation may provide opportunities. However, this transformation should be planned carefully in terms of finance, infrastructure, energy security, and social impacts (Energy Institute, 2024; IEA, 2024; ILO, 2016).

Table 3.5. General comparison of non-renewable energy use in selected country examples

| Country | General Situation Regarding Non-renewable Energy | Key Point for the Energy Transition |
|---|---|---|
| Türkiye | Oil, natural gas, and coal have significant shares; import dependence is high for oil and natural gas. | Renewable electricity generation is increasing, and resource diversification through nuclear energy is targeted. |
| Greece | It was formerly dependent on lignite; oil and natural gas remain important. | The goal of gradually reducing coal-fired electricity generation and increasing renewable energy capacity stands out. |
| Portugal | Coal phase-out has been completed; oil and natural gas use continues. | Wind, solar, hydropower, and storage investments are important in the energy transition. |
| North Macedonia | Coal, oil, and natural gas occupy an important place in the energy mix. | Coal phase-out and renewable energy investments are the main areas of the energy transition. |

Table 3.5 shows that the role of non-renewable energy resources differs across the selected country examples. While Türkiye faces strong import dependence on oil and natural gas, Greece and North Macedonia are closely associated with coal phase-out processes, and Portugal provides an example of completed coal phase-out while still managing oil and natural gas dependence. These examples demonstrate that the transition away from non-renewable resources must be evaluated in relation to national energy security, infrastructure, economic conditions, and social impacts.

### *3.7. Evaluation from the Perspective of Energy Literacy*

Non-renewable energy resources offer a strong learning area from the perspective of energy literacy. Fossil fuels and nuclear energy are related to many dimensions such as climate change, air pollution, energy security, economic cost, local impacts, waste management, and social decision-making.

Therefore, evaluating these resources can help students understand energy systems more holistically (DEO and AAAS, 2017; DeWaters and Powers, 2011).

Issues such as the reduction of fossil fuels, the role of nuclear energy, import dependence, coal phase-out, carbon capture technologies, and the use of natural gas as a transition fuel can create socioscientific discussion areas for students (Sadler, 2004; Zeidler, 2014).

For these discussions to be effective, students need to compare different evidence, evaluate costs and risks, understand stakeholder perspectives, and develop justified decisions. For example, the pace of a country's coal phase-out should be evaluated together with climate targets, electricity supply security, energy prices, the workforce, local economy, health impacts, and renewable energy capacity (Sadler, 2004; Zeidler, 2014; ILO, 2016).

Educational activities related to non-renewable resources contribute to students' understanding of the complex structure of energy systems. Activities that compare coal, oil, natural gas, nuclear energy, and renewable options can transform energy issues from memorized classifications into decision-making areas related to real life (Box 3.2.) (DeWaters and Powers, 2011; Sadler, 2004).

Box 3.2. Classroom discussion suggestion: Difficult decisions in the energy transition

| Activity Stage | Description |
|---|---|
| Aim | To evaluate the advantages and limitations of non-renewable energy resources in the context of the energy transition. |
| Implementation | Students discuss coal, natural gas, oil, nuclear energy, and renewable energy options through a country scenario. |
| Analysis | Each option is scored in terms of energy security, cost, environmental impact, social acceptance, and climate targets. |
| Discussion | The question 'How and at what pace should a country phase out fossil fuels?' is discussed in the classroom. |
| Outcome | Students understand the importance of forming a balanced energy policy rather than seeking a single correct solution. |

### *3.8. Chapter Summary and Discussion Questions*

This chapter has examined non-renewable energy resources together with the decision-making framework developed in Chapter 2. Coal, oil, natural gas, and nuclear energy have advantages such as high energy density, compatibility with existing infrastructure, and supply continuity, but they also have environmental, economic, and social limitations.

The main problems of fossil fuels are greenhouse gas emissions, air pollution, pressures on water and soil, import dependence, and price vulnerability. Although nuclear energy offers some advantages for low-carbon electricity generation, it should be evaluated together with radioactive waste, safety, cost, long project duration, and social acceptance.

Transition approaches such as carbon capture, methane reduction, and fuel switching can contribute to limiting emissions; however, for a sustainable transition, energy efficiency, renewable energy, electrification, storage, grid flexibility, and just transition policies should be considered together.

Selected country examples show that the phase-out of fossil fuels does not occur at the same pace or in the same form in every country. From the perspective of energy literacy, the main learning outcome is that students can evaluate resources not only through their technical characteristics, but also through their climate impacts, costs, energy security implications, social acceptance, and life-cycle consequences.

***Discussion Questions***

1. Why did non-renewable energy resources form the basis of the global energy system for such a long time?
2. In what ways do the environmental impacts of coal, oil, and natural gas differ?
3. Why is coal considered one of the most problematic fossil fuels in terms of climate change?
4. Why is natural gas regarded as a transition fuel in some cases? What are the limitations of this approach?
5. How can methane leakage change the climate impact of natural gas?
6. Why is nuclear energy not accepted as a renewable energy resource?
7. What are the advantages of nuclear energy in terms of low-carbon electricity generation and its limitations in terms of waste management?
8. Why is reducing dependence on fossil fuels important for energy security?
9. Can carbon capture technologies completely solve the fossil fuel problem? Why?
10. In what ways do the energy transition priorities of Türkiye, Greece, Portugal, and North Macedonia differ?
11. Why are just transition policies important in the coal phase-out process?
12. Why can non-renewable energy resources be evaluated as socioscientific discussion topics?

# CHAPTER 4: RENEWABLE ENERGY RESOURCES AND THEIR ENVIRONMENTAL IMPACTS

Renewable energy sources are energy resources that are continuously replenished by natural processes or can be renewed within periods that are relatively short from the perspective of human life. Solar, wind, hydropower, geothermal, biomass, and marine-ocean energy are included in this group (Neha and Rambeer, 2021). These resources are considered among the fundamental components of sustainable energy systems because they generally have lower greenhouse gas emissions than fossil fuels and contribute to the diversification of energy supply (Ember, 2024; IRENA, 2024).

The transition to renewable energy is not merely an environmental preference. It is also important for strengthening energy security, reducing dependence on energy imports, using local resources, developing new technologies, creating economic opportunities, and combating climate change. While fossil-fuel-based energy systems generate problems such as greenhouse gas emissions, air pollution, external dependence, and resource limitations, renewable energy sources offer important options for lower-carbon and more resilient energy systems (IEA, 2024; IRENA, 2024).

Nevertheless, renewable energy sources are not entirely impact-free or problem-free. Issues such as material production for solar panels and wind turbines, the effects of hydropower plants on river ecosystems, the relationship between biomass and land use, the local environmental impacts of geothermal resources, and the siting of renewable energy facilities must be carefully evaluated (IEA, 2024a; NREL, 2021). Therefore, renewable energy projects should not be treated only as a matter of 'clean energy production'; they should also be assessed through criteria such as environmental impact, life cycle, system cost, continuity, energy security, social acceptance, and just transition (Sovacool and Dworkin, 2015; Wüstenhagen et al., 2007).

This chapter discusses the global development of renewable energy use, the situation in Europe, the main reasons for the transition to renewable energy, environmental benefits, limitations, grid integration, storage needs, social acceptance, and the importance of renewable energy from the perspective of energy literacy. Specific renewable energy types are examined separately in the following chapters. The purpose of this chapter is to apply the decision-making framework developed in Chapter 2 to the renewable energy transition and to evaluate renewable energy not merely as a change in energy sources, but as a transformation toward an energy system that is flexible, efficient, environmentally planned, and socially accepted (Box 4.1).

Box 4.1. What will be learned in this chapter

| Learning Objective |
|---|
| Evaluate the role of renewable resources in low-carbon and sustainable energy systems. |
| Explain growth trends, policy targets, and regional differences in the use of renewable energy. |
| Evaluate renewable energy sources in terms of life cycle, land use, ecosystem effects, and recycling. |
| Explain the importance of grid integration, energy storage, demand management, and energy efficiency in the renewable energy transition. |
| Discuss the role of local participation, benefit sharing, energy justice, and just transition principles in renewable energy projects. |
| Interpret renewable energy issues in terms of evidence-based decision-making, sustainability education, and responsible citizenship. |

### *4.1. Global Renewable Energy Use*

The global energy system developed for a long period on the basis of fossil fuels such as coal, oil, and natural gas. In recent years, however, the use of renewable energy sources has increased rapidly (Reuters, 2023). Solar and wind energy in particular have gained greater global importance because of technological advances, falling costs, climate policies, and energy security concerns (Ember, 2024; IRENA, 2024).

Electricity generation is one of the areas in which the renewable energy transition has progressed most rapidly. In 2023, renewable energy sources supplied approximately 30% of global electricity generation (Ember, 2024). This increase was driven especially by the rapid growth of solar and wind energy. Hydropower remains one of the most widely used renewable electricity sources; however, solar and wind have recently emerged as much faster-growing technologies (IRENA, 2025).

The increase in renewable energy capacity continued in 2024. Global renewable energy capacity expanded by 585 GW in 2024, with most of this increase originating from solar and wind energy (IRENA, 2025). This indicates that the energy transition is accelerating. Nevertheless, the share of fossil fuels in the global energy system remains high. For this reason, renewable energy investments must be expanded, energy efficiency improved, grid infrastructure strengthened, and energy storage systems deployed more widely (IEA, 2024a, 2024b; IRENA, 2024).

For the renewable energy transition to succeed at the global scale, simply building new solar, wind, or hydropower plants is not sufficient. Electricity grids must be strengthened, energy storage technologies developed, demand management practices expanded, and energy markets redesigned to accommodate variable renewable generation. The energy transition is a multidimensional process that requires the entire energy system,

from production to consumption, to be re-planned (IEA, 2024a, 2024b; IRENA, 2024).

The main trends in global renewable energy use are summarised in Table 4.1, including developments in electricity generation, solar and wind energy, hydropower, biomass, and the growing importance of grid and storage systems.

Table 4.1. General overview of renewable energy use at the global scale

| Area | General Trend | Explanation |
|---|---|---|
| Electricity generation | The share of renewable sources is increasing. | In 2023, renewable energy sources generated approximately 30% of global electricity. |
| Solar energy | It is among the fastest-growing sources. | Declining panel costs and widespread installation opportunities accelerate growth. |
| Wind energy | It is expanding through onshore and offshore applications. | It is an important electricity source in regions with suitable wind potential. |
| Hydropower | It is a long-established major renewable source. | It has a significant share in electricity generation; however, ecosystem effects must be carefully managed. |
| Biomass | It can be used for heat, electricity, and fuel production. | Sustainable feedstock management is critically important. |
| Grid and storage | They are necessary for the expansion of renewable energy. | Variable solar and wind generation requires flexible energy systems. |

Figure 4.1 shows that the energy transition is not merely a matter of changing energy sources. For renewable energy systems to operate reliably, production, storage, transmission, consumption, and efficiency must be planned together.

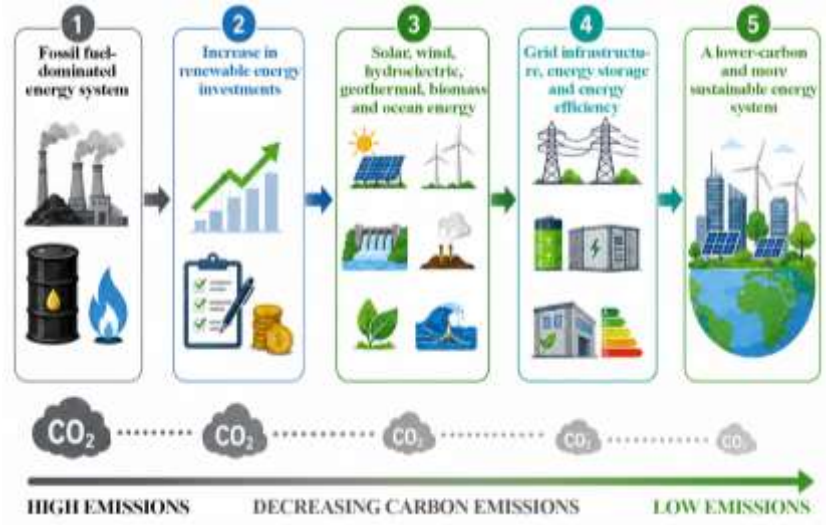


Figure 4.1. Key stages in the transition from a fossil-fuel-dominated energy system to renewable energy

### *4.2. Renewable Energy Use in Europe*

Europe is one of the regions where renewable energy policies are implemented strongly. The European Union supports renewable energy investments in line with its goals of combating climate change, improving energy security, and reducing dependence on fossil fuels (European Commission, 2023; Eurostat, 2024). The European Green Deal, 2030 climate and energy targets, energy efficiency policies, and efforts to reduce fossil fuel imports are important components of this transformation.

According to Eurostat data, renewable energy sources accounted for 24.5% of gross final energy consumption in the European Union in 2023 (Eurostat, 2024). This share has increased compared with previous years; however, renewable energy investments and energy efficiency policies must be accelerated further in order to achieve the 2030 targets (European Commission, 2023).

Renewable energy use in Europe varies from country to country. Wind and hydropower are more prominent in Northern European countries, whereas solar energy has significant potential in Southern European countries. Geothermal energy can be used in regions with geothermal resources, and biomass energy can be developed in rural areas with suitable biomass resources. Therefore, the renewable energy transition in Europe is not a uniform process; each country differs in its geographical conditions, energy infrastructure, economic structure, and policy preferences (European Commission, 2023; Eurostat, 2024).

Table 4.2. Main factors affecting renewable energy use in Europe

| Factor | Effect | Example |
|---|---|---|
| Climate policies | They encourage renewable energy investments. | The European Green Deal and 2030 energy targets |
| Geographical conditions | They determine which source is more suitable. | Solar potential in Southern Europe and wind potential in Northern Europe |
| Energy security | They make the use of domestic resources important. | The goal of reducing fossil fuel imports |
| Technological capacity | It facilitates renewable energy integration. | Smart grids, battery storage, and interconnections |
| Social acceptance | It affects the feasibility of projects. | Wind turbines, solar plants, and local participation processes |
| Finance | It determines the pace of investments. | Public support, private-sector investments, and EU funds |

Solar and wind energy are becoming increasingly central to Europe's energy transition. However, because these sources generate electricity variably depending on weather conditions, electricity grids need to become more flexible. Energy storage systems, interconnected grids, demand-side management, and smart grids are important components of this transformation (IEA, 2024b). The main factors affecting renewable energy use in Europe are

summarised in Table 4.2, including climate policies, geographical conditions, energy security, technological capacity, social acceptance, and finance.

In Europe, the transition to renewable energy requires transformation not only in electricity generation but also in sectors such as transport, heating and cooling, industry, and agriculture. Electrification, green hydrogen, heat pumps, energy-efficient buildings, and sustainable transport solutions are complementary components of this process (IEA, 2024b; IRENA, 2024).

Figure 4.2 shows that the renewable energy transition is not limited to electricity generation. Europe's long-term energy transition requires the joint transformation of sectors such as electricity, transport, industry, buildings, and agriculture (European Commission, 2023; IEA, 2024b).

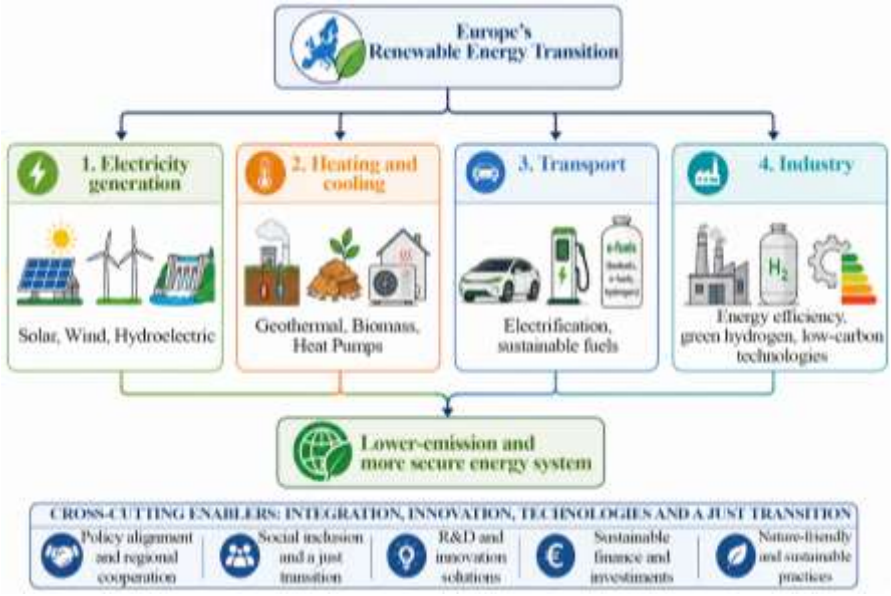


Figure 4.2. Sectoral dimensions of the renewable energy transition in Europe

### *4.3. Main Reasons for the Transition to Renewable Energy*

There are multiple reasons behind the transition to renewable energy. The first is the need to combat climate change. Greenhouse gas emissions resulting from the combustion of fossil fuels are among the most important causes of global temperature rise. Renewable energy sources can reduce the carbon intensity of energy systems by decreasing the use of fossil fuels (IPCC, 2023; IRENA, 2024).

A second important reason is energy security. Fossil fuels such as oil, natural gas, and coal create import dependence for many countries. Countries dependent on energy imports may become more vulnerable to price fluctuations, supply interruptions, and geopolitical risks. The use of local renewable resources such as solar, wind, hydropower, geothermal, and biomass can diversify countries' energy supply and reduce external dependence (IEA, 2024c; IRENA, 2024).

A third reason is economic and technological transformation. Cost reductions in renewable energy technologies, new investment areas, domestic production opportunities, and employment possibilities are accelerating the energy transition. In particular, solar and wind technologies have become capable of providing competitive electricity generation in many regions. In addition, technologies such as energy storage, smart grids, electric mobility, and green hydrogen are creating new economic fields (IEA, 2024b; IRENA, 2024).

A fourth reason concerns environmental and health benefits. The combustion of fossil fuels can cause air pollution, water pollution, soil degradation, and adverse effects on human health. When properly planned, renewable energy sources can help reduce these impacts. In particular, reducing the use of coal and oil can help improve air quality and lower health-related costs (EPA, 2025; IPCC, 2023).

A fifth reason is sustainable development. Energy is necessary for economic development and quality of life; however, sustainable development is not possible without considering the environmental and social impacts of energy systems. When renewable energy, energy efficiency, and sustainable consumption practices are addressed together, they can contribute both to meeting today's energy needs and to protecting the living conditions of future generations (IRENA, 2024). The main reasons for the transition to renewable energy are summarised in Table 4.3, including climate change mitigation, energy security, economic and technological transformation, public health, and sustainable development.

Table 4.3. Main reasons for the transition to renewable energy

| Reason | Explanation | Expected Contribution |
|---|---|---|
| Combating climate change | The need to reduce greenhouse gas emissions from fossil fuels | A lower-carbon energy system |
| Energy security | Reducing dependence on imported fossil fuels | Domestic and diversified energy supply |
| Economic opportunities | New areas of technology, investment, and employment | Green economy and local development |
| Health and environment | Reducing air pollution and environmental pressures | Cleaner air and healthier living conditions |
| Technological innovation | Development of storage, smart grids, and electric mobility | A more flexible and modern energy system |
| Sustainable development | Evaluating energy needs together with environmental and social impacts | A long-term sustainable energy structure |

When these reasons are considered together, the renewable energy transition is not merely a change in energy production technologies. It is a multidimensional process related to climate policy, industrial transformation, urban planning, education, social participation, and economic development (IEA, 2024c; IRENA, 2024).

### *4.4. Environmental Benefits of Renewable Energy*

The most important environmental benefit of renewable energy sources is that they generally have lower greenhouse gas emissions than fossil fuels. Solar, wind, hydropower, and geothermal energy do not produce carbon dioxide emissions directly associated with fossil fuel combustion during electricity generation. From a life-cycle perspective, the greenhouse gas emissions of many renewable electricity technologies are also substantially lower than those of fossil fuels (NREL, 2021).

Renewable energy sources can also contribute to improved air quality. The combustion of fossil fuels such as coal and oil can produce air pollutants including particulate matter, sulfur dioxide, and nitrogen oxides. These pollutants can adversely affect human health, ecosystems, and agricultural production. When renewable energy sources reduce fossil fuel use, air pollution and related health problems may also decline (EPA, 2025; NREL, 2021).

Renewable energy sources may also help reduce pressures on water and soil. In particular, solar and wind energy are more advantageous than many thermal power plants in terms of water use during electricity generation. Nevertheless, water management must be carefully planned in hydropower, biomass, and some geothermal applications. This shows that the environmental benefits of renewable energy sources can be strengthened through appropriate planning and technology selection (NREL, 2021).

Another benefit of renewable energy sources is that they can support the localization of energy production. Rooftop solar systems, small-scale biogas plants, local wind projects, and energy cooperatives can shift energy production from large centralized plants toward more distributed structures. This can contribute both to energy security and local development (European Commission, 2023; IRENA, 2024).

However, environmental benefits do not emerge automatically. Renewable energy projects must be planned in appropriate locations, with suitable technologies, after environmental impact assessment, and with consideration of local community views. Otherwise, even a low-carbon technology may generate ecosystem, land-use, or social acceptance problems at the local scale (NREL, 2021; Wüstenhagen et al., 2007).

