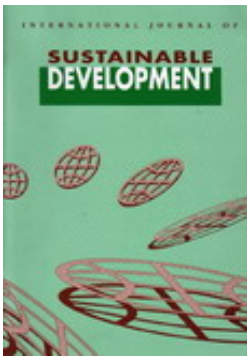

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Assessment of clean energy development path based on carbon emission data: achieving sustainable development goals

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Assessment of clean energy development path based on carbon emission data: achieving sustainable development goals

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Abstract: The development of clean energy is usually influenced by seasonal factors, and traditional manual experience assessment methods often fail to consider these seasonal factors and overlook periodic trends. Through the Holt-Winters method, carbon emission data was comprehensively and accurately evaluated to guide the achievement of sustainable development goals. The relevant carbon emission data was collected, and the Holt-Winters method combined trend, seasonal, and cyclical components to better capture and fit seasonal change patterns, providing more accurate predictions of clean energy development paths. In 2022, the electricity generated by City A using wind power was 31.6% more than that generated by City A using fossil fuels in 2021, and the carbon emissions were 57.1% lower. This data has provided important information for policy makers to help them formulate clean energy policies, regulations, and measures, helping to ensure social, economic, and environmental sustainability.

Keywords: carbon emission data; holt-winters method; clean energy; sustainable development goals; development path.

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1 Introduction

Energy, as an indispensable source of driving force for economic development, determines its sustainability. Therefore, ensuring the rational development and utilisation of energy and maintaining a healthy and sustainable supply of energy have become the fundamental requirements for economic development. Although energy planning continues to improve, there are still problems such as excessive energy exploitation and severe ecological and environmental pollution. Due to the fact that the industrial structure does not break through its dependence on energy during the economic transformation

period in some regions, the development and utilisation situation has become increasingly serious. The traditional energy development model is far from adapting to sustainable economic development. Therefore, while maintaining stable economic development, it is urgent to find a path toward sustainable energy development. Only an energy efficient, environmentally friendly and economically stable energy development system can ensure efficient and sustainable economic development.

Clean energy plays a crucial role in the future global energy landscape, and solar hydrogen production is considered a means of achieving clean energy carriers. Hydrogen is a sustainable energy carrier that can replace fossil fuels and protect the world from the impact of global warming. Hosseini Seyed Ehsan's research mainly focused on solar thermal cracking, solar electrolysis for hydrogen production, thermochemical water cracking, decarbonisation of fossil fuels, and photovoltaic hydrogen production. He discussed the performance of hydrogen production by coupling alkaline water electrolysis, polymer electrolyte membrane electrolysis, and solid oxide electrolysis with solar systems. Due to the use of various technologies, the cost of solar hydrogen is large, and there are also many challenges (Ehsan and Wahid, 2020). The global shift of clean energy from fossil fuels to low-carbon energy sources is frequently considered as being heavily influenced by technology costs and deployment rates depicted as experience curves. As the scope of technology adoption expands to systems, Breetz Hanna underlined the need for new political coalitions to promote complementary system-wide technologies (Hanna et al., 2018). Environmental deterioration brought on by economic activity is a significant issue for governments, and scholars are becoming increasingly interested in the causes of environmental deterioration. Sadiq Muhammad employed ordinary least squares to evaluate the long-term link between regional variables in South Asia from 1995 to 2018 by looking at the effect of growth, carbon footprint, and research and development expenditure on the development of green finance for renewable energy. According to the study, for each 1% increase in research and development expenditure, environmental sustainability decreased by 0.080% (Muhammad et al., 2022). Natural gas is regarded as the ideal transitional fuel for reentering the future carbon-restricted world, and the rising demand for natural gas has caused research and development operations on methane hydrates as future energy sources to continuously expand on a global scale. Both academia and business are interested in the ability to extract energy from methane hydrates that are found naturally. Aiming to achieve long-term commercial production of methane hydrate reservoirs, Yin and Praveen (2019) stressed the scientific, technological, and economic hurdles that must be overcome. China is in a period of accelerated industrialisation and urbanisation, and the demand for energy is increasing day by day. Therefore, whether the production structure of energy is reasonable has become a bottleneck restricting China's economic development.

The technological, social, economic, and environmental benefits of renewable energy cannot be separated from certain power quality challenges, as the power quality of the power grid and load bus also plays an important role, making the overall power quality assessment of renewable energy systems very complex. Bajaj Mohit proposed an evaluation method for the sustainable development of power quality in grid-connected renewable energy systems based on analytic hierarchy process (AHP). This method can simplify the process of discovering and evaluating power quality to the greatest extent and verify the approximation effect of high penetration of renewable energy on system power quality (Mohit and Singh, 2020). Sustainable development has attracted great attention from Bangladeshi managers, but various industries have faced many obstacles

