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Research on the Relationship between Global Temperature Rise and Annual Average Concentrations of Major Greenhouse Gas Emissions

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Abstract: In order to further explore the relationship between global temperature, geographical location, time and greenhouse gas emissions, and to provide better suggestions for global environmental governance, this article collects temperature data and greenhouse gas emissions data from some cities around the world from 1881 to 2020. The Wilcoxon signed rank test and Shapiro Wilk test were used to investigate the degree of temperature differences between the northern and southern hemispheres. We calculated the grey correlation between the emissions of four greenhouse gases CO_2, CH_4, N_2O, SF_6, and the global average annual temperature change, and we established a regression model between the global average annual concentration of four gases and global temperature. It is found that the global temperature is approximately Normal distribution according to the temperature zone division, and the global average annual concentration of carbon dioxide and methane is the main reason for the global temperature rise. Therefore, it is recommended to reduce global carbon dioxide emissions and control their annual concentration between 379.665 and 405.79 ppm, while reducing global methane emissions and controlling their annual concentration between 1831.49 and 1879.59 ppb.

1. Introduction

Scientists from the World Meteorological Organization (WMO) have found that the week starting from July 3,2023 is the hottest on record globally. Under the influence of the EI Nino phenomenon, it is expected that global temperatures will further rise.[1]The latest Global Climate Report 2022 released by the World Meteorological Organization points out that the global average temperature in 2022 was approximately 1.15 degrees Celsius higher than the average from 1850 to 1900,and the period from 2015 to 2022 was the hottest eight years since records began in 1850.The concentration of three major greenhouse gases, carbon dioxide, methane and Nitrous oxide, will reach the highest value since records in 2021.The latest real-time data shows that the concentration of these three greenhouse gases will continue to rise in 2022.[2]

Research has shown that changes in global greenhouse gas concentrations are closely related to climate change. Prior to the Industrial Revolution, global temperature growth was not significant, and carbon dioxide in the atmosphere remained around 280 ppm. With the progress of the Industrial

Revolution, the rapidly developing heavy industry and transportation industry have greatly increased carbon emissions, and the global average temperature has also risen. According to the calculation of the National Oceanic and Atmospheric Administration (NOAA), the carbon dioxide and methane content in the atmosphere will continue to rise by 2020,reaching the highest level in 3.6 million years, and the level of methane, another greenhouse gas, is also rising sharply. According to research by NOAA scientists, the monthly average CO_2 concentration level reached a peak of 421 ppm in May 2022.A report of the OECD also predicts that the carbon dioxide concentration will reach 685 ppm by 2050.Therefore,it is expected that by the end of this century, the global average temperature will rise by 3℃ to 6℃, exceeding the internationally agreed goal of limiting it to 2℃ higher than pre industrial levels. If the threshold of 2℃ is exceeded, the precipitation pattern will be changed, the melting of glaciers and permafrost will be accelerated, the sea level will rise, and the intensity and frequency of extreme weather events will be increased, which will undoubtedly weaken the adaptability of human beings and ecosystems.[3]At the same time, the number of days of extreme high temperature, extreme low temperature, and extreme precipitation events also have a strong response to changes in global average temperature.[4]

Previous studies have found that global temperature changes are closely related to geographical location and greenhouse gas emissions, and there are significant differences in temperature and greenhouse gas emissions with changes in geographical location. However, there is no consensus on the extent to which various geographical locations and greenhouse gases have an impact on global temperature. Therefore, this article will focus on considering the impact of geographical location and greenhouse gas emissions on global temperature changes. Based on geographical location, divide the Earth into the southern and northern hemispheres, and analyze whether there are significant differences in temperature changes between the northern and southern hemispheres; aiming at the annual average concentrations of the four main components of greenhouse gases, namely CO_2,CH_4,N_2O and SF_6,in the atmosphere, a regression model is established to study the impact of greenhouse gas emissions on global temperature. Combined with previous research results and sustainable development goals, scientific guidance is provided for effectively curbing future global temperature rise. This study will help countries and international meteorological organizations better develop reliable greenhouse gas emission regulations, in order to mitigate global warming trends while minimizing the catastrophic effects of climate change.

