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The Role of Renewable Energy in Achieving Carbon Neutrality

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Abstract

With the global population growth and economic development, the demand for energy continues to increase, and the utilization of traditional fossil energy is having a serious impact on the environment. Renewable energy sources such as solar and wind power, as a clean and environmentally friendly form of energy, have gradually become the focus of attention worldwide. Therefore, the use of renewable energy has become an important way to achieve carbon neutrality. This paper expounds the contribution of renewable energy utilization to achieving carbon neutrality from the aspects of reducing greenhouse gas emissions, safeguarding the security of ecological and environmental and promoting sustainable development.

Keywords: Renewable energy; carbon neutrality.

1. Introduction

Energy is the material foundation of human civilization and socio-economic development [1]. At the end of the 20th century, the United Nations Framework Convention on Climate Change was adopted due to the global deterioration of the climate system. This convention aims to reduce greenhouse gas emissions and address climate change through measures such as improving energy efficiency and developing renewable energy [2].

Renewable energy, also called clean energy, derived from natural sources or is automatically replenished/regenerated without human intervention. Generally speaking, the hydroelectric power, wind power, solar energy, biofuels, and geothermal energy are five main types of renewable energy (Figure. 1) [3]. It has been pointed out that promoting the development of these renewable energy should play a crucial role in achieving carbon neutrality and creating a more sustainable future for modern cities and society [4]. By 2022, 166 Parties to the Paris Agreement that submitted Nationally Determined Contributions referred to renewable energy, about 70% of the total included quantified renewable energy development goals [5].

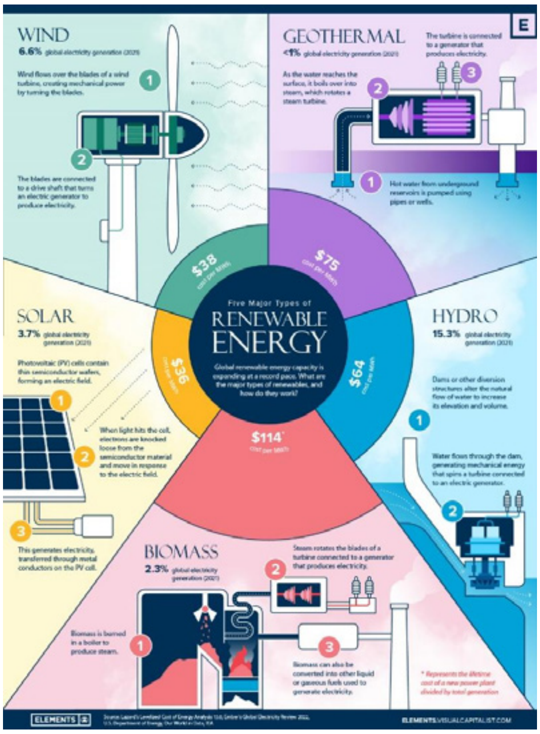

Figure 1. The percentage of the five types of renewable energy for global electricity generation and cost of energy per MWh.

2. Results

2.1. Reducing greenhouse gas emissions

The primary goal of renewable energy sources like hydro-power, wind, and solar energy is to generate electricity with minimal or no greenhouse gas emissions at all. This helps to combat climate change and air pollution and improve overall air quality. The European Union (EU) has always been a leader in the field of renewable energy, and the installed capacity of wind, solar, hydropower, and bioenergy has reached at about 240.6 GW, 194.5 GW, 255 GW, and 41.7 GW as of 2022, respectively [6]. Wind power is the largest renewable energy source in EU, accounting for 16.05% of the total electricity generation. European wind power is mainly which is mainly affected by the Arctic Ocean and the North Atlantic sea breezes, and is mainly distributed along the coast of Danish and around Greenland. The wind shows the characteristics of “big in winter and small in summer” affected by the seasons. Offshore wind power is mainly distributed in the North Sea, the Baltic Sea, the Norwegian Sea and the Barents Sea and other sea areas, but due to the high development cost, the installed capacity accounts for less than 10% of the total. In 2022, the top five countries of the EU-27 countries in cumulative wind power installed capacity are Germany, Spain, the United Kingdom (UK), France, and Sweden in descending order. Among them, Germany has the largest wind power market in Europe, accounting for one-third of the total power generation and installed capacity. The UK has the largest number of offshore winds turbines and has been expanding offshore wind projects in recent years [7]. The Large-scale utilization of renewable energy sources has made some progress in reducing greenhouse gas emissions in the EU. Alola et al. examined the impact of renewable energy and immigration on CO_2 emissions from the largest EU economies, France, Germany, and the UK, over the period 1990-2016. The results show that both the least squares correction and the dynamic ordinary least squares correction are consistent, i.e., renewable energy leads to a decrease in carbon emissions by 0.13% and 0.14%, which is significantly higher than the increase in carbon dioxide emissions caused by immigration (0.04% and 0.05%) [8].