in their efforts to achieve sustainable development. Uddin assessed obstacles by considering effective approaches to sustainable development, in order to address this gap. He used a combination of AHP and elimination selection methods to identify and prioritise obstacles and ranked possible ways to implement sustainable development. The results indicated that green technologies and processes are the most effective ways to achieve sustainable development (Uddin et al., 2019). Renewable energy is being significantly developed due to its advantages such as low greenhouse gas emissions. It is crucial to consider all relevant parameters that affect decision-making in order to achieve favourable goals for energy projects. Lak Kamari proposed a multi-criteria decision-making method, which is a reliable and efficient decision-making tool. This method considers other criteria such as society and risk to achieve more reliable decision-making outcomes and reduce the interference uncertainty of fuzzy sets (Lak Kamari et al., 2020). Green hydrogen energy is a sustainable substitute for fossil fuels and is helpful for enhancing the nation's long-term energy security. Chien FengSheng talked on renewable energy sources and the development of green hydrogen as potential alternative energy sources for Pakistan. The evaluation technique used a fuzzy AHP. The findings demonstrated that wind energy is a plentiful source of renewable energy in Pakistan, making wind power generation the best option for the country's production of green hydrogen (Shahbaz, 2021). Exploring a high-quality clean energy development path is essential from a practical standpoint since it can help reduce emissions by increasing the share of clean renewable energy in overall energy consumption.

In the development of clean energy, seasonal changes may have a significant impact on energy demand and carbon emissions. Therefore, considering seasonal factors is crucial for accurately evaluating the path of clean energy development. The Holt-Winters method not only considers seasonal factors in time series data, but also captures the influence of trends and series polynomials. In the development of clean energy, considering long-term trends and changes can better assess future carbon emissions and clean energy demand. Carbon emissions are one of the serious environmental issues currently facing the world and are the main factors leading to climate change and greenhouse effects. Therefore, in the process of achieving sustainable development goals, reducing carbon emissions is a essential link. By reducing carbon emissions, the environment can be maximally protected; resource utilisation efficiency can be improved; sustainable economic development can be promoted. The achievement of sustainable development goals requires the joint efforts of governments, businesses, and ordinary citizens of various countries. Among them, the government needs to formulate corresponding policies and action plans to promote the realisation of sustainable development. Enterprises and ordinary citizens also need to actively participate to strengthen environmental protection and social responsibility, reduce carbon emissions, and promote sustainable development.

2 Assessment of clean energy development path

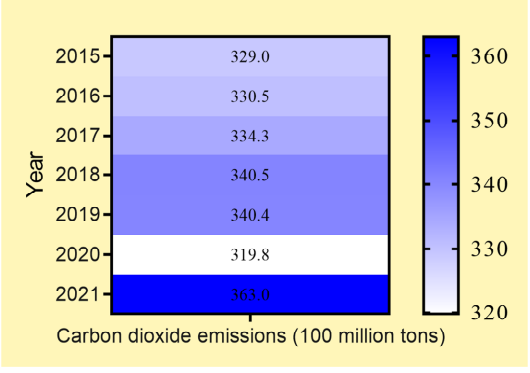
2.1 Carbon emission data collection

Faced with the increasingly severe global warming problem, reducing carbon dioxide emissions is imperative. Adjusting the industrial structure dominated by high energy consumption and heavy chemical industries is the main way for China to transform its

economic growth mode and an important means for China to reduce carbon emissions. In the context of addressing climate change, China's development must consider not only carbon emissions targets, but also economic growth and energy consumption (Krishankumar and Pamucar, 2023; Deng et al., 2019).

The consumption of fossil fuels has indeed raised human activity levels and living standards, but at the same time, it has also brought serious damage to the Earth's environment, especially the excessive emissions of greenhouse gases such as carbon dioxide (Luan et al., 2022; Schroeder et al., 2019). This article first analyses global carbon dioxide emissions data from 2015 to 2021, as shown in Figure 1 (in Figure 1, the horizontal axis represents carbon dioxide emissions, expressed in 100 millions tons, and the vertical axis represents years).

Figure 1 Global carbon emissions data from 2015 to 2021 (see online version for colours)



Source: https://www.yoojia.com/ask/17-11848913059915607204.html

As shown in Figure 1, the global carbon dioxide emissions in the energy sector reach 36.30 billion tons in 2021.

The initial effect of greenhouse gases is to keep the average temperature of the Earth at a level that allows humans and other species to survive. However, excess greenhouse gas emissions cause the climate to become warmer and warmer, endangering all life on Earth.

In the future, China would embark on a comprehensive green and low-carbon transformation of its economy and society. Clean energy is a new development path for countries around the world. China must independently explore relevant paths, proactively respond to challenges and overcome difficulties, and continuously seize various development opportunities brought about by the 'carbon neutrality' goal (Su et al., 2021; Rajendran et al., 2020).

While renewable energy has grown significantly over the last ten years, there hasn't been any large-scale expansion, and its annual percentage of final energy consumption has only grown considerably. The primary causes are the inadequate regulations and execution, the sluggish development of renewable energy-supporting infrastructure, the lack of innovation in certain industries, the high cost of energy in some markets, and the persistence of fossil fuel use in some nations. The carbon dioxide emissions from renewable energy are remarkably low when compared to the combustion of fossil fuels (Chen et al., 2021).

Table 1 displays the carbon dioxide emission coefficients of several energy systems.

