Current Status and Prospects of New Energy Power Generation Technologies from the Perspective of Economic and Environmental Benefits

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Abstract. Driven by the global energy structure transformation and the “Dual Carbon” goals, new energy power generation technologies have become a core method to address the depletion of traditional fossil energy and alleviate environmental pollution. Researchers have found that new energy power generation, with its advantages of cleanness, low carbon and dispersed distribution, is gradually becoming a key element in constructing a new energy system. However, it still faces challenges such as unbalanced regional development and insufficient supporting energy storage facilities. This paper sorts out the current development status and core characteristics of mainstream new energy power generation technologies and discusses them from both economic and environmental perspectives. It analyzes the reasons why new energy power generation technologies can cut down power generation costs, evaluates and forecasts their economic performance, and expounds on their carbon emission reduction benefits and ecological impacts. This research holds significant theoretical value and practical relevance for optimizing the energy structure, promoting sustainable development, and providing decision-making references for the green transformation of the energy sector.

Keywords: New Energy Power Generation Technologies, Economic Benefits, Environmental Benefits, Dual Carbon Goals, Energy Structure Transformation

1. Introduction

Driven by the global energy structure transformation and the “Dual Carbon” goals, new energy power generation technologies have become a core method to address the depletion of traditional fossil energy and alleviate environmental pollution. Since the Industrial Revolution, the excessive exploitation and use of fossil energy such as coal and oil across the world, it has not only intensified the contradiction of energy supply and demand, but also led to a keep rising of greenhouse gas emissions and frequent extreme weather events. Thus, energy security and ecological security have become common challenges for all countries. Nowadays, many countries are increasing their investment in technology and the intensity of industrial layout, push for the continuous decline of new energy power generation costs and improve efficiency. The proportion of new energy power generation in global energy consumption is growing rapidly, becoming the key support for building a new power system and realizing the green and low carbon transformation of energy structure. It also plays an important and irreplaceable role in ensuring the global energy supply is sustainable and alleviating climate change.

Regarding existing research, scholars at home and abroad have deeply studied in new energy power generation technologies, the economic and environmental benefits of new energy power generation also have gained more and more attention. Photovoltaic power generation has been commercialized on a large scale, with continuous breakthroughs in high efficiency battery technologies. The application of intelligent, digital technologies and new materials in wind power generation has improved the stability of grid connection. Ocean energy power generation is now in demonstration and verification phase, and there are still many challenges to its commercialization due to the impact of marine environment.

This paper sorts out the basic situation of mainstream new energy power generation technologies such as solar, wind and ocean power generation, and analyzes the development status, application, advantages and disadvantages as well as development prospects of various technologies. In addition, it summarizes the current situation and prospects of new energy power generation technologies from the economic and environmental perspectives.

2. Classification and Characteristics of New Energy Power Generation Technologies

New energy power generation technologies are a collection of technical approaches that turn unconventional fossil energy sources, such as solar energy, wind energy, biomass energy, geothermal energy, and ocean energy, as well as hydrogen energy, into electrical power. They differ from traditional thermal power and hydropower, have the features of cleanness, low carbon renewability, and are core supporting technologies for energy transition. The main objective is to replace traditional fossil energy power generation and build a clean, low-carbon, safe and high-efficiency energy system.

2.1. Solar Power Generation Technology

Solar power generation technology is a clean and renewable energy technology which turn solar energy into electrical energy. It mainly relies on the photovoltaic effect or concentrated solar power to achieve energy conversion. With its core merits of cleanness and pollution-free, inexhaustible resources, wide distribution, solar power generation technology become one of the key directions of energy transition and is a crucial support of realizing the goals of carbon peaking and carbon neutrality. Solar power generation technology can be divided into photovoltaic power generation and concentrated solar power.

As shown in Figure 1, the core principle of photovoltaic power generation is the semiconductor photoelectric effect, which directly converts light energy into electrical energy. When sunlight shines on the battery surface, semiconductor materials absorb photon energy and excite electrons in the valence band to the conduction band, forming electron-hole pairs. Under the action of the built-in electric field in the P-N junction, electrons are pushed to the N-type silicon while holes move to the P-type silicon, leading to charge accumulation on the two sides of the battery. When using a wire to link the top and bottom electrodes of the battery, the accumulated electrons flow from N-type silicon to P-type silicon through an external circuit, forming a continuous electric current to supply power for the load.