2. Theory and Methods

2.1. Wilcoxon signed ranks test

Wilcoxon signed rank test is a classical test method in non-Parametric statistics test, which is applicable to the population with unknown data distribution. Therefore, the non-parametric test method is more superior in dealing with practical problems, and its conclusions are more robust. Its principle is simple, there is no need to know the overall distribution of data, and there are few assumptions.[5]In terms of constructing test statistics, it has its unique features. Firstly, the observation value is subtracted from the center position value$M_0$of the null hypothesis, and then the rank after taking the absolute value is added according to different symbols.[6]This test is applicable to the Pairwise comparison in the T-test, but it does not require that the difference di of paired data obey the Normal distribution, only requires a symmetric distribution, to test whether the difference of paired observation data comes from the population with a mean of 0.

The main steps of Wilcoxon sign rank test are:(a)Calculate the distance of $|X_i - M_0|$from the representative sample point to M_0($i = 1, 2, \cdots, n$);(b)find the ranks of n absolute value sequences separately, if they have the same sample points, take the average rank for each point;(c)the sum of the ranks of $|X_i - M_0|$ when $W_+$is designated under condition of $X_i - M_0 > 0$,meanwhile the sum of the ranks of $|X_i - M_0|$ when $W_-$is designated under condition of $X_i - M_0 < 0$; (d)conduct bilateral testing and obtain test statistics $W = \min(W_+, W_-)$; (e)based on the obtained W value, use statistical software or look up the distribution table of Wilcoxon sign rank test to obtain the p-value under the null hypothesis;(f)if the p-value is small, the null hypothesis can be rejected; if the p-value is large, there is insufficient evidence to reject the null hypothesis(which does not mean accepting the original hypothesis).[7]

2.2. Shapiro Wilk test

Shapiro Wilk test (also known as W-test) is a correlation based algorithm mainly used to test whether a random sample data comes from a normal distribution. It is suitable for samples with small sample sizes (N<5000), usually with a sample size of 8≤N≤50. By calculating a correlation number, the closer it is to 1, the better it indicates that the data fits the normal distribution.[8] The original assumption of the test is that the data sample comes from a normal population, generally when the p-value of the test is less than 0 At 05:00, the original hypothesis is rejected, that is, the data sample is not considered to come from a normal population, and vice versa, it is considered to come from a normal population, and the test statistic used for calculation is:

$$W = \left(\sum_{i=1}^{n} a_i x_i\right)^2 \Big/ \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2$$

The main steps of the Shapiro Wilk test are as follows:(a)the sample data is rearranged according to the numerical size of $x_1 \le x_2 \le \ldots \le x_n$;(b)calculate the denominator of the test statistic W;(c)check the table to calculate the value of a;(e)if the value of W is less than the judgment limit value Wa obtained by looking up the table, then reject the normality hypothesis based on the significance level α; if W>Wa, accept the normality assumption.[9]

2.3. Grey relational analysis

Grey correlation analysis refers to the analysis of the development trend of a system based on the proximity of the curve shapes of various factor series, in order to provide policy recommendations for decision-makers. In the process of system development, if two factors have a high degree of synchronous change, it can be considered that the two are closely related. Grey correlation analysis provides a quantitative measure of system change trends, making it suitable for dynamic analysis.[10]The calculation steps are mainly as follows:

(a) determine the analysis sequence, firstly, determine the reference sequence that reflects the behavioral characteristics of the system $Y = \{y(k)\},\ k = 1, 2, \cdots, n$; secondly, determine the comparative sequence that affects system behavior $X_i = \{x_i(k)\},\ k = 1, 2, \cdots, n;\quad i = 1, 2, \cdots, m$;