### *4.5. Limitations and Planning Requirements of Renewable Energy*

Renewable energy sources offer important opportunities for combating climate change and improving energy security. However, each of these sources has specific limitations and planning requirements. Therefore, renewable energy projects should not be evaluated only in terms of installed capacity or electricity generation; they should also be assessed through criteria such as environmental impact, life cycle, system cost, continuity, energy security, technological feasibility, infrastructure needs, and social acceptance (IEA, 2024b; IRENA, 2024; NREL, 2021; Sovacool and Dworkin, 2015).

One of the main limitations of solar and wind energy is their variable generation. Solar energy cannot generate electricity at night and is affected by cloud cover, season, and geographical location. Wind energy depends on wind speed and continuity. Therefore, in systems with a high share of solar and wind energy, energy storage, flexible grid management, demand-side management, and the combined use of different energy sources become increasingly important (IEA, 2024b).

Land use is another important issue. Large-scale solar and wind projects may require land. The relationship of these lands with agriculture, grazing areas, forests, tourism, cultural heritage, or natural habitats must be carefully evaluated. Rooftop solar systems, the use of degraded or unsuitable lands for energy production, agrivoltaic applications, and well-planned siting can help reduce such impacts (NREL, 2021).

Material requirements and recycling are becoming increasingly important for renewable energy technologies. Solar panels, wind turbines, batteries, and electric vehicles require various metals, minerals, and industrial materials. The extraction, processing, and end-of-life recycling of these materials are important for sustainability. Therefore, the renewable energy transition should be considered together with circular economy principles and responsible supply chains (IEA, 2024a; IRENA, 2024).

Although hydropower can provide low-carbon and flexible electricity generation, it may have significant effects on river ecosystems. Dams can alter fish migration routes, sediment transport, water temperature, local habitats, and flow regimes. Therefore, ecological flow, fish passages, basin management, and the participation of local communities are important in hydropower projects (NREL, 2021).

Biomass and biofuels can offer opportunities for waste management and local energy production. However, when sustainable feedstock management is not ensured, problems may arise in relation to land use, competition with food production, water consumption, and emissions. Therefore, waste-based resources should be prioritized, life-cycle emissions should be assessed, and local ecosystems should be protected in biomass energy systems (IRENA, 2024; NREL, 2021).

Geothermal energy is an important renewable source that can provide continuous and local energy. Nevertheless, geothermal projects require careful monitoring of reinjection, gas emissions, mineral content, water management, and local geological effects. Marine-ocean energy has long-term potential, but it is still developing in terms of technology maturity, cost, maintenance challenges, and impacts on marine ecosystems (IRENA, 2024; NREL, 2021).

Figure 4.3. Environmental planning process in renewable energy projects

Figure 4.3 illustrates that renewable energy investments require more than technical feasibility. Sustainable project planning should integrate environmental assessment, social participation, economic feasibility, and long-term operation and maintenance processes (NREL, 2021; Wüstenhagen et al., 2007).

Table 4.4 shows that renewable energy sources are generally more environmentally advantageous, but that each source must be evaluated within its own context. Sustainable energy planning does not only mean turning toward low-carbon sources; it also means jointly managing siting, life-cycle impacts, resource efficiency, recycling, local ecosystems, and social acceptance. This approach enables the decision-making framework discussed in Chapter 2 to be applied to renewable energy projects (NREL, 2021; Wüstenhagen et al., 2007).

Table 4.4. Environmental advantages of renewable energy sources and impacts requiring attention

| Energy Source | Main Environmental Advantage | Impact Requiring Attention |
|---|---|---|
| Solar energy | It does not produce direct emissions during electricity generation. | Panel production, land use, and recycling of panel waste are important. |
| Wind energy | It provides low-carbon electricity generation. | Birds, bats, visual impact, noise, and local acceptance should be considered. |
| Hydropower | It can provide long-lived and low-carbon electricity generation. | River ecosystems, fish passages, flow regime, and displacement effects are important. |
| Geothermal energy | It can provide continuous and local energy. | Water use, gas emissions, and local geological effects should be monitored. |
| Biomass energy | It can transform organic waste into energy. | Land use, competition with food production, and sustainable feedstock management are important. |
| Marine-ocean energy | It can obtain energy from waves, tides, and currents. | Marine ecosystems, coastal use, and technological maturity should be considered. |

### *4.6. Grid Integration, Storage, and Energy Efficiency*

The expansion of renewable energy sources requires electricity systems to become more flexible, digital, efficient, and resilient. Because solar and wind energy generate electricity variably depending on weather

conditions, grid management, storage, demand-side management, and energy efficiency should be addressed together in systems where these sources reach high shares (IEA, 2024b).

Grid integration refers to the safe and efficient connection of electricity generated from renewable sources to the electricity system. In systems with high shares of solar and wind energy, transmission lines must be strengthened, distribution grids modernized, and smart meters, digital monitoring systems, and flexible market structures developed. Otherwise, even if renewable energy generation increases, delivering this energy reliably to consumers may become difficult (IEA, 2024b).

Energy storage is an important solution for balancing variable renewable generation. Battery systems, pumped hydropower storage, thermal storage, hydrogen, and other storage technologies can be used over different time scales. For example, batteries are suitable for short-term balancing, whereas hydrogen and some chemical storage methods may be considered for long-duration storage (IEA, 2024b; IRENA, 2024).

Demand-side management can also increase the flexibility of energy systems. Reducing demand during peak electricity consumption periods or shifting certain types of consumption to periods when renewable generation is high can make the energy system more balanced. Smart appliances, time-of-use tariffs, energy management systems, and consumer awareness are important in this process (IEA, 2024a, 2024b).

Energy efficiency is a complementary component of the renewable energy transition. Establishing new renewable energy capacity alone may not be sufficient if energy demand is not reduced. Practices such as insulation in buildings, efficient heating and cooling systems, LED lighting, efficient motors, public transport, electric mobility, and waste heat recovery in industry reduce total energy demand and facilitate the transition to renewable energy (Chen et al., 2022; IEA, 2024; IRENA, 2024).

Table 4.5. Key elements that provide flexibility in renewable energy systems

| Element | Main Function | Example |
|---|---|---|
| Energy storage | To store surplus production and use it when needed | Battery, pumped hydropower, hydrogen |
| Smart grids | To digitally monitor and manage production and consumption | Smart meters and automation systems |
| Demand-side management | To shift consumption to suitable times | Time-of-use tariffs and smart devices |
| Resource diversity | To use different renewable sources together | Combination of solar, wind, hydropower, and biomass |
| Interconnections | To strengthen electricity exchange between regions | National and regional grid connections |
| Energy efficiency | To reduce total energy need | Insulation, efficient appliances, and efficient industrial systems |

Table 4.5 shows that flexibility in renewable energy systems depends not only on storage technologies, but also on smart grids, demand-side management, resource diversity, interconnections, and energy efficiency. Therefore, the energy transition is not limited to establishing new solar or wind capacity; it requires integrated planning and redesign of production, transmission, distribution, storage, consumption patterns, and efficiency policies (IEA, 2024a, 2024b; IRENA, 2024).

### *4.7. Social Acceptance, Local Impacts, and Just Transition*

For renewable energy projects to succeed, technical suitability, economic feasibility, and environmental benefits are not sufficient on their own. Social acceptance, local participation, fair benefit sharing, and trust are also basic determinants of project success. Even if a project is low-carbon and economically feasible, it may encounter social opposition if the concerns of local communities are not taken into account (Sovacool and Dworkin, 2015; Wüstenhagen et al., 2007).

Social acceptance is not simply a question of whether people support a project. It is also related to participation in decision-making processes, the sharing of local benefits, the consideration of environmental concerns, and access to reliable information. For example, in a wind energy project, visual impact, noise, bird migration routes, and land use may be debated; in a hydropower project, river ecosystems, water use, and local livelihoods may become matters of concern. When such issues are not addressed transparently, resistance to renewable energy projects can increase (Wüstenhagen et al., 2007).

Renewable energy projects can create local economic opportunities in some regions. Installation, maintenance, operation, local supply chains, and training programs can create new employment areas. Energy cooperatives, municipal-scale energy projects, and rooftop solar systems can increase local participation. However, these benefits must be shared fairly (IRENA, 2024; Sovacool and Dworkin, 2015).

A just transition is an approach that takes into account the effects of the energy transition on workers, low-income groups, fossil-fuel regions, and local communities. The transition of workers in fossil fuel sectors to new employment areas, fair management of energy costs, the participation of local communities in decision-making, and the creation of social benefits from renewable energy investments are important components of a just transition (ILO, 2015; Sovacool and Dworkin, 2015).

Energy literacy is also important for increasing social acceptance in the transition to renewable energy (Wahlund and Palm, 2022). When people understand the advantages, limitations, environmental impacts, and economic consequences of energy sources, more informed discussions can take place. Therefore, renewable energy education should not only convey technical information; it should also include decision-making, evidence-based thinking,

local participation, and social responsibility (DeWaters et al., 2013; Ramachandran et al., 2024; Wüstenhagen et al., 2007).

These challenges do not mean that the transition to renewable energy is impossible. On the contrary, they show that the energy transition requires careful planning, strong infrastructure, scientific assessment, and social participation. When renewable energy sources are addressed together with energy efficiency and sustainable consumption habits, they can provide a strong basis for a lower-carbon and more secure future (IEA, 2024a, 2024b; IRENA, 2024).

Table 4.6 summarises the main opportunities and challenges of the renewable energy transition. It shows that renewable energy can contribute to emission reduction, employment opportunities, the use of local resources, and climate targets, but it also requires careful planning in relation to land use, financing, grid flexibility, social acceptance, and long-term policy stability.

Table 4.6. Opportunities and challenges in the transition to renewable energy

| Dimension | Opportunity | Challenge |
|---|---|---|
| Environmental | It can reduce greenhouse gas emissions. | Land use and ecosystem effects require attention. |
| Economic | It can create new areas of employment and technology. | Initial investment and financing needs may be high. |
| Energy security | It can increase the use of local resources. | Variable generation may complicate energy system planning. |
| Technological | It promotes storage, smart grids, and efficient technologies. | Grid integration and flexibility are required. |
| Social | It can support energy cooperatives and local participation. | Siting and visual impacts may lead to local opposition. |
| Political | It is compatible with climate targets. | It requires long-term and stable policy support. |

### *4.8. Evaluation from the Perspective of Energy Literacy*

The transition to renewable energy is not only an engineering, investment, and infrastructure issue. For this transition to succeed, society must be able to understand energy sources, energy transformations, environmental impacts, and sustainability options. At this point, energy literacy is a fundamental concept. In the current literature, energy literacy is treated as a multidimensional competence that includes knowledge, attitudes, behavior, decision-making, responsible action, and sustainability awareness (Ayata et al., 2024; DeWaters et al., 2013; Leite et al., 2026; Ramachandran et al., 2024; Santillán and Cedano, 2023).

Renewable energy sources offer powerful learning opportunities in education. Solar panels, wind turbines, hydropower systems, biomass applications, and hydrogen technologies can help connect science, environmental education, technology, engineering, and mathematics with everyday life. Therefore, STEM, inquiry-based learning, gamification, and

activities based on local environmental problems can be used as effective tools in teaching renewable energy topics (Hiğde, 2022; Mylonas et al., 2021; Vasconcelos et al., 2023).

Energy issues are also suitable for socio-scientific discussions. Where a wind farm should be built, how a hydropower project affects ecosystems, how biomass relates to land use, how land should be selected for solar power plants, or in which sectors green hydrogen should be used are not merely technical questions. These decisions include economic, environmental, and social consequences. Therefore, renewable energy education can develop students' ability to evaluate evidence, compare different views, and think about sustainable decisions (Sadler, 2004; Zeidler, 2014).

From the perspective of energy literacy, renewable energy education has three main goals. The first is for students to understand the working principles of energy sources. The second is for them to compare the advantages and limitations of these sources. The third is for them to evaluate energy choices together with their environmental, economic, and social consequences. When these three goals are addressed together, students can develop a more holistic understanding of energy systems (DeWaters et al., 2013; Ramachandran et al., 2024).

Table 4.7. Approaches that can be used in renewable energy education

| Approach | Example Application | Expected Contribution |
|---|---|---|
| STEM activities | Designing a mini solar panel or wind turbine model | Supports energy transformation, measurement, and design skills. |
| Inquiry-based learning | Examining the energy consumption of the school | Develops data collection, analysis, and solution-generation skills. |
| Gamification | Energy-saving competitions or digital simulations | May increase participation, motivation, and behavioral awareness. |
| Local environmental problem | Discussing the environmental effects of a nearby energy project | Connects scientific knowledge with local decisions. |
| Socio-scientific discussion | Evaluating the views of different stakeholders for an energy investment | Supports evidence-based decision-making and critical thinking. |
| Comparative analysis | Comparing solar, wind, hydropower, and biomass according to different criteria | Enables multidimensional evaluation of energy resources. |

Table 4.7 presents educational approaches that can promote renewable energy literacy by connecting technical knowledge with inquiry, local environmental problems, socio-scientific discussion, and comparative analysis. Renewable energy education should not only provide technical knowledge, but also help students develop responsible decision-making skills for a sustainable future. Therefore, energy education should go beyond the transmission of information and encourage students to investigate real-life

energy problems, compare alternative solutions, evaluate environmental and social impacts, and discuss the trade-offs involved in energy decisions (Sadler, 2004; Zeidler, 2014).

### *4.9. Chapter Summary and Discussion Questions*

This chapter examined renewable energy sources and their environmental impacts within a general framework. Renewable energy sources are obtained from resources that are continuously renewed by natural processes or renewed within relatively short periods. Solar, wind, hydropower, geothermal, biomass, and marine-ocean energy are included in this group.

Because renewable energy sources generally have lower greenhouse gas emissions than fossil fuels, they play an important role in combating climate change. They can also improve energy security, reduce dependence on energy imports, support the use of local resources, and create new economic opportunities.

At the global scale, renewable energy investments are increasing rapidly, especially in solar and wind energy. Electricity generation is one of the areas in which the energy transition has advanced most rapidly. However, the share of fossil fuels in the global energy system remains high. Therefore, renewable energy investments must be addressed together with energy efficiency, storage, smart grids, and sustainable consumption.

In Europe, the renewable energy transition is supported by climate policies, energy security concerns, technological capacity, and financing opportunities. However, this transformation requires change not only in electricity generation but also in transport, buildings, industry, agriculture, and heating and cooling.

Although the environmental benefits of renewable energy sources are significant, their impacts are not entirely zero. Issues such as land use, ecosystem effects, material requirements, waste management, recycling, water use, and social acceptance must be carefully evaluated. Renewable energy projects should therefore be addressed through life-cycle and environmental planning principles.

The spread of variable sources such as solar and wind increases the need for energy storage, smart grids, demand-side management, and resource diversity. Energy efficiency is a complementary element of the renewable energy transition. Establishing new generation capacity alone is not sufficient for a sustainable energy system if total energy demand is not reduced.

The transition to renewable energy is also a social process. Local community participation, transparent information, fair benefit sharing, and energy literacy are important for social acceptance. Energy literacy enables individuals to evaluate renewable energy sources not only through their technical characteristics but also through their environmental, economic, and social consequences.

**Discussion Questions**

1. Why are renewable energy sources considered among the fundamental components of sustainable energy systems?
2. Why should the transition to renewable energy be evaluated not only as an environmental process but also as an economic and social process?
3. What are the main factors that have enabled the rapid growth of solar and wind energy at the global scale?
4. What are the main factors accelerating the renewable energy transition in Europe?
5. Why are the environmental impacts of renewable energy sources not entirely zero?
6. What challenges does the variable generation of solar and wind energy create for energy systems?
7. Why are energy storage and smart grids important in the renewable energy transition?
8. Why is energy efficiency as important as renewable energy investments?
9. Which social problems can the just transition approach help address in the renewable energy transition?
10. How can energy literacy affect the social acceptance of the renewable energy transition?
11. Which STEM or inquiry-based activities can be implemented in a school to increase awareness of renewable energy?

## CHAPTER 5: SOLAR, WIND AND HYDROELECTRIC ENERGY

This chapter examines three major resources that are prominent in renewable electricity generation: solar, wind, and hydroelectric energy. These resources are important because they can provide lower greenhouse gas emissions than fossil fuels, diversify energy supply, and make use of local energy potential (Box 5.1). However, each resource differs in terms of technical requirements, environmental impacts, cost structure, continuity, and conditions of social acceptance (IEA, 2024; IRENA, 2024).

The previous chapter emphasized that the renewable energy transition is not limited to installing new generation capacity; it must also be considered together with grids, storage, energy efficiency, site selection, life-cycle impacts, and principles of a just transition. In this chapter, solar, wind, and hydroelectric energy are examined in detail in terms of their working principles, areas of use, advantages, limitations, environmental impacts, and educational applications.

Box 5.1. What will be learned in this chapter

| Learning Objective |
|---|
| Explain the basic working principles of these resources and their role in renewable energy systems. |
| Compare photovoltaic, solar thermal, onshore/offshore wind, and hydroelectric systems in terms of uses and technical characteristics. |
| Discuss the environmental benefits of solar, wind, and hydroelectric energy projects and the life-cycle impacts that require attention. |
| Interpret variable generation, storage, grid integration, and system flexibility in the context of these three resources. |
| Analyze energy projects through environmental impact, cost, continuity, energy security, site selection, and social acceptance criteria. |
| Explain how solar, wind, and hydroelectric energy can be used to support energy literacy and classroom activities. |

Table 5.1 summarizes the common characteristics and differences of the three renewable energy resources examined in this chapter. Solar and wind energy are rapidly expanding variable generation resources. Hydroelectric energy, by contrast, is a long-established renewable resource that can provide flexibility and storage support to electricity systems in some contexts.

Table 5.1. General overview of solar, wind, and hydroelectric energy

| Energy Type | Basic Resource | Main Area of Use | Point Requiring Attention |
|---|---|---|---|
| Solar energy | Solar radiation | Electricity generation, hot water, heating, and industrial heat applications | Production depends on daylight, weather conditions, panel orientation, and storage/grid infrastructure. |
| Wind energy | Movement of air | Onshore and offshore electricity generation | Production depends on wind speed; site selection, bird and bat impacts, noise, and social acceptance are important. |
| Hydroelectric energy | Flowing or stored water | Electricity generation, system flexibility, and in some cases energy storage | River ecosystems, water management, drought risk, and impacts on local communities must be carefully evaluated. |

Figure 5.1 shows the basic roles of solar, wind, and hydroelectric resources in the energy system and indicates that these resources should be evaluated together with local suitability, environmental impacts, continuity and flexibility, social acceptance, and energy literacy dimensions.

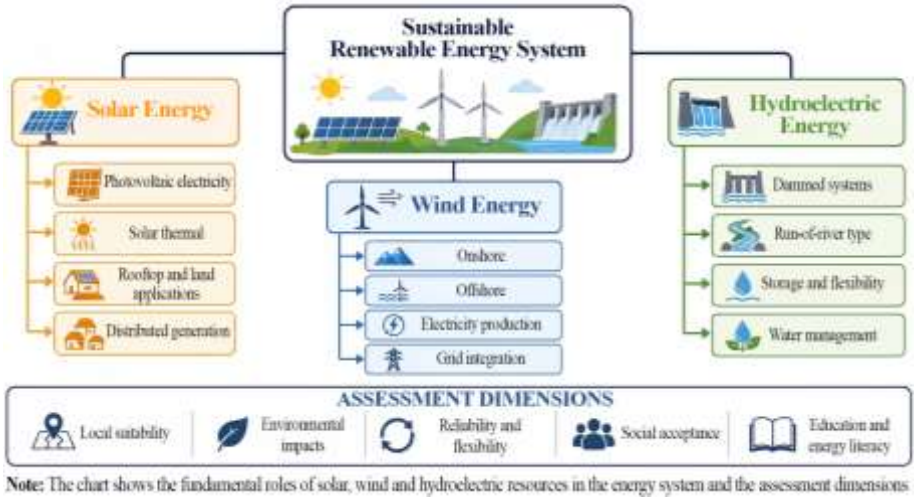


Figure 5.1. Roles of solar, wind, and hydroelectric resources in the energy system.

### *5.1. Solar Energy*

Solar energy is a renewable energy type obtained by converting radiation from the Sun into electricity or heat (Seminario-Córdova and Rojas-Ortega, 2023). The Sun is the fundamental energy source for life on Earth. Plant photosynthesis, the formation of winds, the continuation of the water cycle, and many natural processes depend directly or indirectly on solar energy (DOE and AAAS, 2017).

Solar energy technologies can generally be examined under two main categories. The first is photovoltaic systems, which convert sunlight directly into electrical energy. The second is solar thermal systems, which convert solar radiation into heat energy. Solar thermal systems can be used for water heating, building heating, or electricity generation in concentrated solar power plants (U.S. Department of Energy [DOE], 2026, 2026a).

One of the most important advantages of solar energy is that the resource is widespread and renewable (Maka and Alabid, 2022). Solar panels can be installed at different scales, ranging from small rooftop applications to large-scale solar power plants. Therefore, solar energy is suitable both for individual users and for large energy investments.