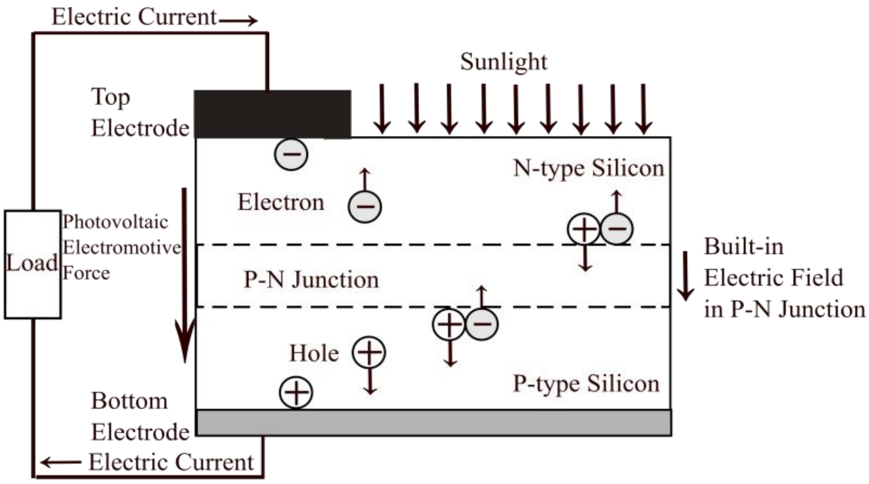

Figure 1. Photovoltaic Power Generation Schematic Diagram.

During photovoltaic power generation, there are no pollutants or greenhouse gases produced. It is clean and environmentally friendly and has low operation and maintenance cost. Solar energy is abundant and widely distributed, especially suitable for remote areas or places without grid coverage.

For example, the “photovoltaic+agriculture” development model in Dayao County, which adopts “forestry-photovoltaic complementarity”, “medicine-photovoltaic complementarity” and “agriculture-photovoltaic complementarity”, has led to the energy and agricultural benefits of the same areas increasing in a coordinated way [1]. However, photovoltaic power generation is greatly affected by sunlight and weather, leading to intermittent and fluctuating power output. To address these challenges, relevant researchers have proposed the honey badger algorithm. By combining the intelligent optimization algorithm with deep learning, this approach eases the volatility and randomness of power generation and improves its predictability [2].

Concentrated solar power (CSP) converts solar energy into thermal energy, then transforms thermal energy into mechanical energy through a traditional thermodynamic cycle, last drives generators to produce electrical energy. CSP has a built-in heat storage system, which can realize stably power supply for 24 hours, and it has strong power generation stability and excellent peak shaving capability. However, it has strict requirements for light intensity and the site flatness, suitable for desert areas with abundant sunlight. According to the data from the National Energy Administration of China, the total installed capacity of CSP in China is expected to reach about 15 million kilowatts by 2030, and the levelized cost of electricity will be basically the same as that of coal-fired power generation [3].

2.2. Wind Power Generation Technology

Wind power generation technology is a kind of renewable energy technology that captures wind energy and converts it into electrical energy. At present, it is one of the most mature and widely used clean energy sources around the world. Its advantages include cleanness and low carbon, flexible installation, and low operation costs. However, power generation is affected by wind speed; thus, it is intermittent and variable, its site selection is restricted, and it also has certain ecological impacts.

It is divided into onshore wind power and offshore wind power by deployment scenarios, and into horizontal-axis wind turbines and vertical-axis wind turbines by turbine structures. As shown in Table 1, onshore wind power features mature technology, convenient operation and maintenance, and low initial and operational costs. However, wind speed is unstable due to terrain effects, it occupies land resources, and its development may be subject to certain restrictions. For example, the development of onshore wind farms in Poland is mainly restricted by its natural landscapes [4]. Offshore wind power has high and stable wind speed with fewer restrictions, but it involves complex technology and high operation and maintenance costs, and relies on professional equipment.

Table 1. Comparison Between Onshore and Offshore Wind Power.

Comparison Items	Onshore Wind Power	Offshore Wind Power
Resource Endowment	Affected by terrain and vegetation, the wind speed is low and unstable	The sea surface is open, so the wind speed is high and stable
Cost Structure	Initial and operation costs are low	Initial and operation costs are high.
Technical Difficulty	Mature technology and short construction period	The technology is complex and restricted by sea conditions
Operation and Maintenance Mode	Easy to operate and maintain, and workable all year round	Relies on professional equipment and is restricted by wind and waves
Environmental Impact	Take up land and conflict with agricultural and ecological protection	No land occupation,but it may affect the marine ecology
Application Scenarios	Decentralized inland areas, low wind speed zones, the "wind power + agriculture" model	Coastal high-load areas, large-scale bases, deep and far-sea development

Table 2. Comparison of Horizontal-axis and Vertical-axis Wind Turbines.