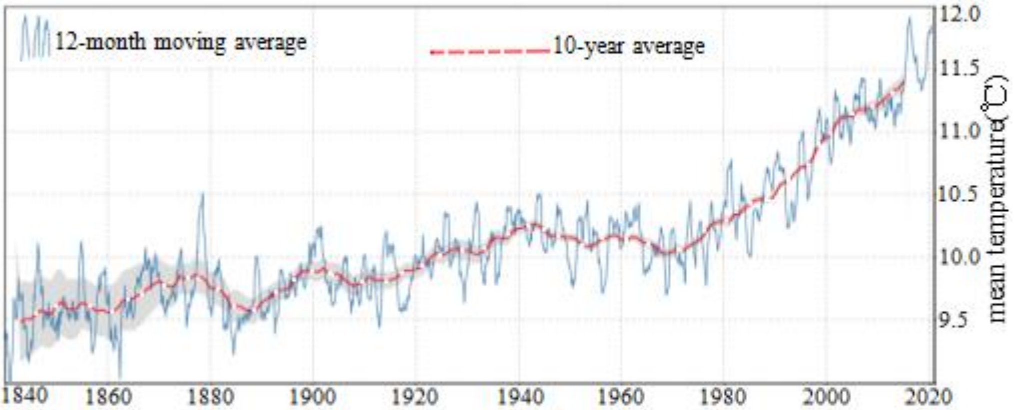
(b) dimensionalization of variables can be achieved using the specific gravity method of $x_i(k) = x_i(k) \Big/ \sum_{k=1}^{n} x_i(k), k = 1, 2, \cdots, n; i = 1, 2, \cdots, m$,to eliminate the influence of the original variable indicator dimension;

(c) calculate the correlation coefficient between $y(k)$ and $x_i(k)$ namely $s_i(k) = \dfrac{\min\limits_i \min\limits_k |y_k - x_i(k)| + \rho \max\limits_i \max\limits_k |y_k - x_i(k)|}{|y_k - x_i(k)| + \rho \max\limits_i \max\limits_k |y_k - x_i(k)|}$,if the resolution coefficient p is smaller, the resolution is greater, generally speaking $\rho \in (0,1)$,usually taken $\rho = 0.5$;

(d) calculate correlation $r_i = \frac{1}{n}\sum_{k=1}^{n} s_i(k), k = 1, 2, \cdots, n$;(e)relevance ranking, if $r_1 < r_2$,then the reference sequence Y is more similar than the comparison sequence X_2 .

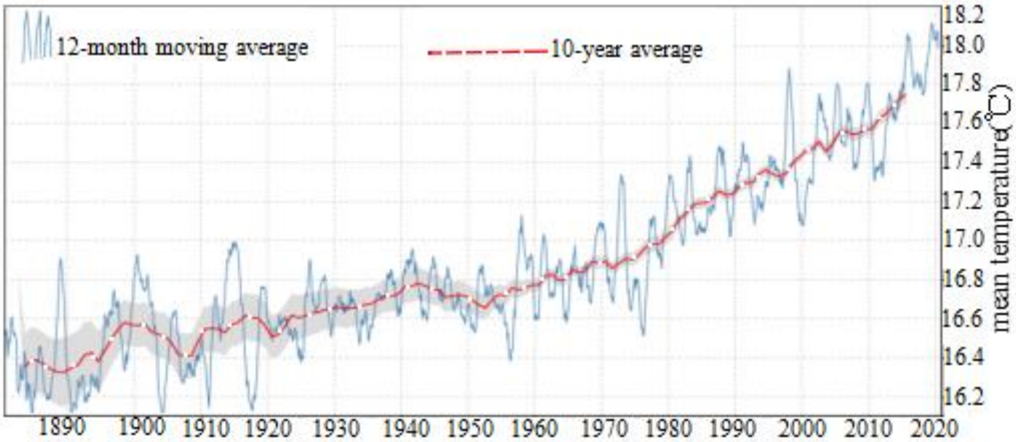
3. Analysis of temperature differences between the northern and southern hemispheres based on Wilcoxon signed rank test

Based on historical data, it is easy to obtain the relationship between the moving average temperature and time in the southern and northern hemispheres as shown in Figure 1 and Figure 2.