Nevertheless, solar energy has certain limitations. Solar energy production depends on daylight; electricity is not generated at night, and cloudiness, season, latitude, panel orientation, and shading affect the amount of production. For this reason, energy storage systems, smart grids, demand management, and planning with other energy resources are important for the more reliable use of solar energy (IEA, 2024).

Table 5.2. Main advantages, limitations, and environmental evaluation dimensions of solar energy

| Dimension | Strength | Limitation / point requiring attention |
|---|---|---|
| Resource and accessibility | Solar radiation is a widespread and renewable resource. | Production is affected by night-time conditions, cloudiness, season, latitude, panel orientation, and shading. |
| Scalability | It can be installed modularly, from rooftop systems to large power plants. | In large facilities, land use, grid connection, and site selection must be planned carefully. |
| Environmental impact | It does not produce direct greenhouse gas or air pollutant emissions during electricity generation. | Panel production, raw material use, and end-of-life recycling processes must be considered. |
| Water and land use | Photovoltaic systems require little water during operation; rooftop systems reduce additional land demand. | Large plants should be evaluated with respect to sensitive ecosystems, agricultural land, and water use in some thermal applications. |
| Economy and infrastructure | Costs have declined significantly over the long term; it can support local electricity generation. | Initial investment, inverters, storage, and grid connection can create costs. |
| Educational and social value | It offers concrete learning opportunities for energy conversion, measurement, and data analysis. | Experiments should be designed safely and appropriately for students' age levels; local acceptance and participation should be considered. |

Table 5.2 summarises the main advantages, limitations, and environmental evaluation dimensions of solar energy. Solar energy technologies have expanded rapidly in recent years, and photovoltaic systems in particular have become one of the most important components of the renewable energy transition because of their modular structure, declining costs, and wide range of applications (Ember, 2024; IRENA, 2024).

### *5.1.1. Solar Energy Conversions*

Solar energy can be converted into different forms of energy in nature and in technological systems. In natural processes, sunlight is used by plants for photosynthesis, enables water evaporation, affects atmospheric movements, and plays an important role in the operation of Earth's climate systems (Maka and Alabid, 2022). In technological systems, sunlight is converted into electrical or heat energy.

In photovoltaic systems, an electric current is formed when sunlight reaches solar cells made of semiconductor materials. This phenomenon is called the photovoltaic effect. Solar cells are combined to form solar panels, and panels are combined to form larger systems (Kataray et al., 2023). These systems can be used at different scales, from rooftop electricity generation to large solar power plants (DOE, 2026).

In solar thermal systems, the main aim is to convert solar radiation into heat. Simple solar collectors can be used for water heating. In larger-scale concentrated solar power systems, mirrors or lenses concentrate sunlight on a specific point. This heat can be used to produce steam and operate turbines (DOE, 2026a).

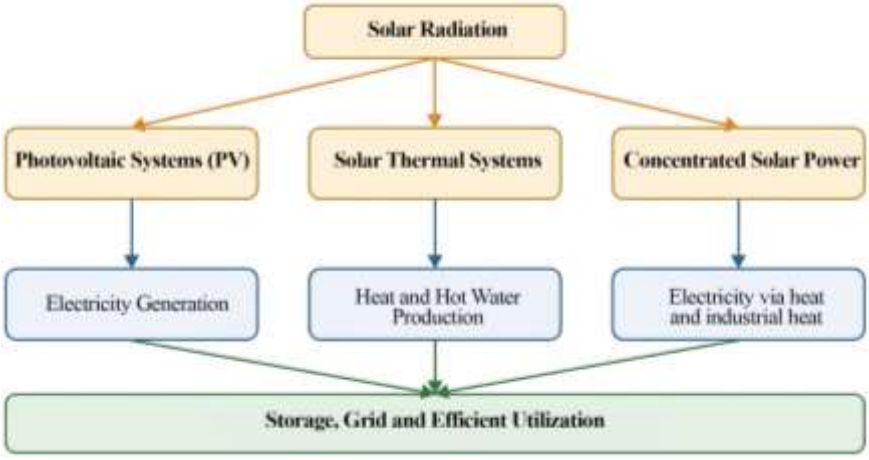


Figure 5.2. Main conversion pathways of solar energy.

Figure 5.2 shows that solar energy can be used not only for electricity generation but also for heating and industrial heat applications. Solar energy

is therefore a flexible renewable resource that can be applied in different sectors.

### *5.1.2. Photovoltaic Systems*

Photovoltaic systems are systems that convert sunlight directly into electrical energy (Muliadi et al., 2021). The basic unit of these systems is the solar cell. Solar cells are generally made from semiconductor materials such as silicon. When sunlight reaches the cell surface, an electric current is generated through the movement of electrons (DOE, 2026).

A photovoltaic system is not composed only of panels. For the system to operate, it also requires inverters, connection equipment, mounting structures, cabling, monitoring systems, and in some cases battery storage units. The inverter converts the direct current obtained from solar panels into the alternating current used in homes and electricity grids.

Photovoltaic systems can be installed at different scales. Small systems are commonly placed on residential rooftops, while medium-scale systems can be used in schools, public buildings, farms, or businesses. Large-scale solar power plants may be installed on suitable land areas, industrial sites, or degraded lands to generate electricity. The basic components of photovoltaic systems are summarised in Table 5.3. The table shows that a photovoltaic system is not composed only of solar panels, but also includes inverters, mounting systems, cabling, monitoring systems, and, in some cases, battery storage.

Table 5.3. Basic components of photovoltaic systems

| Component | Function |
|---|---|
| Solar panel | Converts sunlight into electrical energy. |
| Inverter | Converts direct current into alternating current. |
| Mounting system | Allows panels to be positioned at an appropriate angle and orientation. |
| Cabling and connections | Ensures that electricity is transmitted safely. |
| Monitoring system | Tracks the amount of production and system performance. |
| Battery | Stores generated electricity for later use. |

The most important advantage of photovoltaic systems is their modularity. A small system can be installed initially and expanded as needs increase. This feature makes solar energy attractive for both individual and institutional users. However, modularity does not mean that planning is unimportant; panel orientation, shading, electrical safety, and grid connection should be evaluated properly.

### *5.1.3. Solar Thermal Systems and Concentrated Solar Power*

Solar thermal systems are systems that convert sunlight into heat energy before converting it into electricity, if electricity is needed (Maka and

Alabid, 2022). One of the most common examples is water-heating systems using solar collectors. In these systems, solar radiation is converted into heat on the collector surface, and this heat is transferred to water. They can be used to meet hot-water demand in residences, hotels, sports facilities, and some industrial applications.

Concentrated solar power systems are larger-scale applications. In these systems, mirrors or reflective surfaces concentrate sunlight at a specific point. The high temperature obtained can be used to produce steam and operate turbines used in electricity generation. Concentrated solar thermal technologies can also be evaluated for some industrial heat applications requiring high temperatures, in addition to electricity generation (DOE, 2026a).

Table 5.4 compares the main solar energy technologies in terms of their basic working principles and areas of use. This comparison shows that solar energy is not limited to photovoltaic electricity generation, but also includes heat production, concentrated solar power, and hybrid applications. Especially in applications with high heat demand, solar thermal systems can provide important opportunities for energy savings and emission reduction.

Table 5.4. Comparison of solar energy technologies

| Technology | Basic Working Principle | Area of Use |
|---|---|---|
| Photovoltaic systems | Convert sunlight directly into electricity. | Residence, school, business, solar power plant |
| Solar collectors | Convert sunlight into heat. | Hot water, building heating, pool heating |
| Concentrated solar power | Concentrates sunlight with mirrors to produce high temperature. | Electricity generation, industrial heat applications |
| Solar-assisted hybrid systems | Use solar energy together with other energy systems. | Heating, cooling, agriculture, and industrial applications |

### *5.1.4. Environmental Impacts of Solar Energy*

Solar energy has the potential to reduce greenhouse gas emissions because it does not directly burn fossil fuels during electricity generation. However, the environmental impacts of solar energy systems are not zero. Raw material extraction for panel production, energy use in manufacturing processes, land requirements, and management of panel waste at the end of service life should be carefully addressed (NREL, 2021).

Rooftop solar systems are environmentally advantageous because they can generate electricity without increasing land use. In large-scale solar power plants, however, site selection is important. Projects built on agricultural land, natural habitats, or sensitive ecosystems may create environmental and social debates. Therefore, environmental impact assessment, communication with local communities, and recycling plans are important in solar energy projects.

The strongest environmental feature of solar energy is that it helps reduce fossil fuel use. Yet a sustainable solar energy system must consider the entire life cycle from production to recycling. This approach requires renewable energy technologies to be evaluated within environmental planning and resource management rather than simply being labeled as “clean.”

### *5.1.5. Use of Solar Energy in Education*

Solar energy is a suitable example for helping students learn concretely about energy conversion, electricity generation, sustainability, and climate change. Simple experiments with small solar panels help students understand how sunlight is converted into electrical energy.

School activities related to solar energy can develop measurement, observation, data collection, and problem-solving skills. Students can measure solar panel output at different times, observe the effect of panel angle on production, or examine experimentally how shading reduces electricity generation. Such activities do not leave renewable energy learning at the level of conceptual knowledge alone; they also support data-based thinking, design, and connections with daily life (Hiğde, 2022; Vasconcelos et al., 2023).

From the perspective of energy literacy, solar energy also helps students see the connection between energy production and consumption behavior. For example, a rooftop solar panel application at a school can create a learning environment not only for electricity generation technology but also for discussions on energy saving, carbon footprint, cost, local participation, and sustainability. In this respect, solar energy is a strong educational topic that can be linked to socio-scientific discussions (Sadler, 2004; Zeidler, 2014).

Box 5.2. Classroom activity suggestion: Observing solar panel production

| Activity Stage | Explanation |
|---|---|
| Aim | Observe the relationship between the amount of sunlight and electricity production. |
| Materials | Small solar panel, multimeter, lamp or sunlight, recording sheet. |
| Application | The panel is measured at different angles and under different light conditions. |
| Observation | Voltage or current values are recorded. |
| Discussion | The relationship between light intensity, panel angle, shading, and energy efficiency is evaluated. |
| Extension | Students can compare the school’s energy consumption with possible solar energy production. |

This activity enables students to learn about renewable energy not only theoretically but also experimentally. It also helps establish connections with energy efficiency, technology design, data literacy, and environmental sustainability (Box 5.2).

### *5.1.6. Evaluation from the Perspective of Energy Literacy*

Solar energy is a powerful teaching topic from the perspective of energy literacy, because students can evaluate both basic scientific concepts and daily-life decisions together. Understanding how a solar panel works supports the cognitive dimension; discussing the environmental and social impacts of solar energy supports the attitudinal dimension; and thinking about energy saving, efficient consumption, and renewable energy preferences supports the behavioral dimension (DeWaters et al., 2013; Santillán and Cedano, 2023).

Therefore, solar energy education should not be limited to the information that "a panel produces electricity from the Sun." Students should also be able to evaluate the life-cycle impacts of panel production, the problem of variable generation, the need for storage, site selection, cost, and social acceptance. Such an approach transforms energy into a learning area that links technical knowledge with sustainability and responsible citizenship.

## *5.2. Wind Energy*

Wind energy is a renewable energy type obtained from the movement of air. The Earth's surface is heated at different rates by the Sun, creating pressure differences in the atmosphere (Cevasco et al., 2021). These pressure differences cause air movement, that is, wind. Wind turbines convert this kinetic energy first into mechanical energy and then into electrical energy (DOE, 2026c).

Wind energy has been used for different purposes throughout history. Traditional windmills were used to grind grain or pump water, while modern wind turbines have been developed for electricity generation. Today, wind energy is widely used for electricity generation through turbines installed both onshore and offshore (DOE, 2026c: IEA, 2024).

One of the most important advantages of wind energy is that it does not directly use fossil fuels or generate greenhouse gas emissions during electricity production. In this respect, wind energy is an important component of low-carbon energy systems. However, wind energy production depends on wind speed and continuity. Therefore, appropriate site selection, wind measurements, grid connection, and energy storage solutions are highly important (IEA, 2024b; NREL, 2021).

Table 5.5 summarises the main advantages, limitations, and environmental evaluation dimensions of wind energy. It shows that wind energy is an important low-carbon option, but its sustainable use depends on wind potential, site selection, grid integration, biodiversity protection, social acceptance, and long-term maintenance.

Table 5.5. Main advantages, limitations, and environmental evaluation dimensions of wind energy

| Dimension | Strength | Limitation / point requiring attention |
|---|---|---|
| Resource potential | Wind is renewable and can be a strong energy resource in suitable regions. | Wind speed and continuity vary by region; long-term measurement is required. |
| Emissions and air quality | It does not produce direct greenhouse gas or air pollutant emissions during electricity generation. | Turbine manufacturing, transport, and installation processes have life-cycle impacts. |
| Site selection and scale | It can be installed at different scales, from a single turbine to large onshore and offshore plants. | Site selection, transmission infrastructure, distance from settlements, and social acceptance are decisive. |
| Biodiversity and local environment | Low-carbon generation contributes to reducing climate pressure. | Birds, bats, noise, shadow flicker, visual impact, and marine ecosystems in offshore projects should be evaluated. |
| Grid integration and economy | In suitable regions, it can provide competitive production and complement solar energy. | Because of variable generation, flexible grids, storage, balancing, and maintenance investments are required. |

### *5.2.1. Working Principle of Wind Turbines*

Wind turbines are systems that convert the kinetic energy of wind into electrical energy. When wind strikes turbine blades, a pressure difference forms on the two sides of the blades. This difference causes the blades to rotate. The rotating blades move the rotor, and this rotational motion is transferred to the generator, where electricity is produced (DOE, 2026c).

Figure 5.3 illustrates that wind energy is basically a conversion process from kinetic energy to electrical energy. Wind speed, turbine blade design, tower height, and the wind potential of the region directly affect the amount of electricity that can be generated.

Figure 5.3. Energy conversion process in wind turbines.

A wind turbine is not composed only of blades. For a turbine to operate efficiently and safely, several interconnected components must work together, including the rotor, nacelle, generator, tower, brake system, yaw system, control system, and transformer and connection system. Modern turbines can track wind direction and speed and adjust blade angles. In this way, more efficient electricity generation can be achieved, and system safety can be maintained at very high wind speeds. The basic components of wind turbines are summarised in Table 5.6.

Table 5.6. Basic components of wind turbines

| Component | Function |
|---|---|
| Blades | Convert the kinetic energy of wind into rotational motion. |
| Rotor | The main rotating section to which the blades are attached. |
| Tower | Keeps the turbine elevated so that it can benefit from stronger and more regular winds. |
| Generator | Converts mechanical motion into electrical energy. |
| Nacelle | The upper section that houses the generator, gearbox, and control systems. |
| Yaw system | Allows the turbine to turn toward the wind direction. |
| Control system | Monitors and regulates the safe and efficient operation of the turbine. |
| Transformer and connection system | Makes the generated electricity suitable for grid connection. |

### *5.2.2. Onshore and Offshore Wind Energy*

Wind energy applications are generally divided into onshore and offshore wind energy. Onshore wind turbines are installed on land in areas with high wind potential. These turbines are usually located in hilly areas, open land, coastal zones, and wind corridors. Onshore wind energy is generally easier to install and maintain than offshore systems.

Offshore wind energy refers to electricity generation through turbines installed in seas or large bodies of water. Offshore winds may often be stronger and more regular. Therefore, offshore wind farms have high electricity generation potential. However, installation, maintenance, seabed connections, transmission lines, and environmental monitoring processes may be more complex and costly (NREL, 2021).

As shown in Table 5.7, both onshore and offshore wind energy systems are important for renewable electricity generation. The more appropriate option depends on wind potential, geographical conditions, cost, environmental impacts, grid connection, maintenance requirements, and social acceptance.

Table 5.7. Comparison of onshore and offshore wind energy

| Feature | Onshore Wind Energy | Offshore Wind Energy |
|---|---|---|
| Installation area | Land areas, hills, open fields, coasts | Seas and large water bodies |
| Wind potential | Varies by region | Often stronger and more regular |
| Installation cost | Relatively lower | Higher |
| Maintenance | More accessible | More difficult because of marine conditions |
| Environmental impact | Land use, birds, bats, noise, and visual impact | Marine ecosystems, fisheries, bird migration routes, and marine use |
| Grid connection | May be easier | Requires submarine cables and special connection infrastructure |

### *5.2.3. Wind Potential and Site Selection*

Site selection is one of the most critical issues in wind energy projects. Before a wind turbine is installed in an area, long-term wind measurements are conducted. Wind speed, wind direction, turbulence, terrain structure, distance from settlements, natural habitats, bird migration routes, and grid connection opportunities are evaluated.

As wind speed increases, the amount of energy that a turbine can produce also increases. However, turbines do not operate efficiently at very low wind speeds; at very high wind speeds they may be stopped for safety reasons. Therefore, for wind energy projects, not only the presence of wind but also its speed, regularity, and continuity are important.

As shown in Table 5.8, correct site selection increases both the economic efficiency and environmental sustainability of wind energy projects. Therefore, wind energy investments should be planned together with technical analysis, environmental assessment, grid connection opportunities, and social participation processes.

Table 5.8. Factors affecting site selection in wind energy projects

| Factor | Why It Is Important |
|---|---|
| Average wind speed | Directly affects the amount of electricity to be generated. |
| Wind direction | Required for turbine placement and plant design. |
| Terrain structure | Hills, valleys, and obstacles can affect wind flow. |
| Grid connection | Required to transfer generated electricity to the system. |
| Distance from settlements | Considered in terms of noise, visual impact, and safety. |
| Bird and bat movements | Should be evaluated to reduce ecological impacts. |
| Social acceptance | Informing and involving local communities affects project success. |
| Maintenance access | Regular maintenance and repair of turbines must be possible. |

### *5.2.4. Environmental Impacts of Wind Energy*

Wind energy helps reduce greenhouse gas emissions because it does not directly burn fossil fuels during electricity generation. For this reason, it is an important renewable energy resource in combating climate change (IEA, 2024; Justice et al., 2024; NREL, 2021). However, the environmental impacts of wind energy are not zero.

Wind turbines can pose risks to birds and bats in some regions. Careful environmental assessment is especially necessary for turbines located near migration routes, breeding areas, and sensitive ecosystems. In addition, noise, shadow flicker, visual impact, and land use associated with turbines can also cause local debates (Pacific Northwest National Laboratory [PNNL], 2023).

In offshore wind projects, marine ecosystems, fishing activities, seabirds, marine mammals, and coastal use should be considered. Site

selection, construction-period planning, monitoring systems, and environmental management practices are important for reducing these impacts (NREL, 2021).

The environmental impacts of wind energy can often be reduced through appropriate planning and monitoring methods. For example, avoiding bird migration routes, carefully arranging turbine placement, limiting construction activities during sensitive periods, and involving local people in decision-making processes are important for sustainable wind energy projects.

### *5.2.5. Role of Wind Energy in the Energy System*

Wind energy is one of the important resources that can reduce the share of fossil fuels in electricity generation. Together with solar energy, wind energy is among the main elements of the global increase in renewable energy capacity (IEA, 2024). Especially in countries with suitable wind potential, wind energy can reach significant shares in electricity generation.

However, wind energy production can vary depending on weather conditions. When the wind is weak, generation decreases; during periods of strong and steady wind, production increases. Therefore, for wind energy to be integrated reliably into the energy system, flexible electricity grids, energy storage systems, demand management, and balanced planning with different energy resources are required (IEA, 2024a).

Wind energy and solar energy can complement each other. In some regions, solar energy generates strongly during daytime hours, while wind energy may be stronger at night or in different seasons. Therefore, using different renewable resources together can contribute to a more balanced operation of the energy system. Figure 5.4 shows that wind energy should not be considered alone, but together with other renewable resources and grid technologies. This approach is important for a sustainable and reliable energy system.

Figure 5.4. Integration of wind energy into the electricity system.

### *5.2.6. Use of Wind Energy in Education*

Wind energy is a suitable example for helping students learn about energy conversion, aerodynamics, electricity generation, environmental awareness, and sustainability. By using simple model turbines, the effects of wind speed, number of blades, blade angle, and turbine height on electricity generation can be observed.

Such activities support not only theoretical knowledge but also experimentation, measurement, data interpretation, and design-development skills. Wind energy activities are highly suitable for STEM-based applications that bring together science, technology, engineering, and mathematics.

Renewable energy activities can also help students relate technical knowledge to environmental and social decisions (Hiğde, 2022; Yıldırım and Selvi, 2016).

Box 5.3. Classroom activity suggestion: Designing a mini wind turbine

| Activity Stage | Explanation |
|---|---|
| Aim | Observe the conversion of wind energy from kinetic energy into electrical energy. |
| Materials | Mini motor, cardboard or plastic blades, connecting wires, small LED, fan, ruler. |
| Application | Students design mini turbines with different blade numbers and blade angles. |
| Measurement | Production is compared using LED brightness or simple measuring devices. |
| Analysis | Which design is more efficient is discussed. |
| Discussion | The effects of wind speed, blade design, and turbine height on production are evaluated. |

This activity helps students understand energy production through a concrete model. It also develops design, trial-and-error, teamwork, and environmental awareness skills (Box 5.3).