2.2. Resilience to climate change

As climate change poses challenges like global warming and extreme weather events, renewable energy can provide a more resilient energy infrastructure and is less susceptible to disruptions caused by these events. As mentioned above, the impact of renewable energy on climate change is mainly reflected in the reduction of greenhouse gas emissions. Compared with traditional fossil energy sources, renewable energy produces almost no greenhouse gases in the production process, so it can significantly reduce carbon emissions. Several scientific and technical methods are often used to quantify their carbon emission reductions and environmental impacts [9]. 1) Life Cycle Analysis (LCA): Assess the carbon emissions of renewable energy sources throughout its life cycle, including production, operation, and end-of-life. 2) Carbon Footprint Analysis (CFP): the impact of human activities on the environment is measured by using CO_2equivalent (CO_2eq) to represent the total greenhouse gas emissions from human production and consumption activities. 3) Data model analysis: Simulate the impact of renewable energy on climate change in different scenarios through data modeling. 4) Remote sensing technology: With the advantages of objectivity, continuity, stability, large-scale and repeated observation, it has become an indispensable technical means for monitoring the global carbon inventory and an internationally recognized method for global carbon verification.

Definitely, these methods are not used alone in practical research. Arvesen and Hertwich [10] reviewed the life cycle and carbon footprint studies on wind power generation, estimating 19 (±13) grams of CO_2 emissions per kWh, which has low carbon emissions compared to fossil energy sources. However, which link in the life cycle of wind power brings the most carbon emissions have not been finally determined, after all, the calculation method and assessment objectives are not completely consistent. Sherwani et al. [11] summarized all previous PV full life cycle studies and found that the carbon footprints of three types of solar PV systems, amorphous, monocrystalline and polycrystalline silicon, ranged from 15.6-50 g, 44-280 g, and 9.4 -104 grams per kilowatt hour (gCO_2e/kWh). Additionally, some scholars have complemented remote sensing data from three satellites to investigate a single source of methane emissions as one of the world's largest methane hotspots, located on the west coast of Turkmenistan. It was found that there are 29 different active emission sources with emission rates greater than 1800 kg/h during the period from 2017 to 2020. All sources were associated with oilfields that are mainly used to produce crude oil, of which 24 are inactive natural gas flares. At the regional level, the number of methane plume detected in 2020 increased significantly compared with previous years [12].

2.3. Environmental preservation

Unlike fossil fuel extraction and combustion, the renewable energy production has a much lower impact on the on the environment. It reduces habitat destruction, water pollution, and land degradation.

Rahman et al. [13] reviewed the influences of each renewable energy on all the environmental. Although major renewable energy sources produce less greenhouse gas emissions than non-renewable energy sources, they still have some impact on the environment during the installation, maintenance, and dismantling stages (Table 1). Hydroelectric power plants, for example, which require large tracts of land, not only lead to drying up of downstream rivers, causing drought, soil erosion and even soil degradation, but also contribute to eutrophication and an increase in suspended sediments, altering lagoons and deltas, triggering floods, and altering water temperatures and oxygen levels. Compared with other renewable energy sources, hydroelectric power plants have the greatest impact and damage to the environment and ecosystems. On the other hand, Solar photovoltaic and centralized solar power generation will produce ozone depletion, and dust, heavy metals and other harmful substances will be produced during the production and disposal of solar panels. Even wind turbines and biomass power plants, which have negligible impacts on the environment, have some disadvantages, such as affecting agricultural land, causing noise, and visual impact on wildlife.

Table 1: Impacts of different renewable energy sources on various types of environment[14].