Table 1 Carbon dioxide emission coefficients of different energy technologies

Energy type		*Carbon dioxide emission coefficient*
Fossil energy	Coal	341–385
	Fuel oil	227–351
	Fuel gas	158–936
Renewable energy	Offshore wind energy	7–10.8
	Tidal energy	10–20
	Geothermal energy	15.1–55

Source: Unit: grams per kilowatt hour

As shown in Table 1, the carbon dioxide emission coefficient of fossil fuels is higher than that of renewable energy. Therefore, increasing the proportion of renewable energy in energy consumption can help achieve carbon reduction.

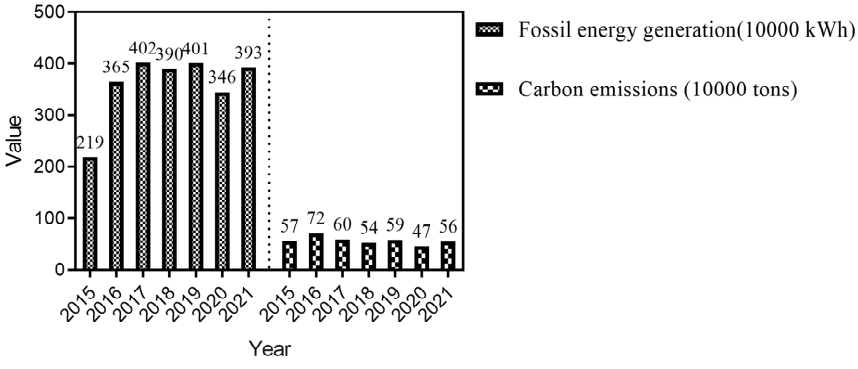
On the one hand, reducing carbon emissions is a global issue that needs urgent attention; on the other hand, due to the differences in traditional energy consumption and economic development among countries, the solutions to this problem are both similar and different (Roberts, 2020; Zantye et al., 2021). The targets of 'peak carbon' and 'carbon neutrality' are difficult to achieve with time, especially for China at the development stage, so complex system engineering is required in the future to drastically reduce emissions.

In recent years, the development of the clean energy field has also attracted increasingly public attention, and research on the factors affecting the development of the clean energy industry is also expanding. These factors include national policies, economic development, research and development level, power grid consumption, carbon prices, especially the relationship between national or regional economic development and non-fossil fuels, the relationship between carbon price setting and clean renewable energy, analysis of clean energy emission reduction potential, new technology development, etc. (Alola et al., 2022; Farquhar, 2022). The energy issue is a key issue that affects the development of globalisation and governance in China today. This is based on the position of the energy industry in the national economy, and it is also a manifestation of the important role that energy plays in the maintenance of the national economy and the operation of people's lives (Fu and Zhou, 2022; Su et al., 2018). Except for natural gas, traditional energy is generally non-renewable, and the ecological environment pollution caused by burning traditional energy is very serious, which has a negative impact on the sustainable development of China's economy and the maintenance of international contracts (Vakulchuk and Overland, 2021).

Along with the development of fossil fuels, many problems have also arisen. One of the most serious issues is the phenomenon of carbon emissions. City A mainly generates electricity from fossil fuels. The changes in fossil energy generation and carbon emissions of City A from 2015 to 2021 are shown in Figure 2 (in Figure 2, the horizontal axis represents the year and the vertical axis represents the numerical value).

Figure 2 shows the development and changes of fossil energy generation and carbon emissions in City A from 2015 to 2021. In 2015, carbon emissions accounted for approximately 26.0% $(\frac{57}{219}\times 100\% = 26.0\%)$ of fossil energy generation.

Figure 2 Changes in fossil energy generation and carbon emissions of City A from 2015 to 2021



Compared to renewable energy, fossil energy has the characteristic of high energy density and can quickly release a large amount of energy. This also means that under the same energy output, a smaller amount of fuel can meet the demand (Tibrewal and Venkataraman, 2021). However, a reduction in fuel consumption does not necessarily mean a reduction in carbon emissions, but rather may lead to higher carbon emission intensity. Fossil energy sources such as coal, oil, and natural gas release energy through combustion during the power generation process, but also produce a large amount of harmful gases such as carbon dioxide, sulphur dioxide, and nitrogen oxides. The most significant impact is carbon dioxide emissions, as fossil fuels are mainly composed of carbon, which reacts with oxygen in the air after combustion to generate carbon dioxide. It is necessary to use clean energy to reduce carbon emissions. However, blind development inevitably leads to resource waste and cannot solve the problems of energy structure and environmental pollution (Wagh and Kulkarni, 2018; Anuenen, 2022). Therefore, formulating reasonable and effective development goals and paths is of great practical significance for optimising the energy structure, achieving coordinated and sustainable development of energy, economy, and environment.