### *5.2.7. Evaluation from the Perspective of Energy Literacy*

Wind energy is a strong learning topic for developing energy literacy. This is because the topic is not limited to explaining how a turbine works; it also requires thinking about variable generation, site selection, environmental impact, energy storage, local acceptance, and energy policy together. Wind energy can therefore help students evaluate energy systems holistically.

The energy literacy literature emphasizes that energy knowledge should be considered together with attitudes, behavior, decision-making, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023). Wind energy provides a good example in this respect: the question of whether a wind turbine should be installed in a region requires the joint discussion of technical, economic, environmental, and social justifications.

For this reason, wind energy can be addressed in lessons not only as a renewable method of electricity generation, but also as a socio-scientific issue. Students can discuss the potential of wind turbines to reduce contributions to climate change, their effects on birds and bats, local community views, and energy security. In this way, energy can be learned within the relationship between scientific knowledge and social decision-making (Sadler, 2004; Zeidler, 2014).

### *5.3. Hydroelectric Energy*

Hydroelectric energy, or hydropower, is a renewable energy type obtained by generating electricity from the energy of moving or falling water (Stocks et al., 2021). Rivers, streams, dams, and water reservoirs can be used for hydropower production. In these systems, the kinetic or potential energy of water turns turbines, and generators connected to the turbines produce electricity (DOE, 2026d). Table 5.9 presents the main strengths and limitations of hydroelectric energy in relation to resource use, system flexibility, environmental impacts, land and water management, social dimensions, and long-term sustainability.

Hydropower is one of the most important renewable electricity resources used worldwide for a long time. Especially in regions with large river systems, high precipitation, or mountainous terrain, hydropower plants can provide significant electricity generation capacity. Hydropower not only generates electricity; in some systems it can also provide functions such as water storage, flood control, irrigation, and balancing in the energy system (IEA, 2026; International Hydropower Association, 2024). Nevertheless, hydropower is not an impact-free resource. Large dams can affect river ecosystems, fish migration routes, water temperature, sediment transport, land use, and local communities. Therefore, when hydropower projects are planned, not only energy production but also ecological balance, water management, local community participation, and long-term environmental monitoring processes should be considered (Kuriqi et al., 2021; U.S. Energy Information Administration [EIA], 2022).

Table 5.9. Main advantages, limitations, and environmental evaluation dimensions of hydroelectric energy

| Dimension | Strength | Limitation / point requiring attention |
|---|---|---|
| Resource and production | Large-scale and relatively controllable electricity generation can be achieved using flowing water and elevation difference. | Production depends on precipitation, flow regime, drought, and water management. |
| System flexibility and storage | Some plants can start quickly and balance the grid; pumped storage supports integration. | Pumped storage requires suitable geography and two reservoirs; all projects require careful operation. |
| Environmental impact | Contributes to low-carbon electricity generation without burning fossil fuels. | River flow, fish migration, sediment transport, water quality, and methane formation in some reservoirs should be considered. |
| Land and water management | Some projects may also provide irrigation, flood control, and local infrastructure benefits. | Reservoirs can affect agricultural, forest, and settlement areas; ecological flow should be maintained. |

| Dimension | Strength | Limitation / point requiring attention |
|---|---|---|
| Social dimension | Can contribute to local development, employment, and energy security. | Displacement, impacts on livelihoods, and local acceptance problems may arise. |
| Long-term sustainability | Can provide long-lived infrastructure and strengthen renewable integration in some systems. | Cumulative impacts at basin scale and water uncertainties caused by climate change must be managed. |

### *5.3.1. Working Principle of Hydroelectric Power Plants*

The basic principle in hydropower plants is to use the movement of water to rotate turbines. When water moves downward from a certain height, its potential energy is converted into kinetic energy. This movement turns the turbine blades. The rotational motion of the turbine is transferred to the generator, and the generator produces electricity (DOE, 2026d). Two basic elements are important in hydropower generation: water flow rate and head height. Flow rate refers to the amount of water flowing in a certain period of time. Head height is the elevation difference that water has before reaching the turbine. In general, as flow rate and head height increase, the amount of electricity that can be generated also increases. Figure 5.5 shows the conversion of hydropower from the potential or kinetic energy of water into electrical energy. The efficiency of a plant is closely related to water quantity, head height, turbine type, generator efficiency, and water management.

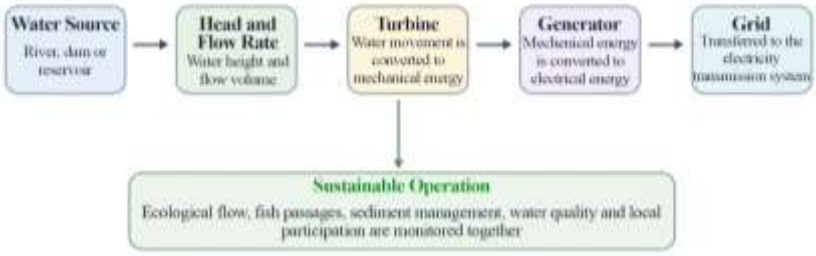


Figure 5.5. Energy conversion process in hydroelectric power plants.

Table 5.10 summarises the basic components of hydroelectric systems and shows how structures such as dams, reservoirs, penstocks, turbines, generators, transformers, transmission lines, and environmental flow systems contribute to electricity generation and ecological management.

Table 5.10. Basic components of hydroelectric systems

| Component | Function |
|---|---|
| Dam or intake structure | Stores water or directs it to turbines. |
| Reservoir | Allows water to accumulate in a defined area. |
| Penstock | Carries water to the turbine under high pressure. |
| Turbine | Converts the kinetic energy of water into mechanical energy. |
| Generator | Converts the mechanical motion of the turbine into electrical energy. |
| Transformer | Adjusts the voltage of generated electricity for the grid. |
| Switchyard and transmission line | Transfers electricity to the grid. |
| Fish passage or environmental flow system | Helps reduce ecological impacts. |

### *5.3.2. Types of Hydroelectric Power Plants*

Hydroelectric power plants can be classified according to different criteria (Parvez et al., 2021). The most common classification is based on the way the plant uses water. In this respect, hydropower plants can be considered as reservoir hydropower plants, run-of-river plants, pumped-storage hydropower plants, and small-scale hydropower plants.

Reservoir hydropower plants are based on storing water in a large reservoir and generating electricity by passing this water through turbines when needed. In addition to electricity generation, these systems can be used for purposes such as flood control, irrigation, and drinking water supply. However, large reservoirs can affect land use, ecosystems, and local communities.

Run-of-river hydropower plants use the natural flow of the river without forming large reservoirs. These systems are generally smaller in scale and have more limited water storage capacity than reservoir systems. However, because they can change river flow, they require careful planning in terms of ecological flow, fish passages, and water quality (Kuriqi et al., 2021).

Pumped-storage hydropower plants are special systems used for energy storage. When electricity demand is low and electricity production is high, water is pumped from a lower reservoir to an upper reservoir. When electricity demand increases, water is released downward again and electricity is generated by passing it through turbines. These systems can play an important role especially in integrating variable renewable energy sources such as solar and wind into the electricity system (IEA, 2024; International Hydropower Association, 2024).

Table 5.11. Comparison of hydropower plant types

| Plant Type | Basic Feature | Advantage | Point Requiring Attention |
|---|---|---|---|
| Reservoir hydropower | Water is stored in a reservoir and used in a controlled way. | Can provide high generation and system flexibility. | There are risks related to land use, ecosystem impact, and displacement. |
| Run-of-river hydropower | Uses the natural flow of the river. | Requires less large-reservoir capacity. | River flow, fish passage, and ecological balance may be affected. |
| Pumped-storage hydropower | Stores electricity as the positional energy of water. | Provides grid balancing and energy storage. | Requires suitable topography and two reservoirs. |
| Small hydropower | Provides lower-capacity generation at local scale. | Can contribute to rural energy needs. | Cumulative environmental impacts can occur at basin scale. |

Small hydropower plants are systems with lower installed capacity that can generate electricity at local scale. Small hydropower projects can be useful in rural areas or for meeting local energy demand. However, their small scale does not always mean that their environmental impacts are low; it should be remembered that multiple small plants in the same river basin can create cumulative impacts (Kuriqi et al., 2021).

Table 5.11 shows that hydropower plant types should be evaluated according to the water potential of the region and the needs of the energy system. Pumped-storage systems in particular are among the important solutions that can support variable resources such as solar and wind.

### *5.3.3. Turbine Types and Application Areas*

The type of turbine used in a hydropower plant is determined according to water flow rate and head height. Different turbines operate more efficiently under different conditions. Therefore, the hydrological structure of the region, water quantity, elevation difference, and operational purpose should be evaluated together in plant design.

In general, Pelton turbines are used in areas with high head and low flow, Francis turbines in areas with medium head and medium flow, and Kaplan turbines in areas with low head and high flow. This classification shows that hydropower plants should be designed according to geographical and technical conditions.

As shown in Table 5.12, turbine selection depends mainly on head height, water flow rate, and operational purpose. Turbine selection is important not only for technical efficiency but also for environmental impact. For example, fish passage, protection of aquatic organisms, and maintenance of ecological flow are closely related to turbine design and plant operation.

Table 5.12. Main types of hydroelectric turbines

| Turbine Type | Suitable Condition | Common Use |
|---|---|---|
| Pelton turbine | High head, low flow | High-head plants in mountainous regions |
| Francis turbine | Medium head, medium flow | Many reservoir hydropower plants |
| Kaplan turbine | Low head, high flow | Wide-flow river systems |
| Pump-turbine | Bidirectional operation | Pumped-storage hydropower plants |

### *5.3.4. Environmental Impacts of Hydroelectric Energy*

Hydropower can contribute to low-carbon electricity generation because it does not burn fossil fuels during electricity generation (Bilgili et al., 2021). However, environmental and social impacts should be carefully managed, especially in large reservoir systems. Dams can alter the natural flow of rivers, reduce sediment transport, interrupt fish migration routes, and cause changes in water temperature and oxygen levels (EIA, 2022).

River ecosystems develop in relation to water flow speed, temperature, chemical structure, and seasonal variations. When hydropower plants change this natural pattern, fish, aquatic plants, invertebrates, and riparian ecosystems can be affected. Therefore, protecting ecological flow, designing fish passages, managing sediment, and monitoring water quality are important in hydropower projects (DOE, 2026d ; Kuriqi et al., 2021).

Large reservoirs may cause extensive areas to be submerged. This can affect agricultural land, forests, natural habitats, or settlements. In some regions, local communities may need to be relocated. In addition, methane emissions may occur in reservoirs, especially in warm climates and in reservoirs rich in organic matter. Therefore, the environmental assessment of hydropower projects should be conducted according to regional conditions.

### *5.3.5. Use of Hydroelectric Energy in Education*

Hydropower is an appropriate example for helping students learn the relationship among energy conversion, the water cycle, turbine technology, electricity generation, and environmental impacts. Simple classroom activities can demonstrate the conversion of the kinetic energy of water into mechanical energy and electrical energy.

Students can use small water wheels or simple turbine models to observe how water flow speed affects rotational movement. In addition, issues such as the environmental impacts of dams, fish migration routes, water use, and climate change can be addressed through classroom discussions.

Hydropower can be taught not only as a technical example of electricity generation, but also as a socio-scientific issue involving water management, ecosystem protection, local community participation, and energy security. This approach contributes to the development of students' evidence-based thinking and decision-making skills (Sadler, 2004; Zeidler, 2014).

Box 5.4. Classroom activity suggestion: Mini water turbine model

| Activity Stage | Explanation |
|---|---|
| Aim | Observe the conversion of the kinetic energy of flowing water into mechanical energy. |
| Materials | Small plastic spoons or cardboard blades, bottle cap, stick, water container, simple LED or mini motor. |
| Application | Students design a small water wheel or mini turbine model. |
| Observation | When the water flow rate is changed, the rotation speed of the turbine is observed. |
| Discussion | The effects of flow rate, head height, and turbine design on production are evaluated. |
| Environmental link | The effects of dams on aquatic ecosystems and fish passages are discussed. |

This activity makes the working principle of hydropower concrete. It also helps students evaluate the advantages and environmental impacts of renewable energy resources together (Box 5.4).

### *5.3.6. Evaluation from the Perspective of Energy Literacy*

Hydropower is a powerful teaching topic from the perspective of energy literacy because it establishes direct links among energy production, the water cycle, ecosystems, climate change, economic development, and social impacts. In this respect, hydropower enables students to evaluate not only how an energy technology works but also the environmental and social consequences of energy decisions.

The energy literacy literature emphasizes that energy topics are not limited to conceptual knowledge; they also include attitudes, behavior, decision-making, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023). Hydropower projects are suitable for concretizing this multidimensional structure. When students evaluate a dam project, they must consider many variables together, including electricity generation, water management, local livelihoods, fish migration, agriculture, flood control, and climate risk.

For this reason, hydropower can be used in the classroom to develop systems thinking and socio-scientific reasoning skills. Students may be asked to compare the views of different stakeholders in a hydropower project, identify possible environmental impacts, and develop a sustainable solution proposal. Thus, energy education moves beyond technical knowledge transfer and becomes integrated with education for informed and responsible citizenship.

### *5.4. Comparative Evaluation of Solar, Wind, and Hydroelectric Energy*

Solar, wind, and hydroelectric energy are important resources for low-carbon electricity generation; however, their roles in the energy system are not the same. Because solar and wind energy have variable generation characteristics, they require storage, flexible grids, demand management, and balancing with different resources. Hydropower, under suitable conditions, can provide more controllable generation and can add flexibility to the energy system, especially in reservoir or pumped-storage systems.

When these three resources are evaluated, not only installed capacity or generation amount but also life-cycle impacts, land and water use, ecosystem effects, cost, local conditions, grid infrastructure, and social acceptance should be considered together. This approach is consistent with the criteria for evaluating energy resources developed in Chapter 2.

Table 5.13 shows that renewable energy resources cannot be evaluated through a single criterion. A resource may be low-carbon; however, site selection, ecosystem impact, cost, infrastructure, and social acceptance are inseparable parts of the decision-making process. Therefore, in sustainable energy planning, resources should be considered in ways that complement each other.

Table 5.13. Comparison of solar, wind, and hydroelectric energy

| Criterion | Solar Energy | Wind Energy | Hydroelectric Energy |
|---|---|---|---|
| Generation character | Variable generation depending on daytime and weather conditions | Variable generation depending on wind speed and continuity | Depends on the water regime; in some systems, generation is more controllable |
| Main advantage | Modular, widespread, and rapidly installable | Can provide large-scale low-carbon electricity generation | Can provide system flexibility and storage support in addition to electricity generation |
| Main limitation | Does not generate at night; may require storage and grid support | Site selection, wind continuity, and social acceptance are important | River ecosystems, water use, and drought risk must be carefully managed |
| Environmental point requiring attention | Panel production, land use, and recycling | Bird and bat impacts, noise, visual impact, and marine ecosystems | Flow regime, fish migration, sediment transport, and local communities |
| Value for energy literacy | Energy conversion, measurement, data analysis, and the production-consumption relationship | Aerodynamics, design, site selection, and socio-scientific decision-making | Water cycle, systems thinking, and the relationship among ecosystems and society |

### *5.5. Chapter Summary and Discussion Questions*

This chapter examined solar, wind, and hydroelectric energy resources in terms of their working principles, areas of use, advantages, limitations, environmental impacts, and educational applications. Solar energy can be used in electricity and heat production through photovoltaic and solar thermal systems. Wind energy is an important low-carbon option for electricity generation through onshore and offshore applications. Hydroelectric energy uses the energy of flowing or stored water and can play an important role in energy storage and grid flexibility in some systems.

The common feature of these three energy types is that they have the potential to reduce fossil fuel use and support low-carbon energy systems. However, no resource is completely impact-free. Material production and recycling in solar energy, site selection and effects on living organisms in wind energy, and water management and river ecosystems in hydropower should be carefully evaluated. From the perspective of energy literacy, these resources help students connect technical knowledge with environmental, economic, and social decisions.

**Discussion Questions**

1. Why does solar energy production depend on factors such as daylight, season, panel orientation, and shading?
2. What are the main differences between photovoltaic systems and solar thermal systems?
3. In what ways do onshore and offshore wind energy applications differ?
4. Why is site selection in wind energy projects not only a technical decision but also an environmental and social one?
5. Why are flow rate, head height, and water management important in hydroelectric power plants?
6. How can pumped-storage hydropower systems support solar and wind energy?
7. In what ways can solar, wind, and hydroelectric energy resources complement each other?

# CHAPTER 6: GEOTHERMAL, MARINE-OCEAN AND BIOENERGY RESOURCES

This chapter examines geothermal energy, marine and ocean energy, and bioenergy resources (Box 6.1). Geothermal energy is mainly associated with heating, greenhouse cultivation, and local electricity generation; marine and ocean energy is linked to coastal and island systems; and bioenergy resources are connected with waste management, rural development, transport, and industrial applications. For this reason, the chapter evaluates not only technical operation, but also environmental impacts, feedstock management, life cycle considerations, social acceptance, local resource use, educational applications, and energy literacy.

Box 6.1. What will be learned inthis chapter

| Learning Objective |
|---|
| Evaluate the formation, applications, and environmental effects of geothermal energy. |
| Explain the basic characteristics of wave, tidal, current, ocean thermal, and salinity-gradient energy. |
| Compare the uses and sustainability conditions of biomass, biogas, biomethane, and biofuels. |
| Analyze renewable resources together with their feedstock, production, use, and waste management dimensions. |
| Relate these resources to environmental, economic, social, and educational decision-making processes. |

Table 6.1 shows that the resources discussed in this chapter perform different roles within renewable energy systems. Their sustainability depends not only on their renewable character, but also on local conditions, technology selection, feedstock management, environmental planning, and social acceptance processes.

Table 6.1. General overview of geothermal, marine-ocean, and bioenergy resources

| Resource | Main Areas of Use | Key Evaluation Dimension |
|---|---|---|
| Geothermal energy | Electricity generation, heating, greenhouse cultivation, and thermal use | Resource dependence, local environmental effects, and sustainable reservoir management are important. |
| Marine-ocean energy | Wave, tidal, current, and coastal/island systems | Technology maturity, marine ecosystems, and maintenance costs should be carefully assessed. |
| Biomass energy | Heat, electricity, biogas, and biomethane production | Sustainable feedstock, land use, and waste management are critical. |
| Biofuels | Transport, industry, aviation, and blended fuels | Food-land competition, life cycle emissions, and the use of advanced feedstocks are important. |

Figure 6.1 illustrates the different roles of geothermal, marine-ocean, and bioenergy resources within renewable energy systems. It shows that these resources are not used in the same way: geothermal energy is mainly linked to heat and local electricity generation, marine-ocean energy is associated with coastal and island systems, and bioenergy resources are connected with waste management, rural development, transport, and industrial applications.

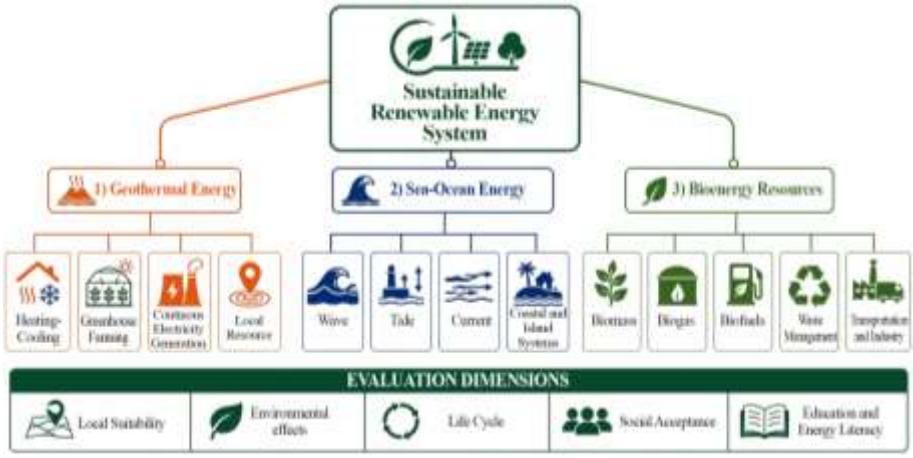


Figure 6.1. Roles of geothermal, marine-ocean, and bioenergy resources in the energy system.

### *6.1. Geothermal Energy*

Geothermal energy is a renewable energy source obtained by using heat energy stored beneath the Earth's crust. Natural heat within the Earth can be transferred toward near-surface areas through hot water, steam, hot rocks, and underground fluids (Igwe, 2021). This heat can be used for electricity generation, building heating and cooling, greenhouse cultivation, thermal tourism, and certain industrial processes (DOE, 2026e; IEA, 2024).

One important characteristic of geothermal energy is that, unlike solar and wind energy, it is not directly dependent on weather conditions. In regions with suitable geothermal resources, continuous heat or electricity generation can be provided throughout the year. Therefore, geothermal energy can be considered a reliable and local renewable resource within energy systems (IEA, 2024). However, geothermal energy cannot be used to the same extent in every region. The temperature, depth, fluid quantity, geological structure, and economic feasibility of geothermal resources determine project success. In addition, geothermal projects require careful assessment of underground fluid management, reinjection, gas emissions, mineral scaling, water use, and local environmental effects (DOE, 2026e; IEA, 2024).