	Environmental impact	Solar	Solar thermal	Wind	Biomass	Geothermal	Hydropower
Air	Greenhouse gas emis sion	Moderate	Moderate	Negligible	Negligible	Moderate	High
	Ozone layer depletion	Moderate	Negligible	Negligible	Negligible	Negligible	Negligible
	Air pollution	Moderate	Negligible	Negligible	Negligible	Moderate	Negligible
	Air toxification	Moderate	Moderate	Negligible	Moderate	Moderate	Negligible
	Change in air temperature	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Change in air precipitation	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
Water	Water pollution	Moderate	Moderate	Moderate	Negligible	Moderate	Moderate
	Water toxification	Negligible	Negligible	Moderate	Negligible	Moderate	High
	The mating process of fish	Negligible	Negligible	Moderate	Negligible	Negligible	Moderate
	Fish migration	Negligible	Negligible	Moderate	Negligible	Negligible	Moderate
	Change in water temperature	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Impact of water flow	Negligible	Negligible	Negligible	Negligible	Negligible	High
	Change in water salinity	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Effect on suspended sediments	Negligible	Negligible	Negligible	Negligible	Negligible	High
	Eutrophication	Moderate	Negligible	Negligible	Negligible	Negligible	High
	Affecting aquatic habitat	Negligible	Negligible	Moderate	Negligible	Negligible	Moderate
	Fish decline	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Flooding	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Dried up rivers	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Water oxygen level	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Affecting deltas and lagoons	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Fisheries influences	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Coastline defense	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

Soil	Land requirement	Moderate	Moderate	Moderate	High	High	High
	Soil pollution/ disturbance	Moderate	Negligible	Moderate	Negligible	Negligible	Negligible
	Soil toxification	Moderate	Negligible	Moderate	Negligible	Negligible	Negligible
	Desiccated soil	Moderate	Negligible	Moderate	Negligible	Negligible	High
	Soil erosion	Negligible	Negligible	Moderate	Negligible	Negligible	High
	Affecting irrigation	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Mangrove forests	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate
	Affects soil efficacy	Moderate	Moderate	Moderate	Negligible	Negligible	Negligible
	Deforestation	Moderate	Negligible	Moderate	Negligible	Negligible	Negligible
	Effect on vegetation	Moderate	Moderate	Moderate	Negligible	Negligible	High
	Seismic activity	Negligible	Negligible	Negligible	Negligible	Negligible	High
	Relocation of wild animals	Moderate	Negligible	Negligible	Negligible	Negligible	Negligible
	Affecting terrestrial habitat	Moderate	Moderate	Negligible	Negligible	Negligible	Negligible
Human	Human health	Moderate	Negligible	Moderate	Negligible	Moderate	Moderate
	Disturbance to humans	Negligible	Moderate	Moderate	Moderate	High	High
	Relocation of native residents	Moderate	Negligible	Moderate	Negligible	High	High
	Visual disturbance	Negligible	Moderate	Moderate	Negligible	Negligible	Negligible
	Unpleasant smell	Negligible	Negligible	Negligible	High	Moderate	Moderate
	Natural esthetic affected	Negligible	Negligible	Moderate	Negligible	Negligible	Negligible
	Tourism potential affected	Negligible	Negligible	Moderate	Negligible	Negligible	Negligible
	Archeological places affected	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate

Miscellaneous impacts	Availability based on time	Moderate	Moderate	Moderate	Beneficial	Beneficial	Beneficial
	Availability based on area	Beneficial	Moderate	Moderate	Moderate	High	High
	Power reduction after installation	Beneficial	Beneficial	Moderate	Negligible	Beneficial	Beneficial
	Dependency on non-renewable energy	Moderate	Moderate	Moderate	Moderate	High	High
	Battery dependency	Moderate	Negligible	Negligible	Negligible	Negligible	Negligible
	Installation noise	Moderate	Moderate	Moderate	Moderate	High	High
	Operation noise	Beneficial	Moderate	Moderate	High	High	High
	Recycling complexity	Negligible	Beneficial	Negligible	Negligible	High	High
	Chance of accident	Moderate	Moderate	Moderate	Negligible	Negligible	Negligible
	Water for cooling	Moderate	Moderate	Negligible	Negligible	Negligible	Negligible
	Susceptible to storms	High	High	Moderate	Negligible	Negligible	Negligible
	Communication of species affected	Negligible	Negligible	Moderate	Negligible	Negligible	Negligible
	Predator inefficacy	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Collision or entanglement	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Miscellaneous impacts	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Impingement	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Biodiversity	Negligible	Negligible	Moderate	Negligible	Negligible	Negligible

2.4. Sustainable development

Renewable energy supports sustainable urban development by providing a clean energy source that doesn't deplete finite fossil fuel reserves. It also reduces the environmental impact associated with energy production and consumption. European countries have adopted a series of policies and practices in the field of energy geography and renewable energy development. Some countries have set renewable energy targets and provided fiscal and tax incentives to encourage investment and innovation.