2.2 Development path assessment based on Holt-Winters method

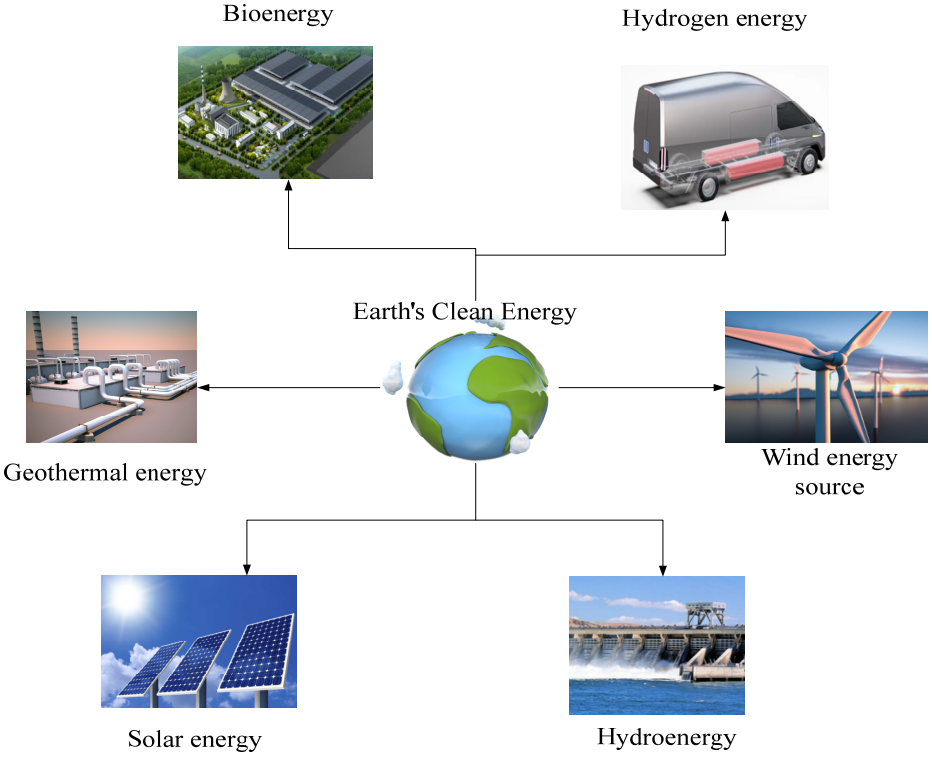
The traditional energy production mode not only causes serious wastes of energy, but also seriously affects the ecological environment, causing increasingly serious problems such as acid rain, greenhouse effect, and air pollution. Therefore, the upgrading of energy production models and the effective development of new energy have become effective paths for sustainable energy development, thereby ensuring the sustainability of economic development and the sustainable supply of energy to the country (Solorio and Tosun, 2023; Azadmanjiri et al., 2018).

Energy, as a source of energy for regional development, is the main driving force for economic development and wealth creation. Therefore, unreasonable energy development

and utilisation have become the main factors restricting regional economic development. With the improvement of technological level, how to achieve the dual goals of rational and efficient energy development and utilisation, as well as stable economic growth, has become the primary task for each economic region. The effective production and rational allocation of energy directly determine the development of the energy industry in many regions, which in turn affects the further development of the entire energy industry.

Clean energy refers to energy that does not emit pollutants, which can save conventional energy and reduce environmental pollution and ecological damage. Clean energy only causes minor damage to the ecological environment and does not emit or emits only very small amounts of pollutants (Attarzadeh and Balcilar, 2022; Kanamura, 2023). The schematic diagram of clean energy is shown in Figure 3.

Figure 3 Schematic diagram of clean energy (see online version for colours)



As shown in Figure 3, common clean energy sources include solar energy, biomass energy, hydrogen energy, wind energy, geothermal energy, and hydropower.

The Holt-Winters method is a time series analysis technique used for trend, seasonal, and periodic decomposition of time series data for prediction. This method consists of three components: trend, seasonality, and periodicity. The trend component represents the long-term trend in time series data, that is, whether the data shows an increasing or decreasing trend. Trends are usually represented by linear or exponential models.

The linear trend can be represented by Formula (1):

$$M_t = d + e_v \tag{1}$$

Among them, M_t is the trend value at time t; d is the initial value; e_v is the slope of the trend.

Seasonal components represent repetitive changes in data caused by seasonal effects, and seasonality is usually cyclical, with a cycle of years, months, or quarters. Seasonality can be represented by Formula (2):

$$S_t = \gamma_t - m \tag{2}$$

Among them, S_t is the seasonal value at time t; $\gamma_t - m$ is the seasonal component at time t; m is the period of the season.

The smoothing parameters in the Holt-Winters method can be adjusted according to the actual situation. The smoothing parameters control the weights of trends, seasonality, and series polynomials, and by adjusting these parameters, the model can respond to varying degrees of change to varying degrees. In order to evaluate the development path of clean energy, it is necessary to collect historical clean energy production data and use the Holt-Winters method to analyse and predict future trends, seasonality, and periodicity. Historical clean energy production data is collected and represented as time series, ensuring that the data includes timestamps and corresponding clean energy production values. The Holt-Winters method is used to decompose time series data and obtain trend, seasonal, and periodic components.