Table 6.2 summarises the main advantages, limitations, and environmental evaluation dimensions of geothermal energy.

Table 6.2. Main advantages and limitations of geothermal energy

| Dimension | Advantage | Limitation |
|---|---|---|
| Resource | Uses natural heat in the Earth's crust. | High potential is not found in every region. |
| Continuity | Can provide energy throughout the year where suitable resources exist. | Reservoir performance may decline if resource management is not properly implemented. |
| Area of use | Can be used for electricity, heating, cooling, greenhouse cultivation, and thermal tourism. | The form of use depends on resource temperature and geological conditions. |
| Environmental impact | May have lower greenhouse gas emissions than fossil fuels. | Underground fluids, gas releases, and mineral contents must be managed. |
| Energy security | Supports the use of local resources. | Initial exploration, drilling, and investment costs may be high. |
| Land use | May require less surface area than solar and wind energy. | Drilling, pipelines, and facility infrastructure require specific planning. |

### 6.1.1. Formation and Operating Principle of Geothermal Energy

High temperatures are found in the inner parts of the Earth. This heat can be transferred toward near-surface zones through rocks and underground fluids. Fractures, fault lines, and permeable rocks in the Earth's crust allow hot water or steam to move. For this reason, geothermal resources are often more evident in tectonically active regions, around fault lines, or in volcanic areas (AGIC Energy, 2024; Igwe, 2021).

In geothermal systems, hot water or steam extracted from underground can be used directly for heating or can drive turbines to generate electricity. The process of injecting the used fluid back underground is called reinjection. Reinjection helps preserve reservoir pressure and supports the more sustainable use of the geothermal resource (DOE, 2026e).

Figure 6.2. Basic energy conversion process in geothermal energy.

Figure 6.2 illustrates the basic conversion process of geothermal energy from underground heat sources to electricity, heating, or direct thermal applications. It also shows that geothermal energy is not limited to bringing hot water or steam to the surface. In a sustainable geothermal system, resource protection, fluid management, reinjection, and environmental monitoring should be implemented together.

### *6.1.2. Applications of Geothermal Energy*

Geothermal energy can be used for different purposes at different temperature ranges. High-temperature resources are more suitable for electricity generation. Medium- and low-temperature resources can be used for direct heating, district heating, greenhouse cultivation, aquaculture, thermal tourism, and certain industrial processes.

Geothermal heat pumps can also use lower-temperature underground conditions for building heating and cooling. These systems take advantage of the relatively stable temperature of the ground after a certain depth. In winter, heat is extracted from underground to heat buildings; in summer, excess heat from buildings can be transferred underground (DOE, 2026e). Table 6.3 presents the main areas of use of geothermal energy and shows that geothermal resources can support not only electricity generation, but also heating, greenhouse cultivation, thermal tourism, and some industrial processes.

Table 6.3. Applications and electricity-generation technologies of geothermal energy

| Use/Technology | Explanation | Suitable Situation / Point Requiring Attention |
|---|---|---|
| Direct heat use | Use of hot water for district heating, greenhouse cultivation, aquaculture, thermal tourism, and some industrial processes. | Suitable for medium- and low-temperature resources; water chemistry and reinjection should be planned. |
| Geothermal heat pump | Use of the ground's relatively stable temperature for building heating and cooling. | Provides building-scale energy efficiency; installation design and ground conditions are important. |
| Dry steam plant | Directly uses steam from underground to drive the turbine. | Requires high-temperature resources containing natural steam. |
| Flash steam plant | Uses high-pressure hot water that becomes steam at the surface and drives a turbine. | Requires high temperature and pressure; fluid management needs attention. |
| Binary-cycle plant | Transfers geothermal heat to a secondary fluid that vaporizes and drives a turbine. | Allows medium-temperature resources to be used. |
| Enhanced geothermal systems | Use engineering methods to extract heat from hot dry rocks. | May expand potential, but technical, economic, and micro-seismicity risks should be assessed. |

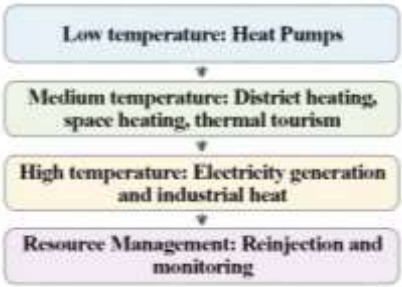


Figure 6.3. Main applications of geothermal energy according to temperature level.

Figure 6.3 shows that geothermal energy has different areas of use depending on resource temperature, local demand, infrastructure, and economic feasibility. It also illustrates that geothermal energy is not limited to electricity generation; in many regions, direct heat applications may be the most efficient and sustainable use of geothermal resources.

### *6.1.3. Types of Geothermal Power Plants*

The technology used in geothermal electricity generation varies according to the temperature and pressure of the resource and the properties of the underground fluid. In general, there are three main types of geothermal power plants: dry steam plants, flash steam plants, and binary-cycle plants (EIA, 2022a; Sharmin et al., 2023).

Dry steam plants generate electricity by sending steam that comes directly from underground to turbines. Flash steam plants operate on the principle that high-pressure hot water turns partially into steam when pressure falls after it is brought to the surface. Binary-cycle plants generate electricity by transferring the heat of the geothermal fluid to a secondary fluid with a lower boiling point.

Enhanced geothermal systems are newer technologies that aim to obtain energy from hot rocks with limited natural permeability or fluid. These systems may expand the geographical use of geothermal energy in the future; however, they require careful technical, economic, and environmental assessment (IEA, 2024).

### *6.1.4. Environmental Effects of Geothermal Energy*

Geothermal energy generally has lower greenhouse gas emissions than fossil fuels. Because coal, oil, or natural gas combustion is not required during electricity generation or direct heat use, air pollution and carbon emissions can be reduced (Idroes et al., 2024). In addition, geothermal facilities can provide uninterrupted energy throughout the year under suitable conditions (DOE, 2026e; IEA, 2024).

However, the environmental effects of geothermal energy are not zero. Hot water or steam extracted from underground may contain dissolved gases and minerals. Hydrogen sulfide, carbon dioxide, boron, arsenic, or

various dissolved minerals may be present at different levels depending on the geological structure of the region (Idroes et al., 2024). Therefore, geothermal fluids should not be allowed to mix with surface waters, soil, or the atmosphere in an uncontrolled manner.

Reinjection is a critical practice for the environmental sustainability of geothermal projects. Injecting the used geothermal fluid back underground helps preserve reservoir pressure and reduce potential surface pollution risks. However, reinjection must also be planned according to appropriate geological conditions.

Some geothermal projects may involve micro-seismicity, or small-scale ground movements. This risk should be considered especially in deep drilling and enhanced geothermal systems. In addition, drilling activities, pipelines, facility areas, and water use can create local environmental effects. For this reason, environmental impact assessment, continuous monitoring, and communication with local communities are important in geothermal projects.

Table 6.4 summarises the main environmental effects and sustainability conditions of geothermal energy, including reservoir management, reinjection, gas emissions, water use, and local environmental impacts.

Table 6.4. Environmental advantages of geothermal energy and issues requiring management

| Environmental Dimension | Advantage | Point Requiring Attention |
|---|---|---|
| Greenhouse gas emissions | Can provide lower-carbon energy than fossil fuels. | $CO_2$ and other gas releases should be monitored depending on the resource. |
| Air quality | Air pollutants may decrease because fossil fuel combustion is not required. | Gases such as hydrogen sulfide should be controlled. |
| Water management | Resource sustainability can be supported through reinjection. | Fluids should be prevented from mixing with surface waters. |
| Soil and mineral effects | Impacts can be reduced in closed systems. | Boron, arsenic, and other minerals must be carefully managed. |
| Land use | May require a relatively limited surface area. | Drilling sites, pipelines, and facility infrastructure should be planned. |
| Geological effect | Safe operation can be ensured with proper planning. | Micro-seismicity risk should be monitored in some projects. |
| Social effect | Can contribute to local heating, greenhouse cultivation, and employment. | Odor, gas releases, and local environmental concerns should be considered. |

### *6.1.5. Use of Geothermal Energy in Education*

Geothermal energy is an appropriate example through which students can learn the Earth's internal structure, heat transfer, energy conversion, renewable energy, and environmental sustainability together. This topic can

be linked with science, geography, physics, chemistry, and environmental education.

Simple experiments and visuals can be used when teaching geothermal energy in the classroom. For example, the basic logic of geothermal energy can be demonstrated through hot water, steam, heat conduction, and insulation. In addition, map studies can help students examine the relationship among fault lines, volcanic areas, hot springs, and geothermal potential.

Such activities show that energy literacy develops not only through conceptual knowledge, but also through observation, data interpretation, spatial thinking, and environmental decision-making skills. Considering the socioscientific nature of energy issues, students should discuss the relationships among technology, environment, and society (Sadler, 2004; Zeidler, 2014).

Box 6.2. Classroom activity suggestion: Preparing a geothermal resource map

| Activity Stage | Explanation |
|---|---|
| Aim | To understand the relationship between geothermal resources and geological structure. |
| Materials | A map of Türkiye or Europe, a fault-line map, colored pencils, and research notes. |
| Implementation | Students mark the regions where geothermal resources are concentrated on the map. |
| Observation | The relationship of resources with fault lines, volcanic areas, or tectonic zones is discussed. |
| Discussion | Students evaluate why geothermal energy cannot be used at the same level in every region. |
| Environmental link | Environmental issues such as reinjection, gas releases, and water management are addressed. |

This activity helps students evaluate geothermal energy not only as a technical energy topic, but also within the relationship between geography, environment, and sustainability (Box 6.2).

### *6.1.6. Evaluation from the Perspective of Energy Literacy*

Geothermal energy is a strong teaching topic from the perspective of energy literacy. It allows the physical basis of the energy resource, the technological conversion process, environmental effects, local geographical conditions, and social acceptance to be discussed together. In this respect, geothermal energy can help students evaluate energy systems multidimensionally rather than in a single dimension.

The energy literacy literature emphasizes that energy issues should be addressed not only at the level of knowledge, but also through attitudes, behaviors, decision making, sustainability awareness, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano,

2023). In the case of geothermal energy, students can see that the renewable character of a resource does not automatically make it environmentally impact-free; reinjection, fluid management, gas releases, and local acceptance should also be considered.

Therefore, geothermal energy education can be associated with map reading, data evaluation, environmental impact discussion, resource management, and local decision-making processes. Such an approach supports students in understanding energy technologies not merely as technical tools, but as decision areas with environmental and social consequences.

### *6.2. Marine and Ocean Energy*

Seas and oceans are natural systems with large renewable energy potential. Wave movements, tides, ocean currents, temperature differences, and salinity differences can be used for energy generation. Energy obtained from these resources is generally referred to as marine energy, ocean energy, or marine renewable energy (DOE, 2026f).

Although marine and ocean energy has not yet become as widespread as solar, wind, and hydropower, it is considered an important renewable resource that can increase energy diversity in the long term. These resources may offer significant potential especially for countries with long coastlines, strong wave regimes, or clear tidal movements. However, technology costs, maintenance difficulties, harsh marine conditions, grid connection, and environmental monitoring needs slow development in this field (DOE, 2026f; REN21, 2025).

Offshore wind energy is technically a subtype of wind energy. However, because it is installed in marine areas and is connected with the seabed, coastal planning, fisheries, maritime transport, and marine ecosystems, it can also be discussed within marine renewable energy policies. The main focus of this section is wave, tidal, marine current, ocean thermal, and salinity-gradient energy; however, offshore wind energy is also briefly mentioned when selected country examples are evaluated.

Table 6.5 shows that marine and ocean energy technologies are not based on a single resource or process. Instead, they use different physical processes such as waves, tides, currents, temperature differences, and salinity gradients. Therefore, marine energy projects should be evaluated by considering wave height, tidal range, current speed, sea depth, coastal structure, environmental sensitivities, engineering requirements, and grid connection together.

Table 6.5. Main types of marine and ocean energy

| Energy Type | Source | Basic Operating Principle | Level of Development |
|---|---|---|---|
| Wave energy | Wave movements on the sea surface | The upward-downward or back-and-forth motion of waves is converted into mechanical energy. | Developing technology |
| Tidal energy | Tides caused by the gravitational effects of the Moon and the Sun | Changes in water level or tidal currents drive turbines. | Some commercial and pilot applications exist. |
| Marine current energy | Continuous or regular marine currents | The kinetic energy of currents is converted into electricity through underwater turbines. | Pilot and early commercial stage |
| Ocean thermal energy | Temperature difference between warm surface water and cold deep water | Electricity can be generated through a cycle system using the temperature difference. | Limited and experimental applications |
| Salinity-gradient energy | Salinity difference between freshwater and seawater | Osmotic pressure differences at river mouths are used. | Research and pilot stage |
| Offshore wind | Winds over the sea | Wind turbines installed at sea generate electricity. | Rapidly developing commercial technology |

### *6.2.1. Operating Principle of Marine and Ocean Energy*

The basic aim in marine and ocean energy is to generate electricity by using the movement or physical properties of water bodies. Wave energy uses the movement of waves on the sea surface; tidal energy uses regular changes in water level or tidal currents; and marine current energy uses the horizontal movement of water (Offshore Energy, 2026; Tsamenyi and Herriman, 1998). Ocean thermal energy uses temperature differences, while salinity-gradient energy uses the density and pressure difference between saltwater and freshwater (DOE, 2026f).

Wave and current systems mostly rely on turbines, generators, or hydraulic systems that convert mechanical motion into electrical energy. In tidal energy, two basic methods stand out: using tidal range through barrage or dam-like structures, and using tidal currents with underwater turbines. Tidal movements arise from the gravitational relationship among the Earth, the Moon, and the Sun; acceleration of tidal currents in narrow straits or channels can create suitable conditions for electricity generation (PNNL, 2026).

Figure 6.4 illustrates the basic conversion process of marine and ocean energy. It shows that different ocean-based physical movements or gradients, such as waves, tides, currents, temperature differences, and salinity gradients, can be transformed into usable electricity. Although these technologies are based on different natural processes, their common purpose is to convert ocean energy into electrical energy.

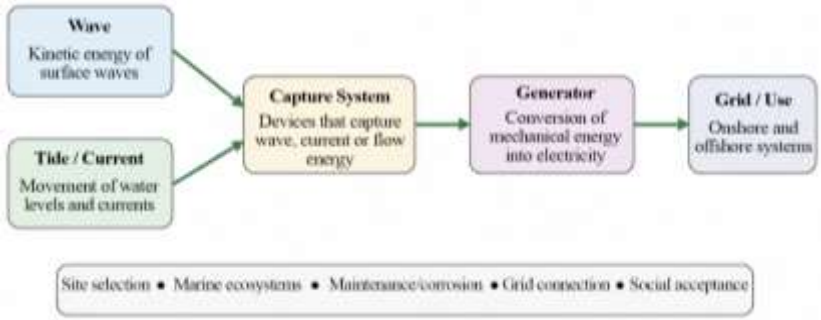


Figure 6.4. Basic energy conversion process in marine and ocean energy.

### *6.2.2. Wave Energy*

Wave energy is a renewable energy type that aims to generate electricity by using wave motion created by winds on the sea surface. Waves create upward-downward and back-and-forth movements on the water surface. Wave energy devices capture this motion and convert it first into mechanical energy and then into electrical energy (Guo and Ringwood, 2021). Wave energy is particularly important in regions with long coastlines and strong wave regimes. Coasts facing the open ocean, island countries, and Atlantic coastlines may be more advantageous for wave energy. However, wave energy technologies must be resistant to marine conditions. Storms, saltwater corrosion, maintenance difficulties, and the connection of devices to the shore or grid are among the main challenges of this technology.

Wave energy devices may have different designs. Some systems use the oscillating movement of the water surface, some use the pressure of waves hitting the shore, and others use the back-and-forth movement of water. This diversity indicates that wave energy technology is still developing and that different solutions are being tested for different coastal conditions.

### *6.2.3. Tidal and Marine Current Energy*

Tidal energy uses the regular rise and fall of seawater caused by the gravitational forces among the Earth, the Moon, and the Sun (Chowdhury et al., 2021). Tides are predictable natural events; in this respect, tidal energy can be forecast more easily than more variable resources such as solar and wind energy (PNNL, 2026).

Tidal energy can be used in two main ways. The first method is to generate electricity from the difference in water level by using barrage- or dam-like structures in bays or estuaries with a high tidal range. The second method is to use underwater turbines in straits or narrow channels where tidal currents are strong. Although these turbines resemble wind turbines in appearance, they are turned by water currents rather than air.

Marine current energy uses continuous or regular marine currents independently of tides. Current speed, water depth, seabed structure, maritime traffic, and ecosystems should be considered when planning such projects.

The most important advantage of tidal energy is its predictability. However, suitable natural conditions are not found everywhere. Therefore, tidal energy should be considered a specialised renewable energy type that can be applied only in regions with appropriate tidal range, coastal structure, and grid connection opportunities. The key differences among wave, tidal, and current energy in terms of resource basis, advantages, limitations, and planning requirements are summarised in Table 6.6.

Table 6.6. Comparison of wave, tidal, and current energy

| Technology | Main Source / Operating Principle | Potential Use | Main Limitation |
|---|---|---|---|
| Wave energy | Wave motion on the sea surface is converted into mechanical energy and then electricity. | Open-ocean coasts, island systems, and strong wave regimes. | Storms, corrosion, maintenance, and grid connection difficulties. |
| Tidal barrage or lagoon | Uses water-level differences created during tides. | Bays and estuaries with high tidal range. | Sediment transport, ecosystem effects, and fish passage. |
| Tidal current turbine | Uses the kinetic energy of tidal currents through underwater turbines. | Narrow straits, channels, and strong current regions. | Marine life, fisheries, maritime transport, and maintenance. |
| Marine current energy | Uses the kinetic energy of continuous or regular currents. | Areas with strong and regular marine currents. | Seabed connection, maintenance, and environmental monitoring. |
| Ocean thermal energy | Uses the temperature difference between warm surface water and cold deep water. | Tropical regions and island systems. | Limited regional potential and high infrastructure needs. |
| Salinity-gradient energy | Uses the density/pressure difference between freshwater and saltwater. | River mouths and suitable coastal areas. | Research and pilot stage; limited technology maturity. |

### *6.2.4. Ocean Thermal Energy and Salinity-Gradient Energy*

Ocean thermal energy uses the temperature difference between warm surface waters and colder deep waters of the oceans. This technology is more suitable in tropical regions because the temperature difference between surface and deep water is more pronounced in these areas. In ocean thermal energy systems, this temperature difference can be used to generate electricity through a cycle system (DOE, 2026f).

Salinity-gradient energy uses the salinity difference that occurs where freshwater and saltwater meet, such as river mouths or deltas. The osmotic pressure difference between freshwater and seawater can be used for energy generation. However, this technology is still at the research and pilot application stage.

These technologies show that seas have energy potential not only in terms of movement, but also in terms of temperature and chemical properties. However, economic feasibility, technological maturity, and environmental assessment processes are still developing.

### *6.2.5. Environmental Effects of Marine and Ocean Energy*

Marine and ocean energy technologies have the potential to reduce greenhouse gas emissions because they do not burn fossil fuels during electricity generation. When properly planned, wave, tidal, and current energy systems can contribute to low-carbon electricity generation. Nevertheless, the environmental effects of these technologies are not zero.

Marine energy projects may affect marine ecosystems, fish, marine mammals, birds, seabed organisms, coastal use, fisheries, and maritime transport. Underwater turbines may affect the movement areas of some marine organisms. Construction and maintenance processes may create noise, vibration, and seabed disturbance. Cables and infrastructure systems can alter seabed habitats.

Some effects also vary by technology type. Tidal barrages can affect water flow, sediment transport, and ecosystem dynamics. Wave energy devices can affect coastal dynamics or local marine use. Offshore wind projects should be assessed in terms of bird migration routes, marine mammals, fisheries, and visual impact.

To reduce environmental effects in marine and ocean energy projects, good site selection, marine ecosystem studies, compatibility with fisheries and tourism activities, consideration of marine protected areas, and continuous monitoring are important. Therefore, marine energy projects should be planned not only from an engineering perspective, but also from the perspectives of marine ecology and coastal management.

Table 6.7 summarises the main environmental effects and planning requirements of marine and ocean energy technologies, including marine ecosystems, navigation, maintenance, and coastal planning.

Table 6.7. Environmental effects and planning conditions of marine and ocean energy

| Environmental Dimension | Advantage | Point Requiring Attention |
|---|---|---|
| Greenhouse gas emissions | Does not require fossil fuel combustion during electricity generation. | Device manufacturing, installation, and maintenance have life cycle impacts. |
| Air quality | Air pollutant emissions are low. | Coastal and port activities may require environmental management. |
| Marine ecosystem | Can reduce climate pressure through low-carbon energy. | Fish, marine mammals, birds, and seabed organisms may be affected. |
| Coastal use | Can provide local energy production. | Fisheries, tourism, maritime transport, and coastal landscape should be considered. |
| Noise and vibration | Some systems may have low operational impacts. | Underwater noise may occur during construction and maintenance. |
| Seabed | In some floating systems, seabed intervention may be limited. | Mooring, cable, and foundation systems may affect habitats. |
| Social acceptance | Can provide economic opportunities for coastal communities. | Communication with local people, fishers, and the tourism sector is important. |

### *6.2.6. Use of Marine and Ocean Energy in Education*

Marine and ocean energy provides a suitable example through which students can learn renewable energy, water movements, the Moon-Sun-Earth relationship, wave formation, coastal ecosystems, and technology design together. This topic can be linked with science, physics, geography, environmental education, and STEM activities.