(Data sourced from Berkelev's official website)

Figure 1: Average Temperature in the Northern Hemisphere from 1840 to 2020



(Data sourced from Berkeley's official website)

Figure 2: Average Temperature in the Southern Hemisphere from 1890 to 2020

According to Figure 1 and Figure 2, it can be seen that the average temperature trends in the southern and northern hemispheres are consistent. In order to determine whether the two hemispheres follow the same distribution, whether there are differences, and whether the degree of difference is significant, we use Wilcoxon signed rank test for difference analysis. [11]

3.1. Analysis of temperature differences between the northern and southern hemispheres

The descriptive statistics and normality test results of sample pairing differences obtained through detection, including mean, standard deviation,etc.,are used to test the normality of the data.[12]Generally, there are two test methods for Normal distribution, one is Shapiro Wilk test, which is applicable to small sample data (sample size $N \leq 5000$);another type is the Kolmogorov Smirnov test, which is applicable to large sample data(sample size N>5000).If the test results show significance ($p<0.05$),it means that the original hypothesis is rejected (the data conforms to Normal distribution), and the data does not conform to Normal distribution,otherwise it means that the data conforms to Normal distribution.[13]Based on the historical data of average temperature in the southern and northern hemispheres collected earlier, the Wilcoxon signed rank test method was used to obtain the normality test results of paired differences for the samples (Table 1).

Table 1: Paired Difference Normality Test Results

The variable name	Sample size	Average value	Standard deviation	Skewness	kurtosis	S-W test	K-S test
Anomaly (south)	1682	0.038	0.515	0.466	-0.086	-------	-------
Anomaly (north)	1682	-0.245	0.514	-0.545	1.279	-------	-------
Anomaly (south) pair Anomaly (north)	1682	0.283	0.618	0.129	0.403	0.997 (0.005***)	0.027 (0.165)
Note: *, ****, * represent the significance levels of 1%, 5% and 10%, respectively**							

It can be seen from Table 1 that the significance P value of the S-W test is 0.005, showing significance at the level. The sample data is rejected as belonging to the assumption of Normal distribution, so the data does not meet the Normal distribution (Figure 3).

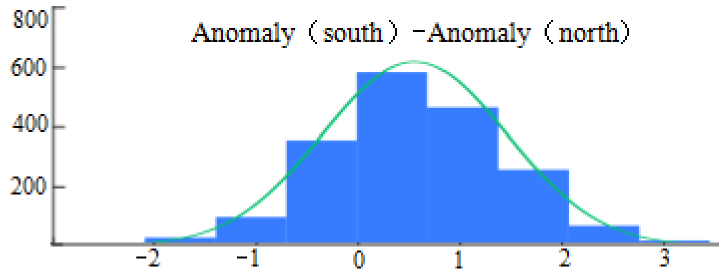


Figure 3: Normal Test Histogram

Figure 3 above shows the results of the normality test of the difference data of the quantitative variables Anomaly (south) and Anomaly(north).[14]If Normal distribution is present,the distribution chart basically presents a bell shape(high in the middle, low at both ends).Figure 3 shows that although the sample data is not absolutely normal, it can also be approximately accepted as Normal distribution.

3.2. Wilcoxon signed rank test for paired samples

Next, Wilcoxon sign rank test will be performed on the paired samples, and the test results are as follows (Table 2).