Comparison Items	Horizontal-axis Wind Turbines	Vertical-axis Wind Turbines
Technical Maturity	The technical system is complete, and large-megawatt development technology is mature	The technical system is not yet complete, and large-megawatt technology needs breakthroughs
Wind Energy Utilization Efficiency	Excellent aerodynamic design, high wind energy capture and utilization efficiency	Limited aerodynamic performance, overall wind energy utilization efficiency is relatively low
Wind Direction Adaptability	Depends on wind direction and requires a yaw system to adjust orientation	No wind direction limitation, no yaw mechanism needed
Site Adaptability	High requirements for site space, weak adaptability to complex terrain	Compact structure, suitable for complex terrain and low wind speed areas
Operating Characteristics	Excellent grid-connected operation stability and good vibration and noise control performance	More prominent vibration and noise, weak grid-connected stability
Application Scenarios	Onshore centralized wind farms, large-scale offshore wind farms	Decentralized, near-ground urban, small-power off-grid wind power

The differences between horizontal-axis wind turbines and vertical-axis wind turbines are shown in Table 2. Horizontal-axis wind turbines have mature technology and high wind energy utilization efficiency, which makes them suitable for large-megawatt and large-scale development, is the mainstream type of wind turbines. Vertical-axis wind turbines are not restricted by wind direction and have strong terrain adaptability, are suitable for decentralized development. They can be used for small-power off-grid wind power systems in residential areas, communication base stations, offshore oilfields and other places [5]. However, their wind energy utilization efficiency is low and the technical system is not yet complete.

2.3. Marine Energy Power Generation Technology

Marine energy power generation is a way to generate electricity by transforming the energy contained in the ocean, such as tidal energy, wave energy, ocean current energy and salinity gradient energy into electric power with corresponding technical equipment. It has the advantages of large reserves, cleanness and stable power generation for some types, and can drive the development of industries related to the marine economy. However, there are some shortcomings, including immature technologies, high costs and unproven ecological impacts. Marine energy power generation can be divided into tidal energy power, wave energy power, tidal current energy power generation and other types.

Tidal energy power generation is a technology that generates electricity by harnessing the potential energy from the tidal range formed by the rise and fall of seawater. It is divided into tidal barrage and tidal lagoon types, featuring the most mature technology and the highest level of commercialization. Its site selection depends on bays or estuaries with large tidal ranges. Researchers have proposed a tidal power generation system integrated with pumped storage. This design not only enhances the stability of grid connection and increases power generation, but also improves the economy of operations by reducing the cost of tidal barrage [6].

Wave energy generation is a marine renewable energy technology that captures the kinetic and potential energy of ocean waves and turns it into electrical energy. It has high energy density and good predictability. Due to the limitations of the harsh marine environment, it is necessary for equipment to have high wave resistance, corrosion resistance and fatigue resistance. The application of various advanced control technologies has greatly improved energy capture efficiency and reduced power generation costs [7].

Tidal current power generation is a technology that converts marine tidal current energy into electrical energy. Through devices like underwater turbines, it directly uses the flow of seawater to strike the turbine blades and make them rotate, then drives a generator to produce electricity. It has high energy density, and its ebb and flow cycles and flow speed can be forecasted. It is environmentally friendly, requires no dam building, and has little impact on marine ecology. Turbine power generation is a relatively traditional type, while other types, such as underwater kites, are also under active exploration [8].

3. The Economy of New Energy Power Generation Technology

3.1. Cost Comparison with Traditional Power Generation Technologies

Fuel costs account for a large proportion of traditional thermal power generation. To meet environmental protection requirements, thermal power enterprises have to install desulfurization, denitration and dust removal equipment. They also need to pay for environmental operation and maintenance as well as pollution discharge fees, which further increase the costs. The price of coal fluctuates frequently due to factors such as the international energy market, mining costs, and transportation logistics. This directly leads to the thermal power generation costs fluctuating sharply and poor stability of long-term profits.

Renewable energy power generation relies on natural resources like solar energy and wind energy, and it does not incur the high costs of fossil energy exploitation, nor is it restricted by geographical regions or resource reserves. The continuous advancement of renewable energy power generation technologies has driven down the power generation costs. For example, the application of intelligent and digital technologies in wind power generation has cut down maintenance costs and ensured economic benefits [9]. The introduction of government policies has reduced the initial investment pressure of renewable energy projects through subsidies, tax reductions, and other measures. For example, to further promote the construction of solar photovoltaic systems, Ghana has adopted relevant policies to reduce the initial investment costs for small and medium-sized enterprises [10].