Box 6.3. Classroom activity suggestion: Designing a wave energy model

| Activity Stage | Explanation |
|---|---|
| Aim | To understand the idea of obtaining energy from wave motion through a model. |
| Materials | A transparent water container, a small floating object, a straw or stick, a simple lever mechanism, and an observation chart. |
| Implementation | Students design a small mechanism that moves with wave motion on the water surface. |
| Observation | The movement of the model is examined when wave height and frequency change. |
| Discussion | Students evaluate why wave energy devices should be designed to be durable and flexible. |
| Environmental link | Possible effects on marine life, coastal use, and fisheries are discussed. |

In the classroom, wave energy can be explained through wave motions created in a small water container, while tidal energy can be explained through the gravitational relationship between the Moon and the Earth. Students can discuss how marine energy technologies work by using simple model turbines, wave buoys, or coastal planning maps.

This activity helps students understand marine energy not only as a theoretical concept, but also within the relationship among motion, design, environment, and sustainability (Box 6.3).

### *6.2.7. Evaluation from the Perspective of Energy Literacy*

Marine and ocean energy is an important learning area from the perspective of energy literacy. It requires renewable energy technologies to be considered not only as technical solutions, but also together with coastal ecosystems, fisheries, tourism, maritime transport, local community participation, and energy security. In this respect, marine energy can help students evaluate energy systems multidimensionally.

The energy literacy literature emphasizes that energy knowledge should be addressed together with attitudes, behaviors, decision making, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023). Similarly, marine energy projects should be evaluated not only by the amount of electricity they will produce, but also by their environmental impacts, costs, relationships with local communities, and long-term sustainability.

Therefore, marine and ocean energy can provide a strong example for socioscientific discussions in the classroom. Students can discuss whether a wave energy or offshore wind project should be built in a coastal region by considering energy demand, environmental impact, tourism, fisheries, cost, and local acceptance. Such activities show that decisions about energy technologies require not only scientific knowledge, but also ethical, social, and environmental evaluation (Sadler, 2004; Zeidler, 2014).

## *6.3. Bioenergy Resources: Biomass and Biofuels*

Bioenergy refers to obtaining energy from organic materials of plant, animal, agricultural, forestry, industrial, or urban origin (Seminario-Córdova and Rojas-Ortega, 2023). Biomass can be used directly for heat and electricity generation and can also be converted into different energy products such as biogas, biomethane, and liquid biofuels.

Bioenergy resources differ from other renewable resources because they can be used not only in electricity generation, but also in heating, transport fuels, industrial processes, and waste management. However, the sustainability of biomass energy depends on the feedstock used, the production method, land use, transport distance, conversion technology, and emissions control. Therefore, biomass energy should not be considered a resource that is clean under all conditions; rather, it should be evaluated as a

renewable energy option that can provide an alternative to fossil fuels when managed sustainably (IRENA, 2022).

### *6.3.1. Traditional and Modern Biomass*

Biomass use can generally be divided into traditional biomass and modern biomass. Traditional biomass mostly refers to obtaining energy through the direct burning of wood, animal dung, agricultural residues, and similar resources. This form of use is common especially in rural areas and places with limited access to energy. However, inefficient combustion, indoor air pollution, and unhealthy use conditions can create significant problems.

Modern biomass refers to converting biomass resources into energy through more efficient, controlled, and technological methods. Biogas plants, biomass power plants, pellet production, sustainable biofuels, waste-to-energy production, and biomethane applications are examples of modern biomass. The IEA states that modern bioenergy can be used in solid, liquid, and gaseous fuel forms and can play a role in different sectors such as industry, transport, and buildings (IEA, 2024c).

This distinction is important because the renewable character of biomass does not mean that every form of use is sustainable. In particular, inefficient and uncontrolled traditional biomass use can create problems for both the environment and human health.

### *6.3.2. Biomass Resources*

Biomass resources are highly diverse. Forest products, agricultural residues, energy crops, animal wastes, food-industry wastes, urban organic wastes, and sewage sludge can be used in energy production.

The selection of biomass resources depends on the region's agricultural structure, forest resources, waste management system, industrial activities, and energy needs. For example, in regions with intensive agriculture, straw, stalks, husks, and animal wastes can be evaluated. In forested regions, wood residues, pruning residues, and sawdust can be used. In large cities, municipal organic waste and sludge from wastewater treatment plants may be suitable for biogas production. Table 6.8 presents the main types of biomass resources and their possible areas of energy use.

Converting these resources into energy can support waste management. However, excessive collection of agricultural residues, weakening of forest ecosystems, or energy crops that compete with food production can create long-term environmental problems. Therefore, biomass resources should be evaluated not only according to their energy potential, but also according to their sustainable use conditions.

Table 6.8. Biomass resources and sustainable use conditions

| Resource Group | Examples | Sustainable Use Condition |
|---|---|---|
| Forestry biomass | Wood residues, sawdust, pruning residues, and forest maintenance residues. | Sustainable harvesting and monitoring are required so as not to weaken the forest ecosystem. |
| Agricultural residues | Straw, stalks, corn cobs, olive pomace, hazelnut shells, and sunflower stalks. | They should be collected only in amounts that do not disturb soil organic matter balance. |
| Energy crops | Miscanthus, sorghum, sugarcane, and fast-growing tree species. | They should be evaluated in terms of food production, water use, and land competition. |
| Animal wastes | Cattle, sheep/goat, and poultry manure. | Hygiene, odor, and leakage control are required for biogas and fertilizer management. |
| Urban organic wastes | Food waste, park and garden waste, and sewage sludge. | Source separation, collection, and quality control should be ensured. |
| Industrial organic wastes | Food-industry wastes, oily wastes, pomace, and by-products. | The chemical content of the waste and process safety should be controlled. |

Figure 6.5 illustrates the general pathway from biomass resources to useful energy products such as heat, electricity, biogas, biomethane, and biofuels. It shows that biomass energy is not obtained from a single feedstock; rather, it depends on the use of different organic resources through appropriate conversion technologies.

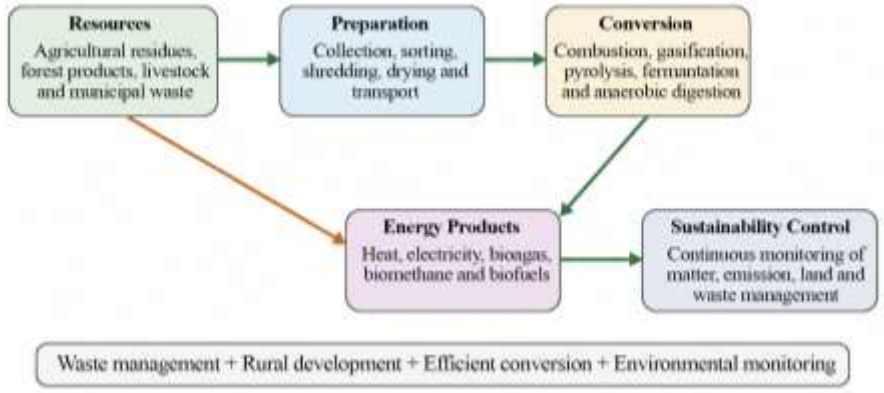


Figure 6.5. Process from biomass resources to energy production.

### *6.3.3. Biomass Conversion Technologies*

Different methods can be used to convert biomass into energy. These methods can be classified as physical, thermochemical, and biochemical processes. Physical processes prepare biomass for energy production. Drying, chopping, grinding, pressing, pelletizing, and briquetting belong to this group. These processes facilitate the transport, storage, and more efficient use of biomass.

Thermochemical processes are based on the high-temperature chemical conversion of biomass. Direct combustion, gasification, and pyrolysis are included in this group. In direct combustion, biomass is burned to produce heat or electricity. In gasification, biomass is converted into synthesis gas in a limited-oxygen environment. In pyrolysis, biochar, bio-oil, and gaseous products can be obtained in an oxygen-free environment.
Biochemical processes occur through microorganisms. Anaerobic digestion produces biogas from organic wastes. Fermentation is used to produce fuels such as bioethanol from feedstocks containing sugar or starch.

The selection of biomass conversion technology depends on the type, moisture content, and intended use of the feedstock. For example, dry woody biomass may be suitable for direct combustion, pelletizing, or gasification, whereas animal wastes and food wastes are generally more suitable for biogas production. Table 6.9 summarises the main conversion pathways of bioenergy resources and shows that biomass can be transformed into useful energy products through physical preparation, thermochemical conversion, and biochemical processes.

Table 6.9. Biomass conversion technologies and outputs

| Conversion Method | Basic Process | Product Obtained | Example Use |
|---|---|---|---|
| Drying and pelletizing | Moisture reduction and densification. | Pellet, briquette. | Heating and solid fuel. |
| Direct combustion | Controlled combustion of biomass. | Heat and electricity. | Biomass power plant, boiler system. |
| Gasification | High-temperature conversion with limited oxygen. | Synthesis gas. | Electricity, heat, and fuel synthesis. |
| Pyrolysis | Thermal decomposition in an oxygen-free environment. | Biochar, bio-oil, and gas. | Soil improvement, fuel, and energy. |
| Anaerobic digestion | Microbial decomposition of organic matter in an oxygen-free environment. | Biogas and digestate. | Electricity, heat, biomethane, and fertilizer. |
| Fermentation | Microbial conversion of sugary or starchy feedstocks. | Bioethanol. | Transport fuel blends. |

### *6.3.4. Biogas and Biomethane*

Biogas is a gas mixture produced when organic materials are decomposed by microorganisms in an oxygen-free environment. It generally consists of methane and carbon dioxide. Animal manure, food waste, agricultural residues, wastewater treatment sludge, and municipal organic wastes can be used in biogas production.

Biogas can be used directly for electricity and heat production. When it is upgraded and its methane content is increased, biomethane is obtained; biomethane can be injected into the natural gas grid or used as a transport fuel (Ali et al., 2023).

In the 2024 country reports update of IEA Bioenergy, bioenergy is considered under the main categories of solid biomass, biogas/biomethane, liquid biofuels, and the renewable fraction of municipal waste (IEA Bioenergy, 2024). This classification shows that biomass energy is not limited to wood or solid fuels.

Biogas plants can provide environmental benefits when planned together with livestock, the food industry, and municipal waste management. However, odor, leakage, methane losses, hygiene, and waste management processes must be carefully controlled.

### *6.3.5. Environmental Effects of Biomass Energy*

The environmental effects of biomass energy vary according to the feedstock and technology used. Biomass obtained sustainably can contribute to reducing greenhouse gas emissions when it replaces fossil fuels. The evaluation of organic wastes in biogas plants can reduce methane emissions that might otherwise occur through uncontrolled decomposition and can improve waste management.

However, biomass energy can create environmental problems if poorly planned. Uncontrolled wood use can lead to deforestation. Energy crops can compete with food production. Excessive collection of agricultural residues can disturb the organic matter balance of soils. During biomass combustion, air pollutants such as particulate matter, carbon monoxide, and nitrogen oxides can be produced.

Three basic principles are important for biomass energy to be sustainable: feedstock should be obtained sustainably, the conversion technology should be efficient and controlled, and environmental effects should be monitored throughout the life cycle. This approach turns biomass not only into an energy source, but also into a tool for waste management and the circular economy (Hameed et al., 2021).

### *6.3.6. Biofuels and Transport Fuels*

Biofuels are energy products obtained from biomass resources and usable as fuels in transport, heating, electricity generation, or industrial processes. Vegetable oils, sugar and starch crops, agricultural residues, forest

residues, animal wastes, food wastes, and algae are among biofuel feedstocks (Khan et al., 2021).

Biofuels are especially important in transport because it is not easy to meet all energy needs in road transport, aviation, and maritime transport through electricity in the short term. Therefore, sustainable biofuels can provide complementary options to fossil gasoline, diesel, and jet fuel.

However, the environmental benefit of biofuels depends on the feedstock used, the production method, land use, transport distance, and life cycle emissions. Biofuels produced from food crops can raise food security and land-use debates, while advanced biofuels produced from wastes and non-food lignocellulosic feedstocks may be more advantageous in terms of sustainability. Therefore, biofuels should not be accepted as clean under all conditions; they should be evaluated together with sustainable feedstock, production method, and life cycle emissions (IRENA, 2022).

### *6.3.7. Types and Applications of Biofuels*

Biofuels can be classified as solid, liquid, and gaseous biofuels according to their physical state. This classification shows that biofuels are not limited to liquid fuels used in automobiles (Mofijur et al., 2021).

Solid biofuels are fuels in solid form, such as wood, pellets, briquettes, biochar, and some agricultural or forestry residues. They can generally be used in heating, industrial boilers, or biomass energy facilities.

Liquid biofuels are the best-known biofuel group in the transport sector. Bioethanol, biodiesel, renewable diesel, biomethanol, bio-oil, and sustainable aviation fuels can be considered in this group. The U.S. Energy Information Administration states that ethanol is generally blended with gasoline and biodiesel with petroleum diesel (EIA, 2024).

Gaseous biofuels include biogas, biomethane, synthesis gas, and biohydrogen. Biogas is produced through the anaerobic decomposition of organic wastes. Biomethane is the upgraded form of biogas with increased methane content.

Biofuels constitute a broad group of energy products that can be used in heating, electricity generation, transport, and industry. Therefore, they require separate attention within the broader bioenergy discussion, especially in relation to transport fuels, aviation fuels, industrial applications, and blended fuel use. Table 6.10 presents the main types of biofuels and their areas of use.

Table 6.10. Types of biofuels and areas of use

| Biofuel Type | Examples | Main Areas of Use |
|---|---|---|
| Solid biofuels | Wood, pellets, briquettes, biochar, and agricultural residues. | Heating, industrial boilers, electricity generation. |
| Liquid biofuels | Bioethanol, biodiesel, renewable diesel, biomethanol, bio-oil, and sustainable aviation fuel. | Road transport, aviation, maritime transport, and industry. |
| Gaseous biofuels | Biogas, biomethane, synthesis gas, and biohydrogen. | Electricity, heat, transport, natural gas grid, and industry. |
| Advanced biofuels | Fuels produced from waste oil, agricultural residues, lignocellulosic sources, algae, or synthetic processes. | Sectors that are difficult to electrify, especially aviation, maritime transport, and heavy-duty transport. |

### *6.3.8. Main Liquid and Gaseous Biofuels*

Bioethanol is an alcohol-based biofuel produced through the fermentation of sugary or starchy feedstocks and is mostly blended with gasoline (Devi et al., 2022). Biodiesel is obtained from vegetable oils, animal fats, or used cooking oils and can be mixed with fossil diesel in diesel engines (Mittal and Lim, 2024). Renewable diesel can be produced from similar feedstocks, but its chemical structure is closer to fossil diesel.

Gaseous biofuels include biogas, biomethane, synthesis gas, and biohydrogen. As explained in the biomass section, biogas and biomethane are important for both waste management and energy production. The environmental benefit of these fuels depends on the feedstock used and the production method.

### *6.3.9. Biofuels by Generation*

Biofuels can be divided into generations according to the feedstock used and the level of technology. This classification is useful because it shows which fuels compete with food production, which are based on waste and residue resources, and which require more advanced technologies.

Biofuel technologies are continuously developing. While first-generation biofuels are more widespread, advanced biofuels receive greater attention in terms of sustainability. IEA Bioenergy Task 39 states that advanced biofuels can play a complementary role especially in transport areas that are difficult to electrify directly, such as aviation, maritime transport, and heavy-duty vehicles (IEA Bioenergy, 2024; Mofijur et al., 2021).

Table 6.11 shows that biofuel technologies differ according to feedstock type, technological maturity, sustainability potential, and possible limitations. It also helps distinguish between fuels based on food crops, waste and residues, algae, and advanced biological or carbon-capture-based systems.

Table 6.11. Biofuels by generation and sustainability conditions

| Generation | Feedstock | Example Fuels | Advantage | Main Limitation |
|---|---|---|---|---|
| First generation | Food crops. | Bioethanol, biodiesel. | Closer to existing technology and infrastructure. | May create debates over food-land competition and water use. |
| Second generation | Agricultural residues, forest residues, and lignocellulosic biomass. | Advanced bioethanol, advanced biodiesel, and biofuel intermediates. | Can reduce competition with food production. | Technology and cost challenges exist. |
| Third generation | Algae and some advanced biological resources. | Algae-based biodiesel and bio-oil. | May offer high productivity potential. | Large-scale production remains difficult. |
| Fourth generation | Enhanced microorganisms and carbon-capture-supported systems. | Advanced biofuels and synthetic biofuels. | May have low-carbon or carbon-negative potential. | Technology maturity and cost problems exist. |

### *6.3.10. Sustainable Aviation Fuels and Advanced Biofuels*

Sustainable aviation fuels (SAF) are low-carbon fuels that can be used instead of or in blends with fossil jet fuel in the aviation sector. Waste oils, agricultural residues, municipal wastes, synthetic fuel processes, and other low-carbon sources can be used in SAF production.

Electrifying sectors such as aviation and maritime transport is more difficult than electrifying road transport. Therefore, advanced biofuels, biomethane, SAF, and e-fuels are considered complementary options in the decarbonization of these sectors.

However, for sustainable aviation fuels to become widespread, feedstock supply, cost, refinery capacity, certification, life cycle emission calculations, and international standards are important (Khoshnevisan et al., 2021). Therefore, SAF should not be viewed as a technology that can solve aviation emissions on its own in the short term; rather, it should be considered together with efficiency, demand management, new aircraft technologies, and low-carbon fuels.

### *6.3.11. Environmental Effects and Sustainability Conditions of Bioenergy Resources*

The environmental effects of bioenergy resources depend directly on feedstock, production method, and area of use. Fuels produced from sources such as waste oils, organic wastes, and agricultural residues can provide advantages; in contrast, using food crops for large-scale fuel production can

cause problems such as land competition, water consumption, and biodiversity loss.

The actual climate contribution of biomass and biofuels should be evaluated through life cycle analysis. It may be misleading to assume carbon neutrality without considering emissions from cultivation, harvesting, fertilizer production, transport, processing, and fuel use. For this reason, bioenergy applications should prioritize waste and residue resources, reduce competition with food production, prevent land-use changes, calculate emissions throughout the life cycle, and use certification systems.

### *6.3.12. Use of Bioenergy Resources in Education*

Bioenergy resources provide a strong example through which students can learn energy conversion, photosynthesis, the carbon cycle, fermentation, waste management, agriculture, and transport policies together. This topic is directly related to biology, chemistry, geography, environmental education, and STEM activities.

In the classroom, students can classify biofuel feedstocks, discuss the food-waste-energy relationship, or compare the advantages and limitations of biofuels. For safety reasons, observation, modeling, and discussion activities should be preferred instead of fuel production in experimental applications. Such activities are important because they show that energy literacy is not limited to conceptual knowledge; it also includes attitudes, behaviors, decision making, and responsible action (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023). This activity helps students evaluate bioenergy resources not simply with a "renewable" label, but within the relationships among feedstock selection, production process, environmental impact, waste management, and sustainability (Box 6.4).

Box 6.4. Classroom activity suggestion: Evaluating bioenergy resources

| Activity Stage | Explanation |
|---|---|
| Aim | To compare biomass, biogas, and biofuel resources from a sustainability perspective. |
| Materials | Feedstock cards, poster paper, colored pencils, and an evaluation chart. |
| Implementation | Students group resources such as agricultural residues, animal manure, waste oil, energy crops, algae, and food waste. |
| Analysis | Each resource is discussed in terms of energy output, food competition, waste recovery, cost, and environmental impact. |
| Conclusion | Students present the most sustainable bioenergy options with their reasons. |
| Environmental link | Life cycle emissions, land use, and waste management concepts are addressed. |

### *6.3.13. Evaluation from the Perspective of Energy Literacy*

Bioenergy resources offer a strong learning area from the perspective of energy literacy. This topic requires students to consider not only obtaining

energy from organic matter, but also food security, land use, waste management, rural development, transport policies, and life cycle emissions together. In this respect, biofuels can be treated as a socioscientific discussion topic. When students evaluate whether a biofuel is environmentally appropriate, they should consider not only technical efficiency, but also the feedstock used, local conditions, social impacts, and long-term sustainability outcomes (Sadler, 2004; Zeidler, 2014).

From the energy literacy perspective, the most important gain is that students can ask "which feedstock, which production method, and which area of use is more sustainable?" instead of making one-sided judgments such as "biofuel is clean." Therefore, biofuels are effective topics for developing decision-making, evidence-evaluation, and systems-thinking skills.

### *6.4. Comparative Evaluation of Geothermal, Marine-Ocean, and Bioenergy Resources*

Geothermal energy, marine and ocean energy, biomass, and biofuels perform different functions within the renewable energy system. Their common feature is that they are strongly dependent on local conditions and areas of use. Therefore, each resource should be evaluated not by a single criterion, but together with resource potential, technological maturity, environmental effects, feedstock continuity, cost, social acceptance, and educational value.