The results of the paired sample Wilcoxon test show that based on the variable Anomaly(south)paired with Anomaly(north),the significance P-value is significantly less than 0.05, showing significance at the level, rejecting the original hypothesis.[15]Therefore, there is a significant difference between Anomaly(south) paired with Anomaly(north).The Cohen's d value of the difference is 0.55, and the difference is moderate.[16]Thus, the following conclusion can be drawn:

there is a significant difference in temperature between the northern and southern hemispheres, with a moderate range of differences, reflecting significant geographical differences.

Table 2: Wilcoxon signed rank test table for paired samples

Pair variables	Median± standard deviation			Z	DF	P	Cohen's d
	Pairing 1	Pairing 2	Pairing difference				
Anomaly(south) pair Anomaly(north)	-0.03±0.515	-0.19±0.514	0.274±0.618	17.284	1681	0.000***	0.55

4. Empirical analysis of the relationship between greenhouse gas emissions and global temperature

4.1. Grey correlation analysis between major greenhouse gas emissions and global warming

Based on the theory and method of grey correlation degree mentioned earlier, the relationship between greenhouse gas emissions and global warming is analyzed using grey correlation degree.[17]The basic idea is to determine whether there is a close relationship between greenhouse gas emissions and global average temperature based on the similarity in the geometric shape of the sequence curve of greenhouse gas emissions and global average temperature. The basic idea of the analysis is to convert the discrete behavior observation values of system factors into piecewise continuous polylines through the Linear interpolation method.[18]The closer the geometric shape of the polylines is,the greater the correlation between greenhouse gas emissions and the global average temperature will be,and vice versa.

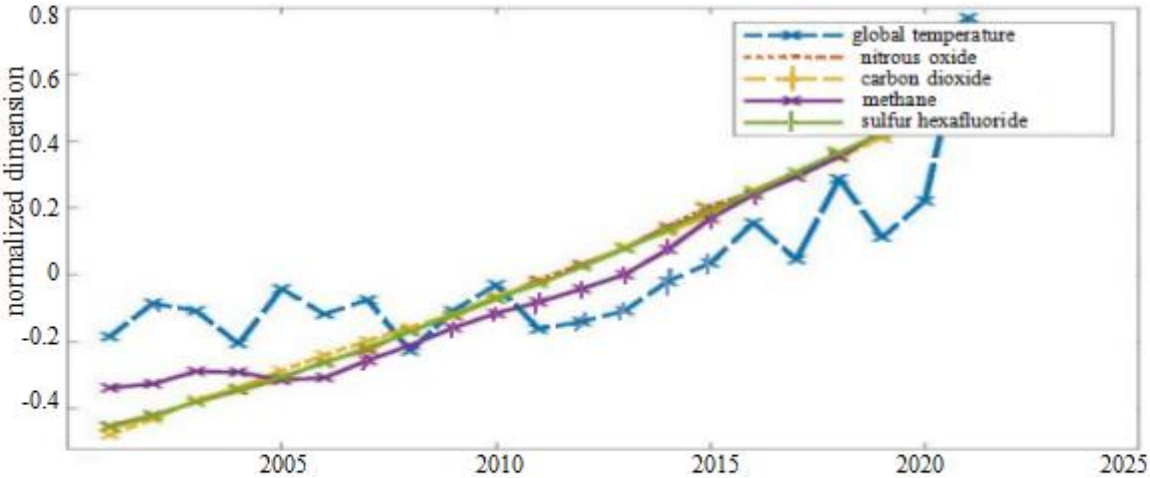


Figure 4: Grey correlation diagram between four greenhouse gases and global temperature

Through the Berkeley official website, data on the emissions of four major greenhouse gases CO_2, CH_4, N_2O,SF_6 and global temperature over time were obtained, and based on this, grey correlation analysis was conducted (See Figure 4 above).

Meanwhile, the grey correlation between the four main greenhouse gas emissions of CO_2, CH_4, N_2O, SF_6 and global warming was also obtained (Table 3):

According to Table 3,based on size comparison and grey correlation ranking, it is easy to conclude that the impact of the four main greenhouse gas emissions on global warming is ranked in descending order:CO_2,CH_4,N_2O,and SF_6.