3.2. Evaluation and Prediction

For the economic analysis of renewable energy power generation, the net present value(NPV) method, calculated as the total present value of future returns from renewable energy minus the total capital investment in renewable energy projects, can reflect the actual economic value of an investment project. The Levelized Cost of Energy (LOCE) method is also applied to calculate the LCOE value, which is used to compare the economic efficiency of different power generation technologies [11].

With the iterative upgrade of new energy power generation technologies, equipment costs will be further reduced, power generation efficiency and stability will also improve, thus boosting the economic benefits of projects from operation and output perspectives. For example, the photovoltaic tracking system based on bionic neural adaptive deep reinforcement learning [12] has shown the potential of improving photovoltaic efficiency and power generation stability. In the future, with the optimization of the algorithm and the reduction of hardware cost, this kind of technology may be applied on a large scale, and increase its economic value.

The power generation mode of new energy power generation features distribution and on-site power supply, which enables electricity to be consumed directly on the user side. This will reduce the reliance on power transmission through the main grid, thus avoiding large-scale investment in expanding the main grid and cutting down the costs of building high-voltage lines and supporting substations. At the same time, it can optimize the regional power supply and demand structure, lower the peak-valley load difference and overload risks of the distribution grid, and reduce the capital investment in the upgrading and renovation of the distribution grid.

4. Environmental Benefits of New Energy Power Generation Technologies

4.1. Carbon Emission Reduction Benefits

The carbon emissions of new energy power generation over its whole life cycle are much lower than those of fossil energy power generation. Its carbon footprint mainly falls in equipment manufacturing, transportation and installation, and there is almost no carbon dioxide emission during the power generation and operation stage. This can effectively cut carbon emissions in the energy sector and help achieve the “double carbon” goals. Relevant practices show that after some buildings use photovoltaic power generation technology, their annual carbon emissions have dropped by more than 30% [13].

4.2. Pollution Emission

New energy power generation produces no air pollutants such as sulfur dioxide, nitrogen oxides and smoke dust, also no discharge of wastewater or waste residue. In contrast, coal-fired power generation releases large number of acidic gases and particulates, which are major causes of environmental problems like acid rain and smog. New energy power generation can reduce such pollutants from the source and improve regional air quality significantly.

4.3. Ecological Impacts

The impact of new energy power generation technologies on the ecological environment is multi-dimensional, which can be mainly divided into positive effects and potential challenges.

Positive impacts include reducing ecological damage from the source, protecting biodiversity, and restoring some degraded land. New energy power generation does not require the exploitation of fossil energy, and no pollutants are produced during power generation, do not cause environmental pollution or damage. The reduced carbon emissions slow down global warming and the loss of animal habitats caused by the greenhouse effect. The innovative model of “photovoltaic+ecological restoration” has improved ecological management in arid areas [14].

Potential challenges include the conflict between land resource occupation and ecological protection, local impacts on aquatic ecosystems, and ecological pressure during the whole life cycle of the equipment. For example, onshore wind farms may bring negative effects to vegetation, soil and insects [15], it also pose certain challenges to the survival and safety of birds. The construction of hydropower stations changes the natural runoff of rivers and affects fish migration. If wind turbine blades and photovoltaic modules are not regularly inspected and maintained, they may lead to them age and fall off. If the recycling is not complete, the remaining composite materials of the equipment will cause certain environmental pollution.

5. Conclusion

In the face of fossil energy depletion and worsening ecological crises, new energy power generation technologies rely on economic and environmental benefits and have become the core of the energy revolution. Major types include solar power generation, wind power generation, and marine energy power generation, with core features such as cleanness and low carbon, decentralized distribution, rapid technological iteration, certain economic efficiency, and environmental friendliness. By comparing costs with traditional power generation technologies, analysis shows that the main reasons for the power generation costs include choosing low-priced raw materials, relevant technologies making progress and the government introducing policies to support them. Evaluate their economic efficiency and provide a reference for project investment. In terms of the environmental benefits of new energy power technologies, compared to wind, photovoltaic, and hydropower power generation and other new energy power generation technologies with traditional fossil energy power generation, found that new energy power generation technologies greatly reduced carbon emission and pollutant emission, protecting the ecological environment. However, there are still some inadequacies. At present, new energy power generation is facing challenges, including unbalanced regional development and inadequate supporting energy storage technologies, which restrict its further development. In the future, new energy power generation technologies should take technological innovation as the core driving force, break through the bottlenecks of supporting technologies such as energy storage and smart grids. With the guarantees of policy guidance and market mechanisms, improve the construction of mechanisms such as green electricity trading and cross-regional power transmission.

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