The Impacts of Different Power Plants on Climate: Evidence from Fossil-fuel, Hydroelectric & Wind Power

Ruilin Xie[1,*]

[1]Wuhan Foreign Language School, 430022 Wuhan, China

Abstract. Contemporarily, global anthropogenic climate anomalies are severe and tend to continue to increase. The large number of power plants built around the world is to blame for this. The largest and most used power generation technologies in the world today are thermal, hydroelectric and wind power. The physical principles and climate impact factors of these three power plants are reviewed and compared, and their respective characteristics and limitations are analysed from a climate perspective. The conclusion is that thermal power plants have the greatest negative impact on the climate and wind power plants are the cleanest and most environmentally friendly. Overall, the current forms of power generation are still very limited and need to be further developed, and more research is needed in the field of power generation technology to protect the earth's natural resources and climate. This paper introduces the climate impacts of each of the three major power plants, provides an overview of current human power generation technologies, and provides an outlook for future developments.

1 Introduction

According to the 2022 Global Climate Report released by China Meteorological News, in terms of temperature, most global land temperatures will be near to above normal in 2022. The global average annual land temperature in 2022 is 1.67°C above the 1850-1900 average, and the global average monthly temperature range in 2022 is higher than normal, except for December, which is 0.24°C lower than normal. For precipitation, the 2022 global average rainfall is higher than normal [1].

According to studies from NASA's Goddard Institute for Space Studies (GISS), the Earth's average global temperature has increased since 1880 by at least 1.1°C (1.9°F). About 0.15 to 0.20 degrees Celsius every decade since 1975, the majority of the warming has taken place [2]. Overall, the climate is in an anomalous state today and this change continues to occur. Such changes are related to natural evolutionary processes, but the impact of human activities on climate is the main cause. The industrialization of human society is undoubtedly a key turning point in the impact of humans on the natural climate. Against the backdrop of global warming, extreme shortage of non-renewable energy sources, and increasing environmental pollution, there is an urgent need to develop a low-carbon economy with low energy consumption and emissions as its prerequisite and hallmark [3].

At present, the world's main power generation methods are thermal power, hydroelectric power and wind power. Among them, thermal power generation is the most traditional and classic way to generate electricity, hydroelectric power generation is renewable energy generation, and wind power generation belongs to new energy generation, similar to solar power and ocean power generation. Each of these three types of power generation has different impacts on the climate in different ways and to different degrees.

This paper aims to summarize and compare the emissions of thermal, hydro, and wind power plants and their impact on the climate, and to provide a summary of the current power generation technologies in terms of environmental protection. In this paper, the author will discuss the working principles and emission levels of thermal, hydro, and nuclear power plants based on the available literature, compare them generally, and discuss the limitations and future outlooks of different power plants.

2 Basic descriptions of the impacts of power plants on climate change

By 2019, the global electricity generation will amount to 27,005 TW · h, of which 72.7% will be generated by non-renewable energy sources, while only 27.3% will be generated by renewable energy sources. Among the

* Corresponding author: wangzhoufu@wust.edu.cn

renewable energy generation, hydroelectric power generation is 4,294 TW · h, accounting for 15.9% of the total generation and 58. 2% of the renewable energy generation; wind power generation is 1,593 TW · h, accounting for 5. 9% of the total generation and 21. 6% of the renewable energy generation; photovoltaic power generation is 756 TW · h, accounting for 2. 8% of the total generation. Photovoltaic power generation is 756 TW · h, accounting for 2.8% of total power generation and 10.3% of renewable energy generation [4]. At present, it is an important development trend in the world to control the damage of power generation technology to the environment and ensure energy security.

As their name suggests, thermal power plants rely on the thermal energy generated by the burning of coal, oil, and wood to supply electricity. Hydroelectric power plants convert the mechanical energy generated by the movement of water into electrical energy and are renewable energy generation. Wind power is a new energy generation, where wind turbines rotate under the action of the wind, driving generators to rotate and generate electricity. All power generation methods have their advantages and disadvantages. Thermal power generation consumes large amounts of fossil fuels and causes environmental pollution; hydroelectric power generation is highly efficient, but the construction period is long and it is easy to cause damage to local ecology; wind power has a short infrastructure cycle and flexible installed size, but has a large footprint and as yet uncontrollable [4].

