



Powering a Sustainable Future: Renewable Energy and Climate Action

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The urgent need to address climate change and ensure a sustainable future has placed renewable energy and climate action at the forefront of global environmental and economic policy. This abstract delves into the critical role of renewable energy sources in reducing greenhouse gas emissions and facilitating the transition to a low-carbon economy. It provides a comprehensive overview of current renewable technologies, including solar photovoltaics, wind turbines, hydroelectric systems, and geothermal plants, analysing their efficiency, scalability, and potential to meet increasing global energy demands. The abstract also explores the economic implications of renewable energy adoption, discussing job creation, energy security, and the long-term cost benefits of transitioning away from fossil fuels. Furthermore, it examines the crucial interplay between renewable energy deployment and climate action initiatives, including international agreements like the Paris Accord, national and regional policy frameworks, and grassroots movements driving public awareness and behavioural change. By highlighting successful case studies and innovative approaches from around the world, this work illustrates the tangible impacts of combining renewable energy integration with robust climate action. The abstract concludes by emphasizing the need for accelerated investment in renewable technologies, stronger policy support, and enhanced international cooperation to overcome remaining challenges and achieve a sustainable, climate-resilient future powered by clean energy sources.

Introduction

The world is increasingly interconnected, with energy demand surging daily across the globe, while the Earth's capacity remains finite. The demand for energy and associated services is essential to fulfill human social and economic development, as well as welfare and health needs. Energy services are critical for meeting basic human necessities such as healthcare, lighting, cooking, space heating, mobility, and communication, all of which drive generative processes. However, the energy sector faces two significant challenges on the path to sustainability: ensuring a secure energy supply and minimizing the sector's impact on climate change. Currently, 1.4 billion people worldwide lack access to electricity, with 85 percent of these individuals living in rural areas—a staggering statistic. Consequently, the number of rural populations relying on biomass for traditional energy purposes is expected to rise from 2.7 billion today to 2.8 billion by 2030 (Kaygusuz, 2012). Coal was first commercially mined in Richmond, Virginia, around 1750, and for a time, it surpassed biomass-based fuels (such as firewood and charcoal) as the preferred fuel for steam engines, owing to its superior energy capacity. Historically, coal was considered a relatively cleaner and more affordable fuel. However, the rapid population growth in recent decades, coupled with the dominance of fossil fuel-based power generation (including coal, oil, and gas), has led to a significant increase in energy demand and global concerns about the corresponding rise in carbon

dioxide (CO₂) emissions. Climate change has emerged as one of the most pressing challenges of the twenty-first century, but its severe impacts may still be mitigated if efforts are made to transform current energy systems. Renewable energy sources hold considerable potential to reduce greenhouse gas emissions from fossil fuel-based power generation and, consequently, to mitigate climate change (Edenhofer et al., 2011).

Sustainable development has become central to the national policies, strategies, and development plans of many countries. The United Nations General Assembly has proposed a comprehensive set of global Sustainable Development Goals (SDGs), comprising 17 goals and 169 targets, as outlined by the Open Working Group at the UN in New York. The SDGs place a greater emphasis on the scientific community's role than the Millennium Development Goals did. Addressing issues such as climate change, renewable energy, food security, health, and water provision requires coordinated global monitoring and modelling of numerous factors that are socially, economically, and environmentally interconnected. Research indicates that replacing fossil fuel-based energy sources with renewable ones—such as bioenergy, geothermal energy, wind, wave, and tidal energy—will gradually move the world closer to sustainability. Given the opportunities presented in recent decades to replace fossil fuel-derived materials with renewable energy sources, governments, intergovernmental organizations, stakeholders, and individuals worldwide are focused on establishing a sustainable future. The recent adoption of global SDGs, aimed at combating climate change and its effects, ensures a sustainable future for coming generations (Edenhofer et al., 2011).