Table 3: Grey correlation between four main greenhouse gas emissions and global warming

greenhouse gases	N_2O	CO_2	CH_4	SF_6
grey correlation degree	0.8330	0.8767	0.8635	0.5404

4.2. Regression analysis of four greenhouse gas emissions and global average annual temperature

4.2.1. Model construction

Global warming is still intensifying, and the impact of human activities on the emissions of greenhouse gases such as CO_2, CH_4, N_2O, and SF_6 released into the atmosphere on global warming needs to be further studied and explored.[19]In order to achieve this goal, we construct regression models between the four main greenhouse gas emissions and global annual average temperature:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \tag{1}$$

In equation (1), y is the global average annual temperature, x_1、x_2、x_3、x_4 represents the global average annual concentrations of the four major greenhouse gases N_2O,CO_2,CH_4,and SF_6,respectively, β_0 is the intercept term, ε is the residual term.

4.2.2. Data sources

In view of the availability of data, we selected the temperature data of 20 representative cities in the southern and northern hemispheres(Table 4)and the above four major greenhouse gas emissions data from 1881-2020 after the Second Industrial Revolution to empirically analyze the impact of these greenhouse gas emissions on the global annual average temperature. When conducting regression analysis, we conducted a three-year moving average treatment on the global annual average temperature to eliminate abnormal fluctuations in the annual average temperature; we use linear interpolation to fill in the missing values of major greenhouse gas emissions in major cities; Finally, the average annual emissions of various greenhouse gases from major cities are taken as the average annual concentration of greenhouse gas emissions.[20]

Table 4: 20 representative cities in the Southern and Northern Hemispheres

number	city	country	hemisphere	number	city	country	hemisphere
1	Beijing	China	N	11	London	Britain	N
2	Bogota	Colombia	N	12	Luanda	Angola	S
3	Buenos Aires	Argentina	S	13	Montreal	Canada	N
4	Bujumbura	Burundi	S	14	Moscow	Russia	N
5	Cape Town	South Africa	S	15	Nairobi	Kenya	S
6	Chicago	America	N	16	New Delhi	India	N
7	Dodoma	Tanzania	S	17	Rio De Janeiro	Brazil	S
8	Hamburg	Germany	N	18	Rome	Italy	N
9	Harare	Zimbabwe	S	19	Sydney	Australia	S
10	Kiev	Ukraine	N	20	Tarawa	Kiribati	S

The descriptive statistical analysis of the main variables is as follows (Table 5).

Table 5: Descriptive statistical analysis of main variables

variables	N	mean	sd	min	max
y	2780	15.09	1.566	13.51	16.68
x_1	2780	0.265	0.138	0.204	0.335
x_2	2780	341.3	0.325	280.1	413.4
x_3	2780	1.566	1.012	1.232	1.925
x_4	2780	0.01	0.489	0.006	0.013

4.2.3. Analysis of Regression Results

Regression analysis was conducted using the econometric software EViews 12.0,and the results are as follows (Table 6).

Table 6: Regression analysis results

Variable	Coefficient	Std.Error	t-Statistic	Prob.
C	11.58112	4.292205	2.708391	0.0002
x_1	0.032076	0.002912	1.982464	0.0004
x_2	0.461108	0.265723	3.087502	0.0000
x_3	0.189022	0.027816	2.158313	0.0000
x_4	0.018207	0.003608	1.866906	0.0005
R-squared	0.899608	Mean dependent var		18907.77
Adjusted R-squared	0.897812	S.D.dependent var		8234.709
S.E. of regression	0.011507	Akaike info criterion		17.29491
Sum squared resid	9097.563	Schwarz criterion		17.56938
Log likelihood	528.1422	Hannan-Quinn criter.		17.40267
F-statistic	17.84601	Durbin-Watson stat		1.822672
Prob(F-statistic)	0.000009			

According to Table 6,the regression equation between the annual average concentrations of four major greenhouse gas emissions in the global atmosphere, namely CO_2,CH_4,N_2O,and SF_6,then the global annual average temperature is: $y = 11.58 + 0.0321x_1 + 0.4611x_2 + 0.1890x_3 + 0.0182x_4$.