3 Detailed overview of three different power plants

3.1 Fossil fuel power station

Fossil fuel power station, in other words, thermal power station, is the most numerous and widely used power plant in the world. According to China's National Bureau of Statistics, by the end of 2021, China had 237,692,000 kilowatts of installed power generation capacity, with 129,687,000 kilowatts of installed thermal power capacity, accounting for 54.56% of thermal power. Thermal power generation occupies a major position in power production and plays an irreplaceable role in securing China's and the world's power supply [5]. However, at the same time, this type of power generation is also facing great environmental pressure.

There are three forms of energy conversion processes in thermal power generation: chemical fuel energy to steam heat, mechanical energy, and then to electrical energy. The thermal energy produced by burning fuels like oil, coal, and natural gas is typically used to heat water, converting it to high-temperature, high-pressure water vapor that subsequently powers a generator to produce electricity [6]. The main equipment systems include a fuel supply system, water feed system, steam system, cooling system, electrical system, and some other auxiliary equipment. This is a technology that relies heavily on non-renewable energy sources for power generation and has a low energy efficiency due to construction costs.

In general, thermal power generation technology faces two problems in terms of environmental climate: firstly, serious coal consumption and secondly, low energy conversion level [3]. Both problems are finally directed to the same root: coal consumption. Coal plays a major role in the power generation industry worldwide. In China, for example, thermal power plants can consume more than 60% of the total coal circulating in the country each year. The amount of coal consumed directly affects the amount of carbon dioxide emissions. In fact, over the past decade, coal demand has grown rapidly, outpacing the growth in demand for oil, nuclear and renewable energy. The foreseeable growth in energy demand will further increase the demand for coal. This is a huge hazard for a low-carbon future and will lead directly to a massive greenhouse effect [6].

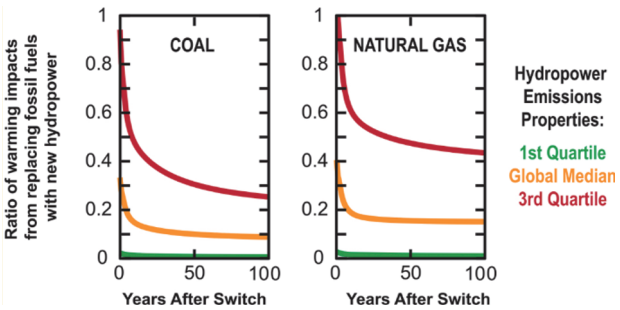
Pollutants from thermal power plants are generally classified as solids, gases, liquids, and noise. Solid pollutants from thermal power plants are generally caused by the coal combustion process, which releases large amounts of heat energy during the combustion reaction of coal but causes large amounts of solid pollution after combustion, such as coal ash, slag, and lighter-density fly ash. Fly ash, which is lighter in mass, is carried around the world by the monsoon winds and can be very harmful to humans and plants. The liquid pollution of thermal power plants is composed of ash flushing water, dust removal water, acid and alkali waste liquid, thermal drainage water, etc. This wastewater volume is large, has complex content, and has a wide range of pollutants. If not treated random discharge will cause serious damage to groundwater resources. Gaseous pollutants are gases such as carbon dioxide, sulfur dioxide and nitrogen oxides that are produced in large quantities during the operation of thermal power plants [7]. These gases contribute to the greenhouse effect and acid rain, which increases global temperatures.

3.2 Hydroelectric power

Hydroelectric energy resources generally use the potential and kinetic energy of river currents to do work, which is renewable, clean, cheap and easy to adjust the peak of the electrical energy resources and can be repeatedly used by human beings continuously [8]. Hydroelectric power generation is the main form of utilization of hydro energy resources and one of the main sources of electricity in the world, occupying an important position in the global energy system, with the global hydroelectric power generation capacity reaching 1308 GW in 2019, accounting for 15% of the total global power generation. At the same time, hydropower is a major source of renewable energy, and although its share in renewable energy has declined with the development of other types of renewable energy, it is still favored by developing countries because of its low cost, high output rate, and mature technology, and still accounted for 48% of

renewable energy generation in 2018 [8]. For instance, the annual installed capacity of hydroelectric power generation in China at the end of the 20th century will be 5.1 times greater by 2020, reaching a total installed capacity of 370.16 million kW; the annual power generation capacity will be 1,355.2 billion kW · h, which is 5. 8 times the annual hydroelectric power generation capacity in China at the end of the 20th century [3].