Renewable energy sources and sustainability

Renewable energy sources, such as bioenergy, hydropower, geothermal energy, solar energy, wind energy, and ocean energy (including tidal and wave energy), are naturally replenishing and inexhaustible within the Earth's ecosystem. According to Tester et al. (2012), sustainable energy can be described as “a dynamic harmony between the equitable availability of energy-intensive goods and services to all people and the preservation of the earth for future generations.” The continuous reliance on fossil fuel-based energy sources—such as coal, oil, and gas—to meet the world's increasing energy demands and accommodate population growth has led to several significant challenges. These challenges include the depletion of fossil fuel reserves, the emission of greenhouse gases and other environmental pollutants, geopolitical and military tensions, and the volatility of fuel prices. These factors contribute to unsustainable conditions that could ultimately pose severe and potentially irreversible threats to human societies.

To address these escalating problems, the most viable and sustainable solution lies in the adoption and expansion of renewable energy sources. Unlike fossil fuels, renewable energy sources significantly reduce greenhouse gas emissions, making them a critical tool in mitigating climate change. Renewable energy is derived from ongoing natural processes in our environment, which means that, in principle, it should be sustainable over the long term. However, for renewable energy to truly be considered sustainable, it must be capable of providing an unlimited supply of environmentally friendly goods and services without compromising other critical aspects of the ecosystem or human well-being. For example, a sustainable biofuel must meet several criteria to be truly beneficial. It should not jeopardize food security by diverting essential agricultural resources away from food production, nor should it increase net CO₂ emissions over its lifecycle. Additionally, sustainable biofuel production should not threaten biodiversity or lead to the degradation of natural habitats. In essence, while renewable energy sources offer a pathway to a more sustainable future, their development and implementation must be carefully managed to ensure that they do not inadvertently create new environmental or social challenges. This holistic approach to

sustainability underscores the importance of balancing energy production with the preservation of natural resources and the well-being of future generations.

Renewable energy and climate change

The term "climate change" has become a focal point of global attention, driving both scientific inquiry and political debate. While the Earth's climate has always been in flux since its formation, the alarming issue today is the unprecedented rate at which these changes are occurring. This rapid shift poses a significant threat to the planet. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as alterations in the global atmosphere's composition, directly or indirectly caused by human activities, leading to variations in the natural climate patterns observed over comparable time periods. Renewable energy technologies are increasingly recognized as clean and sustainable sources of energy. Their optimal use not only reduces environmental impacts but also minimizes the generation of secondary waste, aligning with the economic and social needs of both the present and future. Unlike traditional fossil fuel-based energy sources, renewable technologies offer a crucial opportunity to mitigate greenhouse gas emissions, thereby playing a vital role in combating global warming. By replacing conventional energy sources with renewable ones, we can significantly reduce the environmental footprint of energy production and move toward a more sustainable future. This shift towards renewable energy is essential, as it provides a dual benefit: it helps to address the immediate concerns of global warming and environmental degradation while also ensuring long-term energy security. As the world grapples with the impacts of climate change, the adoption of renewable energy technologies presents a viable path forward, offering the potential to decouple economic growth from environmental harm. Through the widespread implementation of these technologies, we can work towards a more stable and resilient global climate, safeguarding the planet for future generations.

Renewable energy sources and technology

Renewable energy sources are those derived from the continuous, natural flows of energy present in our environment. These sources include geothermal energy, wind energy, ocean energy (such as wave and tidal energy), bioenergy, hydropower, and solar energy. Each of these sources taps into the Earth's natural processes to generate power, offering a sustainable alternative to fossil fuels.

a) Geothermal Energy: Geothermal energy is harnessed from the Earth's internal heat, which originates from the planet's structure and the physical processes occurring deep within it. This heat is extracted from geothermal reservoirs using wells and other technologies. There are two main types of geothermal reservoirs: hydrothermal reservoirs, which are naturally hot and permeable, and enhanced geothermal systems (EGS), which are sufficiently hot but require hydraulic stimulation to become productive. Once brought to the surface, geothermal fluids of varying temperatures can be used to generate electricity or for other applications requiring heat energy.

b) Wind Energy: Wind energy has rapidly become one of the leading renewable energy sources globally. Wind is ubiquitous, and in certain regions, it is particularly energy-dense. Wind energy captures the kinetic energy of moving air through large turbines, which convert this energy into electricity. These turbines can be located onshore (on land) or offshore (in sea or freshwater). Wind energy is particularly significant for mitigating climate change, as it provides a clean, renewable source of electricity that does not emit greenhouse gases.