The main greenhouse gas from burning fossil fuels is carbon dioxide. Based on the consumption of fossil fuels by industry and type, and their corresponding carbon emission coefficients, their carbon emissions are calculated and then summed to obtain the total carbon emissions of the entire industry. The calculation formula is as follows:

$$C_{fuel} = \sum_{i,j} \left(E_{i,j} \times f_i \right) \tag{3}$$

In the formula, C_{fuel} represents the carbon emissions generated by the combustion of various fossil fuels; E represents the energy consumption; f represents the carbon emission coefficient; j represents the industrial sector.

The static input-output model cannot consider the lag and long-term nature of some issues because it can only represent the development and structure of the industry for one year. When the input-output model is used for forecasting and scheduling, the information provided by the static input-output model is somewhat insufficient. Therefore, the dynamic input-output model has emerged, and the discrete dynamic input-output model is as follows:

$$Y_C(t) = X(t) - A_t X(t) - B_t \left(X(t+1) - X(t) \right) \tag{4}$$

A_t is the direct consumption coefficient matrix, and B_t is the investment coefficient matrix. The direct consumption coefficient and investment consumption coefficient can reflect the input-output principle from different perspectives. Although the two coefficients represent different meanings, there is a certain relationship between them. The relationship between the two coefficients can be expressed by the following formula:

$$\Delta U_1 = A_t B_t^{-1} f_t \tag{5}$$

The net carbon dioxide emissions reduced by using wind power generation are as follows:

$$f(t) = n(t) \times (1 - \xi(t)) \times T(t) \times (1 - \beta(t)) \times \eta(t) \tag{6}$$

Among them, $n(t)$ is the cumulative installed capacity; $\xi(t)$ is the electricity consumption rate; $\beta(t)$ is the wind abandonment rate; $\eta(t)$ is the carbon dioxide emission factor.

The development path and emission reduction potential of clean energy are studied with the objective function of maximising the reduction of carbon dioxide emissions by replacing fossil energy with wind energy for power generation (Shahbaz et al., 2018; Boran, 2018). Reasonable arrangements for the development of wind energy can help adjust and formulate corresponding planning and incentive policies.

Future wind energy development in City A is forecast, and a dynamic optimisation model is shown. The goal is to reduce carbon dioxide emissions as much as possible by using wind energy instead of fossil fuels to generate electricity starting in 2022. The following is the final dynamic optimisation model for reducing emissions:

$$\max \sum f(t) = \sum n(t) \times (1 - \xi(t)) \tag{7}$$

The state transition formula for dynamic optimisation is as follows:

$$n(t) = n(t-1) + x(t) - y(t) \tag{8}$$

The equipment cost of wind turbines accounts for the largest share of the investment cost of wind power generation, which is a significant element influencing the development of wind energy. The development of economies of scale lowers the cost of wind turbines at the same time because wind turbine models have reached a mature stage of research and development that allows for mass production.

3 Clean energy development strategy

3.1 Setting emission reduction targets

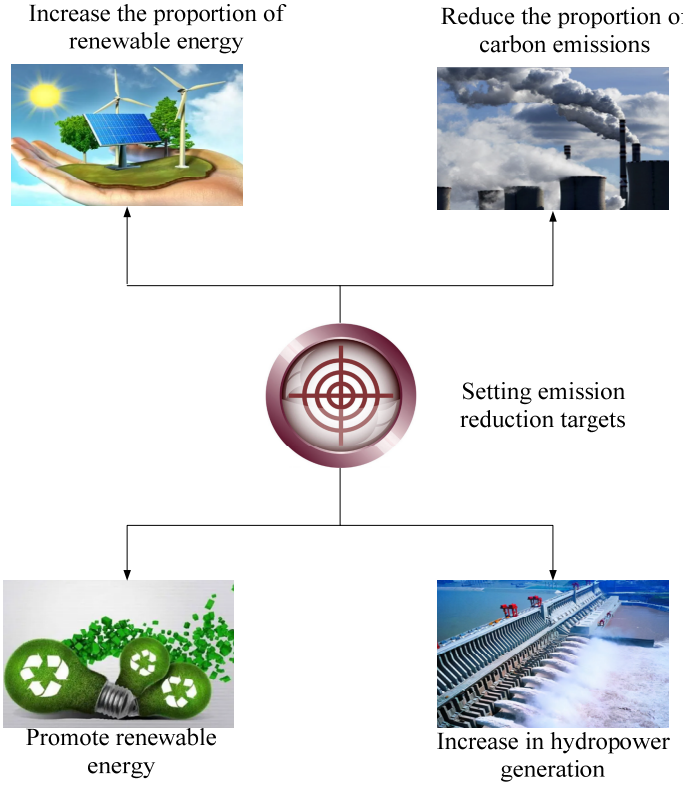
The success of the sustainable development path of clean energy depends on setting clear emission reduction targets (Shah, 2020; Kandakoglu et al., 2019). These goals not only provide a clear direction, but also encourage governments, industry, and society to take targeted measures to reduce carbon emissions and greenhouse gas emissions, thereby achieving the goals of climate change mitigation and sustainable development. By analysing carbon emission data, it is possible to determine which areas are the main sources of carbon emissions, such as energy, industry, transportation, agriculture, etc. This helps to focus resources and efforts on the most important problem areas to achieve more effective emission reduction. Based on carbon emission data, governments and organisations can establish specific emission reduction targets to quantify their commitment to mitigating climate change. The emission reduction targets are shown in Figure 4.