Table 6.12. Comparison of geothermal, marine-ocean, and bioenergy resources

| Criterion | Geothermal Energy | Marine-Ocean Energy | Biomass and Biofuels |
|---|---|---|---|
| Resource character | Based on heat in the Earth's crust; geographically limited. | Dependent on waves, tides, currents, and marine conditions. | Based on organic materials, wastes, and biological feedstocks. |
| Main use | Electricity, heating, greenhouse cultivation, and thermal applications. | Electricity generation, with particular potential for coastal and island systems. | Heat, electricity, biogas, biomethane, and transport fuels. |
| Continuity | Can provide continuous and predictable energy in suitable areas. | Some types are predictable, but they depend on technology and site conditions. | Feedstock supply and sustainable management determine continuity. |
| Environmental concern | Fluid management, gas emissions, and local water and soil effects. | Marine ecosystems, maintenance processes, and coastal use. | Land use, food competition, emissions, and waste management. |
| Energy literacy value | Links geology, heat transfer, and local resource management. | Addresses water movements, coastal ecosystems, and technology design together. | Makes photosynthesis, waste management, the carbon cycle, and life cycle analysis visible. |

Table 6.12 shows that these resources are not alternatives that simply replace one another, but energy options that complement different areas of use. Therefore, when evaluating bioenergy, geothermal energy, and marine-ocean energy, not only technical potential but also environmental sustainability, local suitability, and social acceptance should be considered together.

### *6.5. Chapter Summary and Discussion Questions*

This chapter examined geothermal energy, marine-ocean energy, and bioenergy resources in terms of their complementary roles within renewable energy systems. Geothermal energy can provide continuous heat and electricity in suitable regions; marine and ocean energy offers potential for coastal and island systems; and bioenergy is associated with waste management, heat, electricity, and transport fuels.

Marine and ocean energy includes different technologies such as wave, tidal, current, ocean thermal, and salinity-gradient energy. Although these resources have potential especially for coastal and island systems, they require careful assessment in terms of technological maturity, cost, maintenance, and impacts on marine ecosystems.

Bioenergy resources are based on converting organic wastes, agricultural residues, forestry products, and biological feedstocks into energy. These resources can offer opportunities, but sustainable feedstock supply, land use, food security, life cycle emissions, and social impacts should be considered.

From the perspective of energy literacy, these resources help students evaluate renewable energy technologies not only as technical systems, but also together with the environment, society, economy, resource management, and decision-making processes.

**Discussion Questions**

1. Under what conditions can geothermal energy be a sustainable energy option?
2. What are the main technological and environmental factors limiting the development of marine and ocean energy?
3. What are the main differences between biomass energy and biofuels?
4. Why is food-land competition an important debate in biofuel production?
5. How should a biomass or biofuel project be evaluated through a life cycle approach?
6. Which skills can geothermal, marine-ocean, and bioenergy resources develop in energy literacy education?

# CHAPTER 7: COMPARISON OF RENEWABLE ENERGY TYPES, GREEN HYDROGEN AND INTEGRATED ENERGY SYSTEMS

This chapter is a synthesis chapter that evaluates together the renewable energy types discussed in detail in the previous chapters. Its purpose is to compare the strengths and limitations of solar, wind, hydropower, geothermal, marine-ocean energy, biomass, and biofuels, and then to explain how these resources relate to integrated energy systems and green hydrogen (Box 7.1) (IRENA, 2024b).

The renewable energy transition is not limited to installing new generation capacity. Resource diversity, storage, smart grids, energy efficiency, electrification, sustainable heating, biofuels, green hydrogen, local conditions, social acceptance, and just transition principles should be considered together (IRENA, 2024).

The chapter first compares renewable energy types, then discusses their areas of use and the integrated systems approach, and finally evaluates the complementary role of green hydrogen in this system (IEA, 2025; IRENA, 2024a).

Box 7.1. What will be learned in this chapter

| Learning Objective |
|---|
| Evaluate different resources in terms of areas of use, environmental impact, continuity, cost, social acceptance, and sustainability. |
| Distinguish the roles of energy resources in electricity, heating-cooling, transport, industry, and storage. |
| Plan storage, smart grids, demand management, electrification, biofuels, and green hydrogen together. |
| Explain that hydrogen is not an energy source, but an energy carrier that can complement renewable energy systems. |
| Interpret that the renewable energy transition depends on local resources, infrastructure, policy targets, and social conditions. |
| Evaluate energy options through their technical, environmental, economic, and social dimensions. |

## *7.1. Comparative Evaluation of Renewable Energy Types*

Renewable energy resources offer important opportunities for reducing dependence on fossil fuels, lowering greenhouse gas emissions, improving energy security, and supporting sustainable development. However, renewable energy types do not all have the same characteristics. Solar and wind energy are rapidly expanding technologies that are prominent in electricity generation. Hydropower is a long-established resource that can provide flexibility to electricity systems. Geothermal energy can provide

continuous heat and electricity in suitable regions. Marine-ocean energy has long-term potential, although many of its technologies are still developing. Biomass and biofuels offer important options especially for waste management, heat production, and transport. Green hydrogen is not treated here as a renewable energy source, but is discussed separately as a low-carbon energy carrier that can be produced using renewable electricity (IEA, 2025; IRENA, 2024b; NREL, 2021).

Therefore, renewable energy resources should not be considered as individual technologies that solve all problems on their own, but as complementary energy options. The most appropriate renewable energy mix for a country or region depends on geographical conditions, climate characteristics, water resources, agricultural and forestry structure, technological capacity, energy demand, grid infrastructure, and the level of social acceptance.

Table 7.1 shows that renewable energy technologies perform different roles within sustainable energy systems. Solar and wind energy are rapidly expanding in electricity generation, whereas biomass and biofuels are important for waste management and transport fuels. Hydropower and geothermal energy can provide more continuous or balancing generation, while marine-ocean energy remains more location-specific and technologically developing. Since green hydrogen is not a primary energy source, it is not listed in the table as a renewable energy type; rather, it is evaluated in a separate section as a complementary energy carrier within integrated energy systems (IEA, 2025; IRENA, 2022).

Table 7.1. General and sustainability-oriented comparison of renewable energy types

| Energy Type | Main Source and Use | Strength | Point Requiring Attention from a Sustainability Perspective |
|---|---|---|---|
| Solar energy | Solar radiation; electricity generation, hot water, and heat applications | It is modular, can be installed at different scales, and its costs have fallen rapidly. | Panel production, raw material use, land selection, recycling, and storage needs should be planned. |
| Wind energy | Movement of air; onshore and offshore electricity generation | It provides efficient and low-carbon electricity generation in suitable areas. | Site selection, bird-bat effects, noise, landscape, social acceptance, and blade recycling are important. |
| Hydropower | Flowing or stored water; electricity generation and system flexibility | It can provide flexibility for the electricity system and, in some cases, storage support. | River ecosystems, fish migration, sediment transport, drought risk, and local communities should be considered. |

| Energy Type | Main Source and Use | Strength | Point Requiring Attention from a Sustainability Perspective |
|---|---|---|---|
| Geothermal energy | Heat in the Earth's crust; electricity, heating, greenhouse cultivation, and thermal use | It can provide continuous energy throughout the year where suitable resources exist. | Reservoir management, reinjection, gas emissions, mineral content, and local environmental effects should be monitored. |
| Biomass and biofuels | Organic matter; heat, electricity, biogas, biomethane, and transport fuels | They offer options for waste management, rural development, and some transport/industrial applications. | Feedstock sustainability, food-land competition, pressure on forests, and life cycle emissions should be assessed. |
| Marine-ocean energy | Wave, tidal, current, and ocean-based energy resources | It can provide local potential for coastal and island systems; some forms are predictable. | Technology maturity, maintenance costs, marine ecosystems, and coastal use should be carefully planned. |

### *7.1.1. Comparison from a Sustainability Perspective*

Although the environmental impacts of renewable energy resources are generally lower than those of fossil fuels, they are not completely zero. Therefore, sustainable energy planning requires each resource to be assessed throughout its life cycle. Resource extraction, production technology, facility construction, operation, maintenance, waste management, and recycling processes should be considered together (NREL, 2021).

This assessment shows that energy transition does not simply mean abandoning fossil fuels. For a genuinely sustainable energy system, the environmental, economic, and social impacts of renewable energy projects should be managed together.

## *7.2. Renewable Energy Resources According to Areas of Use*

Renewable energy resources differ in their areas of use. Some resources are more suitable for electricity generation, some for heating, some for transport, and others for industrial processes. Therefore, in the energy transition, it is necessary to consider not only the potential of a resource, but also how it can be used in different sectors.

Table 7.2 shows that renewable energy resources are not equally effective in every area of use. Solar and wind energy are strong options for electricity generation, while hydropower and geothermal energy can provide more continuous or balancing generation in suitable regions. Biomass, biofuels, and biomethane may contribute to heating, waste management, transport, and some industrial applications. However, the direct use of some renewable energy resources in heavy industry or long-distance transport may be limited. In these areas, energy carriers such as biofuels, biomethane, and

green hydrogen may perform a complementary role. For this reason, green hydrogen is not presented in the table as a separate renewable energy source, but is addressed later as an energy carrier within storage, balancing, and hard-to-electrify sector applications (IEA, 2024, 2025).

Table 7.2. Evaluation of renewable energy types according to areas of use

| Energy Type | Strongest Areas of Use | Complementary Uses | Storage/Balancing Role |
|---|---|---|---|
| Solar energy | Electricity generation; hot water and heating | Indirect use in industry and transport | Can be supported by batteries and hydrogen. |
| Wind energy | Electricity generation | Indirect use in heating, transport, and industry through electricity | Requires batteries, hydrogen, and a flexible grid. |
| Hydropower | Electricity generation and system balancing | Irrigation, flood control, and some water management functions | Plays a very strong role with pumped storage. |
| Geothermal | Heating, cooling, greenhouse cultivation, and electricity where resources are suitable | Industrial heat applications | Contributes to the system through continuous generation. |
| Marine-ocean energy | Electricity generation; especially wave, tidal, and current potential | Complementary use in coastal and island systems | May become complementary in the future. |
| Biomass | Heat, biogas, electricity, and local energy production | Waste management, rural development, and industrial heat | Can play a balancing role through controllable generation. |
| Biofuels | Transport, maritime transport, aviation, and some industrial processes | Limited use in heat and electricity generation | Can be stored as fuels. |

### *7.3. Integrated Renewable Energy Systems*

The energy system of the future is unlikely to depend on a single renewable energy resource. Instead, it will involve a mixed energy structure in which different resources complement one another. Solar energy may produce strongly during daylight hours, while wind energy may be stronger at night or in different seasons. Hydropower and geothermal energy may provide more continuous or balancing generation. Biomass, biogas, and biofuels may offer storable energy options. Green hydrogen may also become important for the long-term storage of surplus renewable electricity and for industrial applications (IEA, 2024, 2025).

Figure 7.1 shows that a sustainable energy transition is not limited to renewable electricity generation. It requires the integrated planning of electricity, heating, transport, storage, grid flexibility, energy efficiency, transport electrification, biofuels, sustainable heating solutions, and green

hydrogen. Therefore, integrated renewable energy systems should be evaluated as flexible and interconnected systems rather than as separate technologies.

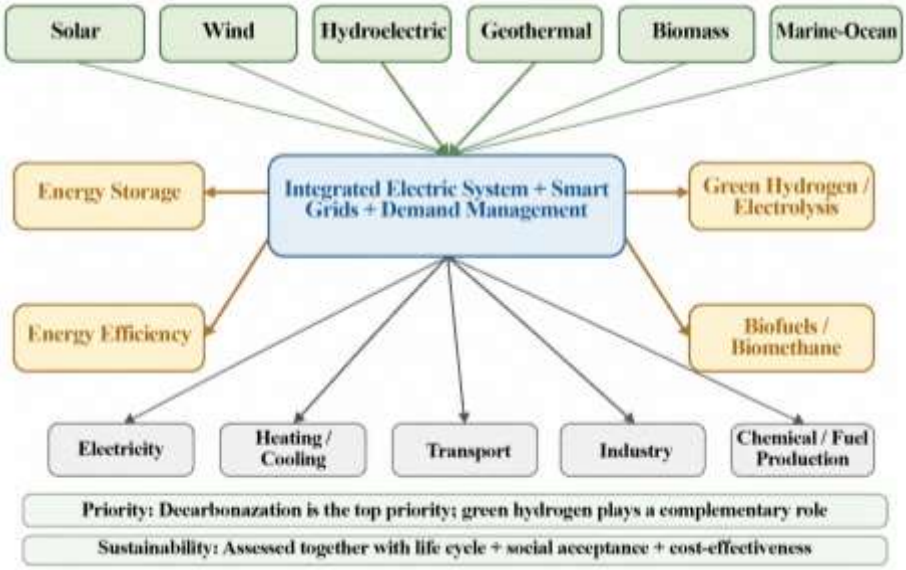


Figure 7.1. Role of renewable energy resources in an integrated energy system.

### *7.4. The Role of Green Hydrogen in Integrated Energy Systems*

Within integrated energy systems, green hydrogen is not considered as a separate energy source, but as a complementary energy carrier that can store surplus renewable electricity and support sectors where direct electrification is difficult. Hydrogen does not generally occur naturally in pure molecular form; it is found in water, organic matter, and various chemical compounds. Therefore, hydrogen to be used in energy systems must first be produced using another energy source (IEA, 2025; IRENA, 2024b).

For this reason, hydrogen is more accurately described as an energy carrier than as a primary energy source. It is produced, stored, transported, and then used in fuel cells, industry, transport, or long-term storage applications.

The environmental impact of hydrogen depends on the production method. Hydrogen produced through the electrolysis of water using renewable electricity can be low-emission, whereas hydrogen produced from fossil fuels without carbon capture can lead to high greenhouse gas emissions (IEA, 2025; IRENA, 2024b).

In integrated energy systems, hydrogen should therefore be evaluated in terms of its production method, storage and transport requirements, possible fuel cell applications, environmental effects, and educational value for energy literacy. Table 7.3 summarises the technical, environmental, and system-level advantages and limitations of hydrogen as an energy carrier.

Table 7.3. Technical, environmental, and system-level advantages and limitations of hydrogen

| Dimension | Advantage / Contribution | Limitation or Point Requiring Attention |
|---|---|---|
| Energy carrying | It can be produced from different sources, stored, and used in different sectors. | Another energy source is required for its production; efficiency losses may occur during production and conversion stages. |
| Carbon emissions | Green hydrogen does not directly produce $CO_2$ at the point of use and can support emission reductions when it replaces fossil fuels. | If the production method is fossil-fuel based, high emissions may occur; life cycle emissions should be assessed together. |
| Storage and system flexibility | It can be used for long-term energy storage, seasonal balancing, and use of surplus renewable electricity. | Because of low volumetric energy density, special infrastructure such as compression, liquefaction, or chemical carriers is required. |
| Area of use | It can play a complementary role in industry, transport, the electricity system, and the chemical sector. | Not every application is economically or technically appropriate; electric solutions should be prioritized where direct electrification is possible. |
| Energy security | When produced from local renewable resources, it can reduce dependence on energy imports. | High investment may be needed for pipelines, storage, safety, and end-use infrastructure. |
| Environmental impact | Under low-emission production conditions, it can support climate targets and cross-sectoral energy transition. | Water use, renewable electricity needs, material requirements, leakage, and safety should be considered. |

### *7.4.1. Hydrogen as an Energy Carrier*

Hydrogen can be used for different purposes in energy systems. First, it is used as a feedstock in industry. Hydrogen has long been used in ammonia, methanol, and refinery processes. Second, it can be used to generate electricity in fuel cells. Third, it can be considered as a chemical energy carrier for storing surplus renewable electricity for later use.

Hydrogen has a high energy content per unit mass; however, under normal conditions it is a low-density gas and therefore has low energy density per unit volume. For this reason, additional infrastructure is required, such as compression, liquefaction, or storage in chemical carriers (DOE, 2026g).

The importance of hydrogen in the energy transition increases especially in areas where direct electrification is difficult. IRENA identifies road freight, maritime transport, aviation, iron and steel, chemicals, and petrochemicals among the sectors that are more difficult to transform (IRENA, 2024b).

The main roles and areas of use of hydrogen in the energy system are summarised in Table 7.4. The table shows that hydrogen can function not only as an industrial feedstock, but also as an energy carrier for electricity

generation, long-term storage, transport, and hard-to-electrify industrial processes.

Table 7.4. Roles and areas of use of hydrogen in the energy system

| Role / Area of Use | Role of Hydrogen | Explanation / Example |
|---|---|---|
| Industrial feedstock | Input for chemical production | Used in ammonia, methanol, and refinery processes; low-emission hydrogen can contribute to emission reductions in these areas. |
| Energy carrier and storage | Can be produced from renewable electricity and used later | Surplus electricity can be stored as chemical energy and used for long-term balancing. |
| Heavy transport | Fuel or input for synthetic fuels | May be a complementary option for heavy road transport, maritime transport, and aviation fuels where battery solutions are limited. |
| Electricity and backup power | Electricity generation through fuel cells | Can be used in backup power systems, remote areas, or specific applications. |
| Industrial heat and hard-to-abate sectors | Low-carbon option for high-temperature or reduction processes | Can partly replace fossil fuels in steel, chemicals, and some industrial processes. |
| Fuel and chemical production | Synthesis of e-fuels and chemical products | Requires a carbon source, low-emission electricity, and suitable infrastructure. |

### *7.4.2. Hydrogen Production Methods and Color Classification*

Hydrogen can be produced by different methods. For a long time, the most common production methods have been fossil-fuel-based processes such as steam methane reforming from natural gas and coal gasification (Xu et al., 2022). These methods create carbon dioxide emissions. For hydrogen to be considered low-carbon or renewable, emissions during production must be reduced.

Color-based classification is commonly used in hydrogen production. However, these colors are not sufficient on their own. What matters most is the life cycle greenhouse gas emission of the production process. Labels such as “green,” “blue,” or “grey” provide a practical explanation; however, the real environmental impact of hydrogen should be assessed together with the production method, energy source, carbon capture rate, and supply-chain emissions.

Table 7.5 shows that hydrogen is not a single type of fuel from an environmental perspective. Although the hydrogen molecule is the same at the point of use, its climate impact depends on the production method, energy source, carbon capture rate, and supply-chain emissions. Therefore, this classification can help students understand why the sustainability of hydrogen should be evaluated according to how it is produced, not only how it is used.

Table 7.5. Common color classification in hydrogen production

| Hydrogen Type | Production Method | General Carbon-Related Assessment |
|---|---|---|
| Grey hydrogen | Produced from natural gas; carbon capture is not applied. | May cause high $CO_2$ emissions. |
| Brown/black hydrogen | Produced through coal or lignite gasification. | Among the hydrogen types with the highest emissions. |
| Blue hydrogen | Produced from natural gas or coal; part of the $CO_2$ is captured and stored. | Can reduce emissions; however, carbon capture rate and methane leakage are important. |
| Green hydrogen | Produced by electrolysis of water using renewable electricity. | One of the most important options for low-emission hydrogen. |
| Pink/purple hydrogen | Produced by electrolysis using nuclear electricity. | May be low-carbon, but it is not renewable. |
| Turquoise hydrogen | Produced through methane pyrolysis; solid carbon is formed. | Depends on technology conditions and carbon management. |

### *7.4.3. Green Hydrogen and Electrolysis*

Green hydrogen is hydrogen produced through the electrolysis of water using renewable electricity. During electrolysis, the water molecule is separated into hydrogen and oxygen with the help of electrical energy (Varsha and Nageswaran, 2020). If the electricity is supplied from renewable sources such as solar, wind, hydropower, or geothermal energy, carbon emissions during production can be substantially reduced.

Electrolysis is one of the critical technologies for low-emission hydrogen production. The IEA considers electrolyzers an important technology for producing low-emission hydrogen from renewable or nuclear electricity (IEA, 2024d).

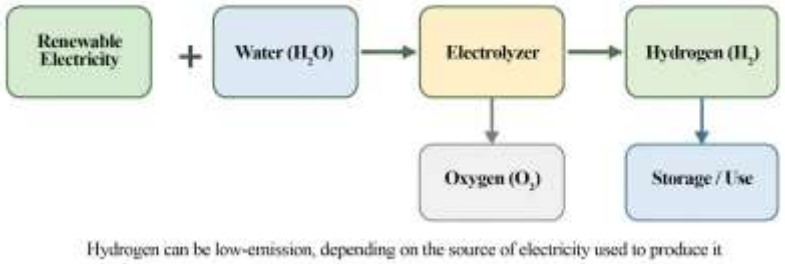


Figure 7.2. Electrolysis process in green hydrogen production.

Figure 7.2 illustrates the electrolysis process used in green hydrogen production. It shows how renewable electricity can be used to split water into hydrogen and oxygen, making hydrogen a complementary energy carrier for integrated renewable energy systems. The figure also highlights that green hydrogen is not obtained directly from nature; rather, it requires renewable

electricity, water, an electrolyzer, and storage infrastructure. Electrolyzer technologies differ in terms of cost, efficiency, flexibility, and material requirements. Although these technical details become important depending on the scale of the application, the main emphasis in this book is that green hydrogen can be low-emission only when renewable electricity, appropriate water management, safe storage, and suitable areas of use are provided.