c) Ocean Energy: Ocean energy is derived from the natural movements of ocean water, including surface waves, tides, currents, and thermal gradients. Surface waves are generated by the wind passing over the water's surface; the greater the wind speed, duration, and distance, the larger the waves and the more energy they contain. The ocean holds vast

amounts of energy, enough to meet global power demands many times over. Harnessing this energy can be done through various technologies that capture the power of waves, tides, and currents, as well as the thermal energy stored in ocean water.

d) Bioenergy: Bioenergy is produced from biological materials, making it a versatile and renewable energy source. It can be used for transportation (e.g., biodiesel), electricity generation, cooking, and heating. The sources of bioenergy are diverse and include forest by-products like wood residues, agricultural residues such as sugar cane waste, and animal husbandry residues like cow dung. One significant advantage of bioenergy is that it often utilizes by-products, residues, or waste from other processes, making it an efficient and sustainable energy source.

e) Hydropower: Hydropower is generated by harnessing the energy of moving water, typically from rivers or dams, as it flows from higher to lower elevations. This energy is primarily used to turn turbines and generate electricity. Hydropower is a crucial energy source, as it emits virtually no particulate pollution and can be rapidly scaled up. Additionally, hydropower reservoirs often serve multiple purposes, including flood and drought control, irrigation, drinking water supply, and navigation. However, the potential of hydropower could be influenced by climate change, with global alterations in existing hydropower systems estimated to be less than 0.1%, although further research is needed to refine these projections (Edenhofer et al., 2011).

f) Solar Energy: Solar energy is captured from sunlight using photovoltaic (PV) cells, which directly convert sunlight into electricity. Solar panels, composed of these PV cells, are commonly installed on rooftops, in solar farms, and even in portable devices. In addition to PV technology, solar thermal systems capture and utilize heat from the sun for water heating, space heating, and electricity generation through concentrated solar power (CSP) systems. Solar energy is one of the most abundant and widely accessible renewable energy sources, offering a clean and sustainable way to meet the growing global energy demand.

Renewable energy and sustainable development

Renewable energy has a direct relationship with sustainable development through its impact on human development and economic productivity. Renewable energy sources provide opportunities in energy security, social and economic development, energy access, climate change mitigation and reduction of environmental and health impacts (Asumadu-Sarkodie & Owusu, 2016). Renewable energy and sustainable development are inextricably linked concepts crucial for addressing global environmental challenges. Renewable energy sources, such as solar, wind, hydro, and geothermal power, offer clean alternatives to fossil fuels, reducing greenhouse gas emissions and mitigating climate change. These technologies align with the principles of sustainable development by meeting current energy needs without compromising future generations' ability to meet their own. Implementing renewable energy solutions supports economic growth, enhances energy security, and improves public health by reducing air pollution. As countries worldwide transition to renewable energy systems, they contribute to the United Nations Sustainable Development Goals, particularly those related to affordable and clean energy, climate action, and sustainable cities and communities. This shift towards renewables is essential for creating a more resilient, equitable, and environmentally conscious global society.



Figure 1: Opportunities of renewable energy sources

Challenges affecting renewable energy sources

The transition to a renewable energy-powered future faces several challenges:

1. Intermittency: Developing advanced energy storage systems and smart grids is crucial for managing the variable nature of some renewable sources.
2. Infrastructure: Upgrading and expanding transmission and distribution networks is necessary to accommodate decentralized renewable energy generation.
3. Economic Transitions: Ensuring a just transition for communities and workers dependent on fossil fuel industries is essential for widespread support of renewable energy adoption.
4. Technological Innovation: Continued research and development are needed to improve efficiency, reduce costs, and develop new renewable energy technologies.

Despite these challenges, the transition to renewable energy presents numerous opportunities:

1. Job Creation: The renewable energy sector has the potential to create millions of new jobs across various skill levels and regions.
2. Energy Security: Diversifying energy sources and reducing dependence on imported fossil fuels can enhance national and regional energy security.
3. Health Benefits: Reducing air pollution from fossil fuel combustion can lead to significant improvements in public health.
4. Economic Growth: Investments in renewable energy and related technologies can drive innovation and economic development.

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