As shown in Figure 4, these goals typically include increasing the proportion of renewable energy, reducing carbon emissions, promoting renewable energy, and increasing hydropower generation. These goals can be short-term, medium-term, or long-term to adapt to different needs and time scales.

Clear emission reduction targets can provide a strong impetus for innovation and investment in clean energy technologies, and governments and the private sector are

more motivated to invest in research and development and adoption of clean energy technologies to meet emission reduction targets. Based on emission reduction targets, the government can formulate policies and regulations to support the development of clean energy. These policies help create an environment conducive to the clean energy industry. Once emission reduction targets are set, monitoring and reporting become important links. This allows the government and organisations to track progress and determine whether the goals have been achieved, and if it is not, appropriate, measures are taken to make adjustments. Setting emission reduction targets also contributes to international cooperation, especially within the framework of global climate change, where countries can share their goals with other countries, cooperate in addressing climate change, and work together to reduce global greenhouse gas emissions.

Figure 4 Emission reduction targets (see online version for colours)



3.2 Implementation of incentive measures

In order to encourage capital investment, foreign enterprises should be exempt from tariffs and import value-added tax on equipment that uses funds to import all renewable energy from other countries in the future, in order to ensure that enterprises with domestic funding and foreign enterprises maintain equal 'national treatment' and promote sustainable development of clean energy (Salman, 2023; Toke and Kalpande, 2018). For the digestion and absorption of key imported technologies, imported equipment, and

technologies required for demonstration projects, import tariffs, import value-added tax incentives, and financing support are provided; for commercial clean coal technology projects, low interest loans or financial discount support are provided. Coal preparation enterprises are supported to increase their technological transformation efforts, and clean coal technology projects are prioritised for inclusion in national key technological transformation projects, enjoying support from energy-saving special loans and enterprise technological innovation loans. In addition, it is necessary to encourage the implementation of segmented sulphur dioxide pollution charging methods: for enterprises that have adopted advanced technology and low emissions, the charging amount should be reduced; for enterprises that have not adopted emission reduction technologies and have a significant impact on the environment but have not exceeded the standard, fee standards should be raised to stimulate enterprises to adopt effective emission reduction technologies; for pollution sources that seriously affect the environment and exceed emissions, punitive collection standards can be implemented.

3.3 Investment and R&D of clean energy technologies

Clean energy technologies, such as solar, wind, nuclear, and energy efficiency improvements, have lower carbon emissions and are more environmentally friendly compared to traditional high carbon energy sources such as coal, oil, and natural gas. By investing in and widely adopting these clean energy technologies, traditional sources of high carbon emissions can be reduced, significantly reducing overall carbon emissions. The promotion and development of clean energy technology can reduce the dependence on energy imports, which helps to reduce the import of fossil fuels such as oil and natural gas, reduce the correlation between carbon emissions and energy supply, and thus improve national and regional energy security.

Investment in the clean energy sector is often accompanied by an increase in employment opportunities. Solar and wind energy projects, energy efficiency improvement, and research and development of clean technologies all require various tasks such as engineers, technicians, installers, maintenance personnel, and researchers, which help reduce unemployment rates and improve quality of life, further promoting the development and popularisation of clean energy technologies, and contributing to emission reduction. With the maturity and scale of clean energy technology, its costs gradually decrease, making clean energy more attractive, not only from an environmental perspective but also from an economic perspective. The increasing price competitiveness of clean energy makes it a sustainable energy choice.

4 Assessment effectiveness

4.1 Reducing carbon emissions

City A relies on the intensive investment in fossil energy power generation as the foundation for economic development, and this model has been able to continue for a considerable period of time. However, as the pollution image caused by it becomes increasingly severe, the effective exploration of energy reform as a starting point to promote sustainable development of City A has become a problem that should be paid attention to. In 2022, the City A used wind power for power generation.

The utilisation of wind power generation in City A in 2022 is shown in Table 2.

Table 2 Utilisation of wind power in City A in 2022

Month	*Wind power generation (10,000 tons)*	*Carbon emissions (10,000 tons)*	*Ratio*
1	31	4	12.9%
2	32	3	9.4%
3	43	3	7.0%
4	36	1	2.8%
5	42	2	4.8%
6	50	1	2.0%
7	44	1	2.3%
8	44	2	4.5%
9	44	1	2.3%
10	49	2	4.1%
11	59	2	3.4%
12	43	2	4.7%
Total and ratio	517	24	4.6%

As shown in Table 2, the electricity generated by City A using wind power in 2022 increased by 31.6% $(\frac{517-393}{393}\times 100\% = 31.6\%)$ compared to the electricity generated by City A using fossil fuels in 2021, and the carbon emissions increased by –57.1% $(\frac{24-56}{56}\times 100\% = -57.1\%)$, which is actually a reduction of 57.1%.