As a renewable energy generation technology and clean energy generation technology, hydroelectric power generation is very different from traditional power generation methods such as thermal power generation. The idea behind hydroelectric power generation is to leverage the variations in water levels in rivers and lakes to turn potential energy into kinetic energy in hydraulic turbines, which are then used to power generators to generate electricity. The energy conversion process is water energy to mechanical energy, and then to electrical energy. Reservoir water energy is mainly composed of water depth pressure energy, water body potential energy, water body kinetic energy and reservoir energy formed by the work of gravity of the reservoir water body [9].



https://pubs.acs.org/doi/abs/10.1021/acs.est.9b05083

Fig. 1. Climate impacts from replacing fossil fuel electricity generation with that from new hydropower facilities.

The environmental impact of hydropower refers to the environmental impact of the reservoir itself and the way it is dispatched and used. The impact of hydroelectricity on the atmosphere is principally in two areas: greenhouse gas emissions and temperature changes, which are interrelated. Since hydro development uses only the potential energy from running water to generate electricity, it emits fewer greenhouse gases like carbon dioxide. Some carbon dioxide may be emitted from plants flooded by the reservoir, but the total amount is small and largely negligible [10]. Because the construction of the reservoir will result in wetter surrounding air, and water has a higher specific heat capacity, the body of water will have a daytime cooling and nighttime warming effect on the temperature around the reservoir, which can suppress extreme maximum temperatures to raise extreme minimum temperatures. Nevertheless, these changes are also relatively small. Thus the general view is that hydropower itself has a negligible impact on climate, but instead can massively reduce emissions of carbon dioxide, sulfur dioxide, nitrogen oxides and other gases caused by coal power, which is important for promoting energy conservation and emission reduction, improving air quality and mitigating the greenhouse effect [10]. Yet according to a study in recent years, there are huge differences in climate impacts between hydroelectric facilities over time. The near-term climate impacts of hydropower plants are much greater than the long-term impacts. Sometimes hydroelectric power plants emit greenhouse gases even comparable to thermal power plants [11]. A typical sketch is given in Fig. 1.

In summary, the climate impacts of hydroelectric power plants vary considerably on an individual and temporal basis and are still being studied. However, they do reduce harmful emissions and mitigate adverse climate conditions such as acid rain.

3.3 Wind power

Wind energy is the earliest energy source used by human beings, and it is also a clean and harmless renewable energy source, which is increasingly used by human beings. In China, the country has abundant wind energy reserves, with a total reserve of $3{,}226\times10^{11}$ W and an actual exploitable capacity of 253×10^{11} W[12]. By the end of 2020, China's cumulative grid-connected capacity reached 281.53 million kW, of which the cumulative installed capacity of onshore wind power was 272.54 million kW and the cumulative installed capacity of offshore wind power was 8.99 million kW, accounting for about 12. 8% of the country's installed wind power capacity. In 2020, China's annual wind power generation capacity reached 466.5 billion kW-h, accounting for 6.1% of the total annual power generation capacity of all power sources [13].

The sun irradiates the atmosphere from above, heating it, and due to the rotation and revolution of the earth, the uneven heating near the ground forms an atmospheric temperature difference, causing airflow. The flow of air in the horizontal direction forms the wind. As long as the sun exists, there can be wind energy, so wind energy also belongs to the category of solar energy [14]. The basic working principle of the wind turbine is relatively simple, mainly the wind drives the windmill blade operation, the operation process in the speed of the speed machine to further increase the blade speed so that the generator's internal rotation and cuts the magnetic field, of the final energy accumulation, the device in the form of electricity to maintain a constant current output. An anemometer, tower, generator, hydraulic system, and wind turbine blades are typically included in a wind turbine [15]. The wind turbine is an apparatus that transforms wind energy into a machine that can alter its direction by the direction of the wind, thereby maximizing the use of wind energy. The tower connects and supports the wind turbine and the generator, and to guarantee the wind turbine operates normally, its height is dependent on the topography and size of the wind turbine. Wind turbine mechanical energy is transformed into electrical energy via a generator [16].

