

# Renewable Energy Sources Towards a Zero-Emission Economy

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## 1. Introduction

Transforming the economy towards climate neutrality is one of the greatest challenges of our time [1]. Achieving zero emissions requires profound changes not only in the energy sector but also in industry, agriculture, and entire socioeconomic systems [2]. Renewable sources—such as wind, solar, hydropower, and biomass—are the foundation of this objective, and their growing importance is reflected in both scientific research and public policy.

Renewable energy sources (RESs) are a key pillar of the contemporary energy transformation, essential to achieving global sustainable development goals and reducing greenhouse gas emissions [3]. Faced with intensifying climate change and growing energy demand, the global economy increasingly requires stable and sustainable energy resources. This, in turn, necessitates the search for new, efficient, and environmentally friendly green energy solutions [4].

Transitioning to zero-emission energy systems is not only a technological challenge but also a social, economic, and organizational one. Therefore, research in this area must cover not only the issues of technological efficiency and their impact on the environment but also management models and potential integration with existing energy infrastructure [5].

This Special Issue focuses on these challenges, bringing together studies that explore innovative pathways towards a climate-neutral economy.

## 2. The Importance of Renewable Energy Sources

The development of renewable energy sources, such as photovoltaics, wind power, biomass, and hydropower, is the foundation for building a climate-neutral economy [6]. In the context of global energy transformation, regional aspects cannot be overlooked. These are effectively addressed, for example, by research on the progress of renewable energy deployment in different countries and continents. These studies show that even in developing countries, the implementation of renewables contributes to improved access to energy, job creation, and the stimulation of technological innovation. At the same time, they highlight barriers related to financing and the need for appropriate energy policy design.

Photovoltaics is currently one of the fastest-growing segments of renewable energy. Technological advances make it possible to reduce solar panels' production costs, increase their efficiency, and integrate them with modern energy storage systems [7]. Similarly, wind energy, both onshore and offshore, is becoming increasingly competitive compared to traditional sources, and its development enhances energy security.

However, it should be emphasized that the rapid expansion of photovoltaics also entails environmental challenges [8]. The production of panels requires significant energy input and the use of raw materials such as silicon, silver, and rare earth metals, the extraction



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and processing of which can create additional environmental burdens. Another critical issue is the disposal of used panels. Although panels' lifespans are usually 20–30 years, in the coming decades, the problem of growing volumes of photovoltaic waste will emerge. The lack of effective recycling systems may negatively affect the environment through the emission of toxic substances and increased pressure on landfills. Therefore, research on renewable energy sources increasingly focuses on developing technologies for material recovery from panels and creating closed-loop product life cycles in line with the principles of a circular economy [9].

Similar environmental challenges apply to wind energy. Although it is considered one of the cleanest energy sources, the construction of wind farms requires the installation of vast foundations that interfere with soil and aquatic ecosystems. In addition, the production of turbine components, such as blades and towers, requires large amounts of steel, concrete, and composites. The extraction and processing of these materials also generate emissions and may negatively impact the environment. Particularly problematic is the recycling of turbine blades made of fiberglass or carbon fiber, whose durability is an advantage during operation but becomes a challenge at the end of their life cycle [10]. For this reason, studies on wind energy increasingly cover not only improvements in turbine efficiency but also the development of more sustainable construction materials and methods for disposal and recycling [11].

Biomass and hydropower, in turn, stabilize the energy system, enabling flexible responses to fluctuations in wind and solar power production [12]. However, their responsible use, with respect for ecosystems and local environments, is crucial [13].

### 3. Carbon Capture and Storage as a Component of Transformation

Although renewable energy sources are the foundation of a zero-emission economy, they alone are insufficient to completely neutralize greenhouse gas emissions. In many sectors—such as heavy industry, cement production, and steelmaking—technological processes generate emissions that are difficult to avoid. For this reason, carbon capture and storage (CCS) technologies are playing an increasingly important role [14].