4.2 Energy utilisation rate

The new energy industry mainly utilises renewable energy, including wind energy, solar energy, tidal energy, etc., and is an important way to achieve energy sustainability. The new energy industry has the characteristics of high technological content and multiple types of energy, which can not only replace traditional energy to provide fuel, but also utilise information technology to innovate the energy industry. However, the development of the new energy industry is currently limited to the initial stage, with difficulties such as high cost and low efficiency, and limited usage areas.

The energy utilisation rates of cities in 2021 (traditional energy) and 2022 (new energy) are shown in Table 3 (the difference is the utilisation rate in 2022 minus the energy utilisation rate in 2021).

As shown in Table 3, the average energy utilisation rate in 2021 was 45.85%, and the average energy utilisation rate in 2022 was 82.20%. The energy utilisation rate in 2022 was 36.35% higher than that in 2021, indicating a higher utilisation rate of clean energy.

The energy utilisation rate in 2022 was higher. Sustainable development of the energy industry refers to meeting the needs of contemporary people for energy consumption as much as possible without harming the interests of future generations.

Table 3 Energy utilisation rates of cities in 2021 and 2022 (%)

Month	*2021*	*2022*	*Difference value*
1	56.95	71.97	15.02
2	55.59	73.30	17.71
3	53.03	75.81	22.78
4	50.69	78.55	27.86
5	47.62	83.37	35.75
6	45.59	82.78	37.19
7	43.14	86.98	43.84
8	42.49	83.68	41.19
9	40.78	90.39	49.61
10	39.96	91.84	51.88
11	37.97	86.63	48.66
12	36.34	81.10	44.76
Mean value	45.85	82.20	36.35

Energy sustainability can reduce the consumption of renewable energy through measures such as developing new energy, improving energy utilisation efficiency, and conserving energy, ensuring coordinated development between energy sustainability, environmental sustainability, economic sustainability, and social sustainability. The process of energy utilisation includes energy development, processing, conversion, etc. In the process of energy utilisation, it is necessary to minimise the formation of by-products to improve utilisation efficiency, improve the technological level to reduce pollutant emissions, and extend the energy industry chain to promote product diversification.

4.3 Achieving environmental sustainability

Environmental sustainability mainly refers to the minimisation and governance of pollution generated during the development and utilisation of traditional energy. Energy pollution mainly includes water pollution, air pollution, solid emissions, and other pollutants. Among them, greenhouse effect, acid rain, and other air pollution have irreversibility, and not only have a wide range of pollution, but also have great destructive power. Environmental sustainability requires environmental protection as the foundation in the process of energy use, reducing pollutant emissions through technological innovation, promoting the use of clean energy, and achieving coordinated development between energy and the environment.

A cohort of 381 people were selected to evaluate the air quality, water environment, green environment, and soil quality of City A in 2021 and 2022, as shown in Figure 5 (in Figure 5, the horizontal axis represents the degree and the vertical axis represents the number of people).

As shown in Figure 5, the number of 381 people who believed that the air quality, water environment, green environment, and soil quality in 2021 were all below 100, while the number of people who believed that the air quality, water environment, green environment, and soil quality in 2022 were all above 100.

Figure 5 Evaluation of City A in 2021 and 2022 (see online version for colours)

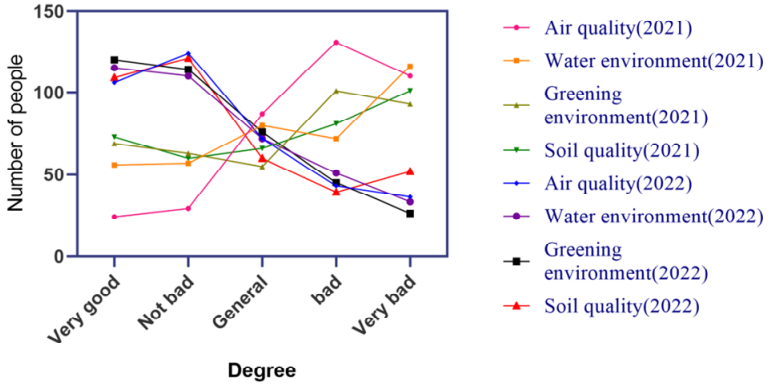


Figure 5 showed that air quality, water environment, green environment, and soil quality were better in 2022. Clean energy sources such as solar energy, wind energy, and nuclear energy emitted fewer greenhouse gases, especially carbon dioxide, compared to traditional fossil fuel burning energy.

By reducing the emissions of harmful gases, the speed of global temperature rise can be reduced, and the environmental damage caused by climate change can be alleviated. The pollutants released by the combustion of fossil fuels have a serious impact on air quality. Clean energy reduces particulate matter and harmful chemicals in the air, thereby reducing the risk of respiratory diseases and improving urban air quality. The extraction and transportation of fossil fuels cause water pollution and damage the aquatic ecosystem. Clean energy production is usually more environmentally friendly, not only reducing the use of water resources, but also reducing the risk of water pollution. Traditional energy extraction and mining activities have damaged ecosystems, leading to the loss of wildlife habitat. Clean energy projects are usually more friendly, reducing this damage and helping to protect ecological diversity.