Unlike other energy conversions, wind power does not pollute in the traditional sense (e.g., large carbon emissions), but the operation of wind farms absorbs the

momentum of air currents in the horizontal direction, converting wind energy into electricity, significantly reducing wind speed in the downstream area of the wind farm, thereby reducing heat transfer, while the rotation of the wind turbine causes changes in the air currents in the vertical direction, causing the air currents to flow upward and the clouds to become thinner and higher, and higher. This changes the normal natural water vapor circulation pattern, which will have an impact on the atmospheric circulation, which may affect the local climate and even trigger a chain reaction [17]. Large-scale wind farm development will alter the surface characteristics of vast areas, may modify the surrounding area and regional climate through processes involving land-air interaction, and may potentially have a greater effect on the climate through remote-related processes [13].

How wind power can affect climate is specifically classified as altering landmass roughness, causing turbulence, and affecting the atmospheric boundary layer. This changes the structure, function and processes of ecosystems at different scales in various ways, directly affecting the hydrothermal and energy balance of ecosystems [17].

The results of wind power on climate are mainly in terms of temperature and precipitation. In a study of climate change from wind power plants in northwestern China, for example, near-surface temperature changes were small at both local and national scales, while total precipitation increased more in some areas [13]. However, a different study reveals that even though the impact of wind power on the climate is minimal when compared to other anthropogenic factors given the current installed capacity of wind power worldwide, with further development, wind power may result in a 0.5K change in the average global temperature during the peak season if it can provide 1/10th of the world's electricity consumption by 2100 (seen from Fig. 2) [14].

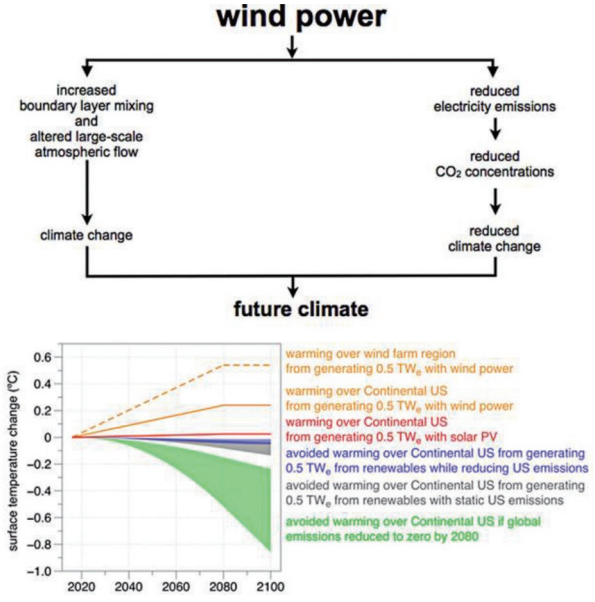


Fig. 2. Graphical overview of the climate impact of wind power.

https://doi.org/10.1016/j.joule.2018.09.009

In conclusion, wind power will have some impact on local temperature and precipitation, but these changes are different from the greenhouse effect and are more similar to the redistribution of atmospheric energy and surface heat.

4 Comparison, limitations & prospects

The climate impacts of three types of power generation - thermal, hydroelectric and wind - are very different. Thermal power generation, which is a traditional power generation method, mainly increases greenhouse gas emissions and causes the greenhouse effect, leading to environmental hazards such as dust and acid rain. Hydroelectric power generation is a renewable energy generation, which does not cause energy consumption but may affect water vapor feedback and cause some greenhouse effects. Wind power generation is a new energy source and is more environmentally friendly. It has more impacts on climate, mainly in terms of increasing temperature extremes and causing uneven precipitation, but the overall magnitude is small. Among the three, thermal power generation is the most mature and stable technology, which has the greatest negative impact on the climate and the lowest energy utilization rate. Hydroelectric power generation is the least expensive, has the highest power efficiency, and is the most vulnerable to climate impacts. Wind power is the cleanest, most flexible, most complex in its interaction with the atmosphere, and the least controllable. Overall, wind power generation has the least impact on the climate, and thermal power generation is the most detrimental to the environmental climate.