According to the regression coefficients, among the four major greenhouse gases mentioned above, CO_2 has the greatest impact on global warming effects, followed by CH_4, and finally N_2O and SF_6.[21]The *P* value of regression equation F-test is 9.0×10-6<<0.001,the estimated standard error of regression is 0.0115,and the observed value of F-statistic is 17.846.The goodness of fit of the regression equation is good, as determined by the determinability coefficient and the adjusted determinability coefficient.[22]

5. Conclusion and Suggestions

5.1. Conclusion

This article uses the theories and methods of Wilcoxon signed rank test, Shapiro Wilk test, grey correlation degree, and regression analysis to explore the internal relationship between the annual average concentration of major greenhouse gas emissions in different geographical locations in the southern and northern hemispheres and global annual average temperature. The research conclusions mainly include: firstly, there are significant geographical differences in the impact of the annual average concentration of major greenhouse gas emissions on global annual average temperature; Secondly, the annual average concentration of carbon dioxide emissions has the greatest impact on global warming, with methane having the second largest impact; Finally, in order to effectively mitigate the warming effect of greenhouse gases, it is estimated that the global annual average concentration of CO_2 in the atmosphere should be controlled within the range of 379.665-405.79 ppm, and the global annual average concentration of CH_4 should be controlled within the range of 1831.49-1879.59 ppb.

5.2. Suggestions

Since the industrial revolution, especially the Second Industrial Revolution, the global greenhouse effect has intensified, the contradiction between the development of human society and the natural environment has become increasingly prominent, and the extreme climate and other natural disasters caused by the greenhouse effect are strongly attacking human beings themselves.[23]Therefore, we suggest that:

Firstly, accelerating the development and utilization of new clean energy is the primary measure to curb the rapid rise in global temperatures. The latest research report from the World Meteorological Organization shows that the current global average temperature has increased by about 1.15℃ compared to before the industrial revolution, and it will continue to accelerate in the future. It is recommended to replace traditional energy sources such as coal, oil, and natural gas with clean energy sources such as hydropower, wind power, solar energy, biomass, tidal energy, and nuclear energy. This will greatly reduce greenhouse gas emissions and other secondary disasters while ensuring human energy supply, and help effectively curb the rapid rise in global temperatures.

Secondly, we need to address the issue of rapid global population growth. The rapid population growth has led to an intensification of human demands and destruction of nature. Starting from July 11,1987, when the global population exceeded 5 billion, it reached 7.5 billion in just 30 years. According to scientific predictions, the global population will reach 8.5 billion,9.7 billion, and 11 billion by 2030,2050,and 2100,respectively.Excessive population will lead to significant energy consumption, and greenhouse gases generated by fossil fuels will accelerate global temperature rise. Therefore, controlling the rapid growth of global population is a necessary issue to slow down the rapid rise of global temperature.

Thirdly, widespread and sustainable afforestation worldwide will help slow down the trend of global warming. For each cubic meter of growth and accumulation, trees absorb approximately 1.83 tons of carbon dioxide and release 1.62 tons of oxygen, exhibiting a prominent carbon sequestration phenomenon. By continuously absorbing carbon dioxide and solidifying it into the trees themselves through trees growth, it achieves a good effect of reducing global greenhouse gas concentrations.

Finally, we vigorously advocate a simple, moderate, green, and low-carbon lifestyle, create a strong atmosphere of energy conservation and carbon reduction in the entire society, strive to achieve green and low-carbon development, promote ecological civilization construction, actively respond to climate change, and promote harmonious coexistence between humans and nature.

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