### *7.4.4. Hydrogen Storage and Transport*

For hydrogen to be used in energy systems, it must be stored and transported safely. Hydrogen can be stored as compressed gas, liquefied at very low temperatures, or stored within carriers such as ammonia, methanol, and metal hydrides (Hwang et al., 2023). The method selected depends on the area of use, distance, cost, safety requirements, and infrastructure.

Hydrogen storage is not simple because hydrogen is a light gas and has low volumetric energy density. Therefore, special solutions such as pressurised tanks, cryogenic liquefaction, or chemical carriers are required (DOE, 2026g).

Table 7.6. Hydrogen storage and transport methods

| Method | Explanation | Advantage | Limitation |
|---|---|---|---|
| Compressed gas | Hydrogen is stored in tanks under high pressure. | Suitable for vehicles and short- to medium-distance applications. | High-pressure tanks and safety measures are required. |
| Liquid hydrogen | Hydrogen is liquefied at very low temperature. | Provides higher volumetric density. | Liquefaction consumes energy and requires cryogenic infrastructure. |
| Ammonia | Hydrogen can be transported within the ammonia molecule. | Can be considered for international transport. | Toxicity, conversion efficiency, and safety are important. |
| Methanol and liquid organic carriers | Hydrogen is stored in chemical carriers. | Can be linked with existing liquid fuel infrastructure. | Conversion processes require energy and technology. |
| Metal hydrides | Hydrogen can be stored in solid form with certain metals. | Has potential for safe and compact storage. | Weight, cost, and heat management can be issues. |
| Pipelines | Hydrogen gas is transported by pipeline. | Suitable for continuous transport in large volumes. | Material compatibility, leakage control, and infrastructure investment are required. |

The main hydrogen storage and transport methods are summarised in Table 7.6. The table shows that each method has different advantages and limitations in terms of energy density, safety, cost, infrastructure needs, and suitability for short- or long-distance transport. Storage and transport are among the most important challenges of the hydrogen economy. It is not enough to be able to produce hydrogen; hydrogen must also be delivered

safely, economically, and with low losses from the place of production to the place of use (Ural and Karaca, 2016).

### *7.4.5. Fuel Cells and Hydrogen Use*

Fuel cells are systems that convert the chemical energy of hydrogen directly into electrical energy. In a fuel cell, hydrogen is supplied to the anode side and oxygen or air to the cathode side. Hydrogen molecules are separated into protons and electrons; electrons pass through the external circuit to create an electric current, while protons pass through the electrolyte and combine with oxygen to form water (Li and Yu, 2021).

Fuel cells generate electricity in a way similar to batteries; however, unlike batteries, they continue operating as long as fuel is supplied. This feature is important for backup power, vehicles, and some stationary power applications (DOE, 2026b).

Hydrogen should not be expected to be used to the same extent in all sectors. In areas where direct electrification is easy and efficient, electric solutions may be more appropriate. Hydrogen should be seen as a more strategic option especially for high-temperature industrial processes, chemical feedstock production, long-distance transport, and long-duration energy storage.

### *7.4.6. Environmental Effects of Hydrogen Energy*

The environmental effects of hydrogen depend on its production method. When hydrogen is combusted or used in a fuel cell at the point of use, carbon dioxide is not produced; however, if hydrogen is produced from fossil fuels, significant greenhouse gas emissions may occur during the production stage. Therefore, the key factor determining whether hydrogen is “clean” is the production process.

Green hydrogen can be a low-emission option when produced with renewable electricity. However, sufficient renewable electricity, an appropriate water source, electrolyzer capacity, and storage and transport infrastructure are required. A report prepared by IRENA and Bluerisk emphasizes that water management is important in hydrogen production and that water use should be considered in project assessments (IRENA and Bluerisk, 2023).

Hydrogen storage and transport also have environmental and safety dimensions. Hydrogen is a small and flammable molecule; therefore, leakage control, ventilation, sensors, appropriate material selection, and safety standards are important. In addition, when hydrogen is converted into carriers such as ammonia or methanol, the environmental and health effects of these substances should also be assessed.

Three basic conditions are important for the sustainability of hydrogen energy: hydrogen should be produced through low-emission methods, it should not be used unnecessarily in areas where direct

electrification is more suitable, and storage-transport infrastructure should be planned safely.

Figure 7.3 shows that hydrogen is not automatically the best solution in every case. It becomes more meaningful especially in areas where direct electrification is difficult and where low-emission production, safe storage and transport infrastructure, and appropriate resource conditions can be provided. The figure also highlights that the sustainability of hydrogen depends not only on its use, but also on how it is produced, managed, and integrated into the broader energy system.

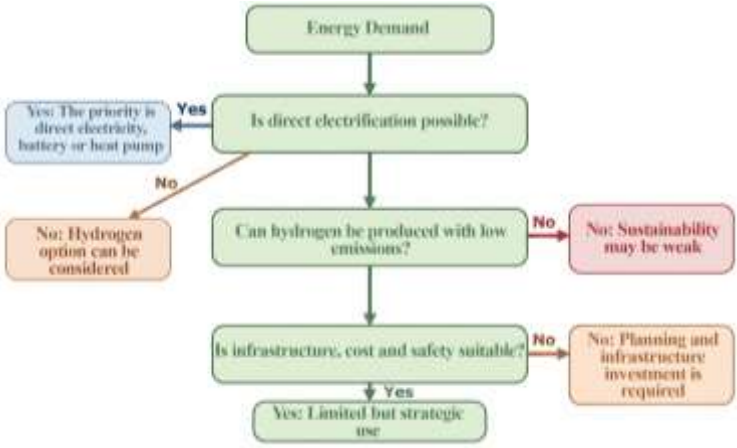


Figure 7.3. Sustainability decision flow for hydrogen use.

### *7.4.7. Educational Use of Hydrogen Energy*

Hydrogen energy is an appropriate example for helping students learn together about energy conversion, chemistry, electricity, water electrolysis, fuel cells, renewable energy, and sustainability. This topic can be linked with science, chemistry, physics, environmental education, and STEM activities.
When hydrogen is discussed in the classroom, a safety-first approach should be adopted. Experiments involving hydrogen gas production and combustion should only be conducted under appropriate laboratory conditions and teacher supervision. Safer activities include electrolysis model drawings, diagrams of fuel-cell operation, hydrogen color classification, and sustainability discussions.

Box 7.2. Classroom activity suggestion: Comparing hydrogen colors from a sustainability perspective

| Activity Stage | Explanation |
|---|---|
| Purpose | To understand that the environmental impact of hydrogen depends on its production method. |
| Materials | Hydrogen type cards, colored pencils, and an evaluation chart. |
| Implementation | Students compare grey, blue, green, pink, and turquoise hydrogen types. |
| Analysis | Each type is scored in terms of emissions, cost, infrastructure, water use, and applicability. |
| Discussion | The question "Is hydrogen always clean?" is discussed in class. |
| Conclusion | Students explain with reasons in which areas hydrogen use is more appropriate. |

This activity helps students evaluate hydrogen not only as a "clean fuel," but also in relation to production method, energy source, infrastructure, water use, and environmental effects (Box 7.2).

### *7.4.8. Evaluation from the Perspective of Energy Literacy*

Hydrogen energy is a strong example from the perspective of energy literacy because it requires students not only to recognize a technology, but also to relate production method, resource choice, area of use, cost, safety, and environmental impact. In the energy literacy literature, energy knowledge, attitudes, behaviors, decision-making, and responsible action are addressed together (DeWaters et al., 2013; Ramachandran et al., 2024; Santillán and Cedano, 2023).

Hydrogen is also a socioscientific discussion topic. Questions such as "Where should green hydrogen be used?", "Is hydrogen or direct electricity more appropriate?", and "How should hydrogen production be planned in water-stressed regions?" require ethical, environmental, and social evaluation in addition to technical knowledge. In this respect, hydrogen can be used to develop students' evidence-based decision-making and sustainability-oriented thinking skills (Sadler, 2004; Zeidler, 2014).

Therefore, hydrogen education should not be limited to presenting hydrogen as a "clean fuel." Students should learn the differences among grey, blue, and green hydrogen, life cycle emissions, water use, storage and transport challenges, and comparisons with direct electrification. Such an approach helps clarify hydrogen's realistic and limited but strategic role in the energy transition.

## *7.5. General Evaluation Based on Selected Country Examples*

Türkiye, Greece, Portugal, and North Macedonia have different potentials in terms of renewable energy resources (IEA, 2021, 2023, 2023a, 2026a). These differences show that the energy transition will not take place in the same way in every country. Each country has a different geographical

structure, energy demand, economic capacity, industrial structure, existing energy infrastructure, dependence on energy imports, and policy priorities. Therefore, the renewable energy transition should be planned by considering each country's own resource structure and development goals.

Within these country examples, green hydrogen can also be considered as a complementary option, especially for transferring renewable electricity potential to areas such as industry, transport, and long-term storage. However, this role of hydrogen should be planned by considering each country's renewable electricity supply, water resources, infrastructure, industrial structure, and cost conditions. Therefore, green hydrogen should be treated not as a separate source replacing renewable energy resources, but as an energy carrier that can support integrated energy systems.

The renewable energy potential of the selected country examples is summarised in Table 7.7, with attention to prominent resources and general transition conditions.

Table 7.7. General evaluation of renewable energy potential in selected country examples

| Country | Prominent Renewable Resources | General Evaluation |
|---|---|---|
| Türkiye | Solar, wind, hydropower, geothermal, biomass, and green hydrogen potential | Due to its broad geography and diverse resource base, it has strong potential for a mixed renewable energy system. |
| Greece | Solar, wind, offshore wind, geothermal, and biomass | The island structure and solar-wind potential support the energy transition; grid connection and storage are important. |
| Portugal | Wind, solar, hydropower, wave energy, biomass, and green hydrogen | Its Atlantic coast, renewable electricity experience, and port infrastructure make it a strong example in the energy transition. |
| North Macedonia | Solar, hydropower, biomass, limited geothermal, and wind potential | Because of its smaller energy system, local and regional renewable energy investments are important. |

The country examples summarised in Table 7.7 show that a sustainable energy transition cannot be explained by a single model. For Türkiye, it is important to evaluate solar, wind, hydropower, geothermal, and biomass resources together, while island systems, offshore wind, and solar energy are prominent in Greece. Portugal is notable for the integration of different renewable resources such as wind, solar, and marine energy into the energy system. In North Macedonia, solar and hydropower resources provide important opportunities for diversifying energy supply and reducing external dependence.

The common conclusion from these examples is that a successful renewable energy transition does not depend only on technical potential. Grid

infrastructure, energy storage, financing opportunities, local participation, environmental planning, education, and energy literacy are also key determinants of success. Therefore, rather than searching for a single correct model across countries, it is more realistic for each country to develop integrated energy strategies appropriate to its own resource structure, development priorities, and social conditions.

This evaluation supports the general message of this chapter: renewable energy resources should be selected according to local conditions, different technologies should be planned in a complementary way, and every energy project should be considered together with its technical, environmental, economic, and social dimensions.

### *7.6. General Evaluation from the Perspective of Energy Literacy*

Comparing renewable energy types is important for the development of energy literacy. An energy-literate individual is not merely someone who knows the names of energy resources; rather, such an individual can evaluate these resources together with environmental impact, cost, continuity, social acceptance, infrastructure requirements, and just transition dimensions.

The comparisons made in this chapter help readers consider renewable energy resources not through a simple "good-bad" distinction, but through a multi-criteria decision-making process. The variable generation of solar and wind energy, the system flexibility of hydropower and geothermal energy, the feedstock management of biomass and biofuels, the technology maturity of marine-ocean energy, and the complementary role of green hydrogen should be considered together.

Therefore, renewable energy education should not be limited to introducing technologies. Students and readers should develop skills in interpreting data, comparing resources, considering local conditions, questioning life cycle effects, and evaluating the perspectives of different stakeholders. Such an approach contributes to more informed, participatory, and sustainable discussion of energy decisions.

### *7.7. Chapter Summary and Discussion Questions*

This chapter evaluated renewable energy types comparatively and discussed the integrated renewable energy systems approach. Solar, wind, hydropower, geothermal, marine-ocean energy, biomass, biofuels, and green hydrogen have different areas of use, advantages, and limitations. Therefore, energy decisions should focus not on a single resource, but on how resources can complement one another.

Integrated renewable energy systems require the joint planning of resource diversity, energy efficiency, storage, smart grids, electrification, sustainable heating, biofuels, and green hydrogen. Within this structure, green hydrogen should be positioned not as a primary energy source, but as an energy carrier that can complement renewable energy systems.

Selected country examples show that the renewable energy transition does not progress in the same way in every country. Geographical resource potential, energy infrastructure, economic structure, policy targets, social acceptance, and just transition conditions determine the direction and speed of the transition.

From the perspective of energy literacy, this chapter helps readers evaluate energy resources not only through their technical characteristics, but also through their environmental, economic, social, and ethical consequences.

**Discussion Questions**

1. Which criteria should be considered when comparing renewable energy types?
2. What needs arise in integrated energy systems because of the variable generation of solar and wind energy?
3. How can resources such as hydropower, geothermal energy, and biomass contribute to system flexibility?
4. Why should green hydrogen be considered an energy carrier rather than a separate energy source?
5. Why should storage, smart grids, and energy efficiency be considered together in integrated energy systems?
6. How do the selected country examples show that the renewable energy transition depends on local conditions?
7. How does energy literacy contribute to decision-making among renewable energy options?

# CONCLUSION

Energy is a fundamental element that shapes almost every sphere of modern life, from production and transportation to housing, communication, agriculture, and industry; however, it is not merely a technical issue. Energy production and consumption are directly connected to climate change, air pollution, natural resource use, economic development, energy security, social inequalities, and the living conditions of future generations. Therefore, understanding the relationship between energy and the environment is one of the most important scientific, social, and educational necessities of our time.

In this book, the relationship between energy and the environment has not been limited to the introduction of energy resources. Instead, it has been examined together with concepts such as energy literacy, sustainability, decision-making, life cycle thinking, social acceptance, and just transition.

### *Energy, Environment, and Energy Literacy*

Energy literacy is one of the distinguishing concepts of this book. An energy-literate individual is not merely someone who knows the names or technical characteristics of energy resources. Rather, such an individual can evaluate the environmental consequences of energy production, the social effects of energy consumption, the economic dimensions of resource selection, and the implications of energy policies for future generations together.

In this context, energy literacy goes beyond the acquisition of information. It includes critical thinking, evidence-based decision-making, the ability to compare different options, the evaluation of uncertainties, and the development of social responsibility (DeWaters et al., 2013; Sadler, 2004). Since energy-related decisions are too socially significant to be left solely to experts, energy literacy is also important for democratic participation and sustainable citizenship.

### *A Multi-Criteria Approach to Evaluating Energy Resources*

Energy resources are often classified as renewable and non-renewable. This classification is instructive and necessary; however, it is not sufficient on its own. The technology through which the resource is used, where and at what scale it is implemented, how it is financed, what social impacts it creates, and what environmental consequences it produces throughout its life cycle must also be taken into account.

For this reason, throughout the book, criteria such as environmental impact, life cycle effects, system cost, continuity, energy security, technological feasibility, infrastructure requirements, social acceptance, and equitable access have been used together to evaluate energy resources. These criteria make it possible to assess energy options not through a simple “good-

bad" distinction, but in a context-sensitive and evidence-based manner (NREL, 2021; Ramachandran et al., 2024).

Solar and wind energy are strong options for low-carbon electricity generation; however, they should be considered together with land use, material requirements, variable generation, recycling, and social acceptance. Hydropower, geothermal energy, bioenergy, and marine-ocean energy also have different advantages and limitations depending on local conditions. Therefore, a sustainable energy mix is based not on the absolute superiority of a single resource, but on the planning of resources in ways that complement one another.

***From Non-Renewable Energy Sources to Sustainable Transformation***

Non-renewable energy sources have historically been among the most important inputs of modern industrialization and economic growth. Coal, oil, natural gas, and nuclear energy have played decisive roles in electricity generation, transportation, industry, heating, and technological development. Nevertheless, an energy system based on fossil fuels has produced serious problems such as climate change, air pollution, health impacts, ecosystem pressure, and external dependence.

Reducing the use of fossil fuels is not merely an environmental preference; it is also a long-term social and economic necessity. Yet this transformation must be carefully planned. If employment in coal regions, energy access for low-income households, the transformation of industrial sectors, energy prices, and supply security are neglected, the energy transition may encounter social resistance. Therefore, the phase-out of fossil fuels should be addressed together with the principle of a just transition (ILO, 2016).

Nuclear energy occupies a more specific position in this debate. Its potential to provide low-carbon electricity during operation is an important advantage. However, radioactive waste management, high investment costs, long construction periods, safety issues, and social acceptance require nuclear energy to be evaluated carefully. This once again demonstrates that energy resources cannot be assessed according to a single criterion.

***Renewable Energy, Integrated Systems, and Green Hydrogen***

Renewable energy resources are at the center of the transition to low-carbon energy systems. Solar, wind, hydropower, geothermal energy, marine-ocean energy, biomass, and biofuels play different roles under different conditions. Their common feature is that they have the potential to reduce dependence on fossil fuels and make energy systems more sustainable.

However, the renewable energy transition is not limited to building new power plants. The high share of variable resources such as solar and wind requires energy storage, smart grids, demand-side management, interconnections, and system flexibility. Hydropower and some geothermal

applications can assume more continuous or balancing roles. Biomass, biogas, and biofuels can provide complementary contributions in terms of storable energy and waste management. Marine-ocean energy, in turn, has long-term potential, especially for coastal and island systems.

One of the points emphasized in this book is that hydrogen is not a primary energy source, but an energy carrier. The environmental value of hydrogen depends less on hydrogen itself than on how it is produced. Green hydrogen produced through water electrolysis using renewable electricity can play a complementary role in low-carbon energy systems (IEA, 2025).

Green hydrogen should not be regarded as a universal solution that can be used in every sector. It may have strategic value particularly in areas where direct electrification is difficult, such as iron and steel, chemicals, long-distance transport, shipping, aviation, and long-duration energy storage. At the same time, energy losses in hydrogen production, costs, water requirements, and challenges related to storage and transportation must be carefully evaluated.

***Social Acceptance, Just Transition, and Local Conditions***

The success of the energy transition does not depend only on technological developments. Social acceptance, local participation, equitable benefit sharing, and access to reliable information directly affect the feasibility of energy projects (Wüstenhagen et al., 2007). Even if a project is technically suitable and economically attractive, it may face social resistance if it does not take into account local people's living spaces, livelihoods, cultural values, or environmental expectations.

For this reason, transparency, participatory planning, environmental impact assessment, local benefit mechanisms, and just transition policies should be core principles in energy projects. The energy transition is not only a process of reducing carbon emissions; it is also an opportunity to build fairer, more inclusive, and more resilient societies.

Selected country examples show that energy transition does not proceed in the same way in every country. Countries such as Türkiye, Greece, Portugal, and North Macedonia have different resource potentials, energy infrastructures, economic conditions, and policy priorities. Therefore, rather than adopting a single uniform model, energy transition should be guided by approaches that are sensitive to local conditions and open to learning.

***Implications for Education and the Future***

Energy and environmental education should aim not only to enable students to recognize energy resources, but also to help them evaluate the environmental, economic, and social consequences of these resources together. The activities, comparison tables, and discussion questions included in this book have been designed to support students in analyzing different energy options in an evidence-based way.

Sustainable energy education requires an interdisciplinary approach. Physics, chemistry, biology, geography, economics, engineering, environmental science, and the social sciences complement one another in energy-related topics. Therefore, energy education should not be addressed only through technical calculations, but also through values, decision-making processes, social impacts, and ethical responsibilities.

The energy system of the future will be lower-carbon, more digital, more flexible, and more open to local participation. In this process, individual energy choices, institutional investment decisions, government policies, and international cooperation will all be decisive. Energy literacy is a fundamental requirement for ensuring that this transformation occurs in a conscious, just, and sustainable manner.

***General Evaluation***

In conclusion, this book shows that the relationship between energy and the environment cannot be explained solely through technological solutions. The energy system is a complex set of relationships among natural resources, climate, economy, society, education, and ethical values. Therefore, solutions to energy problems must also be holistic, multi-criteria, and participatory.

The environmental and social costs of non-renewable energy resources make the transition to low-carbon energy systems necessary. Renewable energy resources form the basis of this transition; however, they too must be carefully planned, their life cycle impacts monitored, their social acceptance processes strengthened, and their integration into the energy system managed in a holistic manner.

Energy transition is not only a matter of meeting today's energy demand. It is also a responsibility to leave future generations a more livable environment, a more secure energy system, a fairer society, and a more informed culture of citizenship. To fulfill this responsibility, energy literacy, scientific knowledge, social participation, and sustainable policy design must be developed together.

The central message of this book is that the energy future cannot be reduced to a single resource, a single technology, or a single policy. A sustainable energy future is possible through balanced integration among energy efficiency, renewable resources, storage, smart grids, green hydrogen, just transition, social acceptance, and informed citizenship. When such integration is achieved, energy can move beyond being a source of pressure on the environment and become one of the fundamental instruments of sustainable development and a fairer future.

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