There are still many limitations to the technologies commonly used by humans to generate electricity. The biggest problem is the relatively low efficiency of energy use and the fact that many power generation technologies are still immature and uncontrollable. The most conventional non-renewable power generation technologies, such as thermal power and natural gas power, are extremely dependent on the Earth's fuel reserves, resulting in large emissions and low utilization rates. Now that fuel reserves have been gradually depleted, these types of power generation are no longer desirable. New energy generation technologies, such as wind power, photovoltaic power, solar power, etc., are not yet mature, resulting in long construction cycles, high costs, instability, and low utilization rates, and cannot be put into large-scale use [4].

At this stage, the further development of power generation technology is very urgent, and it is necessary to raise the attention of society to this issue. The first step is to improve the existing conventional power generation technology, improve the utilization rate, reduce the pollution emission and protect the natural resources and climate of the earth. Secondly, one should invest more in new energy generation technologies, train scientific and technical personnel for different types of technologies, and solve the existing problems of these technologies. Then, to create a future with efficient and clean power

generation technologies, reduce the share of non-renewable power generation technologies in the total global power generation and establish new energy generation technologies on a wide scale.

5 Conclusion

In summary, this paper analyzes and compares the climate impacts of three types of power generation plants: thermal, hydroelectric, and wind power. The climate impacts of the three types of power generation are very different in terms of their effects and results, but all are related to the greenhouse effect and global warming in some way. Among them, thermal power generation is the most detrimental to the climate, and wind power generation has the least negative impact on the climate. The current human power generation technology is mainly limited by both low energy utilization and immature technology. It is necessary to conserve the earth's gas resources and vigorously develop new energy generation technology to ensure the stability of the earth's climate. The purpose of this article is to give an overview of the climate impact of the three mainstream human power generation methods, draw relative conclusions after comparing them with each other, and summarize an outlook of the current human power generation technologies from the perspective of climate and environmental protection.

References

1. Global Climate Report, Quick Read(2023, March). China Meteorological News (2022).
2. Nasa Website, Retrieved from: https://earthobservatory.nasa.gov/world-of-change/decadaltemp.php.
3. B. Zhang, China Mana. Infor., **1673**, 194 (2023)
4. N. Yan, H. Rong, S. Wang, H. Chen, R. Bai, Y. Wang, J. of Elec. Power, **1005**, 6548 (2022).
5. C. Wang, Mech. Mana. & Dev., **12**, 1 (2022).
6. G. Chu, *Research on diagnostic methods of energy efficiency of steam turbine and auxiliary systems in thermal power generating units*. Master's Thesis, North China Electric Power University (2014).
7. H. Yun, Y. Xie, X. Zhang, Ther. Power Plants **7**, 193 (2023).
8. K. Wang, X. Song, Water Reso. & Hydr. Eng. **54**(2), 129**-**141 (2023).
9. F. Kong, J. Wu, Yel. Riv. **11**, 57 (2009).
10. X. Tang, Hydropower and new energy, **5**, 15 (2010).
11. I. B. Ocko, S. P. Hamburg, Environ. Sci. Technol, **9**, 05083 (2019).
12. H. Liang, K. Wei, J. Ma, Clim. & Env. Res., **2020**, 19126 (2021).
13. M. S. Nazir, N. Ali, M. Bilal, H. M. Iqbal, Cur. Opi. in Envi. Sci. & Health, **13**, 85-90 (2020).
14. Q. Zhang, China New Tech. & Prod. **17**, 236, (2015).
15. B. Li, X. Duan, Hubei Elec. Power, **1006**, 3986 (2007).
16. S. Diao, Shihezi Sci. & Tech., **8**, 5 (2021).
17. Z. Wu, W. Liu, S. Wang, Elect. Power, **6**, 5 (2014).