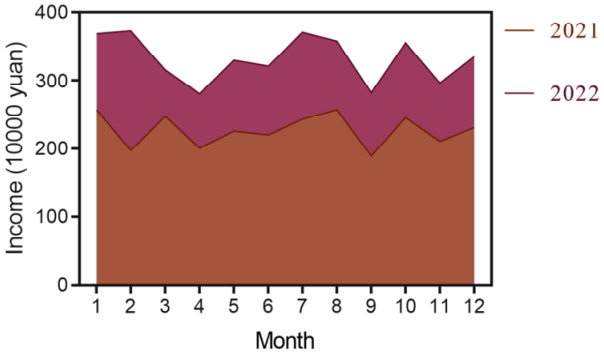
4.4 Sustainable economic development

The energy industry is a fundamental industry for economic development, and the sustainability of energy is an important aspect of achieving sustainable economic development. The extraction and utilisation of energy are related to the quality of people's lives and the healthy development of the economy. Therefore, in the process of energy development, it is necessary to attach importance to the rationalisation of industrial structure, implement long-term industrial development mechanisms, and formulate long-term industrial development strategies, promoting sustainable economic development. The income generated by wind power generation in City A in 2021 and 2022 is shown in Figure 6 (in Figure 6, the horizontal axis represents the month, and the vertical axis represents the income in 10,000 yuan).

As shown in Figure 6, it can be seen that the highest income from wind power generation in 2022 was above 3 million yuan, while the highest income from fossil energy generation in 2021 was below 3 million yuan.

Figure 6 showed that the income generated by fossil energy power generation in 2021 was generally lower. If there is not enough clean energy to support economic development, the economic development of the region would be constrained.

Figure 6 Income from wind power generation in City A in 2021 and 2022 (see online version for colours)



5 Discussion

Table 2 shows that in 2022, the City A utilised more wind power to generate electricity. Wind power is currently a relatively mature, commercialised, and most promising emerging renewable energy technology. Many countries consider vigorously developing wind energy as one of their strategies to address climate change and solve national energy security issues. Replacing traditional fossil fuel power generation with wind energy would greatly reduce carbon dioxide emissions. However, strictly speaking, wind power generation is not an absolute zero emission, as a certain amount of carbon dioxide is emitted during the production, manufacturing, transportation, waste treatment, wind farm construction, operation and maintenance of wind turbines. Ignoring emissions from other links is not conducive to a comprehensive understanding of the emission reduction potential of wind power generation.

After the large-scale development of wind power, if the power grid's grid-connected transmission capacity of wind power cannot keep up with the construction speed of wind farms, the phenomenon of abandoning wind power and limiting electricity once again would greatly stimulate the enthusiasm of wind power manufacturers for wind power investment. Especially when the subsidies received by manufacturers cannot fully cover the operating costs of wind farms, then wind power installation would inevitably decrease. Although overall, the cumulative installed capacity of wind power is gradually increasing, in the stage of deep decarbonisation in the country, the increasing trend of new installed capacity of wind power shows a periodicity of 4–5 years, rather than a continuous increase year by year. This indicates that under the influence of multiple factors, the development of renewable clean energy is not necessarily an increasing trend year by year, but fluctuates.

Table 3 shows that City A has a lower energy utilisation rate in 2021. The utilisation of traditional energy is not only limited by energy reserves, but also suffers from severe pollution and low sustainability. Therefore, in order to ensure the sustainable

development of energy economy ecology, it is necessary to formulate new energy development strategies and explore effective sustainable energy development models.

From Figure 6, it can be observed that the overall revenue generated by wind power generation in 2022 is higher. The development of the energy industry is closely related to population and social development, and the sustainable development of energy depends on the sustainability of various parts of society. Therefore, in the process of energy development, it is necessary to plan the industrial layout reasonably to adapt to the scale of urban development and optimise the urban industrial structure. The negative externalities on society need to be reduced to improve people's livelihoods. It is necessary to extend the energy industry chain, transform the energy development model, and minimise the social problems caused by the energy industry, thereby stabilising social development.

Energy, as the main source of fuel and energy in the process of people's lives and economic development, determines the sustainability of economic development due to its richness and effective utilisation. From the agricultural society to the industrial revolution and then to the information revolution, with the diversity of human life and the increasing demand, the forms of energy products are also becoming increasingly diverse. With the continuous development of technology, not only has the use of energy improved, but also the efficiency, speed, and mode of energy supply have been promoted. The development of energy has driven the development of society. Finally, the innovation of energy production technology and energy products promotes the development of relevant industries in society, giving birth to new industries, which not only changes production methods but also promotes industrial innovation.

6 Conclusions

The development of clean energy is crucial for mitigating climate change, reducing pollution, and ensuring energy security. In order to achieve sustainable clean energy development, decision-makers need to understand the future demand and supply situation. The Holt-Winters method is a time series prediction technique that can be used to analyse historical data and predict future trends and seasonal changes. This article explores how to use the Holt-Winters method to evaluate the development path of clean energy. The assessment of clean energy development paths based on carbon emission data needs to comprehensively consider sustainability goals with multiple dimensions and indicators, in order to more comprehensively address global energy and environmental challenges and provide guidance for a sustainable future.

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