Denmark is one of the first countries in the world to make large-scale investment in renewable energy and one of the world's leading wind power generation countries, which generate more electricity than natural gas and coal [15]. With its abundant wind energy resources, Denmark has established advanced wind power technologies and facilities to achieve a high proportion of renewable energy consumption through policy support and technological innovation. Denmark has also made important breakthroughs in cross-border energy trade and power grid interconnection through international cooperation and energy alliances to strengthen its capacity for sustainable development [16]. Besides, the municipality of Frederikshavn in northern Denmark has developed a variety of renewable energy sources, including offshore wind, waste and low-temperature geothermal energy, and designed energy systems accordingly. Østergaard and Lund [17] surveyed low-temperature geothermal renewable energy heating system in the area to assess the potential for 100% renewable energy city. The results showed that the integration of geothermal energy using absorption heat pumps could meet the needs of urban sustainable energy system.

Germany is the largest energy consumer in Europe, and the total energy consumption reaching 286 million tons of oil equivalent in 2021 [18]. In order to achieve its carbon neutrality goal, Germany has developed an energy transition strategy that relies on 100% renewable energy supplies by 2050. In 2021, renewable energy in Germany accounted for about 41% of electricity consumption. Therefore, Hansen et al. conducted a study to simulate the one-year operation of all energy sectors in Germany using the EnergyPlan model (hourly resolution) to develop a viable strategy for the transition towards 100% renewable energy. The study found that in order to maintain the sustainable resource potential of renewable electricity and biomass, energy saving is very important. Especially in the heating sector, the great potential for energy conservation is feasible, while the industrial and power sectors may achieve more energy conservation [19]. And Pata et al. [20] assessed the impact of renewables on the load capacity factor (LCF) in terms of intensity and share for Germany between 1970 and 2018 using autoregressive distributed lag modeling. In this study, the load capacity factor (LCF) represents how renewable energy intensity and renewable energy share improve environmental sustainability, while the impact of the Kyoto Protocol is used as a pseudo-variable. The results show that a 1% increase in the share of renewable energy intensity in the total energy mix and a 0.48% increase in LCF does not have a statistically significant effect. In contrast, a 1% increase in human capital increases LCF by 3.49%. Based on this study, it is recommended that the German government should consider human capital development and increasing the share of renewable energy as policy instruments development goals to achieve sustainable development.

2.5. Conclusion

Renewable energy plays an important role in global greenhouse gas emission reduction and sustainable development. Representative countries on all continents, including Europe, Asia and the Americas, made some achievements in renewable energy development and carbon neutralization. However, it should be noted that there are differences in renewable energy development, greenhouse gas emission reduction path, technical method evaluation and so on in different countries and regions. On the one hand, there is a need to strengthen international cooperation and exchanges, and on the other hand, there is a need to develop more efficient and environmentally friendly renewable energy technologies to jointly promote the in-depth development of renewable energy and carbon neutralization.

3. Discussion

3.1. The transition to renewable energy is becoming a consensus and pursuit direction in the international community

The signing of the Paris Agreement promotes the transformation of green and sustainable growth in all directions, reverses the growth pattern of the past few decades due to heavy reliance on petrochemical products, avoids continuing to pose a threat to natural ecosystems, and encourages global investment to further tilt towards renewable energy and other fields [21]. Major countries around the world are implementing new energy development strategies one after another.

3.2. Future development trends of renewable energy

Throughout history, the United Kingdom has created an empire that never sets on the sun through the transformation of coal energy, while the United States has upgraded to a superpower based on fossil fuels. Today, we have entered the early stage of a new round of energy technology transformation. Countries should change their thinking, plan ahead, take necessary measures, and seize the opportunity of energy transformation [22].

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