CCS systems involve separating CO<sub>2</sub> from industrial processes and fuel combustion, followed by its safe transport and storage in geological formations, including under the seabed, which allows natural geological structures to be used as long-term gas reservoirs [15,16]. Combined with renewables, these technologies can significantly accelerate the achievement of climate neutrality. It is also worth highlighting the development of solutions based on direct air capture (DAC), which may become an effective complement to the energy–climate relationship in the future, enabling emission reductions in hard-to-decarbonize sectors [17].

### 4. Management Perspectives and Innovative Business Models

The energy transition is not only a matter of technology but also of new business models and corporate management strategies. Companies operating in the energy sector, as well as in related industries, must adapt to dynamically changing market, regulatory, and social conditions. Innovative business models based on the concepts of the circular economy, resource sharing, and the creation of energy ecosystems provide a response to these challenges [18].

In practice, this involves the development of services such as energy prosumerism, where consumers simultaneously become producers of energy, and “energy-as-a-service” models, which enable clients to benefit from renewable energy without the need to invest in infrastructure. Another important direction is the expansion of public–private partnerships, which allow for more effective financing and the implementation of innovative technologies.

From a corporate management perspective, it is also crucial to implement tools for assessing climate and environmental risks, enabling decision-making aligned with long-term sustainable development goals. Companies must incorporate ESG (environmental, social, and governance) criteria into their strategies; this will not only support emission reductions but also build competitive advantages in the global market [19].

## 5. Research Gaps and the Need for Technological Integration

Research on renewable energy sources has traditionally focused on improving energy efficiency and optimizing technologies. However, a key research gap concerns the integration of various renewable sources with CCS systems and with energy and industrial infrastructure. Developing comprehensive models that incorporate not only technical aspects but also environmental, social, and economic dimensions is essential.

Another critical issue is the development of smart grids, which allow for dynamic energy flow management, the integration of distributed sources, and the adjustment of supply for demand [20,21]. In this context, research should concentrate on synergies between different technologies, the creation of hybrid systems, and the use of artificial intelligence and big data to optimize grid performance.

## 6. Conclusions

Renewable energy sources are an indispensable component of advancement toward a zero-emission economy, yet their full potential can only be realized when combined with other technologies, such as carbon capture and storage (CCS). Equally important is the development of innovative business models and modern corporate management strategies, which enable the effective practical implementation of energy transition.

Research objectives that need to be addressed include the integration of various technologies, the analysis of their long-term impacts on the economy and the environment, and the development of mechanisms that will facilitate the broad adoption of innovative solutions. In this context, it is also essential to investigate the strategies of energy enterprises, which increasingly rely not only on the deployment of advanced technologies—such as renewable energy and CCS systems—but also on innovative market structures. Examples include the development of “energy-as-a-service” models, prosumer ecosystems, public–private partnerships, and flexible financing frameworks for energy projects, all of which accelerate the adoption of green solutions.

The analysis and implementation of such strategies will fill an important research gap, as they will help to understand how innovative technologies and new business models can interact to create a coherent system that will accelerate the energy transition. Progress in these areas is a prerequisite for achieving climate neutrality, enhancing energy efficiency, and fostering sustainable development, thereby contributing to the creation of a resilient global economy capable of withstanding future challenges.

## 7. Future Actions and Recommendations

Future research and practical initiatives should focus on the integrated implementation of renewable energy sources, along with complementary technologies such as carbon capture and storage (CCS) and energy storage, to maximize decarbonization potential across sectors. It is recommended to develop a comprehensive framework that assesses not only the technical efficiency of these systems but also their long-term economic, environmental, and social impacts.

Furthermore, the development of innovative business models and business management practices should remain a priority. Actions should include energy-as-a-service solutions, expanding prosumer networks, supporting public–private partnerships, and

designing flexible financing mechanisms for green projects. These initiatives can accelerate technology implementation, reduce market entry barriers, and support the transformation of energy markets towards sustainable development.

Fostering knowledge exchange between academics, industry professionals, and policymakers is also essential. Collaborative platforms, international partnerships, and open data initiatives can facilitate the dissemination of best practices and innovative solutions, supporting a resilient global energy transition that can address future environmental, social, and economic challenges.

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